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Sustained attention and associated memory and other cognitive failures in the young and able elderly

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Declaration

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Summary

The main aim of this thesis was to study how people pay attention over time and how this capacity changes with age. The populations under study were therefore the young and the able elderly and samples from these populations took part in a series of experiments to determine the differences between them in regard to sustained attention and related memory and other cognitive failures. Given that the population throughout the developed world is ageing rapidly, cognitive problems encountered by the elderly are becoming increasingly important areas of research.

The methods used to conduct this research were primarily psychological in nature, complemented by a number of neuroscientific techniques. A relatively recent tool for measuring sustained attention – a computerised, laboratory-based task called the Sustained Attention to Response Task (SART) – was used in conjunction with methods for measuring brain activity including transcranial magnetic stimulation (TMS), event-related potentials (ERPs), quantitative electroencephalography (EEG) and skin conductance response (SCR). In addition a number of standard tests for psychological and neuropsychological assessment were used, e.g., the National Adult Reading Test. The Cognitive Failures Questionnaire (CFQ) and the Memory Assessment Clinics Self-Rating Scale (MAC-S) were used to measure memory and other cognitive failures.

This thesis is divided into ten chapters. The first three chapters provide an introduction to the attention system of the human brain, the sustained attention subsystem and ageing and cognition. Chapters four to nine detail a series of six experiments, exploring: (1) sustained attention as measured by the SART and that task's relationship with the CFQ, (2) the use of TMS in testing sustained attention, (3) high and low sustained attention capacity in the young using ERPs, (4) differences between the young and able elderly in sustained attention performance, (5) ERP activity during such performance, and (6) a qEEG analysis of the high/low sustained attention capacity and the young/old datasets.

The tenth and final chapter consists of a discussion of the issues raised by the six experiments. The results of these studies are summarised and discussed in relation to the tools and techniques used, theory and the target populations.

The most significant finding reported in this thesis was the discovery of a sustained attention deficit in the elderly. Not only was a behavioural difference found between the young and the elderly but also an electrophysiological difference. The SART proved to be an effective tool in testing sustained attention capacity in the young and able elderly. However, its relationship with the CFQ needs refinement. This provides one possibility for future research on this topic of sustained attention and related memory and other cognitive failures, as do techniques for training sustained attention function.

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List of Abbreviations

ACh	acetylcholine
ADHD	attention deficit hyperactivity disorder
CFQ	cognitive failures questionnaire
CPT	continuous performance test
EEG	electroencephalography
ERP	event-related potential
FLH	frontal lobe hypothesis
fMRI	functional magnetic resonance imaging
HADS	hospital anxiety and depression scale
MAC-S	memory assessment clinics self-rating scale
NART	national adult reading test
NE	norepinephrine
PET	positron emission tomography
PCA	principal components analysis
qEEG	quantitative EEG
rCBF	regional cerebral bloodflow
RT	reaction times
SAC	sustained attention capacity
SART	sustained attention to response task
$SART_{fixed}$	fixed sequence SART
$SART_{random}$	random sequence SART
SCR	skin conductance response
TBI	traumatic brain injury
TMS	transcranial magnetic stimulation

1. Taxonomy Of Attention

1.1 Overview

This thesis is primarily about that aspect of attention that allows us to maintain attention, namely sustained attention. However, the sustained attention network is neither functionally nor anatomically isolated. It works with at least two other networks: selective and executive attention. The purpose of this chapter is to introduce the attention system of the human brain. While there are many ways to discuss attention, this chapter charts the changing views of attention from the early theories that emphasised selective attention to more recent theories such as thinking of attention as an organ system (Posner & Fan, in press). The evidence for and against each will be presented chronologically. In this way, it is possible to trace the evolution of the early theories of attention into the neuropsychologically based models researched today.

1.2 A question of when: 1950s and 1960s

In the 1950s and 1960s attention theories focussed on the question of what stage of information processing selective attention took place. Or, to put it another way, to what degree incoming information was analysed by the brain before being selected for further processing. These theories (e.g., Broadbent, 1958; Deutsch & Deutsch, 1963), psychologically based, underpinned the later neuropsychological models of attention, most particularly in regard to selective attention. They translated the subjective experience of attention into observable parameters on experimental tasks and created testable hypotheses.

Broadbent's (1958) filter theory of early selection was one of the most influential theories of attention. He hypothesised that stimuli from the environment, of which there was a surplus, were filtered according to their physical characteristics before being identified. Only attended stimuli were subjected to further processing. However, this idea was criticised on the grounds of the cocktail party effect: you can attend to one conversation yet be aware that your name has been mentioned in another (unattended) conversation. The late selection theories of attention (e.g., Deutsch & Deutsch, 1963) were developed in response to this and other criticisms of Broadbent's theory. As suggested by Broadbent, the late selection theorists began with a surplus of incoming information but argued that all stimuli were processed to the stage of identification. An obvious criticism of this account was that it presupposes no limitations in attentional capacity. How could it be possible to fully assimilate everything we encounter? There were several models that approached a compromise between early and late selection theories of attention (see Pashler, 1998 for a review). Treisman (1964), for example, adapted Broadbent's filter theory to include a flexible 'attenuator'. This selection mechanism allowed for the possibility that some information that had gone unattended could 're-enter' the system for further processing.

1.3 Schneider and Shiffrin, 1970s

Attention was an important component of Schneider and Shiffrin's (1977; Shiffrin & Schneider, 1977) theory of information processing. They described memory as a large and permanent collection of nodes, nodes being information elements (e.g., programs for response). The long-term store (LTS) consisted of passive, inactive nodes whereas the short-term store (STS) comprised a set of currently activated nodes. Control of information processing worked by manipulating the flow of information into and out of the STS. There were two forms of information processing: automatic and controlled. Attention was one of the distinguishing features between these two processes.

Automatic and controlled processing required differing degrees of attention. Automatic processing didn't require conscious attention. It had no capacity limitations and could function without control. In contrast, controlled processing demanded conscious attention and had limited capacity. The efficiency of controlled processing could be

measured by accuracy and speed of performance. Schneider and Shiffrin demonstrated these effects using a basic visual search procedure. Participants were required to search for the presence of one or more of a memorised set of *n* objects among a set of *m* visual inputs. When targets and distractors were not mixed across trials, performance improved over time and these changes were ascribed to automatic detection. When targets and distractors were mixed from trial to trial, then participants had to initiate a slow serial search requiring attention. This qualified as a controlled search. These processes were apparent in experiments on perceptual learning, learning in general, categorisation and the focussing of attention.

1.4 Norman and Shallice, 1980s

Another theory addressing attention from the point of view of cognitive control was that of Norman and Shallice (1986). The Supervisory Attention System (SAS) was a theory of executive abilities that had at its core the separation of routine and non-routine activities. Norman and Shallice's model consisted of four components: (1) cognitive units or modules, (2) schemata, (3) contention scheduling and (4) a supervisory (attentional) system. (1) to (3) were related to routine activities. Basic cognitive operations were carried out in modules and these modules were then controlled by schemata, which were routine programs for over learned skills. Contention scheduling was the term used to describe the mechanisms that control competition among schemata. The fourth component, the SAS, came into play in non-routine situations. This could happen when schemata were insufficient, if one particular schema must be chosen, or an inappropriate schema had to be inhibited. The SAS was also said to function when there was no known solution to the task in hand.

Initially, Norman and Shallice's SAS more or less represented the functions of Baddeley's central executive, the core of his model of working memory (Baddeley, 1986; Baddeley & Hitch, 1974). "Working memory can be defined as a system for the temporary maintenance and manipulation of information" (Baddeley, Della Sala, Gray, Papagno, & Spinnler, 1997, p. 64). As well as the central executive, this model comprised two slave systems co-ordinated by the central executive: the phonological loop and visuospatial sketchpad. The former was a mechanism responsible for the

retention of speech-based material; the latter constructed and preserved visual images. The central executive was a general attentional resource involved in managing all information-processing activities in the brain. However, Norman and Shallice's SAS evolved from a unitary system into a more fractionated one. Dissociable functions associated with the SAS were energising and inhibiting the schemata, adjusting contention-scheduling, monitoring the level of activity of the schemata and also control of 'if-then' logical processes.

The utility of the SAS approach in the study of attention was illustrated by Stuss, Shallice, Alexander and Picton (1995). The authors postulated that the control of attention (i.e., activation of SAS) was shown in the following types of task: sustaining, concentrating, sharing, suppressing, switching, preparing and setting of attention. They then proceeded to define and characterise the processes involved in each task in terms of the SAS model. An example of such a task was one involving concentrating attention, "needed when the required task is demanding and the required responses are occurring too quickly rather than too slowly" (Stuss et al., 1995, p. 199). In SAS terms, this activity would require activation of one schema within contention-scheduling and the inhibition of most others. Performance may be affected negatively if the schema becomes refractory from over-rapid use and/or the schema are not integrated securely because the task is relatively new. The different components of the SAS important to prevent these occurrences happening would include energising and inhibiting schemata where necessary, maybe reducing lateral inhibition and using if-then logical processes. Describing a task such as a concentrating attention task (e.g., serial reaction time task) using the SAS provided a framework in which to place the findings of various anatomical, neuropsychological and physiological studies.

1.5 Neuropsychological models of attention

Stuss and colleagues chose attention to illustrate the usefulness of Norman and Shallice's supervisory system in describing that construct's component processes partly because attention was increasingly being viewed as non-unitary. Researchers such as Mesulam (1981, 1990) and Posner and Petersen (1990) had divided the human attention system into separate component processes based upon their underlying anatomy.

Mesulam's model was based on data from brain-damaged patients and neuroanatomical studies of non-human primates. His theory described a network model of attention in which several distinct cortical regions interacted, including the posterior parietal cortex, the cingulate cortex and the frontal cortex (centred around the frontal eye fields). All of these regions were influenced by the reticular activating system (including noradrenergic, dopaminergic and cholinergic ascending systems) and each had its own spatial coordinate system. Each component was also associated with specific functions. The parietal component provided an internal perceptual map of the external world whereas the cingulate component regulated the spatial distribution of motivational valence. The frontal component was responsible for coordinating the motor programs for exploration, scanning, reaching and fixating. Finally, the reticular component regulated arousal (Marrocco & Davidson, 1998; Marrocco, Witte, & Davidson, 1994; Robbins & Everett, 1995). These various components were reciprocally interconnected with each other.

Mesulam's model sought to explain the neural correlates of attention. The different components were described in brain-based terms. Posner and Petersen (1990) developed a model of the human attention system along similar lines to Mesulam's. However, their version was more cognitively inclined. This model has been extremely influential, informing theory and practice (e.g., rehabilitation techniques) to the present day.

1.6 Posner and Petersen, 1990s

Posner and Petersen (1990) listed three principles fundamental to their theory. Firstly, the attention system of the brain was anatomically separate from data processing systems; data processing systems were those systems that were activated by input or output without attention. Posner and Petersen likened the attention system to other sensory and motor systems of the brain: "it interacts with other parts of the brain, but maintains its own identity" (p. 26). Secondly, attention was carried out by networks of anatomical areas. It was not the property of a single area, nor a general function of the brain working as a whole (Mesulam, 1981, 1990). Thirdly, the brain areas involved in attention were not responsible for the same function, but rather for specific

computations that could be specified in cognitive terms (Mesulam, 1990; Posner, 1988). These fundamental findings were illustrated by dividing the attention system into subsystems that performed different but interrelated functions: orienting, target detection and maintaining a vigilant or alert state. Each subsystem was characterised by its anatomy, the operations it performed and the relationship of the subsystem to data processing systems. The subsystems are described below as they were in the original Posner and Petersen (1990) paper with additional information gathered from more recent research (e.g., Posner & Fan, in press).

1.6.1 Orienting (selective attention)

Orienting can be overt or covert. Overt orienting can be defined as foveating a stimulus. Covert orienting is paying attention to a stimulus without moving the eye or head (Posner, 1988). Either way, attending to a location has been shown to improve processing efficiency (Posner, 1988; Mangoun & Hillyard, 1987; Downing, 1988). Three areas were associated with this subsystem based on monkey (Wurtz et al., 1980) and human (Petersen et al., 1988; Posner et al., 1988) research: the posterior parietal lobe, the superior colliculus and the lateral pulvinar nucleus. Supporting the principle that individual areas within a subsystem were responsible for specific functions, damage to each of the above-named brain areas produced a characteristic deficit. Posner et al. (1984) found that patients with damage to the posterior parietal lobe had difficulty in disengaging from one stimulus to another stimulus contralateral to the lesion. The superior colliculus appeared to be involved in moving attention to a stimulus. A deficit in this ability was apparent in patients with progressive deterioration in this area (Posner, 1988). Finally, patients with lesions of the thalamus and monkeys with chemical injections into the lateral pulvinar were found to have particular difficulty with selective attention on the side opposite to the lesion, namely they tended to respond to distractors (Posner & Petersen, 1990).

More recent studies involving both patients and imaging supported this division of areas and their associated mental operations in general, but not in the detail. In other words, there appeared to be a somewhat different separation of components. As it was, there was some disagreement between the findings of the lesion studies and clinical observations. In the early 1980s the lesion studies indicated that the parietal lobe was

the area most related to disengaging from a stimulus. However, clinical data suggested the involvement of more inferior lesions in the temporal-parietal junction and/or superior temporal lobe. This issue has been resolved by event-related imaging studies (Posner & Fan, in press), which have implied that there are two separate regions involved in shifting attention in contralesional space, but for different reasons (Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000; Friedrich, Egly, Rafal, & Beck, 1998; Karnath, Ferber, & Himmelbach, 2001). The first region is the superior parietal lobe and intraparietal sulcus (IPS). Lesions of this region cause difficulty with voluntary orienting of attention to an area of interest following a cue. The second region - the temporal-parietal junction or superior temporal lobe - is involved with re-orienting to novel or unexpected targets at unattended locations. The suggested roles of the superior colliculus and thalamus in orienting remain as they were. Sapir, Soroker, Berger and Henik (1999) recently provided evidence for collicular involvement in moving attention to a stimulus with a patient with a small spontaneous haemorrhage in the right side of the posterior midbrain. They measured inhibition of return (IOR) - the mechanism by which the attention system favours novel spatial locations by inhibiting already scanned ones (Posner & Cohen, 1984) - using a spatial cueing task. IOR developed only in the hemifields projecting to the intact left superior colliculus and not to those to the damaged right superior colliculus.

1.6.2 Target detection (executive attention)

Posner and Petersen's second attentional subsystem functions to detect signals for conscious processing. It is now more commonly known as the executive network (e.g., Posner, 1995). This subsystem was identified on the basis of the idea that there is a limit to how much we can attend to at any one time. This lack of capacity leads to interference with most other cognitive operations when attempting to detect a target (Posner, 1978). The balance between attended and unattended inputs (determined by our limitations) leads to the "selection of information relevant to the achievement of goals and lends coherence to behavior" (Posner, 1995). Posner and Petersen (1990) cited areas of the midfrontal lobe, including the anterior cingulate gyrus, as important for this 'executive' attention function (Vogt, Finch & Olsen, 1992). Regional cerebral blood flow, for example, was shown to increase in the anterior cingulate gyrus as the number of targets to be detected increased.

A recent development in regard to executive function addresses the question of how and when control is activated. Cognitive control is defined as the ability of the human cognitive system "to configure itself for the performance of specific tasks through appropriate adjustments in perceptual selection, response biasing, and the on-line maintenance of contextual information" (Botvinick, Braver, Barch, Carter, & Cohen, 2001, p. 624). Most researchers have focussed almost exclusively on the nature of the influence exerted by control rather than what makes control 'kick in' in the first place. Botvinick, Braver, Barch, Carter and Cohen (2001) proposed an evaluation system "that monitors for the occurrence of conflicts in information processing". They referred to this function as conflict monitoring. The conflict monitoring system oversees current demands, guiding task performance. Botvinick et al.'s theory helped clarify current thinking on executive attention and informed research into that element of the attention system (Posner & Fan, in press).

Botvinick and colleagues' work resulted in a more explicit version of executive attention compared to the rather vague version of earlier research. They stressed the role of attention in monitoring and resolving conflict between computations occurring in different brain areas. Hence, research into this subsystem of Posner and Petersen's (1990) model has recently taken a turn towards tasks that cause conflict and imaging performance on these tasks. Imaging studies have indicated the involvement of a frontal network including the anterior cingulate and lateral prefrontal cortex in tasks that involve attention when conflict is present (Posner & Fan, in press). Fan et al. (2001) tested participants on three conflict tasks and found that, while all the areas of the anterior cingulate that were activated had the same focus, lateral prefrontal cortex areas differed among tasks. MacDonald, Cohen, Stenger and Carter (2000) dissociated anterior cingulate and prefrontal involvement on the conflict-requiring Stroop task. Lateral prefrontal areas responded to cues indicating whether the task involved naming the word or identifying the ink colour. The cue did not activate the anterior cingulate; rather, the cingulate was more active when participants had to name the ink colour on the incongruent (as opposed to the congruent) trials. It was concluded that the lateral areas represented working memory and the anterior cingulate, the detection of conflict.

1.6.3 Alerting (sustained attention or vigilance)

Alerting concerns "the ability to prepare and sustain alertness to process high priority signals" (Posner & Petersen, 1990, p. 35). Tasks used to study this capacity include long, boring tasks with low target probability and warning signal tasks. There is evidence to suggest that an increase in alertness improves the speed of target detection but at the cost of reduced accuracy (Posner, 1995). Right hemisphere lesions cause difficulty with alerting (Posner & Petersen, 1990). Positron emission tomography (PET) studies of normal, healthy people performing a task requiring sustained vigilance have also shown right hemisphere dominance (Pardo, Fox, & Raichle, 1991). Posner and Petersen combined this observation with that of the close relationship between alertness and attention in suggesting that the norepinephrine (NE) systems play an important role in the alert state. NE is one of the primary catecholamine neurotransmitters in the brain. Many drugs that profoundly affect brain function and behaviour alter the synaptic action of NE, the release of which produces an alerting response (Julien, 1995).

The alerting network will be considered in further detail in the context of sustained attention in the next chapter.

1.7 Independent networks

The independence of the attention networks as outlined was further demonstrated by Fan, McCandliss, Sommer, Raz and Posner (2002) using the Attention Network Test (ANT). This task was designed to assess processing efficiency within each of the three networks and to examine the interaction between the networks. Also, the task was designed to be simple enough to obtain data from children, patients and animals. The goal was to determine if the three networks were functionally independent or if activity in one network was related to activity in another. Other uses identified included studies with event-related functional imaging (to establish the brain areas involved in each aspect of the task) and to measure the influence of various interventions - behavioural and pharmacological - on each of the networks. The authors also wanted a task that could be used as a phenotype for genetic studies designed to determine the sources of individual variation in network efficiency (Fan, Wu, Fossella, & Posner, 2001; Fossella, Posner, Fan, Swanson, & Pfaff, 2002a). The ANT was a combination of the cued

reaction time (Posner, 1980) and the flanker task (Eriksen & Eriksen, 1974). Participants were required to decide whether a central arrow, surrounded by incongruent flankers on fifty per cent of the occasions, pointed to the left or to the right. The arrow appeared above or below fixation and may or may not be accompanied by flankers. Each trial consisted of five events: (1) a fixation period for a random variable duration (400-1600 ms), (2) a warning cue presented for 100 ms, (3) another fixation period for 400 ms, (4) a target and flankers presented until the participant responded but for no longer than 1700 ms, and (5) a posttarget fixation period determined by the duration of the first fixation and reaction time (3500 ms minus duration of the first fixation minus RT). In total, each trial lasted for 4000 ms. Alerting and/or orienting were measured with four warning conditions: no cue, centre cue, double cue, and spatial cue. There were neither alerting nor spatial cues in the no cue condition and the participant was presented only with a fixation for 100 ms. In the cue-cue trials, an asterisk was presented at the location of fixation for 100 ms. The intention of this condition was to involve alerting. In the double-cue trials, there were two warning cues corresponding to the two possible target locations, i.e., up and down. Alerting was also meant to be involved in the double-cue trials but the attentional field was larger. Finally, for the spatial-cue trials, the cue was at the target position all of the time. Both alerting and orienting were thought to be involved in the spatial-cue trials. The time course was the same for cue-cue, double-cue, and spatial-cue trials. Efficiency of the three networks was determined by measuring how alerting cues, spatial cues and flankers influenced reaction times. In a study of 40 normal adult participants, Fan and colleagues found that there was no correlation between any combination of alerting, orienting and conflict resolution (executive), supporting the independence of these networks. However, there was some interaction between alerting and orienting, suggesting they may not be independent in all behavioural studies.

Callejas, Lupiáñez and Tudela (2004) argued that the ANT did not adequately test the interactions between the three attentional networks. In particular, they pointed out that by using different levels of the same variable to measure alerting and orienting there was no way to determine the effect that one had on the other. Consequently, Callejas and colleagues modified the ANT so that on half the trials the fixation point was followed by an alerting signal (a 2000 Hz, 50 ms tone). Callejas and colleagues found a number of significant interactions. Larger congruency and cueing effects were found

when an alerting tone was presented compared to when there was no tone. A larger congruency effect was also found when an invalid cue was presented, i.e., when the cue was presented in a position opposite to the target in comparison to when it was presented in the same place as the target or indeed not at all. Callejas et al. concluded that "even though their functions and neural substrates are different, the three attentional networks act under the constant influence of each other in order to produce an efficient and adaptive behaviour" (p. 227). It would have been interesting, however, if Callejas et al. had conducted the same correlations that Fan et al. did between the three networks. Even though they have established interactions between the three networks, they did not replicate the networks' independence as measured by this modified version of the task.

1.8 Attention as an organ system

In its current incarnation, Posner and Fan (in press) presented this theory with attention as an organ system with its own functional anatomy, circuitry and cellular structure. They followed the dictionary definition of an organ system (Webster's dictionary): "An organ system may be defined as differentiated structures in animals and plants made up of various cells and tissues and grouped with other structures into a system". Posner (2001) likened attention to other physical organ systems in the body such as respiration or digestion, having particular anatomical areas associated with particular operations or functions. There are many brain areas or *sites* affected by attention in the same way that several body areas are affected by other organ systems. For example, attention influences activity in the primary visual cortex. However, attention also has specific attentional networks or *sources* that are responsible for different functions, i.e., orienting to sensory stimuli, executive attention functions, and achieving and maintaining the alert state. Whereas Posner and Petersen (1990) tried to define a system in the brain specific to attention by describing its identity and how it interacted with other systems such as the sensory or motor system, Posner and colleagues (Posner, 2001; Posner & Fan, in press) have taken that system and attempted to qualify it further by comparing it to an organ system. In viewing attention as an organ system, Posner and colleagues are not so much presenting a different model - as before, attention consists of networks of anatomical areas in which specific areas have specific functions

– rather they are breaking it down in much the same way as an organ system can be broken down into differentiated structures, cells and tissues. They are looking at the "smaller picture"; moving beyond specific areas to cellular and synaptic processes.

The tool that Posner and colleagues have used to look at the "smaller picture" is the ANT as described in section 1.7. For example, Fan, Wu, Fossella, and Posner (2001) used the ANT to move beyond specific areas to genetics. Being able to identify specific anatomical areas associated with specific attentional networks meant that Fan et al. could define an appropriate phenotype for a genetic study of attention. The goal of such studies is to better understand individual differences among normal people and also people with various disorders. Fan et al. examined 26 pairs of MZ and 26 pairs DZ same-sex twins to assess the degree to which the different attentional networks was heritable. Heritability is thought to be the proportion of the variance in a population of some measurable trait that can be attributed to genetic rather than environmental factors. Fan et al. used the classical approach to calculate heritability, i.e., by doubling the difference in correlation between monozygotic (MZ) and dizygotic (DZ) twins. They found a high degree of heritability in the network for executive attention (0.89) with a more modest association in the alerting network (0.18). The orienting response showed no evidence of heritability. The authors also replicated these results using an alternative approach to the classical one by applying the structural equation modelling package Mx (Neale, Boker, Xie, & Maes, 1999).

Fan et al.'s (2001) findings supported a role for genes in accounting for variations in efficiency in the executive attention network and, to a much lesser extent, the alerting network. Fossella, Sommer et al. (2002b) went on to examine genetic polymorphisms (meaning many forms or varieties) in four candidate genes (DRD4, DAT, COMT, and MAOA) that are considered to be among the most commonly studied and moreover most often associated with various psychiatric disorders in which an attention deficit is apparent. They also used the relationship of the alerting and executive networks with the neuromodulators norepinephrine (NE; Marrocco & Davidson, 1998) and dopamine (DA; Brozoski, Brown, Rosvold, & Goldman, 1979; Simon, Scatton, & Moal, 1980) as a way of choosing the candidate genes (Fossella, Posner, Fan, Swanson, & Pfaff, 2002). A total of 200 normal, healthy participants who took part in the ANT were genotyped for these candidate genes and two of them – DRD4 and MAOA – were significantly

related to the efficiency of conflict or executive attention. The MAOA gene was also related to the efficiency of the alerting network. These findings were found to be consistent with previous research that showed a significant association between ADHD and the DRD4 gene (Swanson et al., 2001). MAOA associations with ADHD have also been reported (Payton et al., 2001).

Leading on from the studies outlined above, Fan, Fossella, Sommer, Wu, and Posner (2003b) attempted to determine if genetic variation in the DRD4 and MAOA genes associated with efficiency in the executive attention network as measured by the ANT contributed to activity in the anterior cingulate cortex. The anterior cingulate is believed to be part of a network involved in handling conflict between neural areas (Botvinick et al., 2001; Bush, Luu, & Posner, 2000; Fan, Flombaum, McCandliss, Thomas, & Posner, 2003a; MacDonald III et al., 2000). Fan, Fossella, et al. genotyped 16 people for the DRD4 and MAOA genes who had been tested on the ANT while recording their brain activity with event-related functional MRI (fMRI). In each of the two genes identified by Fossella et al. (2002b), Fan, Fossella, et al. found a polymorphism that produced significant differences in the degree of activation in the anterior cingulate during task performance. They suggested that this finding "closes the loop in showing that genes involved in modulating behavioural performance influence brain activity in a node of the network that mediates that performance" (pp. 7409-7410).

1.9 Rehabilitating specific attentional networks

The authors believed that viewing attention as an organ system helped to answer many questions raised in cognitive psychology, psychiatry and neurology. Indeed, recent studies have attempted to rehabilitate specific attentional networks (Robertson, Tegner, Tham, Lo, & Nimmo-Smith, 1995; Sohlberg, McLaughlin, Pavese, Heidrich, & Posner, 2000; Sturm, Hartje, Orgass, & Willmes, 1993; Sturm, Willmes, Orgass, & Hartje, 1997). These studies argued for rehabilitation procedures that take into account not only the attentional operations of the damaged area but also the contribution of the resulting deficits to other attentional functions.

Sturm and his colleagues improved neglect (i.e., an orienting deficit) in a right hemisphere stroke patient by treating her with a task designed to train alertness, termed AIXTENT (Sturm et al., 1993; Sturm et al., 1997). This task consists of a car or a motorcycle presented on a screen. The vehicle is driving and the patient is required to press one of two response keys: one for speed and the other for braking. The instructions are to drive as quickly as possible without crashing into anything. Prior to training, this patient demonstrated severe alertness deficits and neglect symptoms as measured by a visual response time test and four neglect tests (line bisection, line cancellation, letter cancellation, hemifield response test[1]) respectively. Training involved 14 one-hour sessions. After the training, alertness and neglect improvements were observed. Brain activation before and after training was compared using an fMRI analysis of performance during a neglect task similar to the hemifield response test. Before training, there was virtually no activation of the right hemisphere and reduced activation in the left. After training, there was a large right and a much smaller left prefrontal activation, as well as more pronounced left hemisphere parietal focus. Bilateral activation was observed in occipital areas. In addition, there was extended activation of right thalamic structures. It would appear that the alertness training improved the function of at least part of the right frontal alerting network and maybe coactivated parietal and occipital areas (as hypothesised by Fernandez-Duque and Posner (1997)). The functional consequence of this interaction was an amelioration of the neglect symptoms.

The work of Sturm and colleagues (1993, 1997 and see also Sturm & Willmes, 2001) illustrated how an understanding of attention as consisting of separate but related networks, can be used to treat clinical groups. Robertson and colleagues (1995) applied the same understanding, using self-instruction techniques to enhance the level of sustained attention in neglect patients. The patients were instructed to generate a self-alertness signal in response to an external warning signal. The training consisted of a number of stages. In the first stage, the patients started a task and at variable intervals the experimenter would knock on the table. At the same time as knocking, the experimenter said "Attend!" in a loud voice. In the second stage, the patient was required to shout "Attend!" instead of the experimenter as the latter knocked on the

[1] Neglect sub-test of the Test for Attention Performance (TAP) by Zimmermann and Fimm (1995).

table. Finally, the patient would do both the knocking and the vocal command. The command was initially spoken loudly, then subvocally and then mentally. Like Sturm et al., Robertson and his co-workers found that this rehabilitation training improved alertness and also reduced neglect.

Sturm et al. (1997) also developed game-like computerised adaptive training programmes for other attention functions, which they defined as intensity aspects (alertness and vigilance) and selectivity aspects (selective and divided attention). These programmes were studied in patients with left or right focal brain damage of vascular aetiology. Assessment was carried out at the beginning and after two training periods of 14 one-hour sessions each. They found significant specific training effects for both intensity aspects of attention and also for response time in selective attention and error rate in divided attention. Furthermore, their results suggested that the normal functioning of the selectivity aspects of attention depended on the intensity aspects. The findings of Sohlberg et al. (2000) supported this idea. They gave brain injury patients ten weeks of attention process training (APT) and found that, while there was an overall improvement in performance, in some tasks the group that had higher vigilance scores showed better effects of the training.

1.10 Conclusion

"Everyone knows what attention is. It is the taking possession by the mind in clear and vivid form of one out of what seem several simultaneous objects or trains of thought."

William James, 1890

"Attention is not a single entity but the name given to a finite set of brain processes that can interact, mutually and with other brain processes, in the performance of different perceptual, cognitive and motor tasks."

Raja Parasuraman, 1998

In asking what attention is, most reviews begin with the above quote from William James (1890). One good reason for this is because it captures the very essence of what attention is, in simple terms (Coull, 1998). However, together with Raja Parasuraman's definition of attention (1998, p. 3), perhaps the William James quote is more suited to an ending. These quotes span an extremely productive period of research into the study of attention and define this construct at the beginning and end of the twentieth century. They are not so different; James's description of attention is simply more subjective and lacks the information gained by subsequent developments in information-processing and neuroscientific approaches. The integration of these two approaches within cognitive neuroscience - using such techniques as functional imaging and electrophysiology - has greatly advanced attention research and produced viable taxonomies of attention. While it is not yet possible to detail the complete attentional system, there is sufficient evidence to outline a number of networks that subserve attention. By understanding the cognitive neuroscience of normal human attention, we are better placed to understand and treat the consequences of dysfunction within this system. One of these networks - the alerting or sustained attention system - will be the primary focus of this thesis. To this end, the next chapter details the evidence for such a network and its deficit in everyday terms.

2. Sustained Attention, Lapses and Absent-mindedness

2.1 Introduction

Western Canada, 1986: 23 people are killed when a freight train collides head-on with a passenger train. This accident, known as the Hinton train disaster, cost over $30 million in damages, not to mention the human cost. The Canadian government appointed a Commission of Inquiry and they concluded that human error was responsible for the crash. Sustained attention was cited as a major contributing factor, with a work environment that was not conducive to good vigilance performance (Smiley, 1990). Train drivers must remain constantly alert, often under monotonous conditions, and respond immediately to irregular and unpredictable signals. It is therefore unsurprising, in a retrospective analysis of 112 train accidents and near accidents over a three-year period, that sustained attention was found to be "the most salient contributing factor across all incident types" (Edkins & Pollock, 1997, p. 533).

Accidents are perhaps an extreme example of the importance of sustaining attention. However, the capacity of sustained attention is necessary for many everyday activities both in and of itself and in conjunction with other cognitive functions (Fernandez-Duque & Posner, 2001): imagine for instance trying to hold a conversation or drive a car without paying attention. Understanding the maintenance of attention also helps the diagnosis and treatment of clinical disorders of which a deficit in this capacity is apparent, for example, brain injury (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997; Rueckert & Grafman, 1996; Rueckert & Grafman, 1998; Whyte, Polansky, Fleming, Coslett, & Cavallucci, 1995; Whyte, Schuster, Polansky, Adams, & Coslett, 2000; Wilkins, Shallice, & McCarthy, 1987) and attention-deficit disorder (American

Psychiatric Association, Diagnostic and Statistical Manual of Mental Disorders (1994) fourth edition). This chapter traces the development of sustained attention research from the early vigilance studies to more recent studies involving neuroscientific techniques. The evidence for a specialised sustained attention network will be described in relation to its anatomical, physiological and neuropsychological correlates. The subject of sustained attention tasks will then be considered. Finally, the implications of not paying attention will be considered in the context of lapses and absent-mindedness.

2.2 Vigilance

Vigilance research has its roots in industrial studies and studies of lookouts and radar operators in the Second World War (Davies & Tune, 1970). Norman H. Mackworth presented the first comprehensive experimental studies of vigilance performance, defining vigilance as, "a state of readiness to detect and respond to certain specified small changes occurring at random time intervals in the environment" (Mackworth, 1957, p. 389). Mackworth emphasised that vigilance was a state of the nervous system and that an increase in this state resulted in an increase in the ability to make discriminative responses. He recorded in detail the conditions under which radar operators worked and from this devised the Clock Test that simulated those conditions. Most vigilance studies use tests derived from this Clock Test. A clock-hand moved round a blank face in a series of jumps and participants had to detect a double jump of twice the usual distance. This happened approximately 12 times in every half hour. This rare event was relatively easy to detect but Mackworth observed that after the first half hour there was a noticeable decline in the number of targets detected. The rate of such errors increased with each subsequent half-hour block. The term 'decrement' was used to describe this pattern of decline. The vigilance decrement can be contrasted with the overall vigilance level, which reflects accuracy over the task as a whole.

2.3 The performance decrement

A number of theories have been proposed to account for the vigilance decrement. Those theories relating to arousal and signal detection are particularly prominent.

Mackworth (1969) proposed that the decline in vigilance over time was the result of an inability to maintain arousal; as arousal decreased, vigilance decreased. However, the story did not appear to be as simple as that. For example, Ross, Dardano and Hackman (1959) found that skin conductance (a measure of arousal) over a two-hour Clock Test increased in four participants, decreased in three and followed a cyclical pattern in two others. The arousal account of the vigilance decrement was tested in depth by EEG (electroencephalography) and ERP (event-related potential) studies. In the case of ERPs, for instance, this account would be supported if a general reduction in the amplitude of the ERP was apparent rather than a reduction in only some components of the ERP. Initially, findings were consistent with a reduction in cortical arousal over time. Haider, Spong and Lindsley (1964) found a positive correlation between changes in the magnitude of average evoked potentials recorded from the right occipital cortex and the vertex and changes in detection rate during a visual vigilance task. A decrease in amplitude was apparent in an early negativity in the waveform with time on task. This effect was also found with auditory stimuli (Wilkinson, Morlock, & Williams, 1966). However, these early studies had serious problems with their methodology. ERP component analyses were incomplete (Parasuraman, Warm, & See, 1998) and their technique was flawed. For example, the Wilkinson et al. (1966) study was faulted for not controlling eye movements (Koelega et al., 1992).

Later studies did not support the generalised arousal account of the vigilance decrement. Davies and Parasuraman (1977) carried out a complete analysis of the ERPs recorded during a 45-minute visual vigilance task. They looked at four components (N100, P200, N200 and P300) to correct and incorrect responses to signals and non-signals. Signals were flashes of light that were less intense than for the non-signals and participants were required to say 'yes' to a signal and 'no' to a non-signal. Davies and Parasuraman found that only the later ERP components (N200 and P300) reflected detection performance and, as they interpreted it, decision processes in vigilance.

Rohrbaugh et al. (1987) examined the effects of ethanol on visual sustained attention using a discrimination task and also found that only the late ERP components showed a time effect. Koelega et al. (1992) looked at the relationship between time effects on performance and ERPs and found that it manifested itself primarily for components occurring 250-650 ms post-stimulus.

Another account for the vigilance decrement was provided by signal detection theory. When applied to vigilance, this suggested that a participant's performance depended on perceptual and/or decision factors. Decision factors related to the observer's goals, their expectations about the task (e.g., signal probability) and the consequences of a particular response. These factors translated into two measures: sensitivity to signals (d′) and response criterion (i.e., willingness to detect a response; β). These two measures were examined in the context of the vigilance decrement. Generally, it was found that participants' changing criterion over time was more responsible for the decrement than any change in sensitivity or detectability. Baddeley and Colquhoun (1969), for example, tested participants on a 40-minute vigilance task in which they were required to detect one disk that was larger (by 17%) than six other disks in a row. There were four conditions of signal probability: 0.02, 0.06, 0.18, 0.24 and 0.36. When the data was analysed in terms of signal detection theory, the value of d did not change across conditions but the value of β did. As signal probability increased, β decreased and detection rate improved. Performance was clearly linked to changes in participants' response criterion rather than signal discriminability. Williges (1969) provided a possible explanation for this change in response criterion. His 60-minute vigilance task required participants to detect brightness changes in a circular fluorescent tube of long duration (4.65 s) as opposed to short duration (4.00 s). He found that participants began with an intermediate, suboptimal β and then adjusted it as the task progressed according to their performance. They were led to expect a certain ratio of long and short duration brightness changes and as time went on found that they were responding too much or too little, changing to a more stringent or more lax criterion as appropriate. Williges believed that this change in β over time represented more optimal decision behaviour as time progressed.

However, both the mathematical assumptions of signal detection theory as applied to vigilance and its explanatory value for the decrement were questioned (Mackworth,

1970; Taylor, 1965; Swets, 1977). Researchers such as Swets (1977) found that the decrement was not in fact solely due to criterion changes but sensitivity as well. A sensitivity decrement occurred on demanding tasks with a fast event rate, memory load and low signal salience (Parasuraman, 1979; Parasuraman, Warm, & Dember, 1987; See, Howe, Warm, & Dember, 1995).

Given the influence of various task parameters, psychophysical determinants of vigilance became important. Dember and Warm (1979) divided factors affecting vigilance into first-order and second-order factors. First-order factors involved the immediate, physical properties of the stimulus. Arguably the most important of these first-order factors was the background event rate or the non-signal stimulus rate. The event rate determined the speed and accuracy of signal detection and varied with the vigilance decrement (Parasuraman et al., 1998). Second-order factors were related to characteristics of the stimulus derived by the participant based on his or her experience with the task. A prime example of such a factor was signal probability. Parasuraman and Davies (1977) developed a taxonomy of vigilance according to such task parameters and their demands on information-processing. Tasks were organised by such factors as event rate, target discrimination type (successive vs. simultaneous), sensory modality and source complexity. The predictive value of this taxonomy was, however, empirically challenged (e.g., Koelega, 1989).

2.4 Networks of attention

What is the difference between vigilance and sustained attention? The term 'vigilance' is very much linked to the type of task derived from Mackworth's Clock Test in the 1950s: detecting rare targets over long periods of time. Decrements on these tasks are usually not detected before 30 minutes (Mackworth, 1968). Initially, vigilance described performance on such tasks. In contrast, the term 'sustained attention' is associated with activation of a neural network relevant to a specific cognitive task (Oken & Salinsky, 1992). The use of the latter term became more common with the advent of anatomically based models of attention. Models such as that of Posner and Petersen (1990) and Mesulam (Mesulam, 1981, 1990) described networks of attention with independent but interactive neuroanatomical correlates. Both models included a

component related to sustained attention. Mesulam proposed a reticular activating system (including noradrenergic, dopaminergic and cholinergic ascending systems) that provided the underlying level of arousal for attentive processes. Posner and Petersen emphasised the cognitive functions of their model's components rather than their anatomical specificity (Webster & Ungerleider, 1998) and described an alerting network whose function was to maintain the alert state over time. At the time, the brain areas associated with this network were the dorsolateral prefrontal cortex and the parietal cortex, predominantly in the right hemisphere (Pardo et al., 1991; Posner & Petersen, 1990). Similarly to Mesulam's conception of an arousal system, the transmitter norepinephrine (NE) played an important role in the alerting network. The tasks considered to measure alerting capacity were the long, boring tasks with low target probability and warning signals used in the early vigilance research. The work done on vigilance, a concept closely related to arousal and alertness, formed the basis of research into the neural correlates of maintaining attention. Vigilance tasks and methodology were combined with the latest neuroscientific techniques such as PET (positron emission tomography) and fMRI (functional magnetic resonance imaging) and evidence for a specialised network was gathered, increasingly in the name of sustained attention (Cohen et al., 1988; Coull, Frith, Frackowiak, & Grasby, 1996; Parasuraman, Mutter, & Molloy, 1991; Pardo et al., 1991; Rueckert & Grafman, 1996; Sarter, Givens, & Bruno, 2001).

2.5 Sustained attention

2.5.1 Lesion studies

Clinical data seems to suggest that right frontal lesions impair patients' ability to sustain attention (Fernandez-Duque & Posner, 2001). Wilkins, Shallice and McCarthy (1987) tested neurological patients on a counting task. Stimuli were presented in the form of binaural clicks or pulses on the left or right index finger and the patients were required to count the stimuli and report the number in the series when the test ended. There were 2-11 stimuli in each instance. In comparison to patients with left frontal/fronto-temporal, left temporal and right temporal lesions, patients with lesions to right frontal areas performed more poorly on the task when the presentation rate was one stimulus

per second. This was the case regardless of stimulus modality or lateralisation. When the presentation rate was increased to seven per second, this impairment disappeared. Wilkins et al. argued that at the slow rates this monotonous task was more taxing on patients' voluntarily maintained attention. Rueckert and Grafman (1996) compared right and left frontal lesion patients on a continuous performance test (CPT), a traditional task for measuring sustained attention. They found that the error increment over time was larger for right than left frontal patients. This would suggest that right lesions produce a deficit in what was previously described as the vigilance decrement as well as overall ability to sustain attention. Both the Wilkins et al. (1987) and the Rueckert and Grafman (1996) studies provided evidence for right frontal cortex involvement in sustained attention. However, it has been argued that their patients' lesions may not have been restricted to cortical regions, making it "difficult to draw firm conclusions about the laterality and specificity of the observed effect" (Koski & Petrides, 2001, p. 269). Koski and colleagues (2001) explored the role of the frontal cortex in maintaining task performance over time ensuring that their test group excluded any patients with lesions including the corpus callosum or subcortical regions connected to the frontal lobe or lesions extending posteriorly into the pre-central gyrus or temporal lobe. Compared to the control groups (patients with resections from the anterior temporal lobe and neurologically normal participants), right frontal patients were less able to sustain task performance at a consistent level across time as measured by reaction times (RTs). However, the two tasks were primarily selective attention tasks. The first involved responding to a spatially defined target in the presence or absence of a distracting stimulus and in the second participants used cues to direct attention to a peripheral location to detect a target. While there was undoubtedly a sustained attention component in task performance, the observed effects may have been caused by a combination of deficits - including selective attention - rather than sustained attention per se.

2.5.2 Imaging studies

Imaging studies have added to the evidence for right frontal cortex involvement in sustained attention. PET and fMRI have enabled researchers to localise such cognitive functions in normal, healthy participants. One of the first imaging studies of sustained attention, by Cohen et al. (1988), tested normal, healthy participants on an auditory

discrimination task. The task consisted of a random series of tones of varying intensities and participants were required to respond with a button press on hearing the lowest volume tone. Regional brain metabolism determined by PET increased in regions of the right middle prefrontal cortex during auditory discrimination. Lower metabolic rates were observed in the anterior cingulate and superior posterior parietal cortices. Furthermore, a direct relationship was found between metabolic rates in this region and the participants' accuracy on the task. This indicated that prefrontal cortex was important for sustaining attention. In another PET study, Pardo, Fox and Raichle (1991) identified increases in blood flow in the prefrontal and superior parietal cortex primarily in the right hemisphere during performance on simple visual and somatosensory tasks of sustained attention. A particularly interesting aspect of this study was that activation was observed in these areas even when no stimulus actually occurred. The requirement in the visual task was to watch for a change in intensity of a fixation mark that remained invariant over a 2-minute period. Similarly, in the somatosensory task, participants were told to monitor one of their toes for a tactile stimulus that was never presented. Activation was lateralised to the right hemisphere independent of which toe (i.e., left or right big toe) was being monitored. The involvement of frontal regions for sustained attention was again evidenced by Coull, Frith, Frackowiak and Grasby (1996). They measured regional cerebral bloodflow (rCBF) using PET during participants' performance on their rapid visual information processing (RVIP) task. The RVIP task is primarily a test of sustained attention but it also requires working memory for its successful execution. Basically, the task consists of single digits presented pseudo-randomly and participants are instructed to make a mouse-press whenever they detect consecutive sequences of two (e.g., 2-4) or three (2-4-6) digits. In regard to sustained attention, the most interesting comparison in this study was between the RVIP task as described and a control task, which similarly presented digits but simply required participants to respond to the occurrence of single '0's. In comparison to rest (eyes closed), rCBF increases were apparent in multiple areas in the RVIP task including bilateral increases in the inferior frontal gyrus, parietal cortex, fusiform gyrus and the supplementary motor area (SMA) and also right superior frontal gyrus rostrally. In comparison to the control task of simple visual sustained attention, the aforementioned right frontal activations (both inferior and superior gyrus) were no longer significant. Lewin et al. (1996) imaged normal, healthy participants while they performed a task based on Pardo et al.'s visual non-RT measure using fMRI. However, whereas Pardo et

al.'s participants watched for a change in stimulus intensity that never actually occurred, the stimulus in the current study did dim in brightness. Like the PET studies described above, Lewin et al. found right middle frontal gyrus and parietal lobe activation during task performance.

Taken together, the lesion and imaging studies argue for a fronto-parietal network specialised for sustained attention performance, predominantly of the right hemisphere. Furthermore, these studies suggest that sustained attention, like the other attentional functions, is domain general (Fernandez-Duque & Posner, 2001). The sustained attention effects found by the various authors above were found regardless of the content, in visual, auditory and somatosensory domains.

2.5.3 Neurotransmitter studies

Another area of research helping to establish sustained attention as an independent network is that of psychopharmacology. In fact, in some cases, transmitter studies of sustained attention offer greater specificity than anatomical studies. For example, parietal areas appear to be involved in both sustained and selective attention (Manly et al., 2001; Rueckert & Grafman, 1998). At least two cortical neurotransmitters - norepinephrine (NE; also called noradrenaline or NA) and acetylcholine (ACh) - appear to be involved in sustained attention functioning.

NE is one of the primary catecholamine neurotransmitters in the brain. Many drugs that profoundly affect brain function and behaviour alter the synaptic action of NE, the release of which causes an alerting, focusing effect (Julien, 1995). Axons of NE neurons project from the brainstem (locus coeruleus) to nerve terminals in cerebral cortex, limbic system, hypothalamus and cerebellum. Indeed, Posner and Petersen (1990) observed that the right frontal area - where sustained attention would appear to be localised - is of particular importance in the cortical distribution of NE. Drugs that reduce noradrenergic cell firing (e.g., clonidine and guanfacine) block the readiness induced by warning signals in alert monkeys (Marrocco & Davidson, 1998; Witte & Marrocco, 1997). Clonidine increases RT whereas guanfacine decreases it, but both block the warning effect of a preceding cue. Orienting ability is unaffected by both these drugs. Clonidine increases response times in humans as well but the effect is not

unique to alerting; orienting is affected too (Clark, Geffen, & Geffen, 1989). These examples emphasise the importance of NE for achieving the alert state, but research has shown its importance in sustaining attention over time also. Aston-Jones, Rajkowski, Kubiak and Alexinsky (1994) trained monkeys to perform a visual discrimination (vigilance) task in which they had to release a lever they had depressed to start the task upon seeing a target. Stimuli (to which the monkeys were conditioned) were either a vertical or horizontal bar; one orientation would be the target and the other the distractor or non-target. Targets occurred 20% of the time and the monkeys were rewarded with juice upon responding correctly to these targets. Targets were more likely to be missed when they failed to activate the noradrenergic response. In humans, Smith and Nutt (1996) found that clonidine decreased sustained attention leading to more attention lapses. They also found that this effect was reversed by idazoxan, a drug that can block the effects of clonidine, and by increases in environmental arousal (e.g., loud noises). Coull, Robbins, Middleton and Sahakian (1995) tested humans on the RVIP task and found that clonidine impaired performance, particularly during low arousal states.

ACh is a neurotransmitter found in a variety of cerebral locations but the highest concentrations are found in the caudate nucleus, certain brain stem nuclei and cerebral cortex (especially frontal cortex). Evidence from pharmacological studies in animals and humans has suggested that the cholinergic system is involved in attention and arousal processes (Robbins & Everett, 1995; Sarter et al., 2001). Sarter and his colleagues have examined the role of the cholinergic system in rats using a sensitive long-duration vigilance task (McGaughy & Sarter, 1995; Moore, Dudchenko, Bruno, & Sarter, 1992). McGaughy and Sarter (1995) used an operant task that required the animals to respond to the presentation of visual signals by operating one lever and to the absence of a signal by operating the opposite lever. Correct responses were rewarded. The drug chlordiazepoxide (CDP) was administered. CDP is a benzodiazepine receptor agonist which increases GABA function, which in turn inhibits cholinergic neurons in the basal forebrain. The CDP produced an impairment in the rats' ability to discriminate between signal and non-signal events with a consequent increase in the number of misses. There are two types of ACh receptor: nicotinic and muscarinic. Nicotine (a nicotinic receptor agonist) has been shown to increase the speed and accuracy of sustained attention performance, whereas scopolamine (a muscarinic

receptor antagonist) has been shown to decrease accuracy in normal, healthy participants (Wesnes & Warburton, 1984; Wesnes & Revell, 1984). Indeed, "for several decades, human and animal psychopharmacological experiments on the effects of nicotine and muscarinic receptor antagonists...have strongly implicated cholinergic systems in sustained attention" (Sarter et al., 2001, p. 152).

2.6 The importance of task

Generally the kind of task used to test sustained attention performance is a continuous performance test (CPT). There have been many versions of the CPT, often designed with a particular clinical population in mind. For example, Hirshkowitz, De La Cueva and Herman (1993) designed the multiple vigilance test (MVT) as a measure of manifest sleepiness. The stimuli consisted of a pattern resembling the letter 'H' in the standard orientation (target) and the same pattern rotated horizontally by 90° (non-target). Participants – patients with a disorder of excessive daytime sleepiness, obstructive sleep apnoea – had up to two seconds to respond to targets with a spacebar press. In the 30-minute-long task, approximately one third of the stimuli were targets. This task was based on one of the more commonly used vigilance tasks, that of Horne, Anderson and Wilkinson (1983). Horne et al. used an auditory signal detection task consisting of tones of 0.45 and 0.50 seconds in duration. Participants were required to respond to the shorter tones. Hirshkowitz and his colleagues changed the task from auditory to visual stimuli because: (i) auditory stimuli could produce an alerting effect in an inattentive participant, (ii) visual RT tasks were more sensitive to sleep loss (Dinges & Kribbs, 1991), and (iii) keeping one's eyes closed while performing could be conducive to sleep. Results of this experiment showed that patients who fell asleep more rapidly given the opportunity were more likely to demonstrate lapses in response. Performance, however, did not correlate with the participant's self-reported sleepiness.

The lack of a relationship between self, clinician and family reports and lab measures of a construct such as the ability to maintain attention is a common finding. This fact is well-illustrated in the traumatic brain injury (TBI) literature. There is good reason to expect a sustained attention deficit in patients with TBI. Attention disorders are among the most commonly reported cognitive sequelae of this injury (Auerbach, 1986; van

Zomeren & Brouwer, 1987; van Zomeren, Brouwer, & Deelman, 1984; Whyte & Rosenthal, 1993). Patients' families and their doctors report "a broad constellation of symptoms including inattentiveness, slowness, distractibility, difficulty sustaining attention, and difficulty switching and dividing attention" (Whyte et al., 1995, p. 797). In relation to sustained attention specifically, TBI affects brain areas that have been associated with maintenance of the alert state (see Wilkins et al., 1987 and others above). However, studies of sustained attention or vigilance in TBI patients have produced inconsistent results (Brouwer & Wolffelaar, 1985; Loken, Thornton, Otto, & Long, 1995; Parasuraman et al., 1991; Whyte et al., 1995). Whyte et al. (1995) attributed this inconsistency to the confounds inherent in vigilance tasks and designed their own to counteract these. The stimuli in their task consisted of pairs of vertical lines. Fifty per cent of the stimuli were targets (lines of identical length) and fifty per cent were non-targets (one line half as long as the other). Participants were given up to three seconds to respond with a key press. The interstimulus interval was variable, ranging between four and eight seconds. The task in total lasted about 14 minutes. The task took into account the possibility of hemi-spatial neglect by presenting the stimuli vertically on the midline. The stimuli were perceptually simple and presented simultaneously rather than sequentially thus minimising visual and perceptual demands and memory demands respectively. Two aspects of the task allowed Whyte and his colleagues to detect participants' response lapses: the go-nogo format (rather than differential responding) and the fact that it was a limited-hold paradigm, enabling them to differentiate between RT effects and lapses. A slow event-rate was used to ensure they were measuring maintenance of alertness rather than simply speed of processing. Task difficulty for patients and controls was made comparable. RT differences were found between the groups overall and over time. However, there was no group difference in accuracy and performance was not related in any way to available measures of injury severity.

Problems with CPTs have been highlighted not only within TBI research but in other areas of research as well. For example, Silverstein et al. (1998) created the sustained attention test (SAT) to determine the degree of attentional impairment in patients with schizophrenia with a view to tailoring treatment regimes, given that vigilance measures were considered the most successful predictors of treatment outcome (Bowen et al., 1994; Kern, Green, & Satz, 1992). Silverstein and colleagues, however, doubted their

validity as a measure in schizophrenia patients. Key to Silverstein et al.'s criticisms of traditional CPTs was that performance on these tasks often required cognitive functions other than sustained attention. The non-specific nature of the CPT for sustained attention deficits may be exacerbated in populations who perform poorly across a range of tasks. One of the most widely used CPTs in schizophrenia research is the computerised degraded stimulus CPT (DS-CPT; Nuechterlein, 1983). This task consists of brief presentations of single, large numeric stimuli (0-9) that are degraded by a random 40 per cent reversal of black and white pixels. This task has demonstrated an attention deficit in schizophrenia patients and patients and other individuals vulnerable to schizophrenia (Nuechterlein, 1983; Nuechterlein & Dawson, 1984).

What other processes are important for performance on the CPT? For example, Nuechterlein and Dawson (1984) noted that poor performance as manifested in reduced visual sensitivity may be due to the high moment-to-moment demands for processing capacity, rather than simply sustaining attention. Also, the task requires good perceptual organisation (which is deficient in schizophrenia, see for example, Silverstein et al., 1996). Another type of CPT that has cognitive components other than sustained attention are those in which the participant must detect a sequence of events (e.g., an 'A' followed by an 'X'; Cohen & Servan-Schreiber, 1992). There is likely to be a working memory demand in such a task. Recall Coull and colleagues' (Coull, Frackowiak, & Frith, 1998; Coull et al., 1996) rapid visual information processing or RVIP task. In the RVIP task, participants are required to detect consecutive sequences of digits (e.g., 2-4). The authors acknowledge that while this task is primarily a sustained attention task, it also requires both selective attention and working memory for its successful execution.

Robertson, Manly, Andrade, Baddeley and Yiend (1997) devised a sustained attention task that managed to bridge the gap between laboratory measurement and real-life observation of lapses of attention. The task was initially targeted at the TBI population. As outlined previously, there are many reasons to expect sustained attention deficits in this population including family and clinician reports and the neuroanatomical bases of the injury. Robertson et al.'s sustained attention to response task (SART) consisted of 225 numerical stimuli (1-9) presented visually over a 4.3-minute period. Participants were asked to respond with a key press to every number that was presented except for

the number 3 (i.e., the target). This 3 was distributed throughout the 225 trials in a pre-fixed, quasi-random fashion with an 11 per cent probability of occurrence. Each number was presented for 250 ms, followed by a 900-ms mask consisting of a ring with a diagonal cross in the middle. Equal emphasis was placed on speed and accuracy. A practice period of 18 trials preceding testing allowed participants to familiarise themselves with the task.

The SART was tested both within a normal, healthy population and in a comparison between TBI patients and controls. In the first instance, normal participants performed the SART and a more conventional CPT-type task, the Triplets test. The Triplets test was identical to the SART in number of stimuli, target probability, pace and length. It differed in that participants had to detect sequences of digits (e.g., 5-7) and respond with a key press to the target rather than the non-targets. The relationship between these tasks and a real-life measure of attentional and other cognitive failures was tested. A self- and informant-report questionnaire called the Cognitive Failures Questionnaire (CFQ; Broadbent, Cooper, FitzGerald, & Parkes, 1982) was used for this purpose. Accuracy on the SART but not the Triplets test correlated significantly with everyday cognitive failures as reported by the participants themselves and the reports of their relatives and friends. In addition, no effect of age or intelligence was found. These findings suggested that the SART was more sensitive to sustained attention capacity in the normal population than the more traditional Triplets test. Why would this be? One possibility is that performance on the SART was less vulnerable to automatisation than the Triplets test. Monitoring long sequences of stimuli and responding only to infrequent targets can result in less effortful and less controlled behaviour. Tasks such as these do have problems with ceiling effects. Previous attempts to make tasks more difficult have included degrading stimuli as in the case of Nuechterlein's (1983) DS-CPT described above. However, there is the possibility that the discrepancy between SART and the Triplets test was due to a response inhibition component present in the former but not the latter. Since there are likely to be elements of sustained attention and response inhibition in any task of this nature, these two constructs are difficult to disentangle.

Having established a link between the lab-based SART and cognitive failures made in the normal population, Robertson et al. (1997) went on to test the SART's usefulness in

a TBI population. Patients and controls were given a battery of tests to examine the SART in relation to other sustained attention tests, attentional switching and selective attention tests[1]. Groups were also tested on the paced auditory serial addition test (PASAT; Gronwall & Wrightson, 1974; Gronwall & Wrightson, 1975), a widely-used test of attentional deficit following traumatic brain injury. Performance on the SART discriminated between TBI patients and the normal, healthy controls, with the patients making more errors of commission than the controls. Unlike in the normal population, however, performance in the TBI group did not correlate with self-reported cognitive failures as measured by the CFQ. It did correlate with informant-reported failures, suggesting a lack of awareness on the part of the patients. As for the SART measuring the construct of sustained attention, task performance correlated more strongly with other measures of sustained attention than other attentional measures. Also, the SART was associated with injury severity in the form of coma severity as measured by the Glasgow Coma Scale (GCS). There was no relationship between the SART and post-traumatic amnesia (PTA) duration, unlike the PASAT which correlated with both the GCS and PTA duration. This differential correlation is interesting because coma severity has been associated with white matter damage (Wilson, Hadley, Wiedmann, & Teasdale, 1995), which in turn has been associated with poor sustained attention (Stuss & Gow, 1992). The PASAT is a more complex task, probably involving more brain areas than white matter and so less specifically related to coma severity.

2.7 The SART: an overview

Since Robertson et al.'s (1997) original SART study there has been several studies looking at different aspects of the task. These include studies investigating the response

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[1] **Sustained attention** Lottery and Telephone Search subtests of the Test of Everyday Attention (TEA; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1996)

Attentional switching Modified Wisconsin Card Sorting Test (Nelson, 1976), Visual Elevator subtest of the TEA

Selective attention Stroop Test (Trenerry, Crosson, DeBoe, & Leber, 1989), Telephone Search subtest of the TEA

inhibition component of the task (Manly, Robertson, Galloway, & Hawkins, 1999), the relationship between speed and error in participants' performance (Manly, Davison, Heutink, Galloway, & Robertson, 2000), and the task's usefulness in a clinical setting such as Moores and Andrade's (2000) study of dyslexia and a number of studies of brain injury (Manly et al., 2003; McAvinue, O'Keeffe, McMackin, & Robertson, in press). An overview of the SART in the context of these various studies will now be presented.

A recurring question in several of the SART papers relates to response inhibition; that is, the ability to withhold a response. This ability comes into play during SART performance when the participant is required to withhold a response to the target (e.g., the number 3). Robertson et al. recognised that the success of the SART in discriminating between normal, healthy participants and TBI patients where the Triplets test failed may have been due to a difference in the response inhibition requirements of the two tasks. The Triplets test was a more conventional continuous-performance-type test that, unlike the SART, did not require participants to withhold a response but rather to *make a response* when the target appeared. In almost all other respects, the SART and the Triplets test were highly similar with the same number of targets (25), total number of trials (225), pacing (1.15 s per trial), and duration (4.3 min). The SART's success at discriminating between the normal participants and the TBI patients may have been due to the task's greater sensitivity and lower automatisability – as Robertson et al. pointed out, the detection of numerical sequences on the Triplets test was possibly sufficiently familiar to require less sustained attention than withholding a response on the SART – but it could be argued that it was at least as likely that the difference in the two tasks' discriminability was due to the response inhibition aspects of the SART.

Moores and Andrade (2000) recorded a relationship between the SART and the go-gap-stop test (GGST) of response inhibition in the course of comparing controls and teenagers with dyslexia. They wanted to better characterise the attentional deficit associated with dyslexia. The GGST was designed by the first author and involved the presentation of two possible stimuli on a computer; a green circle and a red circle. The green circle was the signal for participants to "go" and to hit the mouse button. However, if a red square appeared on the screen that was a signal for the participants to "stop" and to prevent themselves from hitting the mouse button. The red square

appeared on exactly half of the trials but completely at random so the participant never knew whether they would have to hit the mouse button or not. Also, the interstimulus interval between the green circle and the red square varied so that sometimes it was easy for the participant to stop and at other times it was impossible for them to do so. There was no difference between the teenagers with dyslexia and the controls in terms of their scores on this task but there was a significant relationship between the GGST and the SART for the controls (but not for the teenagers with dyslexia). Moores and Andrade believed that the SART was a more complex task than originally findings suggested and that the response inhibition component was an important part of SART performance.

Manly, Robertson, Galloway, and Hawkins (1999) tackled this issue head on by conducting a series of experiments whose results, they maintained, supported the position that the SART was primarily a measure of sustained attention rather than response inhibition. They achieved this by reducing the sustained attention component of the task and maintaining the response inhibition demands to see how this affected participants' performance. In a series of experiments they manipulated target probability; various versions of the SART were created to test target probabilities set at low (0.11), medium (0.25) and high (0.50) levels. Performance improved with increasing probability for both high and low CFQ scorers. Furthermore, CFQ scores significantly predicted performance on the low probability condition, less so (but still significantly) for the medium probability condition, and not at all for the high probability condition. Manly et al. (1999) concluded that performance on the SART was primarily determined by the participants' ability to endogenously sustain attention. Furthermore, their data demonstrated that reducing the demands on sustained attention while maintaining those on response inhibition abolished the sensitivity of the task to everyday absent-mindedness as measured by the CFQ.

Another issue related to the SART is the role of RTs in performance of the task. The question is could performance on the task be accounted for by a speed/accuracy trade-off rather than simply sustained attention? Differences in RTs did not account for the group differences in SART performance found by Robertson et al. (1997) in comparing normal participants and TBI patients or Manly et al. (1999) in comparing high and low CFQ scorers. However, Robertson et al. found a relationship between speed and

accuracy in that both normal participants and TBI patients responded significantly faster before an incorrect press than they did before a correct withhold. Manly et al. replicated this finding in their high and low CFQ scorers. Consequently, Manly et al. (2000) conducted a detailed analysis of the relationship between speed and accuracy on the SART. They pooled the data from 109 normal participants and found a significant relationship between the number of errors that were made and their RTs to Go trials. Participants who responded faster were more likely to make more errors. Like Robertson et al. and Manly et al. (1999) before them, they also found that participants responded faster before an incorrect press compared to a correct withhold. They also found that participants tended to slow down following an incorrect press and do the opposite – speed up – following a correct withhold.

Manly et al. (2000) concluded that speeding of responses was predictive of subsequent errors of commission and that this finding made it difficult to interpret error rates purely in terms of self-sustained attention. They created a "response-locked" version of the SART. This response-locked version was identical to the original one with the exception that a brief tone (50 ms, 587.3 Hz sine tone) was presented at a fixed interval after trial onset within each trial. The idea was that participants would use the tone to time their responses and that that timing would be set at a level that was associated with accurate performance on the standard SART. This manipulation was successful; participants' responses were "held" at an interval associated with accurate performance on the task. However, error rates did not significantly change and participants' error propensity on the standard SART was predictive of an error on the response-locked SART. Manly et al. (2000) made the point that "if speed factors...were a sufficient account for errors, then it would be expected that error rates would have declined and that the correlation in performance between the two tasks would be small" (p. 176). On the contrary, it seemed as though the results were consistent with a sustained attention account of performance on the SART rather than any relationship between speed and accuracy.

More recently, Manly et al. (2003) described a modified version of the SART designed to place a greater demand on a sustained attention system that was activated during performance on uninteresting tasks. How did they make the SART more uninteresting? The $SART_{fixed}$, as it came to be known, differed from the standard, $SART_{random}$ in the

order that its digits were presented. In the $SART_{random}$, the digits 1-9 were presented in a random fashion and in which the occurrence of the target trial was entirely unpredictable. In contrast, the digits in the $SART_{fixed}$ were presented in the conventional, ascending order (1, 2, 3...9, 1, 2...). Every other element of the task including instructions, visual stimulation, and motoric components remained the same. Manly et al. compared normal participants and TBI patients on their performance on both of these tasks and found that the discriminative power of the $SART_{fixed}$ was stronger than the $SART_{random}$. They argued that while the $SART_{fixed}$ was subjectively easier, this version of the task was more demanding on a system that self-sustains continued performance under conditions of low externally mediated challenge. McAvinue, O'Keefe, McMackin, and Robertson (in press) replicated this finding. However, McAvinue et al. also found that the $SART_{fixed}$ was vulnerable to ceiling effects in normal participants. It may be, as they suggested, that this version of the SART is more suitable for studying populations susceptible to deficit.

Manly et al.'s (2003) PET study of the SART linked the task to the literature on a sustained attention network associated with fronto-parietal areas of the brain, predominantly in the right hemisphere (Cohen et al., 1988; Coull et al., 1996; Koski & Petrides, 2001; Lewin et al., 1996; Pardo et al., 1991; Rueckert & Grafman, 1996; Rueckert & Grafman, 1998; Wilkins et al., 1987). These experiments were conducted in both normal, healthy populations and also in brain-injured ones, using a variety of techniques including PET and fMRI. Manly et al. (2003) hypothesised that the reduced continual challenge and ostensibly lower demand of the $SART_{fixed}$ would be associated with increased activation in the areas previously associated with a sustained attention system in the brain. This hypothesis was supported; significant increases in rCBF were recorded in the dorsolateral prefrontal cortex and the superior/posterior parietal cortex during performance on the $SART_{fixed}$ compared to the $SART_{random}$.

In summary, having considered the research that has been conducted on the SART so far, it can be concluded that the task is a useful tool for studying sustained attention. This computerised, laboratory-based measure has been shown to correlate with a real-life measure of attentional and other cognitive failures, the CFQ. Moreover, it has been shown to be sensitive to attentional deficits in TBI patients. Manly et al. (2003)

associated performance on the task to areas of the brain previously associated with a sustained attention network, namely fronto-parietal systems.

Questions do arise, however, about the exact nature of the SART in terms of response inhibition and the relationship between speed and accuracy. Moores and Andrade suggested "...sustained attention, response inhibition, and speed-accuracy trade-off all contribute to the number of errors made on the SART" (p. 537). However, the work of Robertson, Manly and colleagues as outlined would seem to suggest that performance on the SART was more about successfully maintaining attention than either the ability to inhibit a response per se or speed factors. Of course, these last observations apply only to the standard, $SART_{random}$. The $SART_{fixed}$ is a relatively new version of the task and it has yet to be submitted to rigorous testing. At the same time, it does promise to be a useful tool in terms of studying clinical populations, if not normal ones.

2.8 Making a mistake

Pay attention! How familiar is this phrase? Failure to obey this instruction inevitably leads to a mistake. These mistakes can be as major as the Hinton train disaster described at the beginning of this chapter or as minor as putting on odd socks in the morning. One of the most prominent researchers into these kinds of mistake was James Reason (1977, 1979) who gathered data on absent-mindedness in all its forms from a number of sources, including diaries and questionnaire measures. Such errors can occur when an action is triggered inappropriately, when an action is targeted at the wrong stimulus or when the task in hand is forgotten because of distraction (Reason, 1984). Reason applied his research to a number of practical situations including shoplifting (Reason & Lucas, 1984). He had 166 letters written by 67 individuals who had, they felt, been wrongly accused of theft. They were given a questionnaire - the Absent-Mindedness in Shops Questionnaire (AMSQ) - that asked them how often they had experienced each of 24 varieties of mental lapse while shopping. When the results of the questionnaire were factor analysed, Reason and Lucas discovered that 84.1 per cent of the variance was accounted for by a general absent-mindedness/forgetfulness factor.

Participants in the shoplifting study also completed a measure of general liability to cognitive failures, the Cognitive Failures Questionnaire (CFQ; Broadbent et al., 1982). Scores on the CFQ correlated positively with the AMSQ. This was consistent with previous findings (Broadbent et al., 1982; Reason, 1984) that showed correlations among Herrmann and Neisser's (1978) Short Inventory of Memory Experiences (SIME), the CFQ and split-half versions of an earlier measure of absent-mindedness, the Slips of Action Inventory (SAI). This would suggest that each questionnaire was tapping the same general factor. Indeed large general factors have been found in the AMSQ (Reason & Lucas, 1984), SIME (Reason, 1984) and CFQ (Broadbent et al., 1982; Larson, Alderton, Neideffer, & Underhill, 1997; Matthews, Coyle, & Craig, 1990; Pollina, Greene, Tunick, & Puckett, 1992).

From what does this susceptibility to absent-minded mistakes arise? Reason and Lucas (1984) proposed that it was determined by some superordinate control resource that malfunctions under conditions of stress, manifesting in distractibility, cognitive failures and "an increase in the degree of 'routinization' in the performance of both physical and mental activities" (p. 128). This idea of errors occurring during activities that have become automatic can be related to Shiffrin and Schneider's (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977) theory of information processing. Their two forms of information processing were automatic and controlled, each requiring differing degrees of attention. Automatic processing didn't require conscious processing, had no capacity limitations and could function without control. In contrast, controlled processing demanded conscious attention and had limited capacity. Applying this to absent-mindedness, an error could occur when automatic (or 'routinized') processes interfere with the controlled processes required to perform the task in hand. Alternatively, an error could happen when task demands exceed controlled processing capacity.

Is sustained attention a good candidate for a behavioural correlate of absent-mindedness? Broadbent et al. (1982) found one attentional correlate of cognitive failures. They cited a study by Harris and Wilkins (1981) who instructed participants to watch a film about which they would later be questioned. Behind them was a clock that they could look at whenever they wanted to. Participants were given a series of target times spaced out at three- or nine-minute intervals. When the target time arrived, they were asked to hold up a sheet of paper in front of a TV camera. Harris and Wilkins

found that participants were 15 seconds late on more than ten per cent of trials. High CFQ scorers were more likely to be late than low CFQ scorers. Robertson et al. (1997) established a relationship between absent-mindedness and sustained attention by correlating the number of errors participants made on the SART with self- and informant-reported scores on the CFQ.

Manly et al. (1999) defined absent-mindedness as being "inattentive to ongoing activity, to lose track of current aims and to become distracted from intended thought or action by salient but (currently) irrelevant stimuli" (p. 661). This thesis is primarily concerned with the inattentiveness component of absent-mindedness, a lack of sustained attention. The goal is to establish the range of normal human performance of this capacity including healthy young and old adults as participants. To this end, the next chapter introduces the topic of ageing cognition and what effect age has on sustained attention.

3. Ageing Cognition

3.1 Overview

Earlier chapters introduced the topic of attention and focussed on one of its networks, sustained attention. The anatomical, physiological and neuropsychological correlates of the latter were described in detail. This network – independent but interactive (Fan et al., 2002; Mesulam, 1990; Posner & Fan, in press; Posner & Petersen, 1990) – is important in many aspects of everyday life. Failure to pay attention can result in minor mistakes as well as major ones, such as the Hinton train disaster (Smiley, 1990). A relationship between sustained attention and cognitive failures as measured by the Cognitive Failures Questionnaire (CFQ) has been established (Broadbent et al., 1982; Harris & Wilkins, 1981; Robertson et al., 1997). We wish to describe the range of sustained attention performance in a normal, healthy population and how it changes with age. The current chapter will therefore introduce the topic of ageing and cognition. The theories of cognitive ageing - including processing speed theory and the frontal lobe hypothesis - will be presented and the pros and cons of each considered. These theories will then be applied to sustained attention and finally, the question of whether an age-related deficit in this capacity really exists will be addressed.

3.2 Processing speed theory

Age differences have been observed in a whole host of cognitive processes including memory, reasoning, spatial ability and attention and typically there is a decline with increasing age (Salthouse, 1996b). Timothy Salthouse developed a theory to account for these age differences based on the assumption that a reduction in the speed with which cognitive operations can be executed is a major factor in the decline (Salthouse,

1985b).Two distinct mechanisms were proposed to make the connection between speed and cognition. The first was the limited time mechanism (relevant when there are external time limits or other such restrictions) and the second was the simultaneity mechanism. The basis of the limited time mechanism is "that the time to perform later cognitive operations is greatly restricted when a large proportion of the available time is occupied by the execution of early operations" (Salthouse, 1996b, p. 404). The mechanism is primarily relevant when there are external time limits or other such restrictions. It functions in both simple and complex tasks. The simultaneity mechanism, on the other hand, is based on the idea that the products of earlier processing may be lost by the time later processing is completed. This means that relevant information may no longer be available when needed; this lack of information is manifest in impairments of critical operations.

Salthouse and others (Birren, 1965; Birren, 1974; Cerella, 1985; Cerella, 1990; Myerson, Hale, Wagstaff, Poon, & Smith, 1990) proposed that processing speed was the primary cause of age-related cognitive decline. However, experimentation suggested otherwise. Studies in which old and young participants performed simple reaction time (RT) tasks found that there was little (Salthouse, 1985a; Welford, 1977)or no (Stuss, Stethem, Picton, Leech, & Pelchat, 1989; Welford, 1980) difference between groups. Stuss and his colleagues (1989), for example, compared three groups of participants with ages of 20-29, 40-49 and 60-69 years on a simple and choice a simple RT test and on multiple choice RT tests. The simple RT test required participants to press a button in response to the presentation of a single stimulus randomly selected from among four designs (a circle, square, triangle or cross). The multiple choice tests varied in complexity but were basically of the same design. The same geometric shapes as the simple RT test were used and one shape was designated as the target which appeared 25% of the time. The preferred hand was used to respond to the target, the non-preferred hand to the non-target. Individuals over 60 years of age demonstrated slower RT in the multiple choice tests only and not the simple RT test. To Stuss and his colleagues this suggested that the deficit in ageing was not only a generalised slowing but a more specific impairment in attentional control processes. The latter they submitted as the primary deficit in ageing.

3.3 The frontal lobe hypothesis

One of the most influential theories in the field of ageing and cognition is the frontal lobe hypothesis (FLH), well-described by West (see also, Hartley, 1993; van der Molen & Ridderinkhof, 1998; 1996). The main idea is that due to differential decline in the frontal lobes of the brain, cognitive functions most associated with this area of the brain are more susceptible to the effects of age. This is in comparison to functions associated with posterior and subcortical areas. The two main sources of evidence in support of the FLH are neuropsychological and neurobiological in nature. An age-related deficit is apparent on neuropsychological measures of frontal lobe function (e.g., older adults have been shown to perform more poorly than younger adults on such tasks as the Stroop, Wisconsin Card-Sorting Task and the Tower of London (Phillips & Della Sala, 1998)) whereas on tasks of non-frontal function older adults perform comparably to their younger counterparts (e.g., Ardila & Rosselli, 1989; Whelihan & Lesher, 1985). Perhaps the most convincing body of evidence behind the FLH is, however, from neurobiological studies of ageing. This has been extensively reviewed by Raz (1999) and also by West (1996). The main points of both neuropsychological measures and neurobiology of ageing will now be presented.

3.4 Neuropsychological measures

There is evidence for an age-related decline in several tests typically used to measure frontal function. Several studies, for example, have found age differences using the Wisconsin Card-Sorting Test (WCST; Grant & Berg, 1948). The purpose of the WCST is to test abstract reasoning, particularly participants' ability to identify abstract categories and shift cognitive set (Phillips, MacPherson, & Della Sala, 2002). This is achieved by presenting the participant with four stimulus cards with symbols on them (which differ according to the dimensions of shape, number, and colour) and 128 response cards. These response cards have to be placed under the four stimulus cards until the participant finds a card that matches. The match must be along only one dimension (colour in the first instance). The participant is provided with feedback but he or she can only determine the correct dimension by trial-and-error. When the participant has made 10 correct responses with colour, the criterion is changed to

another dimension (shape) without informing the participant. A shift in cognitive set is required to identify and attend to this change in the correct dimension. Some studies – such as those conducted by Braun and Lalonde (1990) and Haaland, Vranes, Goodwin, and Garry (1987) – found an age-related increase in perseverative errors in particular. As well as finding an age-related decline in perseverative responding, Parkin and Walter (1992) and Spencer and Raz (1994) also found age differences in the total number of errors and the number of categories achieved in the WCST. On the other hand, a study by Boone, Miller, Lesser, Hill, and D'Elia (1990) showed a significant decline in the latter two measures but not in the measure of perseverative responding. More recently, Loveday (1996) found an age-related decline in all three of these WCST measures. She also found significant age-related declines in the ID/ED shift (a component of the Cambridge Neuropsychological Test Automated Battery (CANTAB; Sahakian & Owen, 1992)), which is a similar measure to the WCST.

Other frontal tests that have shown themselves to be sensitive to an age-related decline are the Stroop a classic inhibition paradigm (a classic inhibition paradigm (Smith, Marshuetz, & Geva, 2002); Boone et al., 1990; Daigneault, Braun, & Whitaker, 1992; Whelihan & Lesher, 1985), the Tower of London (which tests a participant's ability to rearrange an array of coloured disks on pegs from a starting position to match a predetermined position (Shallice, 1982); Allamanno, Della Sala, Laiacona, Pasetti, & Spinnler, 1987; Gilhooly, Phillips, Wynn, Logie, & Della Sala, 1999; Loveday, 1996), and measures of fluency (Phillips, 1999; Whelihan & Lesher, 1985). It should be mentioned that it is not entirely clear how exactly age affects fluency measures (Parkin, 1997). Whelihan and Lesher and Phillips found age differences in letter fluency (most commonly administered as the FAS test; Benton & Hamsher, 1976). However, at least two other studies failed to find this difference (Daigneault et al., 1992; Parkin & Walter, 1992). Significant and reliable age effects have, however, been found on more demanding fluency tasks such as category fluency and alternating fluency (Parkin, Walter, & Hunkin, 1995).

In relation to the FLH, many studies have been conducted on age and memory (Phillips et al., 2002). Having reviewed several studies that were conducted into age-related memory loss, Parkin (1997) concluded that, "normal ageing results in a pattern of cognitive decline that particularly reflects loss of functions associated with the frontal

cortex" (p. 184). These studies included both Craik, Morris, Morris, and Loewen (1990) and Glisky, Polster, and Routhieaux (1995) whose work on source amnesia was continued by Henkel, Johnson, and De Leonardis (1998). Henkel et al. (1998) found an age-related deficit in source monitoring which involves judging whether a memory is real or imagined. An everyday example might be mistakenly believing that you have locked the front door on leaving the house when you have not. Specifically, Henkel and colleagues found that the magnitude of this age-related deficit was greater when the items were related either physically (e.g., lollipop and magnifying glass) or conceptually (e.g., banana and apple; in the control condition items were unrelated, e.g., hanger and screwdriver). These items – all common objects - were presented in a line drawing format. The authors argued that this deficit was related to the frontal lobe processes of accessing and evaluating the contextual features of the items. Indeed, it has been shown that older adults are less likely to remember contextual features, for example, whether a test item came from a videotape or from photographs (Schacter, Koutstaal, Johnson, Gross, & Angell, 1997). Support for the involvement of the frontal lobes in source monitoring comes from a variety of neuropsychological studies. Direct evidence comes from several studies of patients with frontal lobe brain damage who have demonstrated a source monitoring deficit (e.g., Janowsky, Shimamura, & Squire, 1989; Schacter, Curran, Galluccio, Milberg, & Bates, 1996; Schacter, Harbluk, & McLachlan, 1984; Shimamura, Janowsky, & Squire, 1990). Support comes from a number of other sources also, including: (1) the observed similarity of source memory deficits in both patients with frontal lobe brain damage and older adults (Janowsky et al., 1989), (2) a study showing an association between older adults low scores on neuropsychological tests of frontal lobe function and a reduction in the subjective vividness of source-specifying features for remembered events (Parkin & Walter, 1992), and (3) correlations between tests of frontal function and older adults' source performance (Craik et al., 1990; Fabiani & Friedman, 1997; Parkin et al., 1995; Schacter, Kaszniak, Kihlstrom, & Valdiserri, 1991; Spencer & Raz, 1994). For example, Craik et al. presented older adults with true and false facts about well-known personalities (e.g., "Bob Hope's father was a fireman" and "Jane Fonda always eats oatmeal for breakfast") and then one week later asked them to state where the source of their information was. The older adults' source performance was measured by the number of false facts that they claimed they had learned from some source other than the experiment. Craik et al. found a significant correlation between these source

performance scores and two frontal tests, the WCST and the Controlled Oral Word Association Test (commonly known as FAS). Henkel et al. added to this evidence by finding a significant correlation between source accuracy and scores on a frontal test battery (as used before by Glisky et al., 1995) which included the WCST, the FAS, the Arithmetic subscale from the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981), and the Mental Control and Digit Span (backward) subscales of the Wechsler Memory Scale-Revised (WMS-R; Wechsler, 1974). However, it should be mentioned that Henkel et al. also found a relationship between source accuracy and medial temporal test scores (including Logical Memory I, Verbal Paired Associates I, and Visual Paired Associates II from the WMS-R and the Long-Delay Cued Recall measure from the California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan, & Ober, 1987). At the same time, when Glisky et al. first used these measures they failed to find a relationship between source accuracy and performance on the medial temporal test battery. They just found the association between source accuracy and frontal test performance. Consequently, only the source accuracy-frontal test performance relationship has been replicated.

Findings from more recent studies are also consistent with the FLH. These studies include Stebbins et al. (2002) and Johnson, Mitchell, Raye, and Greene (2004). Stebbins et al. looked at ageing effects on memory encoding in the frontal lobes. Younger and older adults made semantic (is this word abstract or concrete?) or nonsemantic (is this word printed in uppercase or lowercase?) judgements about words. The younger adults showed greater activation for semantic relative to nonsemantic judgements in several regions, with the greater activation in the left inferior frontal gyrus. This effect was less for the older adults. Stebbins et al. demonstrated a significant association between behavioural tests of declarative and working memory and the extent of frontal activation in older adults. They suggested that age-related deficits in memory may be due to decreased frontal lobe contributions to the initial encoding of experience.

Even more recently, Johnson et al. (2004) demonstrated an age-related deficit in prefrontal cortical function associated with refreshing information. This study represented the culmination of a series of studies that (1) created a paradigm intended to engage the simple, cognitive function of refreshing just-activated information (Johnson,

1992), (2) showed an age-related deficit in this behaviour (Johnson, Reeder, Raye, & Mitchell, 2002) and, (3) used a highly similar version of this paradigm with event-related fMRI to make an association between this behaviour and an area of the left middle frontal gyrus (Raye, Johnson, Mitchell, Reeder, & Greene, 2002). The paradigm involved presenting participants with a series of words which they were asked to read aloud. Verbal response times were compared for items presented once (*read* items), items presented more than once (*repeat* items) and *refresh* items indicated by a dot where the participant had to think of the last word presented and say it aloud again. Johnson et al. (2002) showed that while younger and older adults did not differ in terms of accuracy or response times for repeat items, older adults were markedly slower in saying refresh items. When Johnson et al. (2004) sought to link this behavioural discrepancy between younger and older adults with differences in brain activation, they modified the paradigm in the same way as Raye et al. did, with participants simply reading the words silently on read and repeat trials and on refresh trials being cued with a dot to think of the just-previous word. Consistent with the FLH, the ability to refresh just-activated information – a behaviour associated with activation in an area of the left middle frontal gyrus – was poorer in older compared to younger adults. Furthermore, this behavioural deficit was found alongside a reduction in activity in that same area. Johnson and colleagues concluded that, "it is the frontal aspect of a refresh circuit that may be disrupted by ageing" (p. 131).

3.5 Neurobiology of ageing

Overall, there is evidence for a reduction in gross brain volume with age. This becomes significant when people reach their seventies (Haug & Eggers, 1991). The degree of reduction from young adults' levels is not equal across the brain, ranging from approximately 1% in the temporal, parietal and occipital cortices to 8% in the corpus striatum and 10-17% in the frontal cortex (Haug et al., 1983; Haug & Eggers, 1991). Neuroimaging studies have also shown that the volume of the frontal lobes decreases more than other cerebral areas. Some examples include Coffey et al. (1992) and Raz (1996). Coffey et al. found a 0.55% reduction in frontal volume per year. This reduction was twice as much in frontal areas compared with other areas in the brain. Raz

conducted a review of magnetic resonance imaging studies and found a greater inverse relationship between age and volume in the frontal lobes than elsewhere in the brain.

What causes this reduction in brain volume? It appears to be due to a decrease in neuron size rather than in number (Coleman & Flood, 1987; Haug & Eggers, 1991; Morrison & Hof, 1997). Again, there are regional differences in the degree of this decrease. Shrinkage of neurons in the frontal cortex is more severe and begins earlier than in other areas. Haug and Eggers reported that this shrinkage occurs within the fifth and seventh decades of life. From the age of 65 on, the reduction in cell size became more pronounced in all regions but still more so in the frontal area. This reduction in neuron size or shrinkage is due to a loss of connective processes such as dendritic extensions and numbers of synapses (Gibson, 1983; Huttenlocher, 1979; Uylings & de Brabander, 2002). Masliah, Mallory, Hansen, DeTeresa, and Terry (1993) recorded an age-related reduction in the density of presynaptic terminals that was more prominent in the frontal lobes than other brain areas.

As well as a reduction in gross brain volume and synaptic density, there appears to be "a number of region-specific declines in the concentration, synthesis and number of receptor sites for some transmitters" (West, 1996, p. 273). These include dopamine (DA), norepinephrine (NE) and serotonin (5-HT). The concentration of DA in the prefrontal cortex was found to be reduced by as much as 56% in monkeys of 18 years of age and older, while levels of NE and 5-HT remained the same (Goldman-Rakic & Brown, 1981). A similar pattern was found in the superior and posterior inferotemporal cortex. In parietal and occipital cortices and the hippocampus, in contrast, levels of all three neurotransmitters remained unchanged with age. Goldman-Rakic and Brown also found a reduction in neurotransmitter synthesis in prefrontal, temporal and parietal regions. The role of dopamine in ageing cognition is believed by some to be sufficiently important to warrant an alternative to the FLH, i.e., the dopamine hypothesis. Researchers such as Bäckman et al. (2000), Braver et al. (2001b) and Li et al. (2001) have argued that the loss of DA receptors in the basal ganglia, anterior cingulate and prefrontal cortex can account indirectly for a variety of behavioural age effects (Band, Ridderinkhof, & Segalowitz, 2002).

There is at least one other age-related structural change in the brain and that is an increase in the number of pathological structures (Kubanis & Zornetzer, 1981). Senile plaques, which reflect neuronal degeneration, have been found in greater numbers in the prefrontal and temporal cortices compared to posterior, frontal-parietal, or hippocampal cortices in aged monkeys (Struble, Price, Cork, & Price, 1985). Struble et al. also suggested that the oldest or most mature plaques were found within these two regions. In the same population, Heilbroner and Kemper (1990) also found the highest concentrations of plaques in frontal areas and significantly lower concentrations in the hippocampus and primary visual and auditory cortices. Neurofibrillary tangles constitute another pathological structure associated with ageing. Development in the frontal neurons is believed to disturb cell function, decreasing responsivity to neurotransmitters (Fulop & Seres, 1994).

Taken together, these various measures of age-related decline in the brain – gross brain volume, cell shrinkage, loss of connective processes and an increase in pathological structures – and their apparent localisation to the frontal region more than any other brain area, provide support for the FLH. Relative to single-factor models such as processing speed theory, the FLH is "better grounded in neurobiology and provides more options for explaining disparate changes with age" (Band et al., 2002, p.262).

3.6 Evaluation of the FLH

The above description of age-related biological changes *suggests* concomitant changes in performance. However, that is not necessarily the case. A definite link has not been established. Also, to some extent, loss of neurons is a natural process for the purposes of cleaning up redundant connections – a phenomenon observed in children on a larger scale (Band et al., 2002). Band et al. also suggest that if dendritic loss occurs, then it can be compensated for by improved sprouting of dendrites elsewhere. There is some plasticity in cortical neurons in older adults (Scheibel, 1996; Woodruff-Pak, 1993). In regard to a reduction in synaptic density, it has been suggested that such a change may act in a compensatory capacity. Adams (1987), for example, found an increase in the mean length of the postsynaptic contact zone and a decrease in the mean width of the

presynaptic paramembranous density in the precentral gyrus. He explained these findings as a compensatory mechanism for a reduction in synaptic density.

Greenwood (2000a) evaluated the FLH by testing its basic assumptions, namely that: (1) functions dependent on the frontal lobes undergo age-related decline, (2) functions dependent on non-frontal areas undergo little or no such decline, and (3) brain changes with age are greatest in the frontal lobes. The evidence that she reviewed to test each of these assumptions weakened the FLH considerably, leading her to conclude that, "there is only weak and conflicting evidence that frontal regions are selectively and differentially affected by aging" (p. 705). She selected working memory as a putative frontal lobe function and found that it did decline with age. However, an age-related decline was also observed in several non-frontal functions (visuospatial attention, face recognition and repetition priming). So, while the first assumption outlined above was supported the second was not. Consequently, the usefulness of the model is brought into question. In regard to the neurobiological evidence, Greenwood found that both frontal and non-frontal regions were subject to age-related decreases in regional volume, blood flow and metabolism.

In defence of FLH, West (2000) argued that there is empirical support for the theory's main lines, that age-related declines in cognitive processes supported by the prefrontal cortex emerge at an earlier age and in greater magnitude than declines in processes supported by non-frontal regions. At least two studies have shown that frontal compared to non-frontal supported functions decline earlier. Shimamura and Jurica (1994) demonstrated that performance on the Self-Ordered Pointing Task declines on average at 61 years. This task has been associated with the prefrontal cortex in both humans (Petrides & Milner, 1982) and primates (Petrides, 1995). This can be contrasted with recognition memory, a function associated with the hippocampal complex (Moscovitch & Winocur, 1992) which declines on average ten years later at 71. Furthermore, this behavioural finding is complemented by a neurobiological one. Shaw et al. (1984) found a reduction with age in rCBF (regional cerebral bloodflow) for the prefrontal, but not motor, fronto-temporal, occipital or temporal regions over a four-year period. Similarly, in another PET study looking at age differences in the metabolic uptake of various areas of the brain, Gur, Gur, Obrist, Skolnick, and Reivich (1987) found that blood flow to the frontal lobes is overwhelmingly reduced with age.

There is also empirical support for the assumption that declines in prefrontal functions are greater in magnitude than non-frontal functions. Work with the Stroop has shown that the magnitude of the interference effect is greater for older than for younger adults when colour and word information are integrated at the same location, while the magnitude of the effect is comparable when colour and words are presented at spatially separate locations (Hartley, 1993; West & Bell, 1997). West (2000) takes note of the fact that an extensive meta-analysis of the literature on memory and aging reveals that age-related declines in memory processes associated with the prefrontal cortex (e.g., recall or recollection of the past; Nyberg, Cabeza, & Tulving, 1996) are greater than those memory processes associated with the occipital cortex (e.g., priming, La Voie & Light, 1994).

Despite defending these two basic assumptions of the FLH, however, West (2000) acknowledged that a refinement of the theory may be called for. Questions have been raised by the various imaging studies of age-related decline in cognitive function. They have revealed that age-related decrease in activation of one frontal area is often accompanied by an age-related increase in the activation of another frontal area (Cabeza et al., 1997; Grady, 1998). In this way, the FLH needs to allow for differential decline within the prefrontal cortex and the cognitive processes supported by this region. This idea is explored by Phillips and Della Sala (1998) in the context of intelligence. On the surface, it would appear that different types of intelligence do not decline uniformly with age. Older adults perform poorly on tests of verbal analogies (Jones & Conrad, 1993), the Performance Scale of the Wechsler Adult Intelligence Scales (WAIS; Kaufman, Reynolds, & McLean, 1989), and verbal and spatial abstract reasoning (Schaie, 1995) and yet they perform relatively well on tests of arithmetical reasoning and general knowledge (Jones & Conrad, 1993; Kaufman et al., 1989) and the Verbal Scale of the WAIS (Kaufman et al., 1989). However, if a distinction is made between fluid intelligence (abstract, novel reasoning) and crystallised intelligence (acquired knowledge and interpersonal skills) then the picture becomes clearer. There is evidence to show that fluid intelligence declines with age (Phillips & Forshaw, 1998; Salthouse, 1993) whereas crystallised intelligence does not (Blanchard-Fields, Jahnke, & Camp, 1995; Perlmutter, Kaplan, & Nyquist, 1990). These two types of intelligence are associated with different parts of the frontal lobe; dorsolateral and orbitoventral

prefrontal cortex respectively. Differential decline in fluid and crystallised intelligence is mirrored in the deterioration of these brain areas (De Santi et al., 1995; Haug, 1985; Haug et al., 1983; Haug & Eggers, 1991; Marchal et al., 1992). Even prior to his call for refinement of the FLH in 2000 West (1996) hints at this distinction between the dorsolateral and orbitoventral saying that the latter does not show evidence of decline until the late 7th decade whereas the former shows a straightforward linear decline with age. However, he does not go into any detail. The evidence gathered by Phillips and Della Sala would seem to support this West's later suggestion for refinement of the FLH. As the model would suggest, there may well be differential decline in the frontal lobes of the brain (and in the cognitive functions most associated with this area of the brain) but that this differential decline exists *within* the frontal lobes as well as in comparison to posterior and subcortical areas.

3.7 Memory

One of the most commonly reported impairments in old age is in the ability to learn and remember new information (Della-Maggiore, Grady, & McIntosh, 2002). However, not all memory functions are affected equally, i.e., not all show an impairment. Procedural memory, semantic memory, priming and short-term memory remain relatively spared (Grady & Craik, 2000) whereas deficits in episodic memory (Craik, 1990; Craik & Jennings, 1992; Grady & Craik, 2000), working memory (Craik, Morris, & Gick, 1990) and spatial memory tasks (Uttl & Graf, 1993) are not. It seems that larger age-related deficits are found in memory processes that require greater effort on the part of the participant. For example, tasks that tap primary memory (e.g., holding a sequence of digits, letters or words in mind for a few seconds before repeating the string in the presented order) show relatively small effects of ageing whereas working memory tasks such as mental arithmetic demonstrate large decrements (Craik & Jennings, 1992).

It has been suggested that the elderly can counteract age-related cognitive decline by reorganising brain functions (Cabeza, Anderson, Locantore, & McIntosh, 2002). Imaging studies have shown that higher order functions such as episodic memory are associated with activations in prefrontal cortex (for reviews the reader is referred to Cabeza & Nyberg, 2000; Fletcher & Henson, 2001) and it has been evidenced that this

area of the brain is susceptible to age-related asymmetry reduction. In other words, functions associated with one hemisphere over the other become 'bilateralised' with age. This observation was conceptualised in terms of a model called Hemispheric Asymmetry Reduction in Old Adults (HAROLD; Cabeza, 2002). While support for this model has since been gathered in a number of cognitive domains including working memory (Dixit, Gerton, Dohn, Meyer-Lindenberg, & Berman, 2000; Reuter-Lorenz et al., 2000) and inhibitory control (Nielson, Langenecker, & Garavan, 2002), HAROLD was first observed in regard to episodic memory. Episodic memory refers to memory retrieval of personally relevant events (Tulving, 1983) and it tends to be right lateralised in young adults (Nyberg et al., 1996; Tulving, Kapur, & Craik, 1994). Bilateral prefrontal cortex activations in old adults have been reported in a variety of episodic memory tasks (Bäckman, Almkvist, & Andersson, 1997; Cabeza et al., 1997; Madden, Turkington, & Provenzale, 1999). Cabeza and colleagues (2002) measured prefrontal cortex activity in younger adults, low-performing older adults and high-performing older adults during recall and source memory. Compared to recall, source memory was associated with right prefrontal cortex activity in the younger adults. Low-performing older adults recruited similar right prefrontal cortex regions but high-performing older adults activated bilateral prefrontal regions. This was consistent with a compensatory explanation of asymmetry reductions in old adults. In other words, the low-performing older adults recruited similar regions to the younger adults but used it inefficiently whereas the high-performing older adults counteracted their age-related decline through reorganisation of cognitive networks.

3.8 Sustained attention

There are a number of aspects to the research into age-related memory deficits that would lead us to expect a similar deficit in sustained attention. Larger age-related losses are found with tasks that demand effortful, higher level memory and other cognitive processes (Grady & Craik, 2000) and it seems likely that sustained attention would fall into that category. Also, according to the FLH, sustained attention is a prime candidate for age-related decline (West, 1996). It has been suggested that optimal performance on a sustained attention task is a combination of the ability to focus attention over time, discriminate between target and non-target stimuli, maintain preparatory set and

respond quickly and accurately (Gridley, Mack, & Gilmore, 1986). Each of these skills has been associated with the prefrontal cortex (Fuster, 1980; Posner & Rothbart, 1991). Indeed, numerous studies have suggested a link between sustained attention and the frontal cortex, particularly in the right hemisphere (e.g., Cohen et al., 1988; Pardo et al., 1991; Rueckert & Grafman, 1996). The memory research outlined above suggests that the FLH may need refinement, that it is too simplistic, but it still serves a purpose. Rather than a general decline in processes associated with the prefrontal cortex, there may be differential effects on the variety of processes associated with this region (West, 2000). There is good reason, however, to expect that sustained attention is one of those cognitive processes and as such warrants further consideration.

So, is there an age-related deficit in sustained attention capacity? Previous research has not provided an answer. At least, some studies have suggested that there is a deficit and others that sustained attention is maintained with age. Davies and Parasuraman (1982) reviewed 13 studies that investigated the effect of age on vigilance and found a significant age effect in about half of them. When evident, this age effect manifested itself in hit rate (decrease with age), response time (increase with age) or false-alarm rate (increase with age). Giambra and Quilter (1988) conducted a longitudinal, multi-cohort analysis of sustained attention in adulthood using a Mackworth Clock-Test vigilance task. They found neither age differences nor age-dependent 18-year longitudinal changes in hit rate and false-alarm rate. Plotting response times revealed a U-shaped function with a minimum at middle age. Just the next year, Parasuraman, Nestor and Greenwood (1989) found a difference between young (21-29 years) and older (65-78 years) adults on a more perceptually demanding task. The task was described as a high-event rate digit-discrimination vigilance task presented at three levels of stimulus degradation. Increased stimulus degradation led to a reduction in the hit rate and a greater decline in hit rate over blocks (increased vigilance decrement). Older adults had a lower hit rate and showed a greater vigilance decrement than young adults, especially when stimuli were highly degraded.

An age-related effect in sustained attention performance was also found by Parasuraman and Giambra (1991). They used two 30-minute vigilance tasks, a low event-rate (15 per minute) and a high event-rate (40 per minute) task. The non-target was a square and the target was a slightly smaller square (17 x 17 mm as compared to

20 x 20 mm). Participants - young (19-27 years), middle-aged (40-55 years) and old (70-80 years) - were required to press a spacebar in response to the target. The probability of a target was 0.13 for the low event-rate and 0.05 for the high event-rate condition. This meant that signal probability (but not number of signals) was confounded by event rate. However, studies in which signal probability and event rate were varied orthogonally have shown that the effects of event rate on detection performance are independent and stronger than signal probability within the ranges used by Parasuraman and Giambra (Parasuraman & Davies, 1976). Older participants' detection accuracy was poorer than that of younger participants' for both low and high event-rate tasks and this group difference remained constant over 20 sessions.

However, Giambra (1997) tested the possibility that this difference was due to non-sustained attention components of the task such as perceptual and information-processing components. In replicating Parasuraman and Giambra's high event-rate version of their task, Giambra found no age effect on detection accuracy or decrement. He also manipulated target-non-target discriminability and event exposure time to minimise the influence of these non-sustained attention components of the task but the effects were minimal. He attributes the discrepancy between Parasuraman and Giambra's study and his own to a possible sampling bias in the 1991 study in that their participants may have been disproportionately sampled from the poorer performing end of the sustained attention capacity distribution. It would be difficult to claim representativeness with a sample size of six. Giambra had a much larger sample (n = 158) and so his results are more likely to be reliable in that regard. Also, the earlier study did not report visual difficulties, a not unlikely affliction in old age, and this may have contributed to their poor performance rather than any sustained attention deficit.

More recently, Berardi, Parasuraman and Haxby (2001) conducted a study into overall vigilance and sustained attention decrements that attempted a very careful methodology to avoid the possible confounding factors of previous studies. For example, they placed great importance on evaluating elderly participants' health and excluding those whose health was found to be less than optimal. The old participants' performance on a high event rate digit-discrimination task was compared to that of middle-aged and younger participants. They found no age-related effects in overall vigilance or in time on task. They argued that their results "consistently demonstrate across several dependent

measures that overall vigilance (the overall level of performance on a sustained-attention task), and the ability to sustain attention over time (the vigilance decrement), do not decrease in optimally health-screened...elderly subjects" (Berardi et al., 2001, p. 37).

It can be concluded that there is some disagreement in the literature over whether an age-related deficit in sustained attention exists or not. This may be a product of task. In relating sustained attention to the FLH, West (1996) observed that preserved sustained attention capacity in older adults tends to be found on tasks that place fewer demands on a potentially limited capacity attentional mechanism. For example, Giambra and Quilter's (1988) study used highly discriminable targets and non-targets, short testing periods and relatively low event rates. In contrast, a deficit is often only demonstrated on more demanding tasks such as Parasuraman et al.'s (1989) perceptually demanding task. However, this increases the possibility that age-effects are due to non-sustained attention components of the task such as perceptual and information-processing components rather than sustained attention.

3.9 Concluding remarks

There are two dominant theories of cognitive ageing: processing speed theory and FLH. Of these two, emphasis has probably shifted to the FLH with its support in neurobiology. However, there are weaknesses in the FLH's arguments (Greenwood, 2000a) and a refinement of the theory is called for (West, 2000). If we accept, nevertheless, that the FLH is "a useful but incomplete neuropsychological model of cognitive ageing" (West, 1996, p. 289) then it can be applied to sustained attention research. This capacity has been associated with prefrontal cortex (e.g., Pardo et al., 1991) and is therefore a likely candidate for age-related decline. Experimentation has, however, failed to ascertain if a deficit exists for definite. Further research is required to shed more light on the topic of sustained attention in ageing. Consequently, this topic is addressed in experimental chapters 7-9 of this thesis.

4. Sustained Attention and Cognitive Failures

4.1 Overview

Most measures of human cognitive performance take place inside the laboratory. How much can performance, e.g., on a sustained attention task, on a computer in a laboratory relate to real-life? A direct relationship is difficult to establish. However, correlating task performance with a questionnaire measure can make an association between performance in the laboratory and in everyday life. This is important because the assessment of impairment not only involves tests but also taking note of how that impairment affects everyday functioning (Miotto, Feigenbaum, & Morris, 2000). Robertson et al. (1997) established a link between the Sustained Attention to Response Task (SART) and the Cognitive Failures Questionnaire (CFQ; Broadbent et al., 1982), thereby measuring the consequences of not paying attention both inside and outside the laboratory. The aim of the studies reported in this chapter was to examine in detail the relationship between absent-mindedness as measured by the CFQ and sustained attention as measured by the SART. The first study, "Cognitive failures and the SART", sought to replicate the findings of Robertson and colleagues in regard to the CFQ and the SART in a young, healthy population. In addition to the standard, $SART_{random}$, participants were tested on the $SART_{fixed}$. The second study, "Factor analysis of the CFQ", was conducted to determine if the CFQ was unidimensional or multidimensional and if the latter, how this affected its relationship with the SART. Drawing the findings from the two parts of the study together and considering their implications for further experimentation conclude the chapter.

4.2 Introduction to Study 1: Cognitive Failures and the SART

4.2.1 Absent-mindedness

What does it mean to be absent-minded? Subjectively, it means forgetting what you're doing in the middle of doing it, needing to be reminded of someone's name a minute after they've introduced themselves, leaving behind the peelings and dumping the potatoes in the bin, misplacing the car keys...the list is endless. It is not difficult to think of examples of absent-mindedness in everyday life. However, it is difficult to describe this phenomenon objectively, to quantify it. After all, absent-mindedness could be a function of one or several factors.

James Reason (1977, 1979) studied absent-mindedness in all its forms from a number of sources, including diaries and questionnaire measures. From this work, Broadbent, Cooper, FitzGerald and Parkes (1982) observed that absent-minded slips or lapses involved perceptual failures, or failures of memory or actions which are misdirected; "the common element is that there is a departure from the normal smooth flow of function, and events do not proceed in accordance with intention" (p. 1). Motivated by Reason's research, they developed the Cognitive Failures Questionnaire (CFQ) to test the different types of cognitive failure and bring them all together. The CFQ was presented as an instrument to study individual differences in this attribute, to have external validity and a definite clinical usefulness. The CFQ represented a departure from earlier measures of absent-mindedness, e.g., Herrmann and Neisser's (1978) Short Inventory of Memory Experiences, because it went beyond memory failures.

4.2.2 Cognitive failures in real-life

On a practical level, the CFQ has been applied in a variety of situations. Reason and Lucas (1984) used it to study absent-mindedness in shops. The purpose of the study was to determine if shoplifting was the result of absent-mindedness or wilful intent. Participants were given the CFQ and the Absent-mindedness in Shops Questionnaire (AMSQ), the latter consisting of three groups of items representing risky,

embarrassing/costly and nuisance lapses. They found that the CFQ correlated significantly with the AMSQ and that risky lapses (such as those that might result in a shoplifting charge) were reported as being extremely rare events. Embarrassing and nuisance lapses were reported as occurring more frequently. The authors concluded that most shoppers knew what they were doing and were well aware of the consequences of risky lapses. The correlation of these two measures suggested that they tapped the same general absent-mindedness factor.

Larson and Merritt (1991) used the CFQ to see if accidents could be predicted. A large sample of young men (159 Navy recruits) filled in the CFQ and answered two questions related to their driving records: (1) "How many traffic tickets for moving violations have you received?" and (2) "How many times have you been cited for causing a traffic accident?" There was no difference in CFQ scores among those who had received tickets or caused accidents and those who had not until participants with extremely bad driving records were excluded. This relationship, however, was only revealed following the removal of these extreme cases so Larson and Merritt ran the experiment again in a second, independent sample. This time the CFQ differentiated between participants who had been cited for causing an accident and those who had not, both before and after extremely bad drivers were excluded. No significant differences were found between those who had received tickets and those who had not. However, Larson and Merritt felt that this was to be expected given that tickets are often the result of deliberate or planned actions. Accidents were more likely to occur as the result of absent-minded mishap, as was suggested by the results.

These studies illustrate just a couple of the practical applications of the CFQ but they also provide some insight into what exactly the CFQ is measuring. The Reason and Lucas (1984) study would suggest that the questionnaire is tapping into some general, absent-mindedness factor and that people who score highly on it are more susceptible to errors. The questionnaire's relationship with the AMSQ and also with driving accidents suggests further that it addresses real-life errors, not just ones assessed in the laboratory. However, Larson and Merritt's (1991) research also suggests what kind of cognitive performance the scores are based on. Reason (1988) proposed that CFQ scores were related to the way in which attention was deployed rather than attentional capacity. He believed that a high score on the CFQ reflected a cognitive management style of

inflexible attentional focus. Under these terms, Larson and Merritt's accident-prone Navy recruits who scored highly on the CFQ could be said to have a locked, rigid mental focus, leaving them unaware of surrounding conditions or hazards while in the driving seat.

4.2.3 Clinical applications

Mahoney, Dalby and King (1998) presented a study relating the CFQ to multiple measures of daily stress and anxiety. All measures from 138 volunteers were positively correlated, leading Mahoney and colleagues to conclude that everyday cognitive slips or lapses are associated with stress or emotional state and furthermore, that they may be early indicators of an emotional disorder. This result was evidence, they concluded, for the CFQ's usefulness in testing a clinical population. However, that position has not always been upheld. Studies looking at the incidence of cognitive failures in brain injury patients, for example, have produced mixed results. Brain damage, especially frontal lobe brain damage, increases a patient's susceptibility to stray from their intended goals and make errors (Shallice & Burgess, 1991) so one would expect that the CFQ would differentiate between patients and controls. However, when Miotto, Feigenbaum and Morris (2000) administered the CFQ to patients with focal frontal and temporal lesions they found no difference in CFQ scores among the patient groups or in comparison with healthy controls. Seemingly in contrast, Wagle, Berrios and Ho (1999) found a significant difference between patients with an organic disease (predominantly with probable Alzheimer's or frontal lobe dementia) and patients in whom organic disease had been ruled out (mostly patients complaining of anxiety or depression). However, there appears to be a number of methodological problems with this study, e.g., the absence of a control group, that cast doubt on the findings. In addition, there was a confounding factor of age. Within the organic disease group there was a significant age difference between the dementia patients and all other patients (the dementia patients were older). There was also a between groups difference in age in that the functional patients (i.e., those with anxiety and depression) were significantly younger than the organic patients. Age in and of itself has an effect on CFQ scores. Wagle and colleagues suggested that more investigation was needed before it can be used as a standard measure in clinical practice and this is probably true. Moreover,

studies investigating the usefulness of the CFQ in a clinical setting need to take care of their methodology before reaching any conclusions.

4.2.4 Cognitive failures and ageing

It might be expected that people report a higher incidence of cognitive failures as they age. This is, however, not the case. In an elderly sample CFQ scores correlated negatively with age: participants over 60 reported fewer lapses the older they got (Rabbitt & Abson, 1990). Interestingly, Rabbitt and Abson (1990) found that participants in their 50s were reporting more failures than their older counterparts. They attributed this in part to life-style and environment changes. 50-year-olds are still in the workplace, leading active and demanding lives. Lapses are inevitable but their relatively accurate memories and perhaps apprehensiveness about ageing may make them more likely to recall their mistakes. In contrast, people in their 60s and 70s are starting to live their lives at a slower pace and may begin to forget their lapses. Mahoney et al. (1998) compared cognitive failures across four age groups: 16-29 years, 30-45 years, 46-60 years and 61+ years. They found that age over-all was not correlated with cognitive failure. They did find, however, that the 30-45 year-old participants reported more cognitive failures than the oldest and youngest groups. Mahoney and colleagues explained this finding in terms of stress and anxiety because 31-45 year-olds reported higher state and trait anxiety than other age groups as well as greater mental distress. Whatever the reason for increased cognitive failures in the middle- to late middle-aged groups in both these studies, it does suggest the need for caution when interpreting the results of this questionnaire. This does not, however, diminish the CFQ's usefulness in testing the elderly. Martin (1986) found no significant difference between young and old groups on the CFQ but suggested that overall similarity in performance between groups masked significant differences (in either direction) for individual test items. This was indeed the case. Discriminant analysis revealed that young and old groups were significantly differentiated in their responses to seven items. The old were less prone than the young to reading distraction, laterality error, colliding, word misuse, daydreaming and conversational failures; the converse was true for forgetting names. This is worth taking into consideration in testing young and old participants' cognitive failures.

4.2.5 Performance correlates of the CFQ

In testing the young and old in everyday memory and cognition, Martin (1986) gave her participants the Everyday Memory Questionnaire (EMQ) and the Everyday Attention Questionnaire (EAQ) as well as the CFQ. In the EMQ there was a list of 37 items labelled "Things One Remembers" and participants were required to circle a response from (1) Very poor to (5) Very good. Items included faces, appointments, dreams and television programmes that you have seen. The EAQ was rather more complicated, consisting of 18 items divided into four groups. For example, the first group included such items as "humming or whistling to yourself" and "television" and participants were asked how easy they would find it to pay attention to these items while doing some task they found easy (e.g., peeling potatoes). Participants had to circle one of five numerals like the EMQ but the numerals represented different things for different groups of items (for the first group, (1) Very distracting to (5) Very helpful). Martin found that the CFQ correlated significantly with the EMQ but not the EAQ. The EAQ did not correlate with the EMQ either. She interpreted this finding as evidence for cognitive failures being related more to everyday memory than attention.

However, a number of studies have established a link between the CFQ and attention tasks, specifically those that measure divided attention (Harris & Wilkins, 1981; Martin & Jones, 1983) and selective attention (Meiran, Israeli, Levi, & Grafi, 1994; Tipper & Baylis, 1987; Vom Hofe, Mainemarre, & Vannier, 1998). In the original CFQ study, Broadbent et al. (1982) asked the question of what exactly were the correlates of the CFQ. They were looking for an objective measure to correlate with the CFQ with a view to "escape the problem of unwillingness to admit error" (p. 12). The only such measure that they managed to find was an attention measure. Harris and Wilkins (1981) required participants to watch a film about which they would later be questioned. Behind them was a clock that they could look at whenever they wanted to. Participants were given a series of target times spaced out at three- or nine-minute intervals. When the target time arrived, they were asked to hold up a sheet of paper in front of a TV camera. Harris and Wilkins found that participants were 15 seconds late on more than 10 per cent of trials. High CFQ scorers were more likely to be late than low CFQ

scorers. The CFQ failed to correlate significantly with a whole host of memory measures including immediate memory for nine-item lists visually or acoustically presented and longer-term memory for categorised material. This is contrary to what Martin's (1986) results suggested but then maybe that was because of the items involved in the EAQ.

Other studies have supported the idea that the CFQ relates better to attention rather than memory measures (Meiran et al., 1994; Tipper & Baylis, 1987; Vom Hofe et al., 1998). These studies have explored the role of inhibition in selective attention. Tipper (1985) and Tipper and Cranston (1985) proposed that active inhibition of distractors was one of the mechanisms of effective selection. Tipper and Baylis (1987) hypothesised that high CFQ scorers would be less efficient in their selection of a target and that this was due to their inability to inhibit distraction. The first part of Tipper and Baylis's hypothesis was tested using an interference task: participants were presented with a target word in the centre of a screen surrounded above and below with distractor words and required to name the category that the target word belonged to. High CFQ scorers took longer to respond to the target word than the low CFQ scorers showing that they were less efficient selectors. The second part of their hypothesis – that this poor selection was due to an inability to inhibit the distractors – was tested with a negative priming task. This meant that the target word in a probe display (presented second) was either semantically related or identical to a distractor word in a prime display (presented first). If negative priming was successful then the participants would be slower to respond to the target in the probe display, meaning that they had better inhibited the distractors in the prime display. As expected, the high CFQ scorers were faster to respond to the target word in the probe display than the low CFQ scorers. Tipper and Baylis were therefore able to conclude that the less efficient selection seen in high CFQ scorers was associated with inhibition of distractors.

A subsequent study by Meiran, Israeli, Levi and Grafi (1994) supported this position. They categorised CFQ items according to Norman and Shallice's model of cognitive control (Norman & Shallice, 1986, see chapter 1 for an outline of this model). For example, item 10 "Do you lose your temper and regret it?" was categorised as false triggering of action schemas. They identified two mechanisms behind these categories of cognitive failures: triggering efficiency and distractibility. Under the terms of

Norman and Shallice's (1986) model, the triggering efficiency mechanism was related to failures in executing intended actions and executing actions that were automated and unintended instead. The distractibility hypothesis was more in line with Tipper and Baylis's (1987) idea that high CFQ scorers are more distractible by irrelevant information than low CFQ scorers. Distracting information could lead to the activation of unintended schemas, resulting in the loss of activation in intended schemas. Meiran et al. (1994) measured schema activation efficiency by using tasks that required participants to shift quickly between alternative action modes. An example of these tasks was the Global/Local task (Navon, 1977) in which participants were required to name letters composed of small different letters. In the global condition participants were asked to name the large letter while ignoring its component letters whereas in the local condition they were asked to name the component letters. These two conditions served as the baseline for the critical condition in which participants had to shift continually between global and local modes. Other tasks included shifting from one target colour to another (adopted from Allport, Tipper, & Chmiel, 1985) and shifting between category names. In each case, reaction times (RTs) were slower in the shift condition and participants who were relatively fast shifters in one task were fast in the others. Meiran and colleagues factor analysed the data gathered from these tasks and found that they tapped two distinct attentional functions: shifting-speed and focused-attention performance speed. Only focused attention time correlated significantly with CFQ scores, suggesting that high CFQ scorers were less able to focus attention (and ignore distraction) than the low CFQ scorers. Hence the distractibility hypothesis and the work of Tipper and Baylis (1987) were supported.

Vom Hofe et al. (1998) conducted a study that suggested that selective attention was related to the CFQ, consistent with Tipper and Baylis (1987) and Meiran et al. (1994). However, they believed that interpreting the relationship in terms of active inhibition of distractors was inaccurate. They arrived at this conclusion following comprehensive testing of participants on a wide range of inhibition tasks. They adopted a correlational approach as opposed to comparison of extreme groups (like Tipper and Baylis and Meiran and colleagues). Participants completed the CFQ and Reason's (1984) Short Inventory of Minor Lapses (SIML), a 15-item questionnaire comprising general

descriptions of 12 of the most frequently occurring slips and lapses over a one-year period. They also were tested on two negative priming paradigms[1], two memory tasks with inhibitory control components[2] and two switching tasks[3]. In regard to the CFQ, there was a strong correlation between its scores and the Tipper negative priming task and the Trails switching task and a weak correlation with the Stroop. The correlation with the Tipper and Trails task – in which participants have to join alternately two series of numbered and lettered squares – supports the idea that the CFQ is related to inhibition. However, on closer examination, Vom Hofe et al. failed to find an overall negative priming effect on the Tipper task and also a large number of participants had the highest scores on the selective attention condition. Together with the weak correlation between the CFQ and the Stroop, the authors felt that the results were better interpreted in terms of a selective attention ability than in terms of active inhibition. The CFQ, Vom Hofe et al. concluded, was linked to "some fairly general trait related to the ability to attend to focal stimuli while simultaneously ignoring task-irrelevant distractions (i.e., a selective attention ability)" (p. 53).

4.2.6 Cognitive failures and the SART

The SART, as introduced in chapter 2, was presented by Robertson et al. (1997) as a measure of sustained attention that correlated significantly with cognitive failures. High CFQ scorers in the normal, healthy population made more errors of commission on the SART. In other words, participants who reported themselves as making frequent absent-minded mistakes in real-life made them in the laboratory too. Furthermore, performance on the SART as measured by errors of commission discriminated between healthy controls and traumatic brain injury (TBI) patients. This was somewhat of a success, given the mixed results of previous studies (Brouwer & Wolffelaar, 1985; Loken et al., 1995; Parasuraman et al., 1991; Whyte et al., 1995). In addition, Robertson et al. administered a more conventional, perceptually-based vigilance task, the Triplets test, which failed to discriminate between healthy control and TBI groups. However,

[1] The Stroop (1935) color-word naming task and the Tipper localization task.
[2] Direct-forgetting task and Proactive Inhibition Release Test (Moscovitch & Winnocut, 1983).
[3] The Random Digits Generation Task (Baddeley, 1996) and the Trail Making Test (Halstead-Reitan, 1958).

was performance on the SART really a measure of sustained attention or something else? The prime candidate for an alternative was response inhibition; errors of commission could be due to an inability to inhibit a response rather than an inability to maintain attention. This could explain the discrepancy between the SART and the Triplets test; why one succeeded where the other failed. Robertson et al. cited a series of Australian studies that showed a deficit at the response selection stage of information processing following closed head injury (Murray, Shum, & McFarland, 1992; Shum, McFarland, & Bain, 1994; Shum, McFarland, Bain, & Humphreys, 1990). SART correlated more strongly with other measures of sustained attention than other attentional measures, even ones supposedly sensitive to response inhibition. However, Robertson et al. could not say definitively that the SART related more strongly to sustained attention than response inhibition.

Subsequent studies of the SART have provided more support for the task as a measure of sustained attention. For example, Manly, Robertson, Galloway and Hawkins (1999) reduced the sustained attention component of the SART while maintaining the response inhibition component and studied what effect that had on performance and the task's sensitivity to absent-mindedness. The effects of manipulating target probability and continuous performance on high and low CFQ scorers' performance were examined. On the premise that sustained attention was taxed by long inter-target intervals, target probability was increased. Performance improved across three levels of increasing target probability – 0.11, 0.25 and 0.50. Furthermore, the distinction between high and low CFQ scorers disappeared as the frequency of the targets increased. To test the effect of duration of continuous performance, SART blocks of the standard duration (225 trials) were compared with ten blocks of 45 trials each. Each 45-trial block was followed by an opportunity for the participant to rest. Comparison of errors of commission over two continuous blocks of 225 trials and over ten blocks of 45 trials revealed no statistically significant difference. Reducing the need for self-sustained attention while maintaining the requirement to withhold responses enhanced performance and eroded sensitivity to cognitive failures. This finding supported the position that the SART was primarily determined by a capacity to sustain attention.

Moores and Andrade (2000) demonstrated, however, that even if the SART was predominantly a measure of sustained attention, it did have a response inhibition

component. In testing dyslexic teenagers, they found a strong relationship between errors of commission on the SART and the go-gap-stop test (GGST) of response inhibition in their normal, healthy control group. (This relationship was not apparent in the dyslexic teenagers.) Then again, evidence provided by Manly, Davison, Heutink, Galloway and Robertson (2000) further supported the SART's original aim, viz., to measure sustained attention. They devised a response-locked version of the $SART_{random}$ in which participants were instructed to synchronise their response to a tone produced at a fixed interval after trial onset and within each trial. This manipulation reduced the inhibitory component of the SART. The participant's chances of successfully withholding to a NoGo trial (the number 3) should have been increased because the NoGo trial preceded the tone that acted as a signal to respond. However, even though the response inhibition component of the task was reduced, error rates did not change. This implied that the role of inhibition function in performance on the SART was somewhat less than that of attention.

To reach a conclusive answer in regard to sustained attention and response inhibition and the SART, it would be necessary to find a response inhibition task to compare the SART to. However, as Robertson et al. observed in the first SART paper (1997), "a problem with doing this…is that it is difficult to conceive of such measures that are not themselves vulnerable to a sustained attention to response argument or that are not contaminated with extraneous demands" (p. 756).

A review of the findings of previous SART studies – error rates and RTs – is presented for the purpose of comparison in Table 4.1 below.

Table 4.1: A review of the findings of previous SART studies

Study	Group	Mean Error, max. 25 (S.D)	Mean RT, ms (S.D)	
			4 presses prior to correct withhold (S.D.)	**4 presses prior to incorrect press (S.D.)**
Robertson et al. (1997)	Normal	4.0 (3.2)	397.1 (84.9)	305.9 (24.2)
	TBI	7.6 (4.8)*	372.8 (78.3)	300.4 (43.6)
Manly et al. (1999)	Normal, high CFQ	8.27 (4.03)	366.1 (53.82)	348.38 (74.04)
	Normal, low CFQ	4.60 (3.40)*		
			Go trial (S.D.)	**NoGo trial, incorrect press (S.D.)**
Moores & Andrade (2000)	Normal, mean age = 15.0	10.3 (4.6)	373 (96)	282 (37)
	Dylexia, mean age = 14.6	14.8 (2.8)	326 (50)	278 (45)
	Normal, mean age = 18.8	11.0 (4.7)	297 (49)	253 (40)
	Dylexia, mean age = 19.0	13.7 (3.3)**	334 (54)	295 (43)
			Go trial (S.D.)	
Manly et al. (2000)	Normal	6.36 (4.36)	375 (65)	
Manly et al. (2003)	Normal, $SART_{random}$	7.19 (5.54)	421 (104.79)	
	TBI, $SART_{random}$	11.11 (6.57)*	450 (113.71)	

Study	Group	Mean Error, max. 25 (S.D)	Mean RT, ms (S.D)
			Go trial (S.D.)
	Normal, $SART_{fixed}$	1.12 (1.31)	330 (113.3)
	TBI, $SART_{fixed}$	6.95 (5.94)	398 (88.6)
McAvinue et al. (in press)	Normal, $SART_{random}$	8.94 (4.94)	415.15 (81.85)
	TBI, $SART_{random}$	10.06 (5.3)	441.78 (96.5)
	Normal, $SART_{fixed}$	4.35 (5.37)	327.65 (113.74)
	TBI, $SART_{fixed}$	7.22 (6.00)*	390.48 (90.80)

*Significant between-groups difference.

**Significant difference between normal group and dyslexia group. There was no effect of age.

4.2.8 Aim of the current study

The aim of the current study was to replicate the findings of Robertson et al. (1997) who established a relationship between sustained attention and reported incidences of cognitive failure. In addition to the original, $SART_{random}$, participants were tested on the $SART_{fixed}$. The $SART_{fixed}$ was identical to the $SART_{random}$ in every way except the presentation of the digits. In the former the digits (1-9) were presented in the conventional, ascending order whereas in the latter the same digits were presented in random order. Interest in the $SART_{fixed}$ was increased when Manly et al. (2003) found activation differences between these two versions of the task using positron emission tomography (PET). The $SART_{fixed}$ resulted in greater right dorsolateral prefrontal and parietal cortices activation than the $SART_{random}$. The authors interpreted this as indicative of differing degrees of demand on a sustained attention system between the two tasks. On the surface, the $SART_{random}$ appeared the more demanding because the

appearance of the targets were random and therefore unpredictable. In the $SART_{fixed}$ the targets were entirely predictable. However, the level of perceived difficulty in the $SART_{random}$ helped participants maintain active attention to task. The supposedly easier $SART_{fixed}$ was more boring and hence more challenging to self-sustained attention. The extra effort required in maintaining attention in the $SART_{fixed}$ resulted in the greater activation of right fronto-parietal regions of the brain. If the $SART_{fixed}$ is more taxing on this system, it would have been expected that this version of the task would correlate at least as strongly with the CFQ as the $SART_{random}$.

4.3 Methods

4.3.1 Participants

Initially, 165 undergraduate students (from psychology, computer science, business, economics and social science courses) were recruited to complete the CFQ. The age range was 17-40 years (mean = 20.33, S.D. = 3.33) and there were 86 males and 79 females. 52 of these students then agreed to be tested on the SART. This sample consisted of 27 males and 25 females and ranged in age from 18-29 years (mean = 20.16, S.D. = 1.76). History of head injury, epilepsy or other neurological condition, drug or alcohol problems, and/or major psychiatric disorder resulted in exclusion from the study.

4.3.2 Materials

CFQ

The CFQ is a 25-item self-report questionnaire designed to assess the frequency (over the last six months) of everyday slips and errors. The questionnaire examines the failure of different cognitive domains including perceptual failures (e.g., "Do you fail to notice signposts on the road?") and memory failures (e.g., "Do you forget where you put something like a newspaper or a book?"). Participants are asked to indicate on a five-point scale (ranging from 0 = Never to 4 = Very Often) how often they make a

particular mistake. Scores fall between 0 and 100. A copy of the CFQ can be found in Appendix 1.

$SART_{random}$

In this task, 225 single digits from 1 to 9 (25 of each of the nine digits) were presented over a 4.3-min period. Each digit was presented for 250 ms, followed by a 900 ms mask. Participants were asked to respond with a key press to each digit, except on the 25 occasions when the digit 3 appeared when the response was to be withheld. The target was presented in a pre-fixed quasi-random fashion. Participants used their preferred hand and were told to give equal importance to accuracy and speed.

The digits were presented in one of five randomly allocated font sizes (48, 72, 94, 100, 120 point Symbol, corresponding to a height of between 12 and 29 mm) to enhance the demands for processing the numerical value, rather than simply setting a search template for some peripheral feature of the target.

The mask (29 mm in diameter) consisted of a ring with a diagonal cross in the middle. Both digits and mask were presented in the centre of the display in white against a black background. The screen (32 cm × 23.5 cm) was set approximately 40 cm from the participants' eyes. However, movement was not restricted.

Each session was preceded by a practice period consisting of 18 presentations of digits, 2 of which were targets. See Figure 4.1 for an illustration of the $SART_{random}$ sequence.

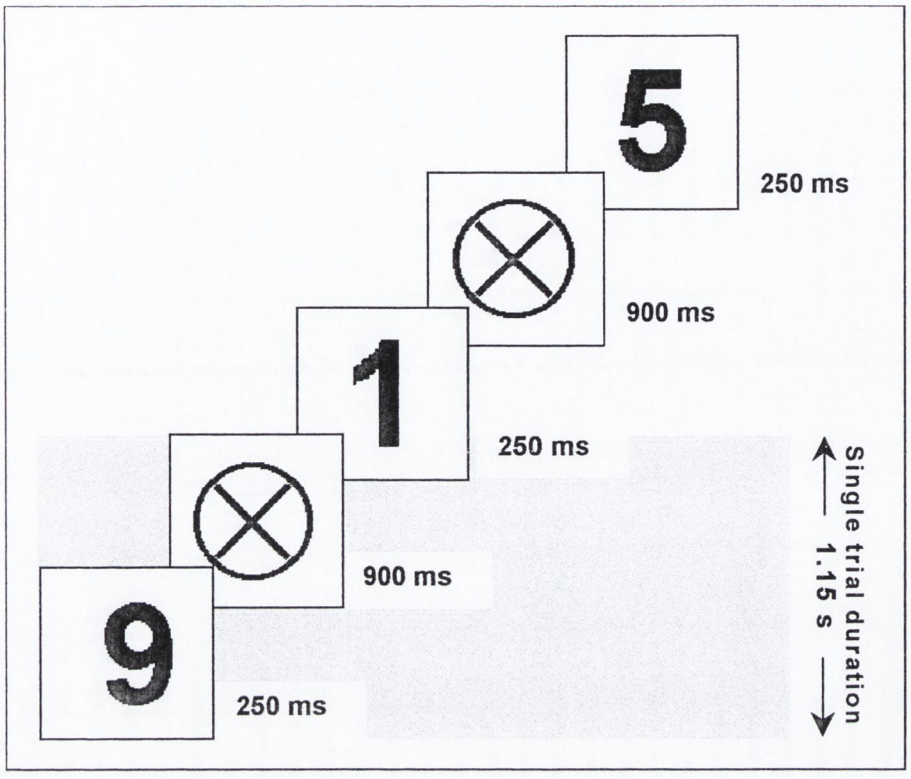

Figure 4.1: $SART_{random}$ sequence.

$SART_{fixed}$

The fixed sequence SART differed from the standard version in that successive digits (1-9) in the conventional, ascending order were presented rather than a randomly generated sequence of digits. This meant that the occurrence of the rare (no-go) target was entirely predictable.

4.3.3 Procedure

Participants completed the CFQ in group sessions supervised by an examiner and an assistant. The SART was administered on an individual basis in a specially designated project room in the Department of Psychology in Trinity College, Dublin. Testing sessions lasted a maximum of twenty minutes. The order in which the $SART_{random}$ and the $SART_{fixed}$ were presented was alternated among participants.

4.4 Results

The mean CFQ score in the sample of 165 students was 43.78 (S.D. = 12.24) with a range of 13-87. The median, quartiles and extreme values of this data are displayed in Figure 4.2. The relationship between age and CFQ scores was examined with a Pearson correlation but nothing of significance was found. An independent t-test found a gender effect, with females scoring slightly higher than males ($t = -2.68$, $df = 163$, $p < 0.01$; see Figure 4.2).

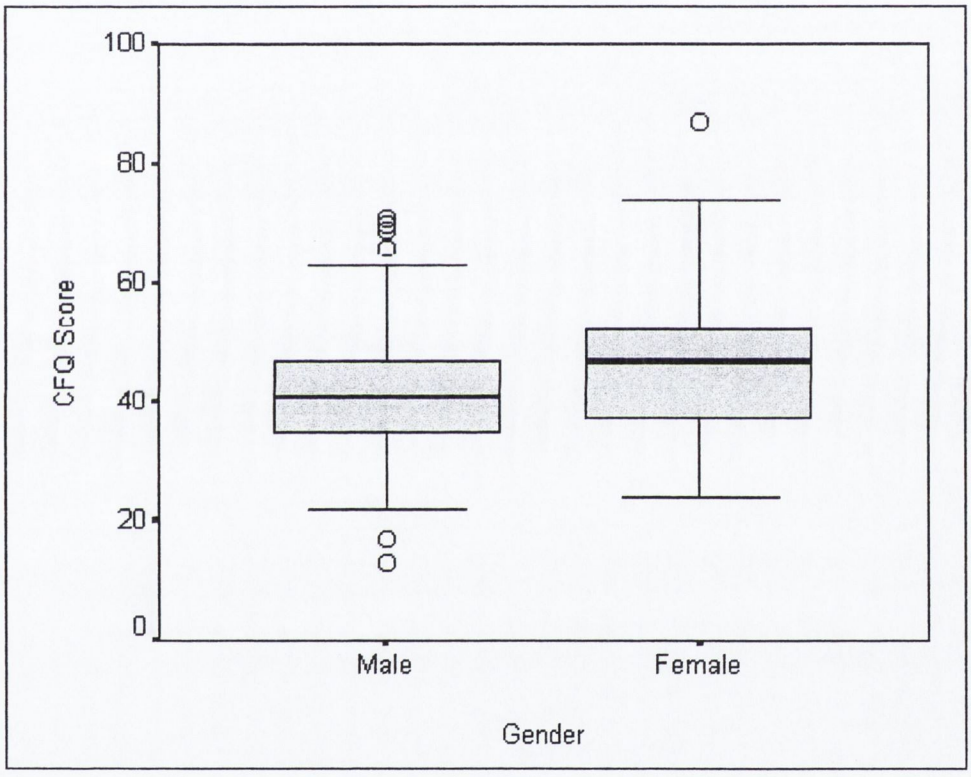

Figure 4.2: Summary plot based on the median, quartiles and extreme values of CFQ scores in the sample of 165 students split by gender.

Pearson correlations (1-tailed) were performed between (1) $SART_{random}$ errors of commission and CFQ scores and (2) $SART_{fixed}$ errors of commission and CFQ scores from the sample of 52 students. CFQ scores correlated significantly with errors on the $SART_{random}$ ($r = 0.27$, $n = 52$, $p < 0.05$) but not with errors on the $SART_{fixed}$ ($r = -0.15$, $n = 52$, $p > 0.05$). The descriptive statistics for each of these measures and scatterplots of the data are displayed in Table 4.2 and Figures 4.3 and 4.4. In addition, a dependent t-

test was conducted on the data to compare mean errors of commission between the $SART_{random}$ and $SART_{fixed}$. Participants made significantly more errors on the former than the latter ($t = 11.86$, $df = 51$, $p < 0.001$). This difference is displayed graphically in Figure 4.5. The mean RT to Go trials was 340.31 ms (S.D. = 86.79) on the $SART_{random}$ and 234.07 ms (S.D. = 76.76) on the $SART_{fixed}$. In comparison, participants responded faster to Go trials on the $SART_{fixed}$ than on the $SART_{random}$ ($t = 12.23$, $df = 47$, $p < 0.001$). Descriptive statistics for RTs are displayed in Table 4.2.

There was no male/female difference in CFQ scores, random or fixed sequence SART errors of commission or RTs.

Table 4.2: Descriptive statistics for the CFQ and the two versions of the SART.

		$SART_{random}$		$SART_{fixed}$	
Statistics/Measure	**CFQ**	**Errors**	**RT (ms)**	**Errors**	**RT (ms)**
Mean	43.90	11.50	340.31	1.60	234.07
S.D.	15.12	6.18	86.79	1.46	76.76
Minimum	17.00	0.00	215.68	0.00	103.00
Maximum	87.00	22.00	622.66	6.00	481.56

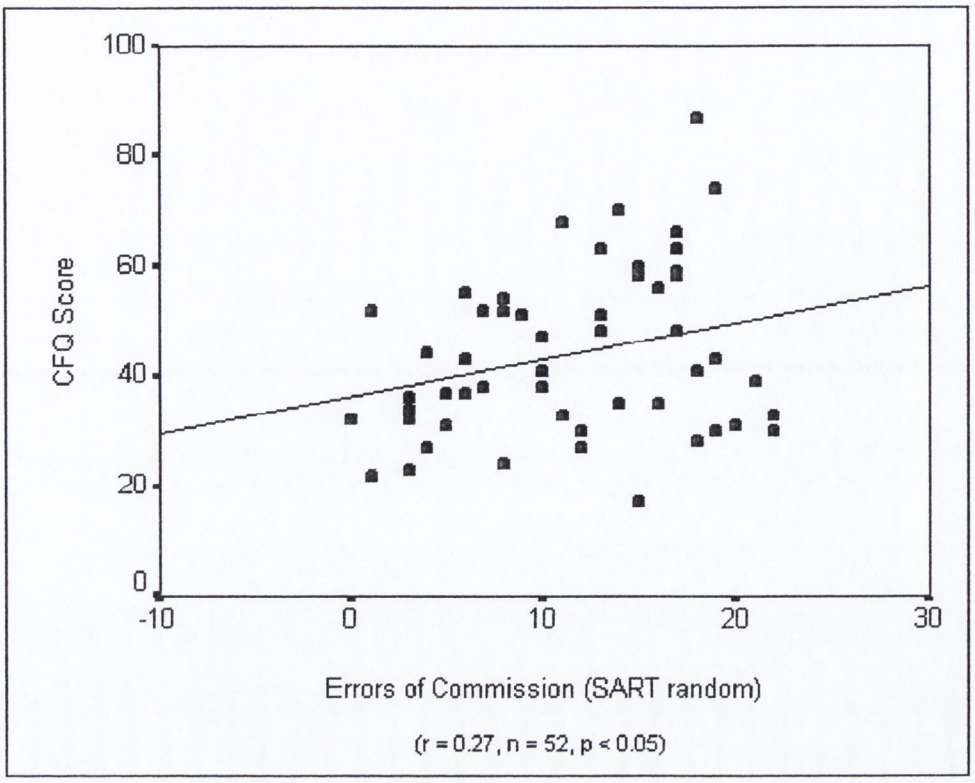

Figure 4.3: Scatterplot of the relationship between CFQ scores and $SART_{random}$.

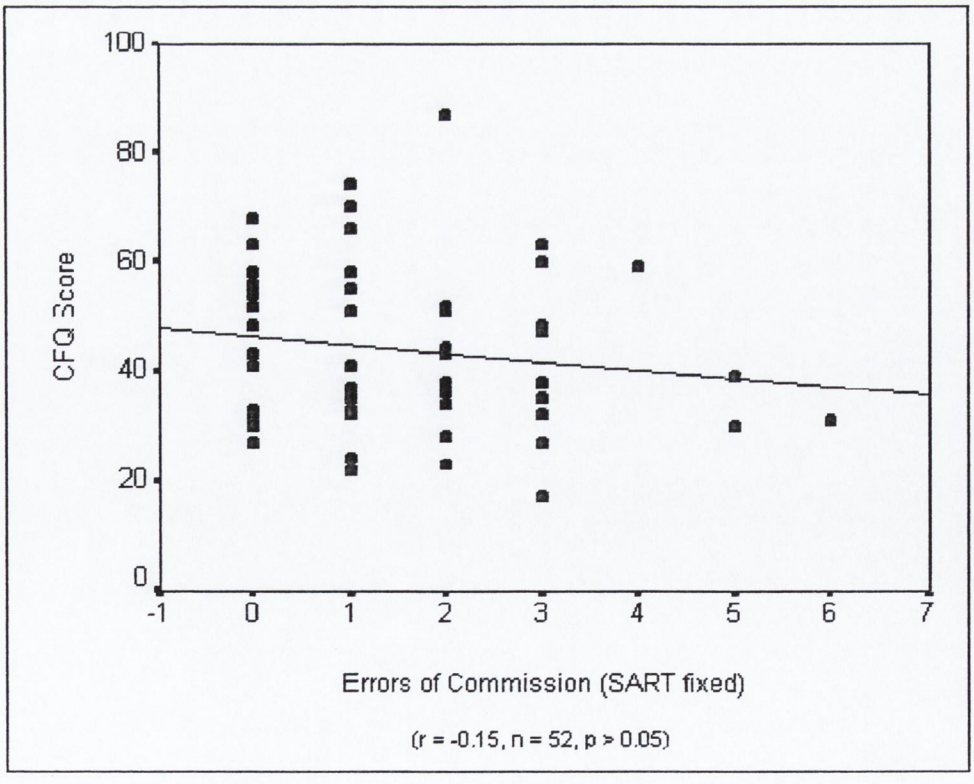

Figure 4.4: Scatterplot of the relationship between CFQ scores and $SART_{fixed}$.

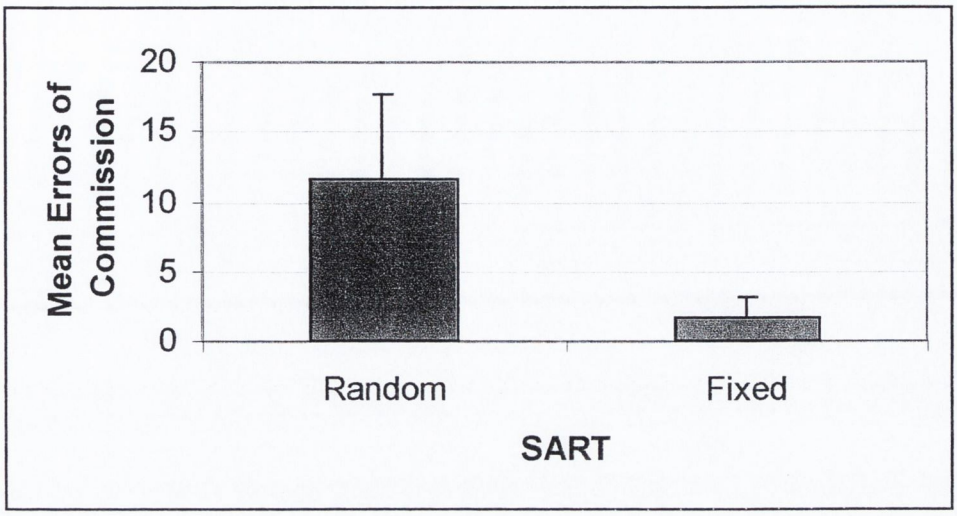

Figure 4.5: Comparing errors of commission between the $SART_{random}$ and the $SART_{fixed}$ ($p < 0.001$).

4.5 Discussion

A significant positive correlation was found between errors of commission on the $SART_{random}$ and CFQ scores. However, no such correlation was found between errors of commission on the $SART_{fixed}$ and CFQ scores. Participants made significantly more errors and responded more slowly on the $SART_{random}$ compared to the $SART_{fixed}$.

4.5.1 Cognitive failures and the $SART_{random}$

The correlation between errors of commission and CFQ scores on the standard, $SART_{random}$ replicated Robertson et al.'s (1997) finding. Even the degree of correlation was very similar ($r = 0.27$ in the present study compared to $r = -0.27$[4] in Robertson and colleagues' study). This confirms a relationship between sustained attention capacity as measured by the SART – a laboratory-based, computerised task – and everyday absent-

[4] The correlation in Robertson et al.'s (1997) study was negative because they compared the number of correct withholds rather than errors of commission. In other words, the more incidences of cognitive failure that a participant reported the more correct withholds they made on the SART.

mindedness. In other words, a person who experiences absent-minded errors in everyday life will experience them in the laboratory on the SART.

This finding is consistent not only with Robertson and colleagues' study but also the literature that suggests the CFQ is more related to attention than memory (Broadbent et al., 1982; Harris & Wilkins, 1981; Martin & Jones, 1983; Meiran et al., 1994; Tipper & Baylis, 1987; Vom Hofe et al., 1998). It is also consistent with the research that suggests that sustained attention plays a role in human error outside of the laboratory, for example in the case of the Hinton train disaster (Smiley, 1990) and other train accidents and near accidents (Edkins & Pollock, 1997).

4.5.2 Cognitive failures and the $SART_{fixed}$

However, no correlation was found between the $SART_{fixed}$ and the CFQ. If the $SART_{random}$ and the $SART_{fixed}$ were essentially the same task – after all, they differed only in the order in which the digits were presented – why did they not display the same relationship with the CFQ? The most likely explanation is that there were simply too few errors made on the $SART_{fixed}$ to conduct an adequate analysis. Participants made 1.6 mean errors of commission on the $SART_{fixed}$ compared to 11.5 on the $SART_{random}$ (and this difference was statistically significant). This quantitative difference was reflected qualitatively, i.e., participants reported the $SART_{fixed}$ as easier than the $SART_{random}$. This has consequences for the use of the SART. It may be that the $SART_{random}$ is more suited to testing sustained attention in a normal, healthy population and the $SART_{fixed}$, in a population in which a deficit is expected. It is true that Robertson et al. (1997) found a difference between controls and TBI patients using the $SART_{random}$ but this finding was not reliably replicated in a recent study by McAvinue, O'Keefe, McMackin and Robertson (in press). McAvinue and colleagues compared controls and TBI patients' performance on the $SART_{random}$ twice and on the $SART_{fixed}$ once. A significant difference in errors of commission between controls and TBI patients was found on only one of the $SART_{random}$ conditions. A significant difference between the groups was found on the $SART_{fixed}$ and moreover, the magnitude of the difference between controls and TBI patients was greater on this version of the SART

compared to the $SART_{random}$. The authors concluded that the $SART_{fixed}$ was superior to the $SART_{random}$ in detecting a deficit in sustained attention.

4.5.3 Sustained attention or response inhibition?

The evidence gathered by Robertson and colleagues (Manly et al., 2000; Manly et al., 1999; Robertson et al., 1997) strongly suggests that the SART is primarily a measure of sustained attention. However, it cannot be denied that there is a certain requirement for response inhibition in the performance of the task. Manly et al.'s (2001) PET study of the SART put forward the view that the $SART_{fixed}$ is more taxing on the sustained attention system of the brain than the $SART_{random}$. Looking at this another way, not only does the $SART_{fixed}$ appear to be more demanding on sustained attention but less demanding on response inhibition. The digits are presented in the conventional, ascending order and therefore the participant knows exactly when the NoGo target is coming up. The observation that RTs to Go trials were significantly faster on the $SART_{fixed}$ compared to the $SART_{random}$ suggests that the participants were aware of this and were consequently more confident in their responses. However, when Manly et al. (2000) reduced the response inhibition component of the $SART_{random}$ in a response-locked version of the task, error rates remained the same. This suggested that the number of errors that participants made was more dependent on their ability to maintain attention than inhibit a response. The results of the current study should be similar. The $SART_{fixed}$ is comparable to Manly et al.'s (2000) response-locked SART in that both place less of a demand on response inhibition than the standard, $SART_{random}$. Yet the error rates on the $SART_{random}$ and the $SART_{fixed}$ were significantly different. It would seem that performance on the $SART_{random}$ has a larger response inhibition component than the $SART_{fixed}$, making the latter a purer measure of sustained attention. This idea is consistent with the PET study conducted by Manly and colleagues (2001) and is something to keep in mind in future experimentation.

4.5.4 Sustained attention or speed/accuracy trade-off?

Could accuracy be interpreted in terms of a speed/accuracy trade-off rather than simply self-sustained attention? Previous studies did not find that differences in RTs to the frequent Go trials accounted for group differences in accuracy, neither between normal, healthy participants and TBI patients (Robertson et al., 1997) nor normal, healthy participants defined by high or low frequency of everyday attentional slips as measured by the CFQ (Manly et al., 1999). However, they did find that an error could be predicted in a given individual's performance by a reduction in RT. In other words, people made mistakes when they increased their speed of performance. For example, Robertson et al. recorded the mean RT for the four trials prior to a correct withhold and for the four trials prior to an incorrect press and found that both TBI patients and controls responded significantly faster before an error than they did before a correct response. Manly et al. found similar results in his high and low CFQ groups. Furthermore, Manly et al. manipulated target probability to study its effect on performance and they found that RT for responses to Go trials slowed and more correct responses were made with increasing target probability (from the original 0.11 to 0.25 and 0.50).

On the basis of these findings, Manly, Davison, Heutink, Galloway, and Robertson (2000) pooled data from 109 normal, healthy participants to allow a more detailed analysis of the relationship between speed and accuracy on the SART. They found a significant relationship between the numbers of errors of commission made by the participants and their Go trial RTs; participants who responded more quickly were more likely to make more errors. They also looked at different categories of trials to examine the effect of changes in RTs during performance, namely Go trials with responses that occurred immediately before and after a correct withhold and before and after an incorrect press. As before, in the studies by Robertson et al. (1997) and Manly et al. (1999), they found that participants were responding faster to the Go trial prior to an incorrect press in comparison with a correct withhold. Manly et al. (2000) also found that participants tended to slow down following an incorrect press and speed up following a correct withhold. To sum up, they determined that speeding of responses was predictive of subsequent errors of commission.

As Manly et al. (2000) observed, this relationship between speed and accuracy on the SART made it difficult to interpret error rates purely in terms of poorly self-sustained attention. They subsequently devised a modified version of the SART that was designed to stabilise RT. This "response-locked" version of the SART was identical to the original one with the exception that a brief tone (50 ms, 587.3 Hz sine tone) was presented at a fixed interval after trial onset within each trial. Participants were instructed to respond in time with the tone which was set at a level that, on average, was associated with accurate performance on the SART. In piloting, Manly et al. (2000) had determined that presenting the tone 100 ms after the trial onset produced RTs within the appropriate range (approximately 380 ms after trial onset). This manipulation was successful in that participants did respond at an interval associated with accurate performance on the task and causing the relationship between speed and accuracy to disappear. However, despite the manipulation's success, error rates did not significantly change and individual's error propensity on the standard SART was predictive of error propensity on the response-locked SART. Manly et al. (2000) argued that if speed factors were sufficient to account for accuracy on the SART then it would have been expected that participants would have made less errors of commission on the response-locked version of the task and further, the correlation in performance between the two versions of the task would have been small. The finding that participants displayed similar error propensities from one version of the task to another suggested that it was some other aspect of their approach that was determining how many mistakes they were making. In fact, Manly et al.'s (2000) results were "consistent with 'attentional' control over action being an important determinant of accuracy in the SART task" (p. 176).

In relation to the results reported in the current experiment, previous studies such as those outlined above do argue for a sustained attention interpretation of the results over and above a speed/accuracy trade-off one. However, as Manly et al. (2000) acknowledged, "the influence of speed determined by other factors cannot be ruled out within an individual case" (p. 177). A participant may emphasise speed over accuracy despite being instructed otherwise and consequently make many errors even if they are paying attention to the task. A possible alternative to the standard task might be Manly et al.'s (2000) response-locked version, which they believed to be very useful and more clearly interpretable.

4.5.5 Conclusion

In conclusion, this study provided further evidence that the SART is linked to everyday absent-minded slips of attention. The lack of a relationship between the $SART_{fixed}$ and the CFQ introduced some doubt as to whether it is measuring exactly the same thing as the $SART_{random}$. It may just be that the $SART_{fixed}$ is better for testing a normal, healthy population. Study 2 describes a factor analysis of the CFQ, with a view to obtaining a better understanding of the relationship between the questionnaire and the SART.

4.6 Introduction to Study 2: Factor Analysis of the CFQ

Factor analysis is a multivariate statistical technique that reduces a large number of variables to a smaller number of underlying factors or dimensions. Indeed, a factor is a "dimension or construct which is a condensed statement of the relationships between a set of variables" (Kline, 1994, p. 5). Conducting a factor analysis on the CFQ will determine if the questionnaire is unifactorial or multifactorial. If it is the former then the CFQ does what it set out to do, i.e., provide a measure for general cognitive failure. If it is the latter, multifactorial, then sustained attention capacity may only relate to a subset of the CFQ factors. This in turn has implications for diagnosis and treatment when using the questionnaire (Matthews et al., 1990).

4.6.1 The CFQ: A unidimensional measure?

Broadbent et al. (1982) conducted both a PCA (principal components analysis) and multidimensional scaling[1] on the CFQ data that they collected. Firstly, they found that all the questions were positively correlated. Secondly, only one cluster of three deviant questions was found in the majority of the groups that they tested. These questions involved one perceptual and one memory failure (items 7 and 20, concerning people's names) and one action failure (item 11, not answering letters). These questions were arguably more social than cognitive in nature and they also correlated with the total CFQ score. Hence, Broadbent et al. decided that it was unnecessary to separate the categories into perceptual, memory and action failure. In other words, the tendency to commit cognitive failures was a general one. Thirdly, James Reason found that the CFQ correlated with a number of other cognitive failure questionnaires, regardless of what aspect of cognitive failure they measured. He administered the CFQ, Herrmann and Neisser's (1978) Short Inventory of Memory Experiences, Reason's own Absent-mindedness Questionnaire and two forms of his Slips of Action Inventory. Correlations between the CFQ and these measures were quite significant, ranging from 0.57 to 0.62. It appeared that the CFQ measured a single, unitary dimension of cognitive failure.

4.6.2 Studies revealing multiple dimensions

Broadbent et al. (1982) may have argued for the unidimensionality of the CFQ but subsequent factor analyses of the CFQ have consistently revealed the questionnaire's multidimensionality (Larson et al., 1997; Matthews et al., 1990; Pollina et al., 1992; Wallace, Kass, & Stanny, 2002). This discrepancy may be due to Broadbent et al.'s small sample size of 77 (Matthews et al., 1990), resulting in there being only three times as many observations as there were variables to be analysed. As a rule, there should be at least five times as many observations as there are variables (Hair, 1998) and/or at least 100 participants (Kline, 1994).

Matthews et al. (1990) – Seven-factor solution

Matthews et al. (1990) conducted an extremely thorough analysis of the CFQ in the context of stress vulnerability. They used four different procedures to determine the number of factors to be extracted, followed by a factor analysis with oblique direct oblimin rotation. They found four alternative factor structures as a function of the four different factor extraction procedures: a one-, two-, seven- and nine-factor solution. The one-factor solution accounted for 20% of the variance. The two-factor solution accounted for 24% of the variance and was made up of a large general factor and a small specific factor (including items 7 and 20 relating to people's names). The seven-factor solution accounted for 37% of the variance. Factors were labelled: (1) *physical clumsiness*, (2) *people's names*, (3) *planned social interaction*, (4) *item 12*, (5) *use of language*, (6) *lack of concentration* and (7) *absent-mindedness*. In general, the factors in the seven-factor solution were suggestive of either categories of cognitive and/or motor processes (Factors 1, 6, 7) or types of context or information (Factors 2, 3, 5). Factor 4 was largely related to item 12 ("Do you find you forget which way to turn on a road you know well but rarely use?"). Matthews et al. also reported a nine-factor solution that was similar to the seven-factor solution but with the addition of two factors associated with specific items (not detailed). The authors believed that the different solutions were due to the four-factor extraction procedures providing different kinds of information about the inter-item correlation matrix. The seven-factor solution was

[1] Multidimensional scaling is a statistical procedure that searches for a small set of dimensions that best fits a large number of data points (Reber, 1995).

selected (as the solution accounting for the largest percentage of variance) to investigate the CFQ's relationship with stress vulnerability. Total CFQ score was correlated with neuroticism as measured by the Eysenck Personality Inventory (EPI; Eysenck & Eysenck, 1963) and use of coping strategies, measured by the Ways of Coping measure (Folkman, Lazarus, Dunkel-Schetter, DeLongis, & Gruen, 1986). This relationship was mediated by a single CFQ factor related to lack of concentration. This confirmed Matthews et al's hypothesis that the use of CFQ factors provided more information than the use of the CFQ total score alone.

Pollina et al. (1992) – Five-factor solution

Following on from Matthews et al. (1990), Pollina et al. (1992) conducted a PCA of the CFQ with varimax rotation. This analysis yielded five internally consistent factors: (1) *distractibility*, (2) *misdirected actions*, (3) *spatial/kinaesthetic memory*, (4) *memory for names* and (5) *interpersonal intelligence*. Altogether, these factors accounted for 49% of the variance with the first factor, *distractibility*, accounting for 27% of the variance. Of particular interest to the current study, Pollina and colleagues regarded the factors labelled *distractibility* and *misdirected actions* as being related to attention. Items loading on *distractibility*, "appeared to reflect disruptions of internalised attentional processes, as would most likely result in inappropriate attentional focus" (p. 313) and included such items as, "Do you read something and find you haven't been thinking about it and must read it again?" (item 1) and "Do you daydream when you ought to be listening to something?" (item 19). Items loading on misdirected actions were interpreted as reflecting disruption of externally, rather than internally, focused attentional processes (e.g., "Do you find yourself suddenly wondering why you went from one part of the house to the other?" (item 14) and "Do you find you forget what you came to the shops to buy?" (item 23)). Pollina et al. failed to find a relationship between these dimensions and measures of traditional intelligence and working memory. Scores on the WAIS-R Vocabulary, WAIS-R Digit Span Forward, WAIS-R Digit Span Backward (Wechsler, 1981), Counting Span (Case, Kurland, & Goldberg, 1982) and Letter Sets tasks (Eckstrom, French, Harman, & Derman, 1976) were recorded. Only the association between the factor labelled *interpersonal intelligence* and WAIS-R Vocabulary reached significance. Items loading on this factor were related to the disruption of some aspect of the respondents' social skills (e.g., " Do you say

something and realise afterwards that it might be taken as insulting?" (item 8)) and the WAIS-R Vocabulary reflected crystallised knowledge, including knowledge of appropriate social behaviours (Horn, 1975) so Pollina et al. concluded that the relationship between these two measures reflected interpersonal perspective-taking. The absence of significant results for any of the remaining dimensions led Pollina et al. to conclude that other experimental measures, more focused on attentional processes might be more appropriate.

Larson et al. (1997) – Three-factor solution

Using the largest sample size (2379 American Navy recruits) of all the studies reported so far, Larson et al. (1997) tested the CFQ's dimensionality using a PCA with varimax rotation. Three factors emerged accounting for 44% of the variance. Factors 1 and 2 appeared to reflect general cognitive failures. Some of the items that loaded on factor 1 related to forgetting (items 2, 6, 12, 16, 17 and 23) but others reflected diverse outcomes such as bumping into people (item 5), confusion and distractibility (items 4, 13, 14 and 25). Factor 2 related to what Larson and colleagues termed 'social poise', including items related to controlling one's temper and avoiding inappropriate utterances (items 8 and 10). However, factor 2 also included some items related to distractibility and forgetfulness (e.g., items 9, 11, 19, 21). In sum, factors 1 and 2, "rather than cleanly representing singular constructs, appear to incorporate a hodgepodge of different types of items" (p. 31). Factor three was represented by only four items, the two highest loading items of which were both related to the processing and remembering of people's names (items 7 and 20). Like Broadbent et al. (1982), Larson et al. decided that there was strong evidence for a general CFQ factor and weak evidence for replicable secondary factors. Apart from the lack of interpretability of multiple factors, factor 1 scores of both Larson et al., Matthews et al. (1990) and Pollina et al (1992) strongly correlated with CFQ total scores. This implied that the different factor 1 scores were all more or less interchangeable with the CFQ total score. Larson et al. went on to use only the CFQ total score in their analysis of objective correlates, showing that high CFQ scorers were more prone to accidents. As will become apparent, however, Larson et al. was the only study to get results which supported Broadbent et al.'s findings. Did the results really support Broadbent et al? After all, Larson et al. did find three factors but could not interpret them. This may have been a function of their

technique. As a factor analysis, a solution that accounts for only 44% of the variance could be considered less than satisfactory (Hair, 1998).

Wallace et al. (2002) – Four-factor solution

More recently, Wallace et al. (2002) conducted a factor analysis (PCA with varimax rotation) of the CFQ using data gathered from both Navy personnel and college students. Their intention was to make the results directly comparable to those of Larson et al. (1997) and Pollina et al. (1992). They used the most stringent factor-analytic criteria for interpreting their results, only including those items with factor loadings greater than 0.40 on any given factor and requiring that the resultant factors be interpretable. A four-factor solution was found that accounted for 54% of the variance. Factors were labelled: (1) *memory*, (2) *distractibility*, (3) *blunders* and (4) *names*. Wallace et al. proceeded to establish construct validity for their factors by correlating them with measures of other related constructs. In selecting these constructs they considered not only cognitive failures but also sustained attention, citing the Robertson et al. (1997) study. All of the factors excluding *names* were correlated with boredom proneness as measured by the Boredom Proneness Scale (BPS; Farmer & Sundberg, 1986). The *names* factor was less related to attention and hyperactivity as measured by the Adult Behavior Checklist (ABC; Barkley & Murphy, 1998) than any of the other factors. Furthermore, *memory* and *distractibility* were more related to attention than hyperactivity, consistent with previous findings that cognitive failures were associated with attentional lapses (Reason, 1979). Wallace et al. also looked at Type A behaviour pattern (excessive competitive drive in the absence of well-defined goals, impatience and hostility; Friedman & Rosenman, 1959)) using the Jenkins Activity Survey (JAS; Heilbrun, Palchanis, & Friedberg, 1986). The speed and impatience subscales of the JAS were significantly correlated with *memory, blunders* and *names* but not *distractibility*. This fits with research that shows that Type A individuals are not prone to distraction (Bermudez, Perez-Garcia, & Sanchez-Elvira, 1990).

4.6.3 The current study

In reviewing the studies described above[2], it is apparent that there is more to the CFQ than a single cognitive failures dimension. What is not clear is how many dimensions there are. The factor analyses of the four studies yielded quite a range of solutions. Using four different factor extraction procedures Matthews et al. (1990) found as many factor solutions, including a one-, two-, seven- and nine-factor solution. A four- (Wallace et al., 2002) and five-factor solution (Pollina et al., 1992) have also been found. Which is right? This is a difficult question to answer, not least because many aspects of factor analysis are highly subjective (deciding how many factors to extract, which factor rotation technique should be used, which factor loadings are significant; Hair, 1998). For example, one of the first decisions that a factor analyst must make is whether to use PCA or common factor analysis. PCA determines the number of factors to be extracted and how each item should correlate with each factor (communality). Common factor analysis does this as well but also has to estimate what the communality of each variable would be if as many factors as variables were extracted (Cooper, 1998). Suffice to say, common factor analysis is a more complicated procedure. All of the studies reviewed above used PCA except Matthews et al. who used common factor analysis. This is important when it comes to considering factor loadings. Matthews et al. has been criticised for using a very liberal factor loading criterion of 0.20 to decide if an item was to be included in a given factor (Wallace et al., 2002). However, loadings obtained from a PCA are always larger than those resulting from a common factor analysis and so the results look more impressive. This has implications for the factor loading criterion and the comparison of studies using different analyses. Despite this, research has shown that the results from a PCA and common factor analysis are similar in many instances (Velicer & Jackson, 1990). Hair et al. (1998) recommends that if there are any concerns about using PCA, then common factor analysis should also be applied to the data to assess its representation of structure. The current study therefore conducted a PCA followed by principal axis factoring in the manner suggested by Kline (1994).

[2] See also the tabulated summary of the four studies and the current one in Appendix 2.

The CFQ total score is reached by adding the scores for each individual item together. This only makes sense if all the items measure the same psychological concept. If we are to relate the CFQ to an objective measure, such as the SART, then it is important to know exactly what the questionnaire measures. In other words, if the CFQ is measuring more than a general cognitive failures factor, it may be that sustained attention is more related to one subset of items than another. Matthews et al. (1990) demonstrated this quite nicely by relating their "lack of concentration" factor to stress vulnerability. Similarly, Wallace et al. (2002) found that different factors in their four-factor solution were related to different subscales of boredom proneness, attention-deficit disorder and Type A behaviour pattern. As well as conducting a factor analysis of the CFQ, the aim of the current study was also to see what factors of the CFQ related to sustained attention as measured by the SART.

4.7 Methods

4.7.1 Participants

Participants from Study 1 were combined with a sample from Cambridge (see Robertson et al., 1997) to give a sample size of 225 (male/female: 103/122, years of age: mean 24.09, range 17-65). This resulted in a ratio of approximately nine times as many observations as there were variables to be analysed. As a rule the minimum is to have at least 5:1 (Hair, 1998).

The participants from Study 1 (n = 165, age in years: mean = 20.33, S.D. = 3.33) were undergraduate students from psychology, computer science, business, economics, and social science courses. Mean years of education for this sample was 14.70 (S.D. = 0.82). Of these, 86 were male and 79 were female.

The sample from Cambridge (n = 60, age in years: mean = 34.34, S.D. = 10.71) were recruited from the MRC Applied Psychology Unit Subject Panel. Of these, 17 were male and 43 were female. National Adult Reading Test (NART; Nelson, 1982) errors were also available for 43 participants in this sample. These error scores were used to predict IQ (mean = 115.44, S.D. = 5.41). Unfortunately, this information was not

available for the full sample and for the participants from Study 1. Similarly, years of education were only available for the participants from Study 1 and not for the Cambridge sample. However, Broadbent et al. (1982) observed that the CFQ does not appear to be very closely related to either test intelligence or educational level.

4.7.2 Materials

The CFQ as before.

4.7.3 Procedure

All participants completed the paper-and-pen questionnaire in quiet conditions supervised by an examiner and/or assistant with no time restrictions.

4.8 Results

4.8.1 CFQ total score

In the current sample, the CFQ total score ranged between 9 and 91. Mean CFQ total score was 43.95 with a standard deviation of 12.77.

4.8.2 Gender differences in CFQ total and item scores

Mean CFQ total score differed significantly between males and females in this sample. An independent t-test revealed that females reported slightly more incidences of cognitive failure (mean = 46.32, S.D. = 13.37) than their male counterparts (mean = 41.15, S.D. = 11.45; $t = -3.09$, $df = 223$, $p < 0.01$). This difference is displayed in a boxplot in Figure 4.6.

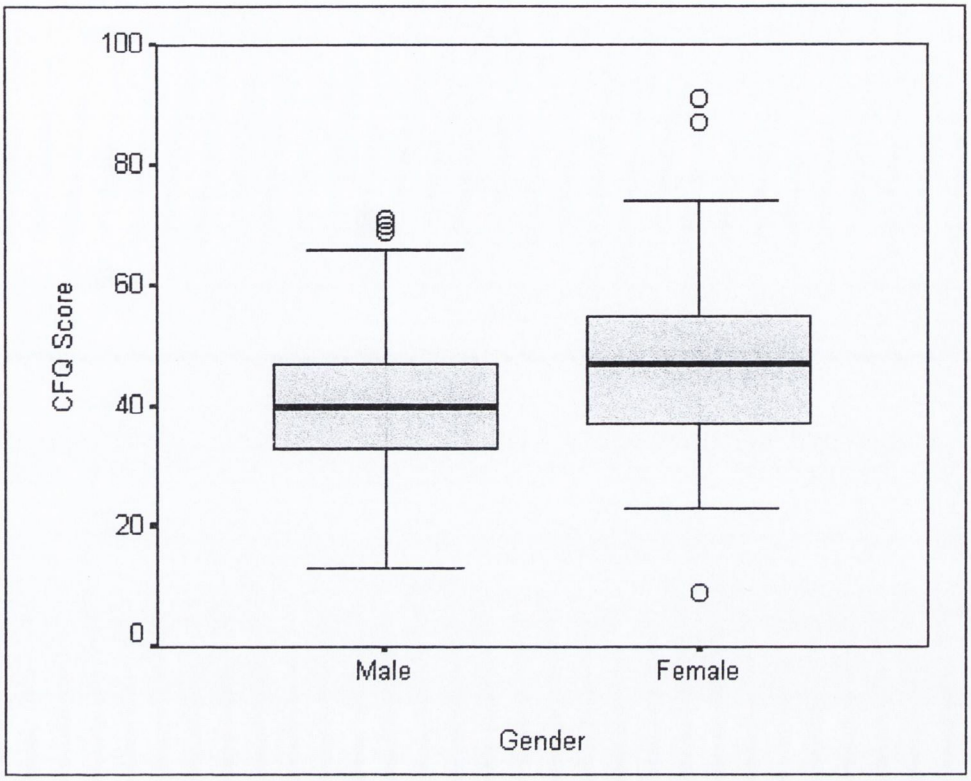

Figure 4.6: Summary plot based on the median, quartiles and extreme values of CFQ scores in the sample of 225 participants split by gender ($p < 0.01$).

After Pollina et al. (1992), it was decided to look at this gender difference in more detail. A MANOVA revealed significant differences between males and females on several items including items 1-7, 10, 12, 15, 18, 20 and 24. Effect sizes associated with these differences were small (η^2 ranged between 0.00 and 0.14). The descriptive statistics for all 25 items of the CFQ and the F statistic for each one are displayed in Table 4.3.

Table 4.3: Mean CFQ item scores and standard deviations split by gender.

CFQ Item	Gender	Mean	S.D.	F
Item 1 read	Male	2.49	0.88	7.48**
	Female	2.80	0.81	
Item 2 house	Male	1.59	0.92	13.51***
	Female	2.06	0.97	

Item 3 signpost	Male	1.18	0.85	9.86**
	Female	1.56	0.92	
Item 4 direction	Male	0.97	1.29	11.26**
	Female	1.53	1.22	
Item 5 bump	Male	1.12	0.78	24.44***
	Female	1.69	0.93	
Item 6 light	Male	1.50	1.07	4.49*
	Female	1.79	0.99	
Item 7 listen	Male	2.67	1.12	8.50**
	Female	2.23	1.13	
Item 8 insult	Male	1.95	1.04	0.81
	Female	1.84	0.89	
Item 9 hear	Male	1.95	1.08	0.08
	Female	1.99	1.01	
Item 10 temper	Male	1.23	0.96	7.01**
	Female	1.57	0.96	
Item 11 letter	Male	1.49	1.31	0.99
	Female	1.66	1.25	
Item 12 road	Male	0.61	0.82	13.53***
	Female	1.08	1.06	
Item 13 supermarket	Male	1.65	1.01	0.31
	Female	1.72	0.91	
Item 14 word	Male	1.48	0.96	0.36
	Female	1.55	0.88	
Item 15 mind	Male	2.13	1.06	8.67**
	Female	2.57	1.16	
Item 16 appointment	Male	1.24	1.06	1.37
	Female	1.09	0.89	
Item 17 newspaper	Male	1.90	0.96	1.83
	Female	2.09	1.10	
Item 18 matchbox	Male	0.74	0.86	5.96*
	Female	1.03	0.94	

Item 19 daydream	Male Female	2.53 2.74	1.07 1.03	2.11
Item 20 name	Male Female	2.62 2.22	1.21 1.01	7.35**
Item 21 distracted	Male Female	2.20 2.41	1.05 0.95	2.38
Item 22 tip of the tongue	Male Female	2.26 2.36	0.85 0.90	0.70
Item 23 shops	Male Female	0.99 1.19	1.03 0.88	2.43
Item 24 drop	Male Female	0.92 1.70	0.85 1.04	37.25***
Item 25 think	Male Female	1.73 1.86	1.21 1.00	0.81

*$p < 0.05$, ** $p < 0.01$, ***$p < 0.001$

4.8.3 Factor analysis

The data were analysed in the manner recommended by Kline (1994). Firstly, the data were submitted to a PCA and second, a principal axis factoring analysis was run on the number of factors extracted by the PCA. Factors were orthogonally rotated to the normalised varimax criterion. An eight-factor solution emerged accounting for 62% of the variance. Variables with loadings higher than 0.4 (or less than -0.4) were selected to make up each factor (this is the conventional cut-off point; Cooper, 1998). Table 4.4 shows the rotated factor matrix and Table 4.5 lists the factors and their labels, the variance each factor accounted for and their internal consistencies. Factors 2-8 inclusive only accounted for an average of 5.04% of the variance each but moderate to good internal consistencies were obtained for the eight factors (α ranged from 0.45 to 0.73) and each was found to be interpretable. Labels were determined by the factor loadings, i.e., the correlation between items and factors. (The higher an item loads on a factor the more important that item is to the factor's meaning.)

Factor 1, *forgetfulness*, accounted for 26.63% of the variance. The four items loading on this factor – "Do you find you forget why you went from one part of the house to the other?" (item 2), "Do you forget where you put something like a newspaper or a book? (item 17), "Do you find you accidentally throw away the thing you want and keep what you mean to throw away..." (item 18) and "Do you find you forget what you came to the shops to buy?" (item 23) – were clearly related to memory failures. All four appeared in Matthews et al.'s (1990) factor 7, *absent-mindedness*, and Wallace et al.'s (2002) factor 1, *memory*. They also overlapped with Pollina et al.'s (1992) factor 2, *misdirected actions*, with the exception of item 2. However, *misdirected actions* included several other items not directly related to memory failures.

Factor 2, *use of language*, to use the label given to these items by Matthews et al. (1990) accounted for 6.45% of the variance. It included, "Do you find yourself suddenly wondering if you've used a word correctly?" (item 14), "Do you have trouble making up your mind?" (item 15), "Do you find you forget what you came to the shops to buy?" (item 23) and "Do you find you can't think of anything to say?" (item 25). There was some overlap between this factor and that labelled by Pollina et al. (1992) and Wallace et al. (2002) as *distractibility* but the highest loading items in this instance (items 14 and 25) were more related to language than anything else.

Factor 3, *names*, consisted of two items – "Do you find you forget people's names?" (item 20) and "Do you fail to listen to people's names when you are meeting them?" (item 7) – and accounted for 5.86% of the variance. Of all the factors, this one was most consistent with previous studies. In every case, a factor made up of only these two items has been found (Larson et al., 1997; Matthews et al., 1990; Pollina et al., 1992; Wallace et al., 2002).

Factor 4, *clumsiness*, accounted for 5.32% of the variance. It received high loadings from item 5, "Do you bump into people?" and item 24, "Do you drop things?" There were overlaps between this factor and factors labelled *physical clumsiness* (Matthews et al., 1990), *spatial/kinaesthetic memory* (Pollina et al., 1992) and *blunders* (Wallace et al., 2002). The two items that made up this factor also appeared in Larson et al.'s (1997) general factor 1.

Factor 5, *social*, appeared to relate to dealings with other people. It accounted for 4.72% of the variance. The two highest loading items were, "Do you leave important letters unanswered for days?" (item 11) and "Do you find you forget appointments?" (item 16). It also included item 17, "Do you forget where you put something like a newspaper or a book?" but the factor loading on this item was relatively low (0.41) and was only just above the cut-off point. Factor 5 overlapped with Matthews et al.'s (1990) factor 3, *planned social interaction* and to a lesser extent Pollina et al.'s (1992) factor 5, *interpersonal intelligence* that the latter interpreted as reflecting disruption of the respondent's social skills.

Factor 6, *distractibility*, accounted for 4.52% of the variance. Items 1, "Do you read something and find you haven't been thinking about it and must read it again?" and 19, "Do you daydream when you ought to be listening to something?" were included in this factor. These items appeared to reflect failures to keep to the task in hand, to be distracted. This interpretation was consistent with factors found in a number of other studies. Both of these items appeared in factors labelled *lack of concentration*, interpreted as, "mentation irrelevant to the task at hand" (Matthews et al., 1990, p. 56) and *distractibility* (Pollina et al., 1992; Wallace et al., 2002).

Factor 7, *spatial*, accounted for 4.37% of the variance and included two items – "Do you fail to notice signposts on the road?" (item 3) and "Do you find you confuse right and left when giving directions?" (item 4). This factor overlapped with Matthews et al.'s (1990) factor 1, *physical clumsiness* and Pollina et al.'s (1992) factor 3, *spatial/kinaesthetic memory*. This factor was clearly related to spatial ability.

Only one item loaded greater than 0.40 on factor 8, viz., item 6, "Do you find you forget whether you've turned off a light or a fire or locked the door?" Factor 8 accounted for 4.01% of the variance. Previously this item has appeared in a variety of factors labelled *absent-mindedness* (Matthews et al., 1990), *spatial/kinaesthetic memory* (Pollina et al., 1992), *memory* (Wallace et al., 2002) and Larson et al.'s (1997) general factor 1. Pollina et al. interpreted their factor 3, *spatial/kinaesthetic memory*, as representing incidences of interrupted processing of sequences of cognitive and motor actions. This is perhaps the most appropriate category in which to place the current factor 8 also.

Table 4.4: Rotated factor matrix

CFQ items		1	2	3	4	5	6	7	8
2.	Do you find you forget why you went from one part of the house to the other?	.64							
23.	Do you find you forget what you came to the shops to buy?	.54	.44						
18.	Do you find you accidentally throw away the thing you want and keep what you mean to throw away – as in the example of throwing away the matchbox and putting the used match in your pocket?	.52							
17.	Do you forget where you put something like a newspaper or a book?	.48							
14.	Do you find yourself suddenly wondering if you've used a word correctly?		.52						
25.	Do you find you can't think of anything to say?		.49						
15.	Do you have trouble making up your mind?		.48						
22.	Do you find you can't quite remember something although it's 'on the tip of your tongue'?		.43						
20.	Do you find you forget people's names?			.69					
7.	Do you fail to listen to people's names when you are meeting them?			.67					
5.	Do you bump into people?				.57				
24.	Do you drop things?				.54				
11.	Do you leave important letters unanswered for days?					.51			

16.	Do you find you forget appointments?	.48		
17.	Do you forget where you put something like a newspaper or a book?	.41		
19.	Do you daydream when you ought to be listening to something?		.62	
1.	Do you read something and find you haven't been thinking about it and must read it again?		.56	
3.	Do you fail to notice signposts on the road?			.60
4.	Do you find you confuse right and left when giving directions?			.40
6.	Do you find you forget whether you've turned off a light or a fire or locked the door?			.54

Table 4.5: Types of cognitive failure represented by eight-factor solution.

Factor	Item content	% variance	α
1	Forgetfulness	26.63	0.73
2	Use of language	6.45	0.72
3	Names	5.86	0.65
4	Clumsiness	5.32	0.59
5	Social	4.72	0.55
6	Distractibility	4.52	0.55
7	Spatial	4.37	0.45
8	Item 6	4.01	-

4.8.4 Gender differences in CFQ factor scores

A MANOVA was conducted to test gender differences in the factor structure of the CFQ. There were significant differences between males and females on all of the factors except factor 5 *social*. Effect sizes associated with these differences were small (η^2 ranged between 0.00 and 0.17). The descriptive statistics for the eight factors and the F statistic for each one are displayed in Table 4.6.

Table 4.6: Mean CFQ factor scores and standard deviations split by gender.

CFQ Factor	Gender	Mean	S.D.	F
Factor 1 Forgetfulness	Male	5.22	2.72	9.15**
	Female	6.37	2.92	
Factor 2 Use of language	Male	8.58	3.50	4.23*
	Female	9.52	3.35	
Factor 3 Names	Male	5.29	1.94	10.79**
	Female	4.45	1.89	
Factor 4 Clumsiness	Male	2.04	1.28	45.80***
	Female	3.39	1.66	
Factor 5 Social	Male	4.63	2.31	0.41
	Female	4.84	2.47	
Factor 6 Distractibility	Male	5.02	1.63	5.94*
	Female	5.53	1.53	
Factor 7 Spatial	Male	2.16	1.69	16.45***
	Female	3.09	1.75	
Factor 8 Item 6	Male	1.50	1.07	4.49*
	Female	1.79	0.99	

*$p < 0.05$, ** $p < 0.01$, ***$p < 0.001$

4.8.5 Eight-factor solution and SART

Given that the a factor analysis of the CFQ revealed multiple dimensions, the next step was to test how many of these dimensions correlated with sustained attention as measured by the SART. A total of 112 out of the 225 participants who completed the CFQ did the $SART_{random}$. Pearson correlations were carried out on the data and significant relationships were found between $SART_{random}$ errors of commission and factor 2, *use of language* ($r = 0.26$, $n = 112$, $p < 0.006$) and factor 6, *distractibility* ($r = 0.31$, $n = 112$, $p < 0.006$). (α set at 0.006 to control for conducting multiple correlations.)

4.9 Discussion

A factor analysis of the CFQ data revealed an eight-item factor solution accounting for 62% of the variance. The eight internally consistent factors were labelled according to the kinds of failures the items represented: (1) *forgetfulness*, (2) *use of language*, (3) *names*, (4) *clumsiness*, (5) *social*, (6) *distractibility*, (7) *spatial*, (8) *item 6*. Factors 2 and 6 correlated significantly with performance on the SART. Gender differences in cognitive failures were addressed in the same manner as Pollina et al. (1992). When a significant difference was found between males and females on the CFQ total score, an analysis of the CFQ item scores was conducted. Females reported more incidences of cognitive failures than males on several items and vice versa on two items. Gender differences in the factor structure of the CFQ were found in all factors except one, viz., factor 5.

4.9.1 Multidimensionality of the CFQ

This study confirmed the multidimensionality of the CFQ as suggested by previous factor analyses of the data (Larson et al., 1997; Matthews et al., 1990; Pollina et al., 1992; Wallace et al., 2002). It adds further support to Matthews et al.'s (1990) assessment of Broadbent et al.'s (1982) factor analysis of the CFQ in that their sample sizes were probably too small for an adequate analysis. Subsequent studies used more than the minimum required (i.e., $n \geq 100$; Kline, 1994) and all found multiple dimensions. More of the variance was accounted for by the solution produced by the current study than any of the others, however. Wallace et al.'s (2002) four-factor solution came closest, accounting for 54% of the variance. In addition, the factors were all reasonably interpretable. Larson et al. (1997) and to some extent Matthews et al. (1990) believed that no more than two factors were interpretable, i.e., a *general* factor and a *names* factor. This study provided evidence to the contrary, consistent with Pollina et al. (1992) and Wallace et al. (2002).

There appears to be a number of factors that are particularly consistent from one study to the next. In the current study, items 7 and 20 loaded strongly – both 0.70 – on factor

3. Labelled *names*, this same factor has been found in all previous factor analyses of the CFQ (Larson et al., 1997; Matthews et al., 1990; Pollina et al., 1992; Wallace et al., 2002). Even Broadbent et al. (1982) reported three items that formed a cluster in the majority of the groups that they tested, including 7 and 20. What kind of failure does this factor represent? Pollina et al. (1992) interpreted the factor as reflecting memory for names and labelled it accordingly but as Broadbent et al. pointed out, item 20 is a memory failure and item 7 is a perceptual failure. As mentioned, both of these items had the same loading on the factor in this study so one cannot be given precedence over the other in regard to interpretation. It may best be described as a problem with names or indeed some kind of social failure (Broadbent et al., 1982).

Another factor that has appeared relatively consistently is related to action failures. In the current study, this factor was labelled *clumsiness* and consisted of items 5 and 24. These items asked about how often the respondent bumped into people and dropped things. Similar factors have appeared in Matthews et al. (1990, *physical clumsiness*), Pollina et al. (1992, *spatial/kinaesthetic memory*) and Wallace et al. (2002, *blunders*). Broadbent et al. (1982) intended the CFQ to include action failures, just not in a category that could be separated from the other types of cognitive failure. However, the occurrence of this factor in this study and similar factors in at least three other studies would suggest that it is in fact separable.

The factor labelled *forgetfulness*, accounted for the largest portion of the variance (26.63%). At first glance, this factor appeared to be consistent with the large general factors reported by, e.g., Larson et al. (1997). However, the items loading on the *forgetfulness* factor were much fewer in number and more interpretable than Larson et al.'s general first (and second) factor, which he described as a, "hodgepodge of different items" (p.31). The items loading on the current factor 1 were clearly related to memory failures including such items as "Do you find you forget why you went from one part of the house to the other?" and "Do you find you forget what you came to the shops to buy?". Nevertheless, the four items loading on factor 1 were also found in the factor analyses of Matthews et al. (1990) and Wallace et al. (2002) in factors labelled *absent-mindedness* and *memory* respectively. Like action failures, Broadbent et al. (1982) intended to include memory failures in the CFQ. Like action failures, this type of cognitive failure appears to be separable too.

The third question to form a cluster in Broadbent et al.'s (1982) analysis of the CFQ was ostensibly an action failure, item 11, "Do you leave important letters unanswered for days?" However, the authors acknowledged that it could also be considered more social than cognitive in nature. This fits in with the interpretation of factor 5 in the current study. Labelled *social*, this factor received high loadings from item 16, "Do you find you forget appointments?" as well as item 11. Similar factors were described by Matthews et al.'s (1990) factor 3, *planned social interaction* and Pollina et al.'s (1992) *interpersonal intelligence*. The item content of these two factors and the current factor 5, *social*, were not exactly the same but they do suggest the existence of an additional category of social failures as well as memory, perceptual and action failures. Factor 5, *social* and factor 3, *names*, may both fall into this category.

4.9.2 CFQ factors and the SART

Items 1, "Do you read something and find you haven't been thinking about it and must read it again?" and 19, "Do you daydream when you ought to be listening to something?" loaded above the cut-off point on factor 6. These items both appeared to be related to not paying attention to the task in hand, whether it was reading or listening to something. This factor was labelled *distractibility*, like Pollina et al.'s (1992) and Wallace et al.'s (2002) factors 1 and 2 respectively. There were overlaps not only among these three factors but also with Matthews et al.'s (1990) factor 6, *lack of concentration*. Perhaps there is a case to be made for an attention category of cognitive failures, as well as memory, perceptual, action and social failures. This is not to say that attention does not play a role in most, if not all, other cognitive failures but rather more so in this factor. That this might be the case is supported by Wallace et al.'s finding of a correlation between their *distractibility* factor and boredom proneness (also related to vigilance; Kass, 2001) and adult attention behaviour. Furthermore, in the current study, *distractibility* was found to correlate significantly with sustained attention performance as measured by the SART. A participant who scored highly on this factor made more errors of commission on the computer task.

Factor 2, *use of language*, also correlated with SART performance. The relationship between this factor and sustained attention is not as obvious as *distractibility* but it is not difficult to see how a failure to pay attention could lead on the one hand to cognitive failures related to language (e.g., item 14, "Do you find yourself suddenly wondering if you've used a word correctly?") and on the other to action failures (e.g., item 5, "Do you bump into people?"). One of the reasons for doing a factor analysis of the CFQ was to determine if its component factors would be more useful in relation to the SART than the CFQ total score. The relationships between *use of language, distractibility* and SART performance would seem to indicate that such is the case. However, the degrees of correlation (0.26 and 0.31) were the same or only marginally more than the correlation between SART performance and the CFQ total score (0.27). The question must be asked: is it worth using a reduced version of the CFQ? Larson et al. (1997) concluded that only the total CFQ score was useful in the analysis of objective correlates. Despite finding a three-factor solution, they argued that only the large general factor and the specific *names* factor were interpretable. Name processing was unlikely to be important to their correlate of interest (accidents) so that was discarded for further analysis. The large general factor that they were left with correlated strongly with the total CFQ score (0.94) and, in line with Broadbent et al. (1982), decided there was no reason to use a reduced CFQ, that the total score was sufficient. In regard to factor 6, *distractibility*, in the current study and the total CFQ score, the two measures correlated significantly ($r = 0.56$, $n = 225$, $p < 0.001$). So perhaps the CFQ total score is adequate for the analysis of the relationship of cognitive failures with the SART.

4.9.3 Interpretability

There were a number of potential problems with the current factor analysis. Firstly, while factors 1, 3, 4, 5 and 6 were consistent with previous studies, factors 2, 7 and 8 were not. Factor 2, *use of language*, was the least well-defined. This factor was so labelled because the highest loading item was related to correct word usage and also because it overlapped with Matthews et al.'s (1990) factor of the same name. However, there was also some overlap with factors labelled *distractibility* in two other studies (Pollina et al., 1992; Wallace et al., 2002) and *use of language* received loadings, albeit relatively low, from items not directly related to language. Factor 7, *spatial*, seemed to

be mostly related to spatial ability, including item 4, "Do you find you confuse right and left when giving directions?" This was further supported by its overlap with Pollina et al.'s (1992) *spatial/kinaesthetic memory* factor but less so by its overlap with Matthews et al.'s (1990) *physical clumsiness* factor. Item 3 did not appear at all in Larson et al.'s (1997) factor solution and both items 3 and 4 loaded on Wallace et al.'s (2002) *distractibility* factor. The reason for this discrepancy among studies may lie in the relevance of these particular items to the respondents. Item 3, "Do you fail to notice signposts on the road?" has little relevance to someone who doesn't drive a car and likewise item 4. In fact, several of the students in the current study remarked on this. It seems likely that students answering these questions would respond differently from, e.g., Larson et al.'s American Navy recruits who must all have driven a car so that the authors could correlate their CFQ scores with measures of driving frequency, traffic tickets and accidents. Finally, factor 8 was related to only one item, "Do you find you forget whether you've turned off a light or a fire or locked the door?" (item 6). Why this should be considered a separate factor is unclear. If anything, this item would appear to be related to memory failures but it received a very low loading on the *forgetfulness* factor. There is little to be learned from looking to see what factors this item loaded on in previous factor analyses, as it varies from one to the next.

4.9.4 Variation in the CFQ total score among studies

Another problem related to the variation in the CFQ total scores among studies. To pick one of the groups that Broadbent et al. (1982) studied using a version of the CFQ most closely aligned to the current one, skilled men, their mean CFQ total score was 36.65 (S.D. = 9.41). This was close to Larson et al.'s (1997) Navy recruits (mean = 33.6, S.D. = 12.8) and a little bit less so to Wallace et al.'s (2002) sample (Navy personnel and college students; mean = 43.46, S.D. = 17.02) and the current study in which the majority of respondents were college students (mean = 43.95, S.D. = 12.77). Much more remarkable was the difference between these CFQ total scores and that of Pollina et al.'s (1992) sample of college students, whose mean score was a low 19.1 (standard deviation not reported). It is difficult to see why there should be such a discrepancy in scores. There was nothing distinctive about Pollina et al.'s sample that suggested why

they might report so few incidences of cognitive failures. Whatever the reason, it is one cause for caution in comparing CFQ studies and factor analyses of the questionnaire.

4.9.5 Gender differences

The current study's main problem was probably the underlying gender differences in CFQ scores. A sample used in a factor analysis should be homogenous with respect to the underlying factor structure. If two subsamples, in this case males and females, are combined, "the resulting correlations may be a poor representation of the unique structures of each group" (Hair, 1998, p. 375). Previous analyses of the CFQ have dealt with this gender difference in different ways. Matthews et al. (1990) did not exactly report a gender difference but as a preliminary they checked the similarity of interitem correlation matrices in the male and female subsamples. The intercorrelation was relatively modest (0.48) but nevertheless they decided against obtaining separate solutions for males and females. Furthermore, a relatively large number (59) were reported as being of unrecorded gender, raising questions about the reliability of their calculations in this regard. Pollina et al. (1992) reported a difference between males and females and then proceeded to examine this difference at an individual item level and then in the factors revealed by their PCA. Ideally, one would conduct separate factor analyses for each subsample (Hair, 1998) but in the current study this would have reduced the sample size considerably, subsequently increasing the standard errors of the correlations. However, rather than ignore the issue, the data for males and females were analysed in the manner of Pollina et al. to examine exactly where the differences lay. Females reported significantly more incidences of cognitive failures than men on a large number of items and in all but one of the factors. The only exception in the direction of this difference was in regard to names. Males reported a greater frequency of failing to listen to and remember people's names. These gender differences should be checked in any study using the CFQ. It may be the case that none exists (as in Wallace et al., 2002) but if one does then its consequences should be considered. Larson et al. (1997) may have avoided this issue by using a sample entirely made up of male respondents but it does mean that his results are not generalisable to the population as a whole despite the large sample size on which they are based. This may also explain why Larson et al.'s solution seemed different from all the others. Their finding of a three-

factor solution with only two interpretable factors – a solution they considered in line with Broadbent et al.'s (1982) findings – may be a function of sample characteristics.

In sum, this factor analysis found the CFQ to represent multiple dimensions of cognitive failures. Broadbent et al. (1982) created the CFQ to measure different types of cognitive failures – memory, perceptual and action failures – but believed that there was no reason to separate the categories. They argued that the CFQ measured a single, unitary dimension of cognitive failure. This study, like several others, provided evidence to the contrary. Eight internally consistent, relatively interpretable factors were found that together accounted for 62% of the variance. The finding of such factors as factor 5 and factor 6 suggested that additional categories of cognitive failures might be appropriate, relating to social and attention failures. Two of the factors (2 and 6) correlated with errors of commission on the SART. However, there were some concerns about the degree of the correlations involved. In fact, it seems unlikely that the use of CFQ factors provides more information than the use of the total score alone in regard to sustained attention and the SART.

4.10 General Discussion

What can be learned from bringing together the results from the two studies reported in this chapter? Study 1, "Cognitive failures and the SART", confirmed that there was a relationship between absent-mindedness or everyday cognitive failures as measured by the CFQ and sustained attention as measured by the SART. This relationship was not found in a fixed sequence version of the task, probably because of the significantly lower number of errors made. Young, healthy participants found the $SART_{fixed}$ easier than the $SART_{random}$. Study 1 also showed that sustained attention performance on the $SART_{random}$ was related to speed; faster reaction times overall resulted in more errors of commission.

Study 2, "Factor analysis of the CFQ", was conducted to determine whether Broadbent et al.'s (1982) questionnaire measured a single or multiple dimensions and, if the latter rather than the former, which dimensions were related to SART performance. As with several other factor analyses of the CFQ (Larson et al., 1997; Matthews et al., 1990;

Pollina et al., 1992; Wallace et al., 2002), a multiple factor solution was found. Scores from two factors out of eight correlated significantly with errors of commission on the $SART_{random}$: *use of language* and *distractibility*. This provided more information about the relationship between the CFQ and the SART in this sample. In particular, participants who reported themselves as being more susceptible to distraction and language-related cognitive failures were more likely to experience absent-minded slips of action on the SART.

Does this information help in any way towards answering the question as to what exactly the SART measures? Although evidence has been provided supporting the idea of the SART as a measure of sustained attention (Manly et al., 2000b; Robertson et al., 1997), the possibility still exists that it is a measure of response inhibition. After all, Moores and Andrade (2000) did find a correlation between performance on the SART and on the GGST, a test of response inhibition. Perhaps it is not a case of one or the other, but both. The results of the factor analysis suggested that the relationship between the SART and the CFQ was mediated by cognitive failures related to distractibility and use of language. Either of these types of failure could arguably be related to sustained attention or response inhibition. One thing to keep in mind, however, is the research conducted by Vom Hofe et al. (1998) who found that the CFQ was related to selective attention. In the process, they also found evidence that suggested the CFQ was not so much related to inhibition. This tentatively suggests that the SART – a measure that correlated with the CFQ – is more a measure of attention than response inhibition.

5. A Magnetic Stimulation Study of Sustained Attention: Problems and Solutions

5.1 Overview

A pilot study was conducted to explore the use of the transcranial magnetic stimulation (TMS) technique in conjunction with the SART. TMS is a relatively new neuroscientific technique that offers excellent spatial, temporal and functional resolution, i.e., the ability to determine what areas of the brain are necessary to perform a particular function. It is in essence a 'virtual lesion' technique, producing temporary and reversible lesions in the participant. The aim of the current study was to produce such a lesion in at least one of the areas associated with sustained attention and to see what effect that had on SART performance. The capacity of sustained attention has been linked with the right dorsolateral prefrontal and posterior parietal cortex (Cohen et al., 1988; Coull et al., 1996; Koski & Petrides, 2001; Lewin et al., 1996; Pardo et al., 1991; Rueckert & Grafman, 1996; Wilkins et al., 1987). Experiments using the SART have added to this body of evidence. For example, Manly et al. (2001) found dorsolateral prefrontal and parietal cortex activation during SART performance using positron emission tomography (PET).

Posterior parietal cortex was selected for this study because prefrontal cortex can sometimes be problematic for TMS (the close proximity of facial nerves often produces slight muscle twitches, including eye-blinks, causing discomfort to the participant and influencing cognitive performance; Walsh & Cowey, 1998). Magnetic stimulation was used to 'knock out' right posterior parietal regions during performance on the SART and its effect on errors of commission, errors of omission, and RTs were examined. There were two control conditions; TMS applied to the left posterior parietal cortex (location control) and a condition with no TMS, just SART.

It became apparent during the course of testing that there were a number of serious problems with the study's methodology. These problems related to: (1) picking the parietal cortex as the area to be stimulated, (2) selecting the precise location of stimulation for each participant and, (3) controlling for potential confounds. The results obtained from this study were not wholly reliable because of these problems. Therefore, the emphasis of the discussion is on identifying the study's methodological flaws and ways to ameliorate those flaws in the future. Some of these are incorporated into an alternative methodology for the study.

5.2 Introduction

5.2.1 Sustained attention and associated brain activity

Extensive experimentation has shown that sustained attention is associated with activity in fronto-parietal areas of the brain, predominantly in the right hemisphere (see chapter 2; Cohen et al., 1988; Coull et al., 1996; Koski & Petrides, 2001; Lewin et al., 1996; Pardo et al., 1991; Rueckert & Grafman, 1996; Rueckert & Grafman, 1998; Wilkins et al., 1987). These experiments were conducted in both normal, healthy populations and also in brain-injured ones, using a variety of techniques including PET and fMRI.

Lesion studies such as the one carried out by Wilkins et al. (1987) compared patients with different lesion sites on tasks that tested their sustained attention ability. It was found that patients with lesions in the right frontal cortex performed more poorly on these tasks than those who had lesions elsewhere or indeed, as in the case of Koski et al. (2001), normal, healthy participants. The problem with lesion studies is, however, twofold. Firstly, in studying patients with brain damage of some kind one is making inferences about normal brain function from what is not normal. Secondly, the patient's damaged brain can change with time (e.g., by compensatory plasticity) resulting in changes in behaviour.

Using imaging techniques such as PET and fMRI enabled researchers to study sustained attention ability in the normal, healthy population, thereby avoiding the problems

associated with studying patients with brain injury. PET studies by Cohen, Pardo, Coull and their respective colleagues (Cohen et al., 1988; Coull et al., 1996; Pardo et al., 1991) added to the evidence for right frontal cortex involvement in sustained attention performance. Evidence was also found for right parietal cortex involvement. In an fMRI study, Lewin et al. (1996) found right middle frontal gyrus and parietal lobe activation during performance on a task based on Pardo and colleagues' task.

5.2.2 Sustained attention as measured by the SART and associated brain activity

There would then appear to be significant evidence to suggest a fronto-parietal network specialised for sustained attention provided by the lesion and imaging studies listed. However, what about sustained attention as measured by the SART? Does performance on this task correlate with activity in the right frontal and parietal cortex?

Manly et al. (2003) conducted a PET study on sustained attention as measured by the $SART_{random}$ and the $SART_{fixed}$. The purpose of this study was to look at the definition of sustained attention in more detail; comparing different versions of the SART in order to determine which was the most demanding on a sustained attention system that was activated during performance on uninteresting tasks. Manly and colleagues put forward the argument that the very fact that these tasks were uninteresting resulted in a greater demand on an endogenously maintained attention system. All of the imaging studies that had come before had compared the demands of the test condition or sustained attention task with the control condition of rest. When compared with a rest, a wide variety of tasks with ostensibly different demands have activated the same frontal areas associated with the sustained attention studies including (Duncan & Owen, 2000). This means that it cannot be said with certainty that the sustained attention system *specifically* is associated with such activation. Consequently, in their PET study, Manly and colleagues compared activation of the sustained attention system within two versions of the same task. The first version of the task was the standard, $SART_{random}$ in which the participant responded to the digits 1-9 presented in a random fashion and in which the occurrence of the target trial on which the participant had to withhold a response was entirely unpredictable. The second version of the task was the same in terms of instructions, visual stimulation, and motoric components but differed in its

presentation of the digits. The digits were presented in the conventional, ascending order with the consequence of the target trial appearing at a predictable point. This made the $SART_{fixed}$ subjectively easier but according to the authors, more demanding on a system that self-sustains continued performance under conditions of low externally mediated challenge.

The results supported Manly et al.'s hypothesis that the reduced continual challenge and ostensibly lower demand of the $SART_{fixed}$ would be associated with increased activation in the areas previously associated with sustained attention. Significant increases in rCBF were recorded in the dorsolateral prefrontal cortex and the superior/posterior parietal cortex during performance on the $SART_{fixed}$ compared to the $SART_{random}$.

5.2.3 Introducing Transcranial Magnetic Stimulation (TMS)

In sum, so far, there have been several studies linking fronto-parietal areas of the brain to sustained attention performance and, moreover, to sustained attention performance as measured by both the $SART_{random}$ and the $SART_{fixed}$. Studying the brain activity associated with sustained attention using techniques such as PET and in such as the brain-injured population has much to recommend it but with the following caveat; the findings of such studies can only ever suggest a correlational relationship and not a causal relationship between the function in question and activity in the associated areas of the brain. The technique to do this is a relatively new and exciting technique called TMS. TMS comes far closer to determining the causal relationship between behaviour and brain than any of its predecessors.

TMS can be used to study the organisation of sensory and cognitive functions and cortical development and plasticity. It also has clinical uses, for example in the treatment of depression (George, Lisanby, & Sackheim, 1999). TMS makes use of a method called reverse engineering. This method involves selectively removing components from information processing and recording the effects of that removal on subsequent behaviour, thereby linking cause and necessity with brain activation and perceptions and action (Walsh, 2000). As observed by Walsh and Pascual-Leone (2003), this method has proven successful for several decades in the case of

neuropsychological studies of patients (e.g., Critchley, 1953; Milner, 1966; Shallice, 1988) and animal lesion studies (Butter, 1968; Butter, 1969; Butter, 1972; Cowey & Gross, 1970; Gross, Cowey, & Manning, 1971; Riopelle & Ades, 1953; Riopelle, Alper, Strong, & Ades, 1953; Walsh & Butler, 1996). In this way TMS goes one step further than PET, fMRI, ERPs and MEG, in answering the questions "what?" as well as "where?" and "when?" in regard to what is happening in the brain during some behaviour.

5.2.4 How exactly does it work?

Walsh and Pascual-Leone (2003) recommend looking at TMS as operating in two ways: a disruptive mode and a productive mode. In the disruptive mode (the one of most interest to psychologists), TMS is applied during a participant's performance on a task, inducing neural noise into the signal-processing system. In the productive mode TMS adds signal rather than noise. An example of the latter would be when phosphenes[1] are produced (Kammer, 1999; Kammer & Nusseck, 1998).

TMS uses the principle of electromagnetic inductance, i.e., that a changing magnetic field can induce an electrical current in a nearby conducting material (in this case the head). TMS works by applying a brief magnetic pulse, or a train of pulses, to the scalp. This induces an electrical field that alters the local electrical field in the underlying surface of the brain. Stewart et al. (2001) describe the sequence of events in the delivery of a single pulse: an electrical current of up to 8 kA is generated by a capacitor and discharged into a circular or figure-of-eight-shaped coil that produces a magnetic pulse of up to 2 T (duration of 1 ms). The pulse changes at a rapid rate because of its intensity and brevity. The electrical field generated by the magnetic field results in neural activity. This sequence is illustrated in Figure 5.1. As well as single pulse TMS, some stimulators produce trains of pulses, or rTMS (rapid rate TMS). These reach a rate of up to 50 Hz. However, rTMS carries with it a risk of seizures and strict safety guidelines must be adhered to (Wasserman, 1998).

[1] Phosphenes are sensations of light produced by stimulation of the eye or the brain other than by light entering the eye (Stewart et al., 2001).

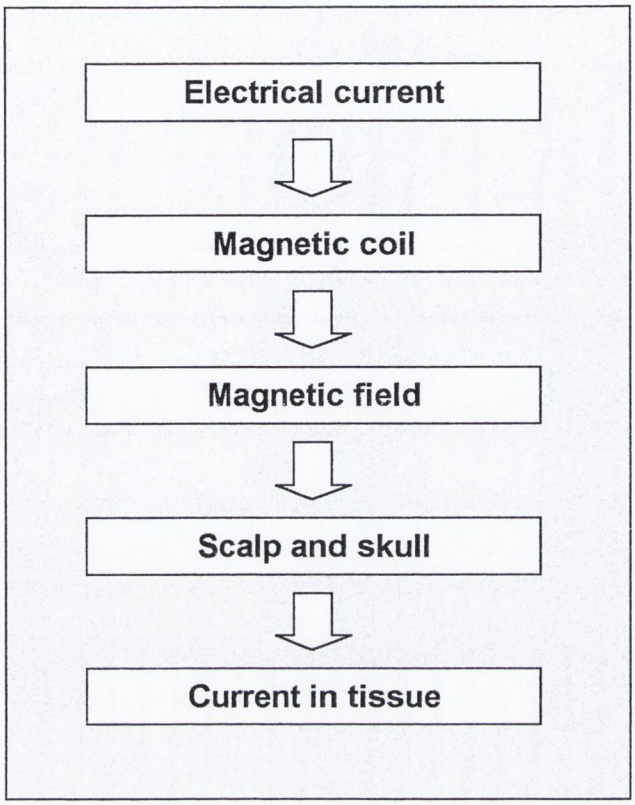

Figure 5.1: Sequence of events in TMS

5.2.5 TMS in comparison to other techniques

How does TMS compare to other techniques used to study brain activity? There are a number of neuroimaging techniques that are from the same time period as TMS including event-related potentials (ERPs), positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and magneto-encephalography (MEG).

ERPs will be covered in some detail in chapters six and eight but briefly, it is a technique based on recordings of electrical brain activity measured from the surface of the scalp. This is an excellent technique in regard to timing but relatively poor in localising cognitive processes. In ERPs, the electrical signal from the brain must travel through brain, skull and scalp before being registered and is somewhat distorted in the process. The techniques PET and fMRI exhibit the opposite condition: good spatial resolution, less reliable temporal resolution. PET is a method of mapping brain activity by recording the emission of radioactivity from injected chemicals. An area of activity

can be located to within about three or four millimetres. The technique fMRI – which measures energies released by haemoglobin molecules in an MRI scan, and then determines the brain areas receiving the greatest supply of blood and oxygen – has even better spatial resolution than PET; in the range of 1-2 millimetres (Raichle, 1994). However, both PET and fMRI suffer from poor temporal resolution, the latter in the order of several seconds. The temporal resolution of PET is very poor, indicating the total amount of activity in each brain area over a period of 60 seconds or longer.

MEG is a device that measures the faint magnetic fields generated by the activity in the brain (Hari, 1994). Like ERPs, MEG has excellent temporal resolution and shows changes in the brain's activity from one millisecond to the next. It does not, however, provide structural or anatomical information because magnetic detectors on the surface of the skull record the net activity over a fairly large area. Consequently, it is necessary to obtain an MRI in conjunction with information from MEG to determine what areas are active.

In contrast with all these other techniques – PET, fMRI, ERPs and MEG – TMS combines good temporal and spatial resolution. The technique's temporal resolution varies slightly depending on the type of TMS, ranging from a matter of milliseconds for single-pulse TMS to 500-1000 ms for rTMS (Walsh & Pascual-Leone, 2003). In terms of spatial resolution, a peak focal activity of somewhere between 0.5 and 1.0 cm has been suggested (Savoy, 2001). However, the TMS technique's main strength is its functional resolution. Both PET and fMRI have the ability to determine *where* in the brain the activity associated with a behaviour is happening and ERPs and MEG can determine *when* it's happening. MEG, when combined with MRI, can even offer both spatial and temporal resolution. TMS goes one step further in that it can determine the *necessity* of a particular brain area for a named function. If the question is, "Can [TMS] offer a more elegant, quicker or less invasive solution to some of the problems that can be addressed through other techniques?" (Stewart et al., 2001, p. 277) then the answer is yes.

Table 5.1 summarises the similarities and differences among the various techniques discussed above.

Table 5.1: TMS compared to ERPs, PET, fMRI, and MEG in terms of temporal, spatial, and functional resolution.

Technique	**Resolution**		
	Temporal	*Spatial*	*Functional*
ERPs	✓	✗	✗
PET	✗	✓	✗
fMRI	✗	✓	✗
MEG	✓	✗	✗
TMS	✓	✓	✓

5.2.6 A virtual lesion technique

The similarities and differences between TMS and neuroimaging techniques in terms of spatial, temporal, and cognitive resolution have been demonstrated but how does the technique compare with neuropsychology, given that it uses reverse engineering methods as it does? Quite simply, it bypasses a number of problems inherent in patient studies. TMS can test normal, healthy participants and has effects that last only a few tens of milliseconds, thereby avoiding the problem of reorganisation in the brain. Furthermore, the fact that the lesions that TMS induces are reversible means that the normal participants can act as their own controls.

This effect of TMS – to produce a reversible lesion – has been called a "virtual lesion" (Pascual-Leone, Bartres-Faz, & Keenan, 1999) and the normal participant that experiences it, a "virtual patient" (Walsh & Cowey, 1998).

5.2.7 Limitations

So far, it would appear as if TMS is an ideal technique but it does have its limitations and to give an accurate impression of the technique these should be mentioned. The two biggest concerns centre on safety and spatial resolution (Savoy, 2001).

Single-pulse TMS is generally accepted as safe but there are a number of problems that have been recognised with rTMS. Single pulses are separated by more than one second whereas repeated pulses are presented at a rate of 5-10 pulses per second. This has been associated with seizures in normal, healthy participants (Savoy, 2001). So saying, it is relatively easy to follow the guidelines set out by Wasserman (1998) and also Pascual-Leone et al. (1993) and use minimal intensities and durations of TMS and avoid inducing such seizures.

Other aspects of the TMS procedure that have proven a problem are the loud noise, headaches or nausea and discomfort (Walsh & Pascual-Leone, 2003). What is more, these concerns are connected to the short-term effects but relatively little is known about the long-term ones in this regard. However, it seems likely that those long-term effects do exist given the efficacy of TMS in treating depression (George et al., 1999). Further, there is nothing to say that these effects would necessarily be of benefit to the participant. Walsh and Pascual-Leone (2003) recommend that researchers take the precaution of not testing their participants in TMS experiments repeatedly in a short time period in order to avoid these possible long-term effects.

Another notable limitation of TMS is related to its spatial resolution. It is difficult to be precise about the depth and spatial extent of the areas affected by stimulation and while it has been suggested that peak focal activity falls within the range of 0.5 to 1.0 cm this is somewhat misleading on the grounds that it is not clear how much TMS activates away from the peak focus point and it is likely that propagation of the effects by the axons affects other areas (Savoy, 2001). In addition, temporally, it is difficult to determine how long the effects in the cortex last because it may be that the neurons stimulated by the TMS take time to recover their normal function and interaction with other cells (Walsh & Pascual-Leone, 2003).

5.2.8 The current study

The techniques that have already been used to study the maintenance of attention - PET, fMRI, and ERPs - have provided us with a correlate between this capacity and certain brain regions, namely the right dorsolateral prefrontal and posterior parietal cortex. As Stewart et al. (2001) pointed out, TMS can go one step further and can determine whether or not these areas are *necessary* for a particular function, in this case, sustained attention performance as measured by the SART.

For the purposes of this pilot study we selected the posterior parietal rather than prefrontal region because TMS applied to prefrontal areas can cause some discomfort to the participant (due to its close proximity to the facial nerves). In general, muscles and nerves that lie near the stimulating coil are activated by TMS. This is particularly uncomfortable for the participant when repetitive-pulse TMS (rTMS) is applied to frontal areas because there is more muscle overlying the skull there (Wasserman, 1998). Applying TMS to these areas has also been found to result in behavioural/mood changes. Crying was observed in some participants following rTMS applied to the left prefrontal cortex in studies of speech arrest (e.g., Pascual-Leone, Gates, & Dhuna, 1991).Further, a knock-on effect of this discomfort would be that it could potentially cue participants' to the coming of the target trials, thus aiding performance.

It was hypothesised that applying TMS to the right posterior parietal cortex would disrupt functioning in that area, thereby interrupting sustained attention. This interruption would in turn manifest itself in increased errors of commission on the SART, i.e., responding on the NoGo trial. Sustained attention is, as outlined, presumed to be a predominantly right hemisphere function and so left posterior parietal cortex was selected as a location control (although in Manly and colleagues' (2003) PET study they did not directly address the laterality of activation associated with a sustained attention (or other interpretation) of the results). A second control condition was included in which no TMS was applied; this provided a control for the effects of the technique itself. Overall RTs and errors of omission were also recorded.

Manly et al. (2003) found that normal, healthy participants' performance on the $SART_{fixed}$ resulted in greater activation of the supposed fronto-parietal sustained attention system than the $SART_{random}$. However, the $SART_{random}$ was selected for use in the current study because the $SART_{fixed}$ is susceptible to ceiling effects in that same population. Manly and colleagues increased the number of potential errors from 25 to 30 (block duration was set at 90 trials to cover the PET acquisition period) and even at that only five of the seven participants made errors with a mean number of 2.00 errors made (S.D. = 2.08) on the $SART_{fixed}$. In comparison, all of the participants made mistakes on the $SART_{random}$ (mean = 3.57, S.D. = 1.27). This finding is in keeping with results reported both in the current work (see chapter 4) and also McAvinue, O'Keefe, McMackin and Robertson (in press).

5.3 Methods

5.3.1 Participants

Eight healthy volunteers (four males, four females, age in years: mean = 25.75, S.D. = 4.71) participated in this pilot study. Participants were right-handed with normal or corrected-to-normal vision. History of head injury, epilepsy or other neurological condition, drug or alcohol problems, major psychiatric disorder, and migraine resulted in exclusion from the study. All participants gave informed consent.

5.3.2 Materials

TMS Equipment

The stimulator was a MagStimTM Model 200 (Whitland, Dyfed, UK) with a maximum output of 2.0 tesla. A figure-of-eight stimulation coil (with each wing 70 mm in diameter) was used. There are different configurations of coils used to apply TMS; the most commonly used types are circular and figure-of-eight shaped. There are advantages in using the figure-of-eight configuration coil over the circular one relating to the focality of stimulation (Ueno, Tashiro, & Harada, 1988). The two circular components of the figure-of-eight coil carry current in opposite directions and there is a

summation of the electric field where the two meet. Focality is further increased when the centre of the figure-of-eight is placed over the region of interest because the outer parts of the coil are usually several centimetres away from the scalp and so are unlikely to induce effective electric fields (Walsh & Pascual-Leone, 2003). The figure-of-eight coil has indeed been reported to have good spatial resolution, for example, effects that are restricted to within a radius of 1 cm (e.g., Jalinous, 1991; Oyachi & Ohtsuka, 1995). In the pilot study reported here, stimulation was applied at 60 to 80 per cent of the maximum. The intensity of stimulation was based on participants' motor thresholds, as is common practice for cognitive studies. The purpose of establishing a participant's motor threshold is to set the level of stimulation suitable for that participant. Motor thresholds are usually determined by recording activity elicited from an intrinsic hand muscle, e.g., the abductor pollicis brevis (APB). Such activity is elicited by applying TMS over the motor cortex and the "threshold is set arbitrarily as the lowest level of stimulation capable of eliciting MEPs of at least 50 μV peak-to-peak amplitude in half of the trials" (Walsh & Pascual-Leone, 2003, p. 77). Stimulation is expressed as a percentage of motor threshold thereby ensuring that the safety guidelines are adhered to (Wasserman, 1998).

$SART_{random}$ stimuli

A total of 225 single digits from 1 to 9 (25 of each of the 9 digits) were presented over a 4.3-minute period. Each digit was presented for 250 ms followed by a 900 ms mask. Participants responded with a key press to each digit unless that digit was a 3 when the response was to be withheld. In this version of the SART, the target was presented in a pre-fixed quasi-random fashion. Participants were instructed to place equal emphasis on speed and accuracy.

The digits were presented in one of five randomly allocated font sizes (48, 72, 94, 100, 120 point Symbol, corresponding to a height of between 12 and 29 mm) to enhance the demands for processing the numerical value, rather than simply setting a search template for some peripheral feature of the target.

The mask (29 mm in diameter) consisted of a ring with a diagonal cross in the middle. Both digits and mask were presented in the centre of the display in white against a black background. The screen was set approximately 70 cm from the participants' eyes (the

magnetic coil cannot be any closer to the computer). However, movement was not restricted.

Each session was preceded by a practice period consisting of 18 presentations of digits, 2 of which were targets.

5.3.3 Procedure

The stimulation site used was over the posterior parietal lobe of the left and right hemisphere. Participants wore a cap on which two points were marked by measuring 9 cm above the inion and 6 cm lateral to the left and to the right of that point (this was consistent with a number of studies carried out on the posterior parietal cortex in the department at that time; e.g., Walsh, Ellison, Ashbridge, & Cowey, 1999). The coil was placed tangential to the surface of the skull. Participants received 225 trials with stimulation being delivered on 100% of the target trials. A train of rTMS at the intensity of motor threshold (see above) was initiated 1.15 s prior to target presentation (i.e., on the trial preceding the target trial). The rTMS train frequency, intensity and duration were well within safe limits (Wasserman, 1998).

There were three conditions: (1) No TMS, (2) TMS applied to the left posterior parietal cortex, and (3) TMS applied to the right posterior parietal cortex. Participants performed the SART under condition (1) first. The order of conditions (2) and (3) was alternated between participants to avoid order effects. In each condition participants' errors of commission, errors of omission and RTs on the SART were recorded.

The $SART_{random}$ was administered on an individual basis in a room designated for TMS research at the University of Oxford's Department of Experimental Psychology.

5.4 Results

Errors of commission, errors of omission and RT were compared across the three conditions outlined above in three separate repeated measures ANOVAs. (Descriptive statistics are displayed in Table 5.2.) There was no difference in errors of commission

($F = 1.21$, $df = 2$, $p > 0.05$) or errors of omission ($F = 0.56$, $df = 2$, $p > 0.05$) across the three TMS conditions (see Figures 5.2 and 5.3 respectively). However, a significant difference was found in RT across conditions ($F = 28.67$, $df = 2$, $p < 0.001$). To find out where the differences lay, paired samples t-tests were carried out on the data. RTs differed significantly between the No TMS condition and the conditions in which TMS was applied to the left parietal ($t = -5.08$, $df = 7$, $p < 0.01$) and the right parietal ($t = 7.10$, $df = 7$, $p < 0.001$). As can be seen in Figure 5.4, applying TMS decreased RT. In other words, participants responded slower in the No TMS condition than the two conditions in which TMS was applied. There was no difference in RTs between the left and right parietal conditions ($t = 1.32$, $df = 7$, $p > 0.05$).

Table 5.2: Descriptive statistics for errors of commission, errors of omission and RTs for the three TMS conditions (No TMS, Left and Right Parietal).

	No TMS		**Left Parietal**		**Right Parietal**	
	Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
Errors of commission	9.50	3.89	7.38	3.89	7.63	4.17
Errors of omission	0.75	1.39	1.00	1.31	1.50	1.60
RTs (ms)	303.77	66.97	252.94	69.78	243.90	65.82

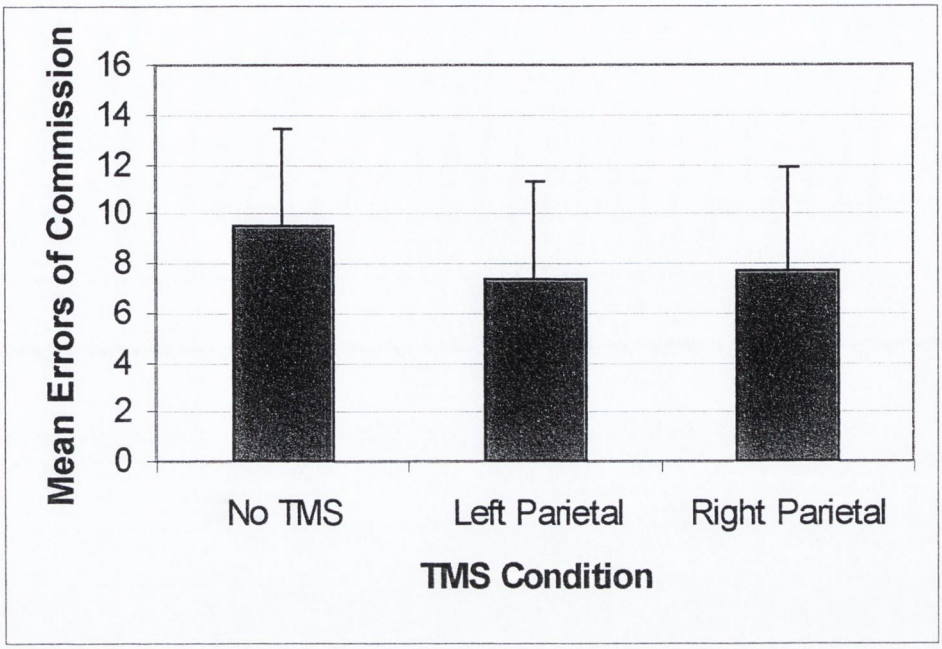

Figure 5.2: Errors of commission over the three TMS conditions (No TMS, Left and Right Parietal).

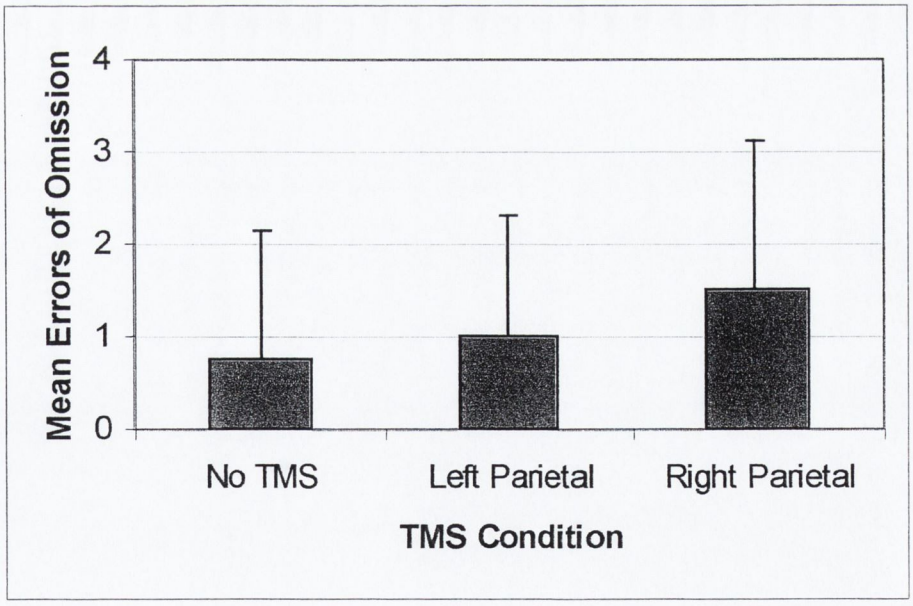

Figure 5.3: Errors of omission over the three TMS conditions (No TMS, Left and Right Parietal).

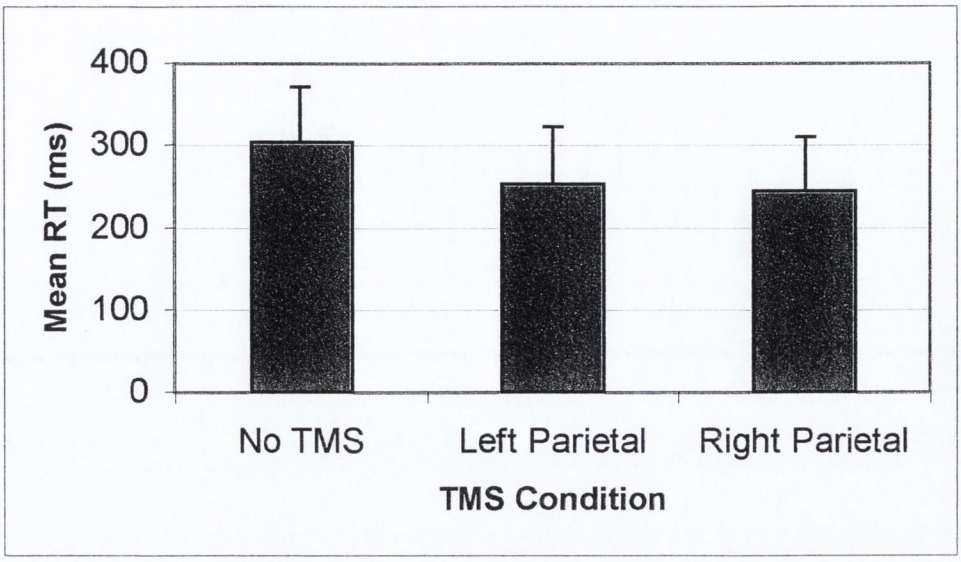

Figure 5.4: RT over the three TMS conditions (No TMS, Left and Right Parietal).

5.5 Discussion

In summary, the only statistically significant effect found was of TMS on RT, with RT in the TMS conditions being markedly faster than in the No TMS condition. There were no differences in RT between the right and left parietal TMS conditions. Errors of commission (responding to a NoGo trial) and errors of omission (not responding to a Go trial) did not differ significantly across conditions.

Typically, the discussion section considers the results of the experiment in the light of the literature reviewed in the introduction, considers the strengths and weaknesses of the current study and perhaps provides at least one alternative explanation for the results that were found. Usually, such a study concludes with suggestions for future research. However, this is likely not the most appropriate approach to take with this pilot study because there were several problems inherent in the design of the experiment that arguably render the results – such as they are - less than reliable. While all of the above listed aspects of a typical discussion will be treated, the emphasis will therefore be on how this study was flawed and how, if it were conducted again, those flaws could be remedied. In that context, an alternative methodology will also be provided.

5.5.1 Location of stimulation

The parietal cortex was selected for stimulation for a number of reasons. Firstly, along with the prefrontal cortex, this area has been associated with sustained attention performance in the past (e.g., Cohen et al., 1988; Pardo et al., 1991). Furthermore, the task that we intended to use to measure sustained attention performance – the SART – was associated with activity in these two areas. Manly et al. (2003) found increased activation in the dorsolateral prefrontal cortex and the superior/posterior parietal cortex during performance on the SART, albeit more for the $SART_{fixed}$ than the $SART_{random}$. Secondly, the parietal cortex was selected for stimulation because it was thought to be a more comfortable area for the participant to have stimulated than the prefrontal cortex. Due to the prefrontal cortex's proximity to the facial nerves it can cause some discomfort when stimulated. Given that this was primarily a pilot a study, i.e., conducted to see how everything would work together, it seemed more sensible to go for the more comfortable area. Besides, if stimulation of the prefrontal cortex was uncomfortable for the participant it would have had a knock-on effect in aiding their performance by cueing the coming of the target trials.

Was this the right decision? It could be argued that the effects of stimulation on the prefrontal cortex should have been tested as well as on the parietal cortex. There is more evidence to support the involvement of the former in sustained attention than the latter. In Lewin et al.'s (1996) replication of Pardo et al.'s (1991) study, they found similar areas of activation. Pardo et al., using PET, found increased rCBF relative to rest in the right dorsolateral prefrontal cortex and in the right superior parietal cortex. The area of greatest activation in Lewin et al.'s fMRI study significantly overlapped with Pardo et al.'s in the right frontal lobe. However, activation in the parietal cortex – found in seven of the nine participants – failed to reach statistical significance.

So saying, a large body of evidence supports the involvement of the parietal cortex in sustained attention. Furthermore, in regard to TMS, there have been numerous studies conducted on this area of the cortex (e.g., Ashbridge, Walsh, & Cowey, 1997; Fierro et al., 2000; Oliveri et al., 2000; Pascual-Leone et al., 1994; Seyal, Ro, & Rafal, 1995;

Walsh, Ellison, Ashbridge, & Cowey, 1999). In contrast, there have been relatively few studies conducted on the prefrontal cortex and more specifically on the dorsolateral prefrontal cortex. One such study was carried out by Mottaghy et al. (2000) who looked at the effects of stimulation on the prefrontal cortex as participants performed a 2-back verbal working memory task. Participants were presented by way of a monitor with 20 letters (A-D five times, each time in a randomised order) with an interstimulus interval of 1.5 s. They were required to press one of two buttons to indicate whether each presented letter was the same or not the same as the letter presented two letters earlier in the sequence. rTMS was applied to the right or left dorsolateral prefrontal cortex and to the midline frontal cortex (as a location control). Stimulation to both the right and left dorsolateral prefrontal cortex resulted in significantly poorer task performance, as measured by RT. This effect was not found in the midline frontal cortex. As well as showing increased RTs when rTMS was applied to dorsolateral prefrontal areas, participants demonstrated significant reductions in rCBF at both the stimulation site and distant brain regions showing how the technique results in temporary functional lesions in parts of a neuronal network, changing activity in the brain and concurrent behaviour.

5.5.2 Location of stimulation and the SART

While studies such as that of Mottaghy and colleagues show that the prefrontal cortex can be stimulated despite the potential discomfort to the participant, this does not mean the technique used in this way would be suitable for measuring the effects of stimulation on participants' SART performance. As previously mentioned, not only might stimulation of the prefrontal cortex cause some discomfort but in addition alert participants to the arrival of the target trial. Manly, Hawkins, Evans, Woldt and Robertson (2002) showed the effectiveness of producing a random tone during performance on the $SART_{random}$ in a group of normal, healthy participants. Errors of commission were significantly reduced. This improvement in performance was attributed to the externally alerting effect of the tones that reminded participants of their goal. It seems likely that the discomfort caused by stimulation of the prefrontal cortex would have a similar alerting effect and consequently improve performance unless the discomfort was so intense as to be detrimental to performance. Either way, the discomfort would act as a confounding variable.

5.5.3 Confounding factors, stimulation, and the SART

Stimulating the parietal instead of the prefrontal cortex may have avoided a confounding variable in the shape of participants' discomfort and possibly that discomfort acting as an alert or cue for the NoGo trial but a more serious confounding variable was apparent in the current study connected to the side-effects of stimulation. Just prior to a NoGo trial (i.e., the number 3) the magnetic pulse was triggered and applied to the participant's head with the figure-of-eight coil. In TMS, the coil is held tight to the scalp and the participant can feel a slight vibration. In addition, the TMS is accompanied by a 'clicking' noise. Also described as a 'sharp crack', this noise can be uncomfortable for participants (Walsh & Cowey, 1998). At a distance of 10 cm, with 100 % stimulation intensity, a Magstim stimulator (the type of stimulator used in the current study) creates a maximum peak sound intensity level of 110 dB (Starck, Rimpilainen, Pyykko, & Esko, 1996). In the current experiment, it became apparent that this noise was acting as a cue for the participant to tell him or her that the NoGo trial was coming, thus aiding performance. Several participants passed comment on this fact after the testing session was over. However, some participants seemed to be unaware of it. There is little doubt that it did help all the participants to some extent, if not by cueing the no-response then by improving their overall alertness. Manly, Hawkins, Evans, Woldt and Robertson (2002) showed the effectiveness of producing a random tone during performance on the $SART_{random}$ in a group of normal, healthy participants. Errors of commission were significantly reduced. This improvement in performance was attributed to the externally alerting effect of the tones that reminded participants of their goal. Either way, suggestions for avoiding this potential confound are made in the alternative methodology presented in section 5.5.4 below, mostly related to control measures.

5.5.4 An alternative methodology

The first consideration in terms of an alternative methodology is the precise location of stimulation for participants. It must be acknowledged that this precise anatomical information about the brain area stimulated in each participant's case was lacking in the current pilot study. Consequently, an alternative methodology would ideally involve

determining exactly where participants should be stimulated. Walsh and Pascual-Leone (2003) describe a 'hunting paradigm' for applying TMS to areas that do not have a reliable stimulation signature. Typically, a site for stimulation is selected based on earlier studies that have published scalp coordinates or that include reference to ERP electrode sites that may be relevant. For the current study, perhaps the coordinates from Manly and colleagues' (2003) PET study could have been used. They observed activity in the dorsolateral prefrontal cortex and also in the superior/posterior parietal cortex, more so during performance on the $SART_{fixed}$ than on the $SART_{random}$. However, with this method, there would be some intersubject variability in the relative location of cortical areas.

Mottaghy et al.'s (2000) working memory study suggests a method more precise and further, more specific, to the participants in a particular study. Stimulation in Mottaghy et al.'s study was applied in accordance with the international 10-20 system (Jasper, 1957); rTMS was applied centred over F3, F4 or Fz for stimulation of the left dorsolateral prefrontal cortex, right dorsolateral prefrontal cortex or Fz respectively (Grafman et al., 1994; Jahanshahi et al., 1998). Mottaghy and colleagues determined exactly where should be stimulated with a 3-dimensional reconstructed brain MRI for each participant. They then taped vitamin A capsules onto the to-be-stimulated scalp locations (F3, F4, and Fz).

A further refinement of this method would be to show the position of the coil on a computer screen in the same frame as the MR images during a session of TMS (see, for example, Kähkönen, Wilenius, Komssi, & Ilmoniemi, 2004).

As well as considering where to stimulate, another concern would be how to control for the effects of the sound and vibration of the TMS coil. One way would be to stimulate the brain on various non-targets as well as the target. With stimulation no longer coming at a predictable point, i.e., prior to the NoGo trial, the participants would be unable to use the sound and/or vibration of the coil as a cue to aid their performance on the task.

Another way to control for the effects of the sound and vibration of the coil would be to have a condition in which there would be little or no TMS-evoked activation, leaving

only the sound and vibration. How could this be done? In a study looking at differences in cortical reactivity of motor and prefrontal cortices to magnetic stimulation, Kähkönen et al. (2004) described a procedure to evaluate the auditory (and vibratory) activation induced by the coil click. This procedure involved placing a 2 cm piece of plastic between the stimulator and the scalp (Kähkönen et al., 2001; Nikouline, Ruohonen, & Ilmoniemi, 1999) so that little TMS-evoked activation was possible although the sound and vibration would remain similar.

If the above control condition was incorporated into an alternative methodology, this would mean an experimental protocol consisting of four conditions in random order in a within-subject design: (1) control condition with the coil 2 cm above the scalp over the right parietal cortex , with a plastic piece, (2) control condition with the coil 2 cm above the scalp over the left parietal cortex, with a plastic piece, (3) right parietal cortex TMS, (4) left parietal cortex TMS.

It would be possible to have a second session in which participants received TMS to the right and left prefrontal cortices in the same manner as above. Of course, the order of stimulation sites – the parietal cortex and the prefrontal cortex - would have to be counterbalanced across participants.

So far, methods of determining the precise location of stimulation for participants, control conditions, and experimental protocol have been considered for an alternative methodology. What about the task itself, the $SART_{random}$? It could be argued that a technique such as TMS is only as good as the task that it is being used in conjunction with, in this case the $SART_{random}$. Some researchers are of the opinion that RT is a more versatile dependent variable than error rates; if TMS disrupts functioning by introducing noise, then this noise is usually only sufficient to delay that functioning (Walsh & Pascual-Leone, 2003). However, assuming that the SART is the task of choice to study participants' ability to sustain attention, then the measure of interest is typically error rates. It was error rates and not RTs that differentiated between TBI patients and controls in the original SART study conducted by Robertson et al. (1997). So saying, Walsh and Pascual-Leone also make the point that if a task is difficult enough and the magnetic stimulation is intense enough, then TMS can produce errors. However, there are relatively few errors to make in the $SART_{random}$ (a potential total of

25). Participants' in this pilot study made 8.17 mean errors of commission (S.D. = 3.93) across the three conditions. This resulted in few trials in which to study the effect of the TMS. One way to ameliorate this might be to increase task difficulty. So saying, it is difficult to think of ways in which the SART could be made more difficult without compromising the sustained attention component of the task. For example, Manly, Robertson, Galloway and Hawkins (1999) increased target probability from 0.11 to 0.50. A manipulation such as this, increasing the number of NoGo trials (and consequently the number of chances to make a mistake), might be thought to increase task difficulty. However, this reduced the sustained attention component of the SART and participants' performance actually improved. Similarly, when Manly et al. introduced three levels of target probability - 0.11, 0.25 and 0.50 - performance improved with increasing probability. It was argued that the high frequency of targets acted as external support to performance and so reduced the need for internal attention to response. Considering this, it could be concluded that the SART at least should remain the same in an alternative methodology. The fact that participants still made errors at all in the TMS conditions argues for the robustness of the SART. Despite being cued they were still making errors in both the left (mean = 7.38, S.D. = 3.89) and right (mean = 7.63, S.D. = 4.17) parietal TMS conditions.

5.5.5 RTs

As mentioned above, RTs are generally considered to be a more sensitive measure than error rates in cognitive TMS studies. Despite the current study's problems it is perhaps worth noting that participants did respond faster in the two TMS conditions than in the condition without TMS. This difference was statistically significant. However, a review of the literature would suggest that TMS applied to parietal cortex should have resulted in a slowing of response times. For example, TMS applied to participants' parietal cortex for 20 minutes before they performed a spatial imagery task resulted in increased RTs compared to sham TMS and TMS applied to occipital cortex (Aleman et al., 2002). This was interpreted as evidence for the parietal's involvement in visuospatial mental imagery, consistent with functional imaging methods such as fMRI (Mellet, Petit, Mazoyer, Denis, & Tzourio, 1998; Trojano et al., 2000; Yoshino, Inoue, & Suzuki, 2000). What does it mean then that in this instance that TMS decreased RTs? Did the

application of TMS enhance performance? It is difficult to say, considering the confounds already outlined. One possibility is that the coil click, in providing the participants with a cue for the NoGo trial, allowed them to proceed at a faster pace without compromising accuracy. Unfortunately, until this confound is removed, there can be no further speculation.

5.5.6 Conclusion

The study described in this chapter had a lot of problems, mainly methodological. This discussion has attempted to recognise those problems and present an alternative methodology and propose some solutions to those problems. Firstly, it was acknowledged that the prefrontal cortex would have been a better area to stimulate, if not instead of the parietal cortex then at least in addition to it. Secondly, also in relation to the area of stimulation, it was determined that more elaborate measures were required to pinpoint the precise area of stimulation according to each participant. This could perhaps be done using the coordinates obtained by Manly et al. (2003) or better yet, by using MRI in the manner of Mottaghy et al. (2000) and others. Thirdly, questions were raised as to the suitability of the SART and the usefulness of examining error rates in the context of a TMS study. In future, further consideration could be given to ways in which the SART could be made more difficult without compromising the sustained attention component of the task.

In sum, what can be taken from this pilot study? On a very basic level, more preparation was needed in terms of familiarity with the TMS technique. Greater familiarity with the technique could have avoided such confounds as the coil click. It also would have allowed for the possibility of testing both the prefrontal and parietal cortices. Furthermore, it would have been obvious that more time and effort were required to target the location of stimulation for each participant. As it was, these various problems hindered the current study to such an extent that the results were not reliable. To achieve more reliable results and carry out a more successful magnetic stimulation study of sustained attention some or all of the proposed solutions and the alternative methodology would be necessary.

6. An ERP Study of Sustained Attention Capacity

6.1 Overview

Why are we interested in the brain activity underlying sustained attention? To begin with, it is a matter of definition. Much confusion has arisen in the literature over terminology. The term sustained attention has been used interchangeably with arousal, alertness, vigilance, etc. Studying the brain activity underlying sustained attention clarifies its definition. Understanding sustained attention in these terms enables exploration of its parameters within a normal, healthy population. This not only informs theoretical knowledge but also has practical applications in the diagnosis and treatment of clinical populations in which a sustained attention deficit is apparent, e.g., attention-deficit disorder (DSM-IV (1994) fourth edition; Swanson et al., 1998).

The experiment described in this chapter used event-related potentials (ERPs) to examine the electrophysiological correlates of sustained attention in normal, healthy participants. Participants were divided into high and low sustained attention capacity groups based on their performance on the $SART_{random}$. Their EEG was recorded during task performance. Measures of everyday cognitive failures, adult attention-deficit disorder and memory were also taken. Groups were found to differ significantly on a number of these measures. Electrophysiological differences took the form of differences in P300 amplitude, a late positive complex found at fronto-central and parietal sites. The results are discussed in the context of what is currently known about the P300 and how it relates to attentional function.

6.2 Introduction

Transcranial magnetic stimulation (TMS) proved unsuitable for testing sustained attention as measured by the SART. When the magnetic pulse was applied to the head, the TMS coil produced a noise that cued the NoGo trial and consequently aided performance (see chapter 5). The ERP method was selected as a viable alternative. Components of the ERP can be reliably linked to sensory, perceptual and cognitive processes in humans (Hillyard, 2000). This technique has poor spatial resolution because any volumetric localisation within the head has to be generated from data collected at or just outside the scalp (Savoy, 2001). However, ERPs do offer excellent temporal resolution and safety and so are appropriate for the study of sustained attention that, after all, is the study of attention over time.

6.2.1 What are ERPs?

"The ERP is an 'answer' from the brain that is 'time-locked' to the stimulus or event." (Hugdahl, 1995, p. 266). ERPs originate from the flow of electrical (ionic) currents across the membranes of active nerve cells. When a sufficient number of neurons are active at the same time, the additive current flow may generate signals that can be recorded from the scalp (Hillyard, 2000). In an ERPs experiment, participants are fitted with an electrode cap that picks up these signals while they are performing a task. The signals are then amplified and signal-averaged over many trials to produce an average waveform with an adequate signal-to-noise ratio. Peak amplitudes and latencies for individual components of the ERP are detected by specially developed peak detection software before being submitted to statistical analysis.

6.2.2 Labelling the waveform

Wave components are labelled according to their polarity (positive or negative) and latency (milliseconds post-stimulus). For example, the P300 is a positive wave occurring approximately 300 ms after the stimulus. Sometimes waveforms are labelled according to their relative position in a given window. In that case, P300 is just called

P3, meaning the third positive wave in the window. Different components are associated with different functions. The earlier components such as the N200 and the P200 are associated with more automatic functions, e.g., stimulus perception. Later components, including P300, are associated with more complex, controlled functions.

6.2.3 ERP correlates of attention

ERP components can be considered to be either exogenous or endogenous (Donchin, Ritter, & McCallum, 1978). Exogenous components of the ERP usually occur within the first 100-200 ms post-stimulus and reflect the first neural processing of the stimulus (Hugdahl, 1995). Examples of such exogenous components associated with attention are the N100 and the P200. Hillyard, Hink, Schwent and Picton (1973) were the first to fully explore the N100 in a selective attention paradigm. Participants were required to ignore tones presented to one ear while attending to tones of a different frequency presented to the other ear. The N100 was recorded at a central scalp location (Cz), enhanced for stimuli presented to the attended ear. Hence, this component was thought to reflect an early selection process in selective attention. The P200 is closely related to the N100, often occurring together in the auditory modality. However, these two components can be dissociated, e.g., by their scalp distributions. Whereas the N100 is maximal over Cz, P200 is not so focally localised (Hugdahl, 1995).

Components of the ERP associated with cognitive processes occur later post-stimulus and can be called endogenous ERPs, i.e., "ERPs that are linked to changes in an individual's internal cognitive state, rather than to an external stimulus event" (Celesia & Brigell, 1992, p. 733). Endogenous components associated with attention include the P300 and the N400. An example of N400 modulation by attention comes from a study by McCarthy and Nobre (1993). They looked at spatial selective attention and found that the N400 was enhanced by words in an attended visual hemifield but not by words in an unattended hemifield. The P300 is the most prominent ERP component sensitive to cognitive processing (Verleger, 1988) and the most studied endogenous ERP (Celesia & Brigell, 1992). Sutton and colleagues first identified the P300 in the 1960s as an ERP component evoked by infrequent, random stimuli embedded among frequent stimuli in a measure called the oddball paradigm (Sutton, Braren, Zubin, & John, 1965). As well

as reflecting attentional processes, the P300 is also associated with activation of immediate memory (Polich & Kok, 1995).

6.2.4 Sustained attention

Previous research into sustained attention using ERPs went under the heading of 'vigilance'. Vigilance, as Paus et al. (1997) described it, is "a low-target-rate, long-watch-period variety of sustained attention" (p. 393). Sustained attention as measured by the SART has a low target rate (the probability of a NoGo trial is 11%) but it is based on the idea that lapses in attention can occur over relatively short periods of time.

The first ERP studies of vigilance investigated the generalised arousal account of the vigilance decrement. Put simply, it was thought that performance on a vigilance task declined over time as a result of a reduction in arousal. If this were the case, a general reduction in the amplitude of the ERP would be apparent rather than a reduction in only some components of the ERP. Initially, findings were consistent with a reduction in cortical arousal over time. Haider, Spong and Lindsley (1964) found an early negativity in the waveform that decreased in amplitude with time on task and Wilkinson, Morlock and Williams (1966) reported similar findings with auditory stimuli. However, these early studies had serious problems with their methodology. ERP component analyses were incomplete (Parasuraman et al., 1998) and their technique was flawed, e.g., the Wilkinson et al. (1966) study was faulted for not controlling eye movements (Koelega et al., 1992).

Later studies did not support the generalised arousal account of the vigilance decrement. Davies and Parasuraman (1977) carried out a complete analysis of the ERPs recorded during a 45-minute visual vigilance task. They looked at four components (N100, P200, N200 and P300) to correct and incorrect responses to signals and non-signals. Signals were flashes of light that were less intense than for the non-signals and participants were required to say 'yes' to a signal and 'no' to a non-signal. Davies and Parasuraman found that only the later ERP components (N200 and P300) reflected detection performance and, as they interpreted it, decision processes in vigilance. Rohrbaugh et al. (1987) examined the effects of ethanol on visual sustained attention using

Nuechterlein, Parasuraman and Jiang's (1983) degraded digit-discrimination task and found, like Davies and Parasuraman, that only the late ERP components showed a time effect. Finally, Koelega et al. (1992) looked at the relationship between time effects on performance and ERPs and found that it manifested itself primarily in components occurring 250-650 ms post-stimulus.

Parasuraman, Warm, and See (1998) summed up the findings of these vigilance studies as (1) that ERP components decrease over time on task, and (2) that this reduction in amplitude of ERP components is related to decreased detection performance. For the current study, the information most relevant is perhaps that vigilance effects are most apparent in the later components of the ERP. The P300, in particular, is considered sensitive to cognitive processes (Verleger, 1988).

6.2.5 Distractibility

The construct of distractibility is closely related to sustained attention and there is a growing body of literature regarding its electrophysiological bases, particularly in regard to children. If we consider successful task performance as a delicate balance between voluntary, controlled sustained attention on one hand and involuntary, distracted attention on the other, then we cannot look at either of these processes in isolation from the other. Escera, Alho, Schröger and Winkler (2000) defined distractibility as "the involuntary redirection of one's attention from some goal-oriented behaviour to other aspects of the environment" (p. 152). It is the struggle between top-down and bottom-up processes.

Woods and Knight (1986) found electrophysiological evidence for increased distractibility after dorsolateral prefrontal lesions. They compared right and left dorsolateral prefrontal cortex lesion patients and controls on a dichotic attention task. Participants were instructed to attend to a sequence of tones (25 ms duration) and respond to intermixed target tones of a longer duration (75 ms) presented in one ear. The target tones occurred 10% of the time. Participants were also instructed to ignore tones of a different pitch in the other ear. Woods and Knight were interested in the processing negativity or Nd component of the ERP, which is typically enhanced to

attended inputs (Naatanen, 1982). They examined specific evidence for distractibility by comparing Nd waves obtained when stimuli were preceded by attended stimuli to those obtained when stimuli were preceded by distracting stimuli in the to-be-ignored ear. Patients were less accurate than controls at detecting target stimuli. Furthermore, right frontal patients performed more poorly than left frontal patients but the difference was not significant. Electrophysiologically, patients with left frontal lesions showed results generally similar to those of control participants. However, patients with right frontal lesions exhibited evidence of increased distractibility to right ear inputs. Nd waves elicited by right ear tones were reduced when preceded by distracting stimuli in the left ear. When directing attention to tones in one ear, patient groups showed a reduced Nd wave compared to controls when the tones were presented at long interstimulus intervals (ISIs) compared to short ISIs. This difference was most marked for the right frontal patients, which Woods and Knight interpreted as an inability to sustain attention at long ISIs. Their findings are consistent with behavioural studies showing increased distractibility in human (Stuss et al., 1982) and nonhuman primates (Bartus & Levere, 1977; Brutkowski, 1965) with prefrontal lesions and a growing body of evidence linking sustained attention function with right frontal cortex (Cohen et al., 1988; Coull et al., 1996; Koski & Petrides, 2001; Lewin et al., 1996; Pardo et al., 1991; Rueckert & Grafman, 1996; Wilkins et al., 1987).

In the last two decades, the electrophysiology of distractibility has been studied in children. There are a number of researchers in Finland (including Gumenyuk et al., 2001; Kilpelainen et al., 1999a; Kilpelainen, Partanen, & Karhu, 1999b) who have described a frontally distributed P300 in relation to distractibility. Kilpelainen (1999a) divided nine-year-old children into high and low distractibility groups based on their assessment on the Freedom from Distractibility (FFD) factor (Arithmetic and Digit Span; Kaufman, 1975). He then tested the children on an auditory oddball paradigm. The easily distractible group showed a more persistent frontal P300 to target stimuli than their less distractible counterparts. Gumenyuk (2001) presented children with stimulus pairs consisting of a task-irrelevant sound (a tone or a complex, 'novel' sound such as a telephone) followed by an image (drawings of animals and non-animals). The children were told to ignore the sounds and respond with different button presses depending on whether the image was animal or non-animal. The ERPs elicited by the distracting sounds showed a prominent positive deflection.

6.2.6 Go-NoGo tasks

The standard, $SART_{random}$ is a Go-NoGo task considered to be a measure of sustained attention (Manly et al., 2000; Manly et al., 2001; Manly et al., 1999; Robertson et al., 1997). ERP studies using Go-NoGo tasks have generally looked at response inhibition. In this context, the trial on which response inhibition (successful or otherwise) is demonstrated – the NoGo trial – is of most interest. Studies using visual Go-NoGo tasks generally report: (1) a NoGo-N2 maximal at Fz with a latency of 150-400 ms and (2) (less consistently) a NoGo-P3 maximal at Fz and Cz with a latency of 300-500 ms (Falkenstein, Hoormann, & Hohnsbein, 1999). Falkenstein and colleagues (Falkenstein et al., 1999; Falkenstein, Koshlykova, Kiroj, Hoormann, & Hohnsbein, 1995) tested the hypothesis that the frontal negative deflection (N2) seen on NoGo trials was a real-time correlate of inhibition. The fact that the NoGo-N2 was not apparent in auditory as well as visual Go-NoGo tasks seemed to invalidate the inhibition hypothesis. However, when Falkenstein et al. (1999) compared good inhibitors (low error of commission rate) with poor inhibitors (high error of commission rate), the good inhibitors displayed a NoGo-N2 that was about twice as large as the poor inhibitors' NoGo-N2. Furthermore, the NoGo-N2 began about 30 ms earlier for good compared to poor inhibitors. This supports the inhibition hypothesis, suggesting that the NoGo-N2 reflected an inhibition process that was stronger and began earlier for good compared to poor inhibitors. The timing of the NoGo-N2 was also consistent with this hypothesis, with an onset of about 200 ms, i.e., well before the overt response in Go trials. As Falkenstein et al. (1995) found, the NoGo-N2 was larger after visual than after auditory stimuli. Falkenstein et al. (1999) explained this modality asymmetry by locating the inhibition mechanism at pre-motor rather than motor level.

The NoGo-P3 has also been associated with inhibition (Karlin, Martz, & Mordkoff, 1969; Roberts, Rau, Lutzenberger, & Birbaumer, 1994). However, the problem with this interpretation is that the NoGo-P3 has been shown to peak at or shortly after the overt response (Falkenstein et al., 1995), or in some cases far later than the overt response (Eimer, 1993). It is assumed that the timing of processing of Go and NoGo stimuli is similar, even though the onset of the NoGo-P3 seems too late for this

component to reflect inhibition (Falkenstein et al., 1999). When Falkenstein et al. (1999) compared good and poor inhibitors, there was no difference in the NoGo-P3 between groups. Hence, the inhibition hypothesis for the NoGo-P3 is not strongly supported.

6.2.7 ERP studies of the SART

To date, there have been two previous studies of the Go-NoGo SART that have used ERPs. The first, by Manly et al. (2000), focussed on events preceding the NoGo trial in an attempt to determine if some component of the signal evoked by such an event was predictive of an error on the subsequent trial. The P300 was the component of choice because it: (1) is thought to index higher level processes that are sensitive to task context, such as attentive selection (e.g., Karlin, Martz, Brauth, & Mordkoff, 1971; Ritter, Simson, & Vaughan, 1972), (2) has been associated with Go-NoGo tasks and increases in amplitude if a participant is aware that they have made an error (Donchin, Gratton, Dupree, & Coles, 1988; Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Falkenstein et al., 1995) and (3) is reduced in an error-prone population, e.g., TBI patients (Campbell, Houle, Lorrain, Deacon-Elliott, & Proulx, 1986; Rugg, Cowan, Nagy, Milner, & Brooks, 1988; Segalowitz, Dywan, & Unsal, 1997). They found that the amplitude of the P300 on the Go trial preceding a NoGo trial was predictive of an error and that the amplitude of the P300 across the task as a whole was predictive of a given participant's performance. Manly et al. concluded that the predictive value of the P300 for subsequent action suggested that it reflected a control process modulating the production of a response that was in place before the critical trials were presented.

There was, however, a serious flaw in the methodology of Manly et al.'s study. Their results in regard to the P300 were based on a comparison of the trial preceding an error of commission and the trial preceding a correct withhold. However, participants made fewer errors than correct withholds so there were fewer trials contributing to the average for error trials than to the average for correct trials. The averaging procedure, used to reduce the EEG noise that the ERP signal is embedded in, would therefore have been less effective for the error average compared to the correct withhold average. This could have been responsible for the observed difference between the two averages.

Nevertheless, the Manly et al. study does suggest that the P300 component of the ERP may be important in sustained attention as measured by the SART.

The second study by Armilio, Mazaheri, Robertson, Stuss and Picton (2002) used the SART to provide a detailed description of the electrophysiological bases of error-processing and response inhibition in a Go-NoGo task. Firstly, Armilio et al. reported early posterior ERPs: N175* and N225. These were interpreted as two phases of stimulus evaluation in which the basic number forms were analysed before categorising them into Go-NoGo trials. Secondly, this posterior activity was mirrored by activity at frontal sites in the same time period. A P225 wave was recorded, larger on a correct withhold to a NoGo trial. This component was rather more difficult to explain. Standing alone, it could have represented some kind of stimulus processing. However, if the P225 was caused by a combination of different cerebral processes (e.g., an intended response that was never carried out) then it could have reflected activation of response systems. Thirdly, Armilio et al. described an N300 recorded at front-central electrodes which they interpreted as being similar to the NoGo-N2 (see also Falkenstein et al., 1999; Falkenstein et al., 1995). Finally, a NoGo P500 was observed and this was thought to index some kind of context updating.

6.2.8 The current study

The current study examined ERPs recorded during the Go trials of the SART. Armilio et al. focussed on the electrophysiological bases of response inhibition whereas Manly et al. were more concerned with sustained attention. However, both of these studies focussed on the NoGo trials and participants' errors. Researchers encounter several difficulties when looking at the NoGo trials in Go-NoGo tasks, specifically that they are typically less frequent than Go trials and that the cognitive processes and consequently their electrophysiological bases are more complex. Go trials, in contrast, are more frequent and more straightforward. The motor response is relatively similar from one

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* It should be noted that some ERP researchers label their components with the exact latency they were observed at rather than the label that they are commonly known by. For example, the frontal negativity that Armilio and colleagues call the N300 is usually labelled N200 or NoGo-N2.

Go trial to the next. Also, there is no requirement for response inhibition. So, in effect, the Go trials offer an on-line window to the participants' sustained attention.

Participants in this study were divided into a high sustained attention capacity (SAC) group and a low SAC group based on SART performance. The behavioural study reported in chapter 4 suggested that the $SART_{fixed}$ was a purer measure of sustained attention than the $SART_{random}$. However, that study also showed that the $SART_{fixed}$ was significantly less sensitive to sustained attention performance than the $SART_{random}$ in a young, healthy population. Errors on the $SART_{fixed}$ were minimal. For this reason, the $SART_{random}$ was used in the current study.

Prior to ERP testing, participants' self-reported incidence of cognitive failures was assessed using the Cognitive Failures Questionnaire (CFQ, Broadbent et al., 1982) and the Memory Assessment Clinics Self-Rating Scale (MAC-S; Winterling, Crook, Salama, & Gobert, 1986). The CFQ (covered in depth in chapter 4) assesses the frequency of everyday slips in the perceptual, motor and memory domains. The MAC-S concentrates on memory failures, testing participants' ability to remember and recording the frequency with which memory failures occur. Given that CFQ scores have been shown to correlate with SART performance in the past (Robertson, 1997, see also chapter 4), a group difference on these two measures of cognitive failure was expected in the current study. Participants were also tested on the Brown Attention-Deficit Disorder (ADD) Scale for Adults (Brown, 1996). This scale is intended to measure symptoms of ADD. It consists of 40 items that group into five clusters: (1) Organising and activating to work, (2) Sustaining attention and concentration, (3) Sustaining energy and effort, (4) Managing affective interference, and (5) Utilising "working memory" and accessing recall. While we did not expect any of the participants to score in the ADD range, it seemed likely that the scale might differentiate between the groups on some level.

In regard to the ERPs, endogenous ERPs such as the P300 show rapid recovery that makes them particularly suited for monitoring high-speed cognitive processing (see Woods & Knight, 1986). This makes them useful for the SART. In an extensive literature, the P300 has been repeatedly associated with attention. More specifically, Manly et al. (2000) linked P300 amplitude with an individual's error propensity on the

SART. Therefore, if participants are divided into groups defined by their capacity to sustain attention, a significant difference in this component of the ERP would be expected.

6.3 Methods

6.3.1 Participants

Participants for this study were selected on the basis of their SART performance in an earlier experiment (see chapter 4). Scorers within the upper and lower quartiles of the sample (n = 52) from this earlier experiment were taken to reflect high and low sustained attention capacity. A total of 20 students took part in the current study but two were subsequently excluded due to contamination from movement artefacts (e.g., frequent blinking). This left nine participants in the high SAC group (male/female: 4/5, age: mean = 21.30, S.D. = 1.49) and nine participants in the low SAC group (male/female: 6/3, age: mean = 21.16, S.D. = 1.01). All participants were right-handed. Written consent was given after the nature and consequences of the experiment were explained. For the purposes of recording EEG, each participant was fitted with a 32-channel Quikcap connected to the Neuroscan Synamps (Scan 4.1) ERP recording system (Medtech Systems, Horsham, UK). Participants were paid a nominal sum of €20 per testing session.

6.3.2 Stimuli

The stimuli were in the form of the $SART_{random}$. A total of 225 single digits (25 of each of the digits 1 to 9) were presented over a 4.3-min period. Each digit was presented for 250 ms, followed by a 900 ms mask. Participants were asked to respond with a key press to each digit, except on the 25 occasions when the digit 3 appeared; on these occasions the response was to be withheld. The 3 or 'NoGo' trial was presented in a pre-fixed quasi-random fashion. Participants were instructed to place equal emphasis on speed and accuracy of response. The screen was set approximately 40 cm from the participants' eyes.

6.3.3 Questionnaire measures

CFQ

The CFQ is a 25-item self-report questionnaire designed to assess the frequency of everyday slips and errors in the last six months. Each item refers to a particular type of mistake (e.g., bumping into people, forgetting names), and participants are asked to indicate, on a five-point scale, how often they commit that particular error.

MAC-S

The MAC-S is a self-report rating scale for evaluating everyday memory. It includes 21 Ability to Remember items (e.g., item 10, "How well would you describe your ability to remember telephone numbers that you use on a daily basis?") and 24 Frequency of Occurrence items (e.g., item 38, "How often do you arrive at a shop and forget what you intended to buy?"). In addition to these two subscales there are four global items assessing overall comparison to others (item 1, "In general, as compared to the average individual, how would you describe your memory?"), comparison to the best one's memory has ever been (item 2, "How would you describe your memory, on the whole, compared to the best it has ever been?), speed of recall (item 3, Compared to the best your memory has ever been, how would you describe the speed with which you now remember things?"), and concern or distress over one's memory (item 4, "How much

concern or distress do you feel about your memory at this time?"). Responses are recorded on a five-point Likert scale (from "very poor" to "very good" on the Ability scale and from "very often" to "very rarely" on the Frequency scale). A copy of the MAC-S is provided in Appendix 3.

Brown ADD Scale for Adults

The Brown ADD Scale for adults is a 40-item self-report scale that measures symptoms of ADDs. The 40 items group into five clusters of conceptually related symptoms of ADDs: (1) Organising and activating to work, (2) Sustaining attention and concentration, (3) Sustaining energy and effort, (4) Managing affective interference, and (5) Utilising "working memory" and accessing recall. The examiner reads the list of symptoms, item by item, and circles the number beneath the words that tell how much the participant believes that feeling or behaviour has been a problem in the past six months (0 = Never, 1 = Once a week or less, 2 = Twice a week, and 3 = Almost daily). A copy of the Brown ADD Scale can be found in Appendix 4.

6.3.4 EEG recording

The EEG was recorded in AC mode (gain 500, band pass 0.15-30 Hz). The A/D conversion rate was 500 Hz and the range was 11 mV. Ag/AgCl electrodes were used in a 32-channel Quikcap with linked ear reference electrodes and an anterior scalp reference site (AFz). The electrode array consisted of 12 frontal, 15 central/temporal/parietal and 3 occipital electrodes conforming to the International 10-20 System. Vertical and horizontal eye movements were recorded with VEOG and HEOG electrodes placed above and below the left eye and at the outer canthus of each eye respectively. Recording commenced when electrical impedance had been reduced to less than 15 kΩ by Quikgel application combined with light abrasion of the scalp.

6.3.5 General procedure

Participants were tested in a specially designated project room at the Department of Psychology in Trinity College, Dublin. Testing sessions consisted of 4 blocks of 4.3 min SARTs, counterbalanced among subjects with a 3-5 min break between each block.

6.3.6 EEG measurements

All NoGo trials and the subsequent two Go trials following NoGo trials were excluded from the analysis. Trials were epoched around the stimulus: 200 ms pre-stimulus to 950 ms post-stimulus. All sweeps were baseline corrected using the 100 ms pre-stimulus interval as the baseline. Epochs were subjected to ocular artifact reduction to remove artifactual scalp potentials caused by eye-blinks. Trials that were still contaminated were rejected according to a cut-off threshold of ±70 μV. Remaining epochs were averaged for each individual and then combined into a grand average for each group.

6.4 Results

6.4.1 Behavioural results

SART

On average, the high SAC group made 6.28 (S.D. = 4.28) errors of commission and the low SAC group made 14.06 (S.D. = 4.00) errors of commission on the $SART_{random}$ (see Figure 6.1). An independent t-test found this difference to be significant ($t = -3.86$, $df = 15$, $p < 0.01$). Errors of omission were too few in number to submit to statistical analysis. There was a group difference in mean reaction times to Go trials (with the two Go trials subsequent to a NoGo trial removed; $t = 2.47$, $df = 11.16$, $p < 0.05$). Mean RT was 420.78 ms (S.D. = 99.59) for the high SAC group and 330.85 ms (S.D. = 45.16) for the low SAC group.

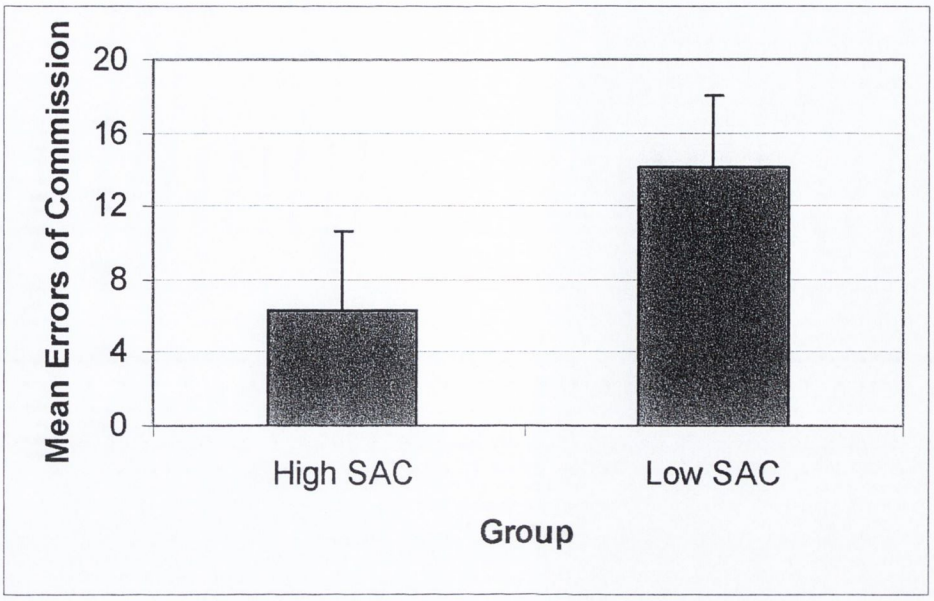

Figure 6.1: Mean errors of commission on the $SART_{random}$ ($p < 0.01$).

Questionnaire measures

The means and standard deviations for the questionnaires' total scores are summarised in Table 6.1 below. CFQ scores were significantly different between groups ($t = -2.57$, $df = 16$, $p < 0.05$), with the low SAC group reporting more incidences of cognitive failure than the high SAC group. The MAC-S total score, a combination of Ability to Remember and Frequency of Occurrence items, also differed between groups ($t = 2.66$, $df = 16$, $p < 0.05$). The low SAC group scored higher than the high SAC group, which implies that the former experience poorer memory and more often compared to the latter. There was a trend towards a difference between groups on the Brown ADD Scales but it was not significant ($t = -1.86$, $df = 16$, $p > 0.05$). There was also no difference between groups on any of the Brown ADD subscales. The only subscale approaching significance was number (5), related to forgetfulness in daily routines and problems in recall of learned material (e.g., forgets intended tasks, loses track of needed items, has excessive difficulty recalling learned material and memorising; Brown, 1996). The low SAC group scored higher than the high SAC group on this subscale, indicating that the former reported more forgetfulness and problems than the latter.

Five of the nine low SAC participants and one of the nine high SAC participants scored over 50 on the Brown ADD Scales. Brown (1996) observed that if an individual obtains a total score of 50 or higher, it indicates a significant possibility that the person will meet diagnostic criteria for ADD. Of course, the Brown ADD Scales alone are not sufficient to make an adequate diagnosis. However, they do suggest that several members of the low SAC group experienced such problems on a relatively regular basis in the six months prior to testing.

Table 6.1: Means and standard deviations for questionnaire measures.

Measure	Max. Score	High SAC		Low SAC		Sig.
		Mean	*S.D.*	*Mean*	*S.D.*	*p*
CFQ	100	34.00	11.54	52.11	17.76	0.02*
MAC-S	225[1]	179.00	20.04	148.89	24.47	0.02*
Brown Total	120	37.22	12.19	49.22	15.01	0.08
Brown Memory	18	3.89	2.62	7.11	4.23	0.07

*$p < 0.05$

6.4.2 Electrophysiological results

Visual inspection of the data revealed a late positive deflection at a latency of 350-550 ms, labelled P300. The low SAC group displayed greater amplitude P300 at fronto-central sites than the high SAC group. A MANOVA was carried out on each channel with ERP components' amplitude and latency as the dependent variables and group as the independent variable with two levels (high SAC and low SAC). Cases contributing to the analysis were weighted by the number of trials that made up their individual average (to account for the inter-subject variation). This was achieved by carrying out a weighted least-squares (WLS) analysis. Group differences in P300 amplitude were found to be significant at F7, F3, FZ, F4, and FCZ channels. The means and standard

[1] The MAC-S maximum score represents good everyday memory. The opposite is true for the CFQ and the Brown ADD Scales, i.e., maximum score represents a higher incidence of cognitive failures and more symptoms of ADD respectively.

deviations, and the F and p values for these channels are listed in Table 6.2. Channels at which the group differences approached significance are also listed. Grand average ERPs for the 32 scalp locations are displayed in Figure 6.2 and channel FZ alone in Figure 6.3. Figure 6.3 also shows the participants' reaction times in relation to their ERPs.

Table 6.2: Means, standard deviations, F and p values for P300 group differences.

Measure	Channel	High SAC		Low SAC		Significance	
		Mean	*S.D.*	*Mean*	*S.D.*	*F*	*p*
Amplitude (μV)	F7	0.88	1.42	2.56	1.85	5.57	0.03*
	F3	1.38	2.14	4.57	3.03	13.97	0.00**
	FZ	2.34	2.91	6.19	3.20	11.96	0.00**
	F4	2.03	2.35	5.43	2.56	13.97	0.00**
	F8	1.91	2.19	2.93	1.76	3.40	0.08
	FCZ	4.82	5.05	8.09	4.09	5.01	0.04*
	FC4	4.47	3.43	7.12	3.08	4.50	0.05
	FT8	2.13	2.11	3.38	1.33	4.17	0.06

*p < 0.05, **p < 0.01

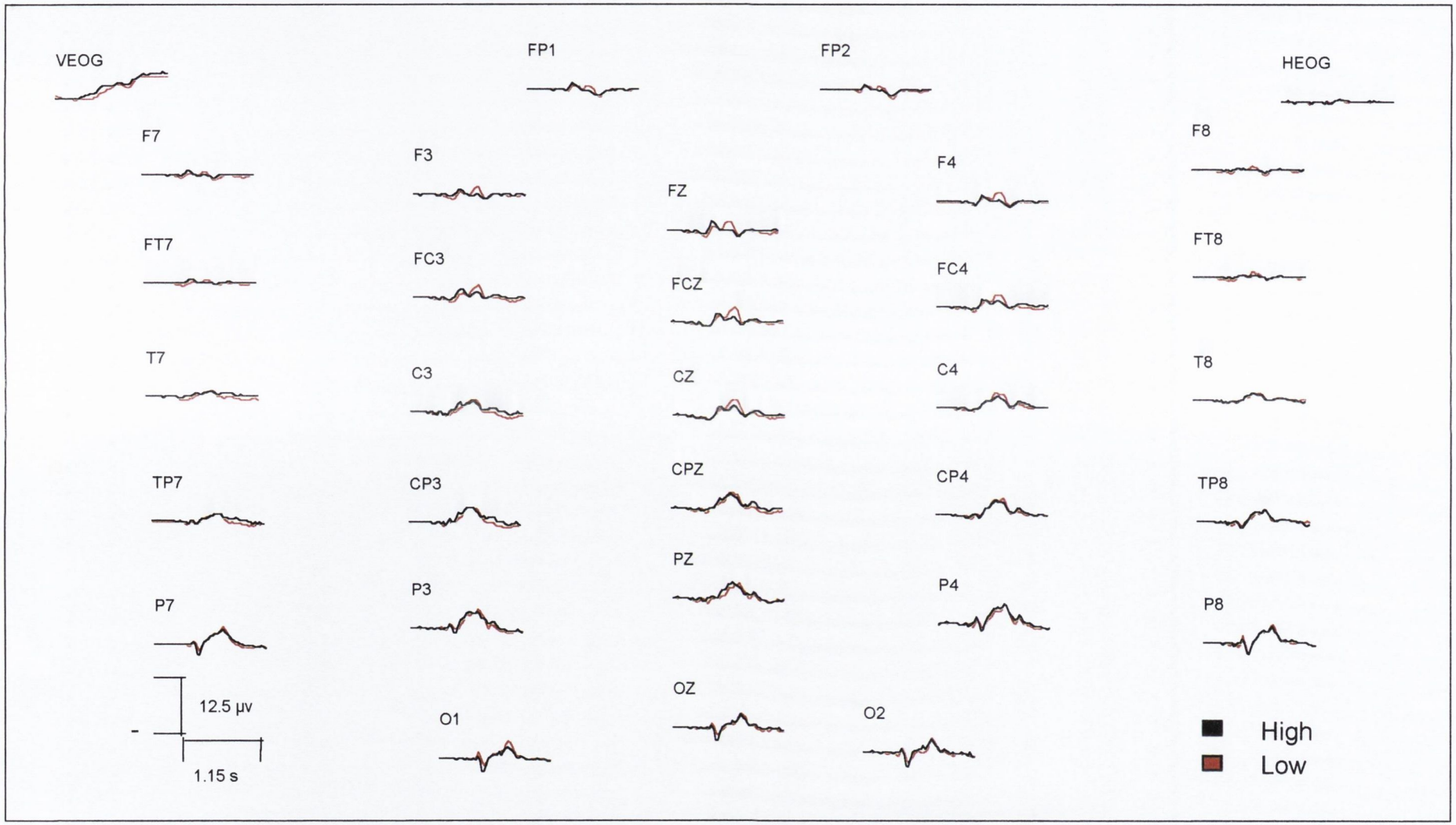

Figure 6.2: Grand average ERPs for the 32 scalp locations. Superimposed are the ERPs for the high and low SAC group.

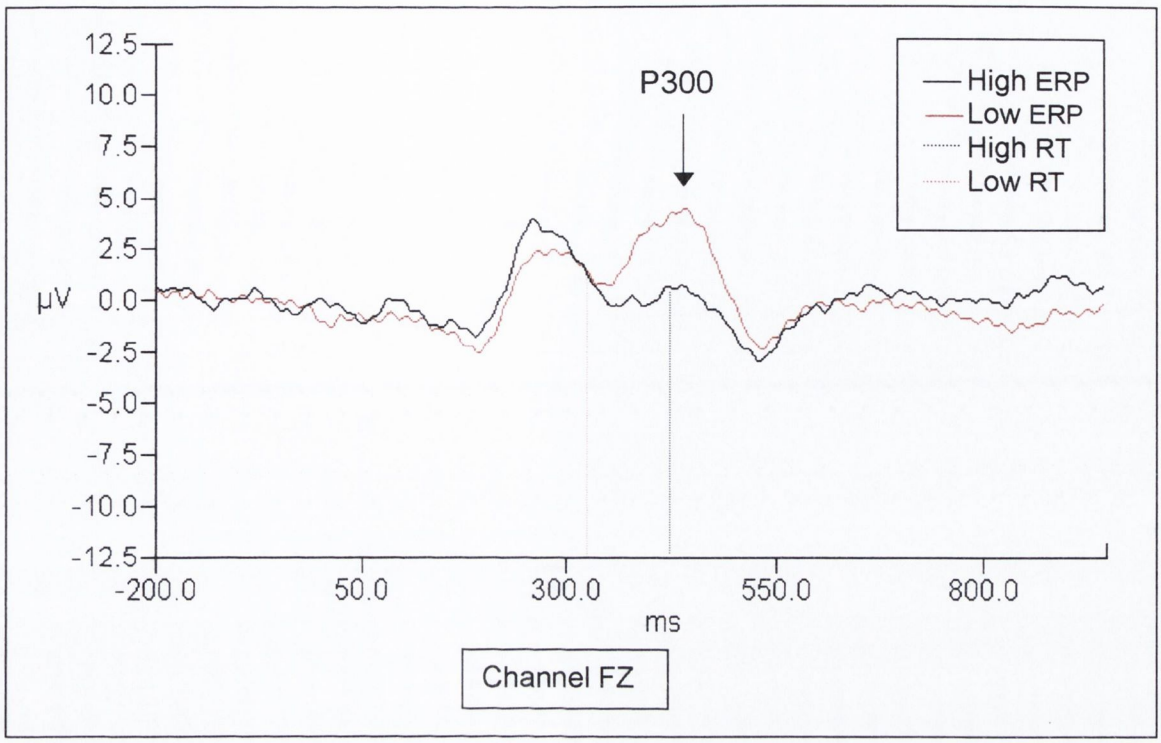

Figure 6.3: Grand average ERPs for the channel FZ showing the groups' mean RT to Go trials on the SART.

The possibility exists that the data could be explained in terms of a speed-error trade-off. In order to assess this hypothesis, the error rate was plotted against the peak latency (see Figure 6.4). As is apparent from the plot and the lack of a significant correlation between these two variables ($r = -0.33$, $n = 18$, $p > 0.05$), it is unlikely that the data is due to a speed-error trade-off.

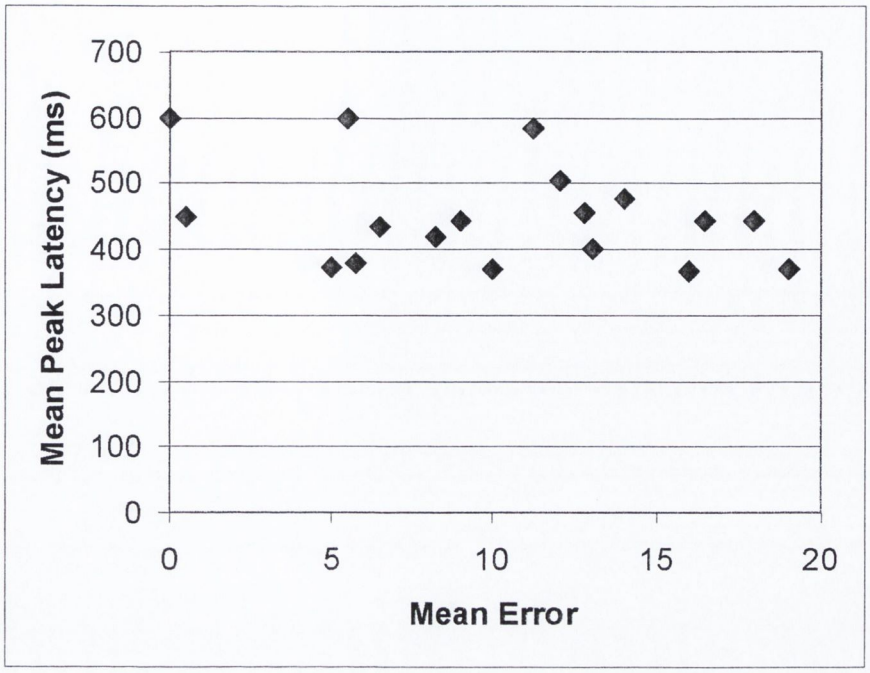

Figure 6.4: Error rate plotted against peak latency.

6.5 Discussion

6.5.1 Behavioural effects

The high SAC group made significantly more errors of commission than the low SAC group on the $SART_{random}$. Errors of omission were insufficient in number for statistical analysis. Reaction times to Go trials did differ significantly between groups, with the low SAC group responding slightly faster than the high SAC group. More everyday cognitive failures were reported by the low than the high SAC group as measured by the CFQ and the MAC-S. In other words, participants who made more mistakes on the $SART_{random}$ experienced greater absent-mindedness, poorer memory ability and more frequent memory problems in their everyday life than the participants who made fewer mistakes on the task. There was no group difference in scores on the Brown ADD Scales but there was a trend for the low SAC group to report more symptoms of ADD than the high SAC group, especially on the subscale related to forgetfulness in daily routines and problems in recall of learned material. Furthermore, several of the low SAC group scored highly enough on the Brown Scales to qualify as ADD probable.

SART performance

Previous studies have used the SART to differentiate between patient groups and normal, healthy controls. Robertson et al. (1997) demonstrated a significant difference between traumatic brain injury (TBI) patients and normal, healthy controls on SART performance. The current study was one of the first, however, to explore the extremes of sustained attention capacity within a normal, healthy population. The results show that the SART is clearly sensitive to a wide range of action error propensity.

The low SAC group responded faster to Go trials than the high SAC group. This makes interpretation of the error rates purely in terms of a sustained attention deficit more difficult. However, the electrophysiological differences between the groups (see below) suggest that the performance differences are due to higher order cognitive processes rather than basic reaction times. Perhaps the only way to ascertain how much performance reflects sustained attention rather than reaction times is to manipulate the task parameters in such a way as to control such variations in reaction times. This idea is implemented in the next experiment (chapter 7).

Memory failures and attention deficit

High and low SAC groups differed on cognitive failures as measured by the CFQ and more specifically, memory failures, as measured by the MAC-S. This was as hypothesised, with the low SAC group reporting more failures in both cases than the high SAC group. This adds further support to Robertson et al.'s (1997) finding that the SART has a real-life correlate in everyday cognitive failures.

No significant group differences were found on the Brown ADD Scales for Adults. However, certain aspects of this measure are of interest. Firstly, several of the low SAC group scored in the ADD probable range. Without a comprehensive evaluation by a clinician using a variety of measures, the Brown Scales are not sufficient for making or ruling a diagnosis of ADD. Yet Brown (1996) recommends that if a person scores at or above the clinical cut score (i.e., a total score of 50), that person should receive a comprehensive evaluation for the possibility of an Attention-Deficit Disorder.

Considering that the majority of the low SAC participants scored above the clinical cut score, it is unclear why the Brown Scales failed to differentiate between them and the high SAC participants. Nonetheless, despite the lack of a statistically significant difference between the groups, the results are somewhat consistent with participants' sustained attention performance. Furthermore, the Brown ADD subscale that most approached a significant group difference was related to forgetfulness in everyday life. This is consistent with the CFQ and MAC-S results and reinforces the SART's relationship with absent-mindedness.

6.5.2 Electrophysiological effects

A P300 amplitude difference was apparent between groups at fronto-central sites, whilst a P300 latency difference was revealed at fronto-central and parietal sites. The low SAC group displayed a larger P300 than the high SAC group. Only the Go trials (excluding the two Go trials following a NoGo trial) were included in the analysis and so the amplitude difference is believed to represent the maintenance of attention over the course of the task. This was a rather novel approach to the traditional Go-NoGo task. Traditionally, analyses focussed upon errors of commission and correct withholds of the NoGo trial (e.g., Armilio et al., 2002). The goal of the current study was to look at the electrophysiological bases of those trials most likely to reflect uncontaminated sustained attention (i.e., Go trials). There are likely to be several processes at work in and around a NoGo trial, including type of response and the participant's reaction to that response. For this reason the two trials following a NoGo trial, as well as the NoGo trial, were excluded from the analysis. During this time the participant is responding rhythmically to stimuli and should be monitoring his or her own performance to avoid making a mistake.

Marker of sustained attention capacity

Differences in the P300 component of the waveform were expected. Paying attention to a stimulus is known to modulate the ERP (Coull, 1998). However, the direction of the amplitude difference is more difficult to explain. Coull (1998) observed that the amplitude of a component increases when a stimulus is attended to. Surely, the high

SAC group were attending more than the low SAC group? Indeed, Manly et al. (2000) found that the mean amplitude of the P300 across the task as a whole was predictive of an individual participant's propensity to make an error. There are at least two possible explanations:

1. Too much attention? The effort hypothesis

In their PET study of sustained attention, Manly et al. (2001) found that performance on the $SART_{fixed}$ resulted in increased right frontal and parietal activation. More activation was seen for the fixed sequence version of the task than the standard, random sequence version. Manly et al.'s explanation for this was that the two tasks occupied different positions along a continuum of task difficulty that ran from 'unchallenging' to 'challenging'. The $SART_{fixed}$ was less challenging in terms of perceived difficulty and information processing demands but more challenging in terms of bridging routine and monotony with sustained attention and so performance on that version of the task resulted in greater activation of right fronto-parietal areas.

In the current study, we propose that the high SAC group and the low SAC group were experiencing differing degrees of task difficulty *within* the version of the SART used for the experiment. The low SAC group found it more difficult in one sense – paying attention to a superficially non-challenging, monotonous task – and the increased sustained attention required was reflected in their larger P300.

The vigilant state is made up of several components including an effortful arousal linked to the task and to cognitive factors (Marrocco & Davidson, 1998). Perhaps one way to determine if the low SAC group found this task more taxing on their sustained attention capacity than the high SAC group would be to take a measure of arousal during task performance. For this reason, skin conductance response (SCR) is recorded in the ERP study reported in chapter 8.

2. Too little attention? The distractibility hypothesis

The P300 component of the ERP can be split into two sub-components: P3a and P3b. P3a is generally more frontal, and P3b more centro-parietal. Given that the P300

differences observed in the current study are all at frontal sites, is what we are seeing the P3a component? Assuming that it is, the high SAC group and low SAC group may be displaying differing degrees of distractibility. There are several researchers (Escera et al., 2000; Gumenyuk et al., 2001; Kilpelainen et al., 1999a; Kilpelainen et al., 1999b; Woods & Knight, 1986) who consider the frontal P300 or P3a to be an index of distractibility. For example, the more distractible nine-year olds in Kilpelainen's (1999a) study showed a more persistent P300 to target stimuli compared to their less distractible counterparts. Is the low SAC group displaying a persistent P300? In normal, healthy participants the frontal P300 has been shown to decrease in amplitude over repeated stimulus presentations (Donchin, Karis, Bashore, Coles, & Gratton, 1986; Polich, 1989; Ravden & Polich, 1998). If, in the case of the low SAC group, it did not, this would explain the greater amplitude P300 that they displayed in comparison to the high SAC group.

The persistent P300 has been recorded in narcoleptics too. Narcolepsy is a disorder "characterised by excessive daytime sleepiness, sleep attacks, cataplexy and abnormal manifestations of rapid eye movement sleep" (Naumann, Bierbrauer, Przuntek, & Daum, 2001, p. 2807). Cognitive impairments associated with narcolepsy include memory and attention deficits. However, the memory deficits may be secondary to the attention deficits, which manifest themselves in decreased alertness and fluctuations in vigilance (Schulz, Wilde-Frenz, & Grabietz-Kurfurst, 1997). Naumann et al. (2001) compared narcoleptics with controls on an auditory oddball paradigm in which participants were asked to silently count the target stimuli. The narcoleptics demonstrated a larger, more frontal P300 than the controls and the authors attributed this finding to a reduced habituation to stimuli, associated with altered functioning of the prefrontal cortex.

The problem with this argument, however, is that the frontal P300 or P3a is usually seen on the rare targets (in the current study, the NoGo trial) as opposed to the more frequent non-targets (Go trials). The P3a is thought to represent an alerting process produced by 'novel' stimuli (e.g., the telephone sound in Gumenyuk et al.'s (2001) distractibility experiment). Participants in the current study performed the SART in a quiet, darkened room. It is difficult, therefore, to see what distracted them. However, it must be remembered that the low SAC group were highly susceptible to distraction.

They scored significantly higher on the CFQ than the high SAC group and high CFQ scorers have been associated with an inability to inhibit distraction (Meiran et al., 1994; Tipper & Baylis, 1987). Perhaps the low SAC group were distracted by external stimuli, e.g., noises outside the room, that the high SAC group did not notice. Of course, distraction may not have been caused by stimuli external to the participants. Factor analyses of the CFQ have consistently revealed a factor related to distractibility that receives high loadings on items representing disruptions of internalised attentional processes, e.g., "Do you daydream when you ought to be listening to something?" (item 19) (see chapter 4, Matthews et al., 1990; Pollina et al., 1992; Wallace et al., 2002). Perhaps during the Go trials, when there was nothing much going on and the low SAC group lapsed into a kind of automatic responding, their minds wandered to other things. In this way, the increased frontal P300 could be interpreted as representing a lack of sustained attention to the task consequent to distraction by internal and/or external stimuli.

6.5.3 Relation to reaction time

In the current study, using Fz as an example, the high SAC group responded 55 ms before the peak of the P300 and the low SAC group, 94 ms before. This observation is consistent with early studies of the P300, demonstrating that the reaction time occurs 50 ms before the peak of the wave (Picton, Hillyard, & Galambos, 1976; Ritter et al., 1972). This means that because of the time required for the impulse to travel from the brain to the muscle, it is impossible for the P300 to represent the decision process that results in a response (Picton, 1992). Kutas, McCarthy and Donchin (1977) suggested that it might represent the completion of stimulus evaluation. They showed that when accuracy was emphasised, the reaction time tended to come after the peak of the P300. Alternatively, when speed was emphasised, the reaction time occurred well before the peak. In addition, many of the early responses were incorrect. This would suggest that Kutas et al.'s participants initiated their responses before the stimulus was fully evaluated. Could this be the reason for the low SAC group's poor performance; they failed to fully evaluate the stimulus before responding? The low SAC group responded much earlier than the high SAC group relative to the peak of the P300.

6.5.4 Conclusions

Clearly, there is a wide range of sustained attention performance within the normal, healthy population. The $SART_{random}$ has shown itself to be sensitive to this range of performance. Furthermore, the high and low SAC groups tested in the current study could be distinguished on the basis of memory and other cognitive failures. The low SAC group reported more cognitive failures (CFQ), more memory failures (MAC-S) and a trend towards more forgetfulness in everyday life (Brown ADD subscale) compared to the high SAC group. These findings strengthen the association between sustained attention as measured by the SART and memory and other cognitive failures.

The behavioural difference between the groups was complemented by an electrophysiological difference in the P300 component. The low SAC group displayed a significantly larger P300 amplitude than the high SAC group at fronto-central sites. The direction of this difference was somewhat difficult to interpret. On the one hand, it may have been that the low SAC group found the SART more difficult than the high SAC group and therefore their increased P300 amplitude indexed increased effort. On the other hand, perhaps the increased P300 reflected the low SAC group's susceptibility to distraction. Of these two possibilities, the first one seemed the most plausible. The distractibility hypothesis was based on the assumption that the observed P300 component was actually P3a. However, for this to be true the wave would have to peak earlier (near 250 ms; Picton, 1992) than it did in the current study (between 350 and 550 ms) and have been recorded during the targets or NoGo trials rather than the Go trials. The distractibility hypothesis could not be completely dismissed but it was a lot less likely when these aspects of the P3a were considered.

In conclusion, the current study explored the extremes of sustained attention capacity within a young, healthy population. Behaviourally, the two extremes – high and low SAC – were apparent in differences in errors of commission on the SART and associated memory and other cognitive failures. Electrophysiologically, differences between high and low SAC were manifested in the P300 component of the ERP. For future studies, the P300 would seem to be a good candidate for the electrophysiological correlate of sustained attention.

7. Sustained Attention in the Young and Able Elderly

7.1 Overview

The study reported in chapter 4 confirmed that there was an association between sustained attention and absent-mindedness as measured by the CFQ (see also Robertson et al., 1997). Chapter 6 consisted of an ERP study of sustained attention in which high and low sustained attention capacity groups differed significantly, not only electrophysiologically but also on several measures of absent-mindedness. To be specific, the low SAC group reported more cognitive failures (CFQ), more memory complaints (MAC-S) and a tendency towards more forgetfulness in daily routines (Brown ADD Scales, subscale 5) than the high SAC group. There does appear to be a link between not paying attention and absent-mindedness. The study described in the current chapter was primarily concerned with age-related sustained attention deficit but also absent-mindedness in the same context. Many older adults complain of memory problems (Lowenthal et al., 1967). Indeed, age stereotypes bias the interpretation of memory successes and failures; successes are seen as less typical in older adults and their failures are attributed to lack of ability, and are considered more worrisome and less controllable than in their younger counterparts (Bieman-Copland & Ryan, 1998). Appearances aside, frequency and severity of attentional lapses are of particular importance in an ageing population with, for example, increased numbers of older drivers. Driving accidents are related to performance on information-processing measures of different components of attention (Parasuraman & Nestor, 1991).

The current study – split into two experiments looking at the two versions of the SART - revealed a sustained attention deficit in the able elderly. Young and old participant groups demonstrated a significant difference in the number of mistakes they made on the SART. Participants were also given measures of cognitive failures, memory ability,

intelligence, anxiety and depression. There was no group difference in any of these measures except memory ability. The elderly participants demonstrated poorer memory ability than their young counterparts but this did not appear to influence performance on the SART. These findings are discussed in the context of previous literature on age differences in sustained attention, absent-mindedness and the suitability of self-rating questionnaires in ageing research.

7.2 Introduction

7.2.1 Theories of cognitive ageing

Theories of cognitive ageing were introduced in chapter 3; what follows is a brief recap of that chapter's contents. There are two main theories about cognitive decline with age: processing speed theory (Salthouse, 1985b; Salthouse, 1996a) and the frontal lobe hypothesis (Hartley, 1993; van der Molen & Ridderinkhof, 1998; West, 2000; West, 1996). There are many cognitive processes in which a decline with age has been observed including memory, reasoning, spatial ability and attention (Salthouse, 1996b). Processing speed theory proposes that this decline is due to a reduction in speed with which cognitive operations can be executed, mediated by two mechanisms called the limited time mechanism (a time restriction on cognitive operations caused by time used up by earlier cognitive operations) and the simultaneity mechanism (when the products of earlier processing are lost by the time later processing is completed). Developed by Timothy Salthouse, this theory has received a lot of support (Birren, 1965; Birren, 1974; Cerella, 1985; Cerella, 1990; Myerson et al., 1990) but experimentation suggests that it is incorrect to view processing speed as the primary cause of age-related cognitive decline (Salthouse, 1985a; Stuss et al., 1989b; Welford, 1977; Welford, 1980).

The main tenet of the FLH is that due to differential decline in the frontal lobes of the brain, cognitive functions most associated with this area of the brain are more susceptible to the effects of age. Supporters of the FLH (e.g., West, 2000; West, 1996) cite extensive neuropsychological and neurobiological evidence for this theory. Neuropsychologically, older adults show deficits on a number of measures of frontal

lobe function including the Stroop, Wisconsin Card Sort and the Tower of London (Phillips & Della Sala, 1998) and preserved performance ability on tasks of nonfrontal function (e.g., Ardila & Rosselli, 1989; Whelihan & Lesher, 1985). Neurobiologically, there are several measures of age-related decline in the brain that appear at an earlier age and in greater magnitude in frontal compared to nonfrontal areas of the brain, e.g., gross brain volume (Coffey et al., 1992; Haug et al., 1983; Haug & Eggers, 1991; Raz, 1996). Critics of the FLH (namely Greenwood, 2000a), argue that there is only "weak and conflicting" (p. 705) evidence to support differential decline of the frontal lobes and in functions associated with the frontal lobes. Greenwood found evidence for an age-related decline in several nonfrontal functions (visuospatial attention, face recognition and repetition priming) and neurobiological evidence for age-related decreases in regional volume, blood flow and metabolism in nonfrontal regions. In defence of the FLH, West (2000) insisted that there was empirical support for the main ideas behind the theory (including Shaw et al., 1984; Shimamura & Jurica, 1994). However, West did acknowledge that there was a need to refine the FLH, to account for differential decline within the frontal lobes and the cognitive processes supported by these brain areas. This point is well illustrated by the imaging studies of age-related changes in episodic memory (memory retrieval of personally relevant events; Tulving, 1983), a function associated with activations in prefrontal cortex (Cabeza & Nyberg, 2000; Fletcher & Henson, 2001). With age, activations associated with episodic memory become bilateralised or susceptible to hemispheric asymmetry reduction (Bäckman et al., 1997; Cabeza et al., 1997; Madden et al., 1999). Furthermore, Cabeza, Anderson, Locantore and McIntosh (2002) found that it was high-performing older adults who displayed this bilateralisation, whereas low-performing older adults recruited similar regions to the younger adults. It is clear that age-related differences in cognitive processes and their associated activations in the brain are not as straightforward as the FLH (or indeed speed processing theory) would suggest.

7.2.2 Sustained attention and ageing

Nevertheless, even if the decline does not happen earlier and in greater magnitude, age-related decline in the frontal lobes does exist. This would lead us to expect an age-related deficit in sustained attention capacity. Over two decades of research into the

neuroanatomical substrates of sustained attention argues for the dominance of right dorsolateral prefrontal (and parietal) cortex in this capacity (Cohen et al., 1988; Coull et al., 1996; Koski & Petrides, 2001; Lewin et al., 1996; Pardo et al., 1991; Rueckert & Grafman, 1996; Wilkins et al., 1987).

The theories of ageing cognition might suggest that there should be a decline in sustained attention capacity with age but a review of the literature in this area presents an unclear picture. Some studies have found an age-related deficit in sustained attention (Parasuraman & Giambra, 1991; Parasuraman et al., 1989) and some have not (Berardi et al., 2001; Giambra, 1997; Giambra & Quilter, 1988). In the main, the type of task used in these studies was a conventional vigilance test. Giambra and Quilter, for example, used a Mackworth Clock-Test. The deciding factor in relation to finding an effect of age on vigilance or sustained attention seemed to be the demand that the task placed on a potentially limited capacity attentional mechanism (West, 1996). However, increasing demand often meant switching the emphasis of the task from sustained attention to some other cognitive or perceptual process (e.g., Parasuraman et al., 1989).

7.2.3 Using the SART

The two experiments described in the current study used the SART to ascertain if a sustained attention deficit exists in the able elderly. The SART has shown itself to be sensitive to attentional lapses in traumatic brain injury (TBI; Robertson et al., 1997) and to extremes of sustained attention capacity within the normal, healthy population (see chapters 4 and 6). The SART differs in several ways from the kind of sustained attention or vigilance task that has been used in the past (including Berardi et al., 2001; Giambra, 1997; Parasuraman et al., 1991) in that: (1) it assumes that an attention decrement can occur in a relatively brief period of time, (2) participants are asked to respond to the long sequences of Go trials and to withhold on the rare, NoGo trials and (3) SART minimises demands on other cognitive processes such as memory and those involved in discrimination of targets. With respect to the last point, participants were given the standard, $SART_{random}$ in Experiment 1 and the SARTfixed (in which successive digits (1-9) are presented in the conventional ascending order) in Experiment 2. The $SART_{fixed}$ could be considered a purer measure of sustained attention and it has

also shown itself to be sensitive to sustained attention deficit following brain injury (McAvinue et al., in press) see also chapter 4. The response inhibition component in the $SART_{fixed}$ is certainly less than in the $SART_{random}$. This is perhaps particularly important in an ageing study, in that inhibitory control is thought to decline in late adulthood (Christ, White, Mandernach, & Keys, 2001; Dempster, 1992; Hasher, Stoltzfus, Zacks, & Rypma, 1991). Nonetheless, participants were given the $SART_{random}$ in Experiment 1 because the study reported in chapter 4 suggested that normal, healthy participants found the $SART_{fixed}$ too easy and relatively few errors were made on the task.

7.2.4 Memory and other cognitive failures

The elderly may complain of memory decline (Lowenthal et al., 1967) but that decline neither exists in everyone nor in all memory functions. As mentioned above (and in chapter 3), Cabeza et al. (2002) conducted a study that compared high- and low-performing older adults and younger adults on a memory task while monitoring prefrontal cortex activity using positron emission tomography (PET). Whereas the low-performing older adults recruited similar right prefrontal areas of the brain to the younger adults, the high-performing older adults recruited bilateral prefrontal areas. It appeared that the high-performing older adults were able to counteract their age-related decline through reorganisation of cognitive networks. Just as not all older adults display behavioural and brain decline equally, not all memory functions are affected by age equally (Craik, 1990; Craik & Jennings, 1992; Craik et al., 1990b; Grady & Craik, 2000; Uttl & Graf, 1993, see chapter 3 for more detail). The question is, do memory failures and other cognitive failures or absent-mindedness increase with age? If sustained attention is related to absent-mindedness and an age-related deficit in sustained attention is expected, should concomitant changes in absent-mindedness be expected too?

In addition to the $SART_{random}$ in Experiment 1 and the $SART_{fixed}$ in Experiment 2, participants in the current study were also tested on memory and other cognitive failures. Two measures of cognitive failures were included: the Cognitive Failures Questionnaire (CFQ, Broadbent et al., 1982) and the Memory Assessment Clinics Self-Rating Scale (MAC-S; Winterling et al., 1986). The former encompassed motor,

perceptual and memory failures whereas the latter only assessed memory failures. Previous research has shown that the relationship between ageing and cognitive failures is not a straightforward one. Three studies reviewed in chapter 4 related to cognitive failures and ageing: (1) Martin (1986) who failed to find any difference between young and old groups on the CFQ total score but significant differences on individual items of the CFQ, (2) Rabbitt and Abson (1990) who found that participants in their 50s reported more failures than their older counterparts, and finally (3) Mahoney, Dalby and King (1998) who found that their 30-45 year-old participants reported more failures than those participants aged 16-29, 46-60 and 61+ years. For the most part, Martin found that the young scored higher than the old and this appeared to set the trend for the later studies. However, several problems have been identified with using questionnaires as a tool in the study of ageing that ambiguate interpretation of these studies including failure to remember memory failures, influence of self-image, individual differences in life-style and response biases (Rabbitt & Abson, 1990). Nevertheless, the results of such self-rated questionnaires cannot be dismissed. Knowing what the elderly believe about their own memory performance is important, "it may affect their self-confidence, the way they manage their everyday lives, and the kind of tasks and activities they are willing to attempt" (Cavanaugh, 1989; see Cohen, 1989; Maylor, 1993, p. 513). Furthermore, it was important to include measures of memory and other cognitive failures in the current study to extend the research reported in chapters 4 and 6. It was also a possibility that the informant-report CFQ would succeed where the self-report CFQ had failed. Robertson et al. (1997) found that SART performance correlated strongly with informant reports of cognitive failures but not self-reported failures in a group of brain injured people. Ageing and TBI are believed to have similar effects on behaviour (Stuss et al., 1989b).

Participants' memory ability was also tested using a subtest of the Wechsler Memory Scale, the Associate Learning Subtest (Wechsler, 1974). Research has shown an age-related difference in associative learning; older adults tend to recall fewer paired associates after a single learning trial and shallower learning curves over multiple trials (Dunlosky & Connor, 1997; Salthouse & Dunlosky, 1995). There are a number of variables that influence the magnitude of this age difference including the relatedness of the to-be-associated pairs (Connor, Dunlosky, & Hertzog, 1997; Zaretsky & Halberstam, 1968). In reviewing the literature concerning age differences in associative

learning, Kausler (1994) attributed at least some of the age differences to deficiencies in learning strategies and experimentation has shown this to be the case (Rogers, Hertzog, & Fisk, 2000).

7.2.5 Other measures

Participants were also tested on the National Adult Reading Test (NART; Nelson, 1982) to predict IQ and the Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983) to account for the influence of these factors on task performance. Several studies have suggested that depression is an important component of memory complaints among elderly adults (Gagon et al., 1994; Kahn, Zarit, Hilbert, & Niederehe, 1975; La Rue, Swan, & Carmelli, 1995; Levy-Cushman & Abeles, 1998; Poitrenaud, Malbezin, & Guez, 1989; Popkin, Gallagher, Thompson, & Moore, 1982). Mahoney et al. (1998) interpreted the age-related differences that they found in memory and other cognitive failures in terms of stress and anxiety. Similarly, intellectual functioning is also thought to be an important influence on memory complaints (Bolla, Lindgren, Bonaccorsy, & Bleeker, 1991; Derouesne et al., 1993; Gagon et al., 1994; Lamberty, Bieliauskas, Chatel, & Holt, 1993).

7.3 Experiment 1

7.3.1 Methods

Participants

There were two groups in the current study: old (n = 38, male/female = 4/34, right-/left-handed = 37/1, age in years: mean = 72.39, S.D. = 4.65) and young (n = 40, male/female = 2/38, right-/left-handed = 36/4, age in years: mean = 19.84, S.D. = 0.78). All participants had normal or corrected-to-normal vision. History of head injury, epilepsy or other neurological condition, drug or alcohol problems, or major psychiatric disorder resulted in exclusion from the study. The young group was recruited from the student population in the Department of Psychology, Trinity College, Dublin. The students participated for course credit. The old group was recruited from active retirement groups around Dublin. They were paid a nominal sum of €7.60 for their participation. Participants gave informed consent and were debriefed at the end of the study.

Materials

$SART_{random}$

A total of 225 single digits from 1-9 (25 of each of the 9 digits) were presented over a 4.3 min period. Each digit was presented for 250 ms, followed by a 900 ms mask. Participants were asked to respond with a key press to each digit, except on the 25 occasions when the digit 3 appeared, when the response was to be withheld. The 3 or 'NoGo' trial was presented in a pre-fixed quasi-random fashion. Participants were instructed to place equal emphasis on speed and accuracy of response. The screen was set approximately 40 cm from the participants' eyes.

CFQ for Self

The CFQ is a 25-item self-report questionnaire designed to assess the frequency of everyday slips and errors in the last six months. Each item refers to a particular type of mistake (e.g., bumping into people, forgetting names), and participants are asked to indicate, on a five-point scale, how often they commit that particular error (from 0 = Never to 4 = Very Often). The maximum score is 100.

CFQ for Other

This informant-report version of the CFQ is an 8-item scale designed to assess the frequency of those slips and errors that are observed by others (e.g., During the last two months has your relative/friend been forgetful, such as forgetting where he/she has put things, or about appointments, or about what he/she has done?). The CFQ for Other has the same five-point scale as the CFQ for Self with a maximum score of 40. A copy of the CFQ for Other can be found in Appendix 5.

MAC-S

The MAC-S is a self-report rating scale for evaluating everyday memory. It includes 21 Ability to Remember items (e.g., item 10, "How well would you describe your ability to remember telephone numbers that you use on a daily basis?") and 24 Frequency of Occurrence items (e.g., item 38, "How often do you arrive at a shop and forget what you intended to buy?"). In addition to these two subscales there are four global items assessing overall comparison to others (item 1, "In general, as compared to the average individual, how would you describe your memory?"), comparison to the best one's memory has ever been (item 2, "How would you describe your memory, on the whole, compared to the best it has ever been?), speed of recall (item 3, "Compared to the best your memory has ever been, how would you describe the speed with which you now remember things?"), and concern or distress over one's memory (item 4, "How much concern or distress do you feel about your memory at this time?"). Responses are recorded on a five-point Likert scale (from "very poor" to "very good" on the Ability scale and from "very often" to "very rarely" on the Frequency scale).

HADS

The HADS is a 14-item self-report measure of anxiety and depression. A separate score is given for each and pre-determined cut-off points indicate when a participant is within

the normal range, or in a mildly, moderately or severely disordered state. A copy of the HADS is provided in Appendix 6.

Wechsler Memory Scale (Associate Learning Subtest)

This subtest of the Wechsler Memory Scale measures associate learning as part of a battery to assess adult (16-89 years) memory ability (see Appendix 7).

National Adult Reading Test (NART) (Nelson, 1982)

The NART provided a reliable estimate of intelligence. The test consisted of 50 words to be read aloud (see Appendix 8).

7.3.2 Results

SART$_{random}$

Mean errors of commission were 6.24 (S.D. = 4.90) for the older participants and 6.80 (S.D. = 3.87) for the younger participants. An independent t-test was carried out on the data but no statistically significant difference was found ($t = -0.57$, $df = 76$, $p > 0.05$; see Figure 7.1). The young group's mean RT to Go trials was 354.76 (S.D. = 46.67) and the old group's mean RT to Go trials was 447.64 (S.D. = 71.51). This between-groups difference in RT to Go trials was significant ($t = 6.83$, $df = 76$, $p < 0.001$).

Descriptive statistics (means and standard deviations) for errors of commission and RT on the SART$_{random}$ are displayed in Table 7.1 below.

Table 7.1: Errors of commission and RT (ms) for the SART$_{random}$.

SART	**SART$_{random}$ (25 NoGo)**			
Group	*Old*		*Young*	
	Mean	S.D.	Mean	S.D.
Errors	6.24	4.88	6.80	3.87
RT to Go (ms)	447.64	71.51	354.76	46.67

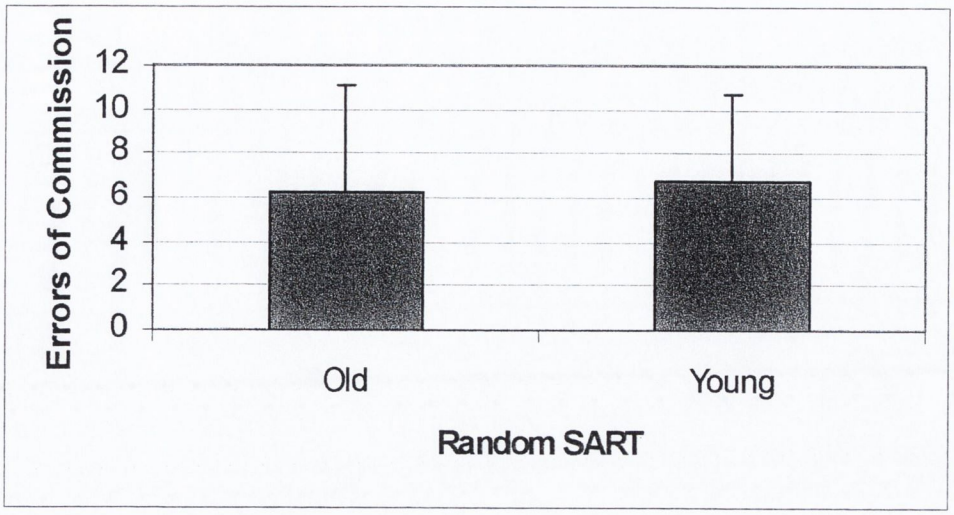

Figure 7.1: Group differences in errors of commission made on the $SART_{random}$.

Descriptive statistics (means and standard deviations) for all the paper-and-pen measures are summarised in Table 7.2 below. Descriptive statistics and statistical tests for each measure follow.

Table 7.2: Descriptive statistics for paper-and-pen measures.

Measure	**Max. Score**	**Old**		**Young**		**Sig.**
		Mean	*S.D.*	*Mean*	*S.D.*	*p*
CFQ Self	100[+]	35.89	10.44	39.85	7.31	0.06
CFQ Other	40	7.55	4.78	12.61	3.95	0.00***
MAC-S	225	156.45	20.09	162.40	17.00	0.16
HADS Anxiety	21[+]	6.32	3.69	6.98	2.69	0.37
HADS Depression	21[+]	2.89	1.94	2.17	1.80	0.09
Associate Learning	21	14.09	3.71	19.29	1.68	0.00***
NART	131	89.58	9.71	88.95	6.02	0.73

[+] Poor performance

*** $p < 0.001$

Cognitive Failures Questionnaire (CFQ)

There was no difference between old and young self-reported cognitive failures ($t = -1.91$, $df = 63.90$, $p > 0.05$) with the young group reporting more failures (mean = 39.85, S.D. = 7.31) than the old group (mean = 35.89, S.D. = 10.44). However, the reports given by participants' friends and families did differ significantly between old and young ($t = -4.69$, $df = 64$, $p < 0.001$). The young participants' informant-reports (mean = 12.61, S.D. = 3.95) scored significantly higher than the old participants' informant-reports (mean = 7.55, S.D. = 4.78). Two Pearson correlations were conducted to see if there was any relationship between CFQ scores and errors of commission on the $SART_{random}$ in the young ($r = -0.19$, $n = 40$, $p > 0.05$) and the elderly ($r = 0.36$, $n = 38$, $p < 0.05$). Only the correlation in the elderly was significant.

Hospital Anxiety and Depression Scale (HADS)

Mean scores for the young group were 6.98 (S.D. = 2.69) for anxiety and 2.17 (S.D. = 1.80) for depression. For the old group, mean scores were 6.32 (S.D. = 3.69) for anxiety and 2.89 (S.D. = 1.94) for depression. Groups did not differ on either anxiety ($t = -0.90$, $df = 76$, $p > 0.05$) or depression ($t = 1.70$, $df = 76$, $p > 0.05$).

Memory Assessment Clinics Self-Rating Scale (MAC-S)

In terms of total scores on the MAC-S, the young group's mean score was 162.40 (S.D. = 17.00) and the old group's mean score was 156.45 (S.D. = 20.09). Mean scores for the young group on the subscales were 74.38 (S.D. = 9.16) for the ability to remember subscale and 88.03 (S.D. = 10.55) for the frequency of occurrence subscale. For the old group, mean scores were 72.95 (S.D. = 10.92) and 83.50 (S.D. = 12.00) for the ability to remember and frequency of occurrence subscales respectively. Scores on the global items of the MAC-S were as follows for the young group: (1) mean = 3.72, S.D. = 0.78, (2) mean = 2.55, S.D. = 0.60, (3) mean = 2.53, S.D. = 0.64, and (4) mean = 4.32, S.D. = 0.66. The same scores for the old group were: (1) mean = 3.18, S.D. = 0.80, (2) mean = 2.34, S.D. = 0.81, (3) mean = 2.11, S.D. = 0.65, and (4) mean = 4.03, S.D. = 0.85.

A one-way MANOVA was carried out on the data. Significant group differences were only apparent on Global item 1 (In general, as compared to the average individual, how would you describe your memory?; $F(1,76) = 9.08$, $p < 0.01$) and on Global item 3 (Compared to the best your memory has ever been, how would you describe the speed

with which you now remember things?; F (1, 76) = 8.27, $p < 0.01$). In comparing their memory to the average individual, older participants rated themselves worse than the young participants did. The group difference in Global item 3 was in the same direction with older participants rating their speed of remembering as slightly slower and young participants rating it at about the same as it had ever been.

Descriptive statistics for the subscales and the global items of the MAC-S are also displayed in Table 7.3.

Table 7.3: Descriptive statistics for the subscales and the global items of the MAC-S.

MAC-S measure	**Max. score**	**Old**		**Young**		**Sig.**
		Mean	*S.D.*	*Mean*	*S.D.*	*p*
Ability to remember	105	72.95	10.92	74.38	9.16	0.53
Frequency of occurrence	120	83.50	12.00	88.03	10.55	0.08
Global item 1	5	3.18	0.80	3.72	0.78	0.00**
Global item 2	5	2.34	0.81	2.55	0.60	0.20
Global item 3	5	2.11	0.65	2.53	0.64	0.01*
Global item 4	5	4.03	0.85	4.32	0.66	0.09

* $p < 0.05$, ** $p < 0.01$

Associate Learning

The young participants scored higher (mean = 19.29, S.D. = 1.68) on the Associate Learning Subtest of the Wechsler Memory Scale than the older participants (mean = 14.09, S.D. = 3.71). An independent t-test found this difference to be significant (t = -7.90, df = 50.89, $p < 0.001$). Two Pearson correlations were conducted to see if there was any relationship between associate learning and errors of commission on the $SART_{fixed}$ in the young ($r = 0.29$, $n = 40$, $p > 0.05$) and elderly ($r = -0.29$, $n = 38$, $p > 0.05$). No significant correlations were found.

NART

There was no difference between groups in predicted IQ as measured by the NART (young group: mean = 88.95, S.D. = 6.02, old group: mean = 89.58, S.D. = 9.71; t = 0.34, df = 61.20, $p > 0.05$).

7.3.3 Discussion of Experiment 1

There was no difference between the young and able elderly in errors of commission made on the $SART_{random}$. There was no difference between the young and the elderly in self-reported cognitive failures as measured by the CFQ or memory failures as measured by the MAC-S. Despite this, according to two of the global items on the MAC-S, the elderly participants perceived their memory as being worse than the average individual's and slower than it used to be. Their ratings on these items were higher than the young participants' ratings. The Associate Learning Subtest of the Wechsler Memory Scale was sensitive to an age-related deficit in memory ability, with the young participants scoring significantly higher on the test than the elderly participants. No correlation was found between the Associate Learning scores and errors of commission on the $SART_{fixed}$ in either group. There was no group difference in IQ as predicted by the NART, anxiety or depression.

The lack of a significant finding with the $SART_{random}$ suggests that either there is no age-related deficit in sustained attention or that this version of the task was not sensitive enough to detect one. Considering that both ageing and TBI are thought to have similar effects on brain function and behaviour (Stuss et al., 1989b) and also that Robertson et al.'s found a difference between controls and TBI patients sustained attention performance as measured by the $SART_{random}$, a similar age-related deficit on the task was not unexpected. So saying, both Manly et al. (2003) and McAvinue et al. (in press) found the $SART_{fixed}$ to have stronger discriminability than the $SART_{random}$ when they compared controls and TBI patients. Consequently, Experiment 2 was carried out to test for an age-related decline in sustained attention as measured by the $SART_{fixed}$.

7.4 Experiment 2

7.4.1 Methods

Participants

Participants in the current study were the same as in Experiment 1 (see above).

Materials

$SART_{fixed}$

The $SART_{fixed}$ differed from the $SART_{random}$ (as described above) in three ways: (1) digits were presented successively in the conventional, ascending order, (2) 378 digits from 1-9 (42 of each of the 9 digits) were presented over a 7.3 min period, and (3) the mask was divided into four components as illustrated in Figure 7.2. This mask sequence lasted for 900 ms in total and gave the impression of a 'blip' in the mask. Participants were instructed to respond upon seeing this 'blip' unless the 'blip' followed a 3. The purpose of this manipulation was to control RTs. All other aspects of the task remained the same. The justification for the inclusion of this 'blip' was to ensure that the findings with the $SART_{fixed}$ would be consistent with an fMRI study of the $SART_{fixed}$ being conducted and recently published by Fassbender et al. (2004).

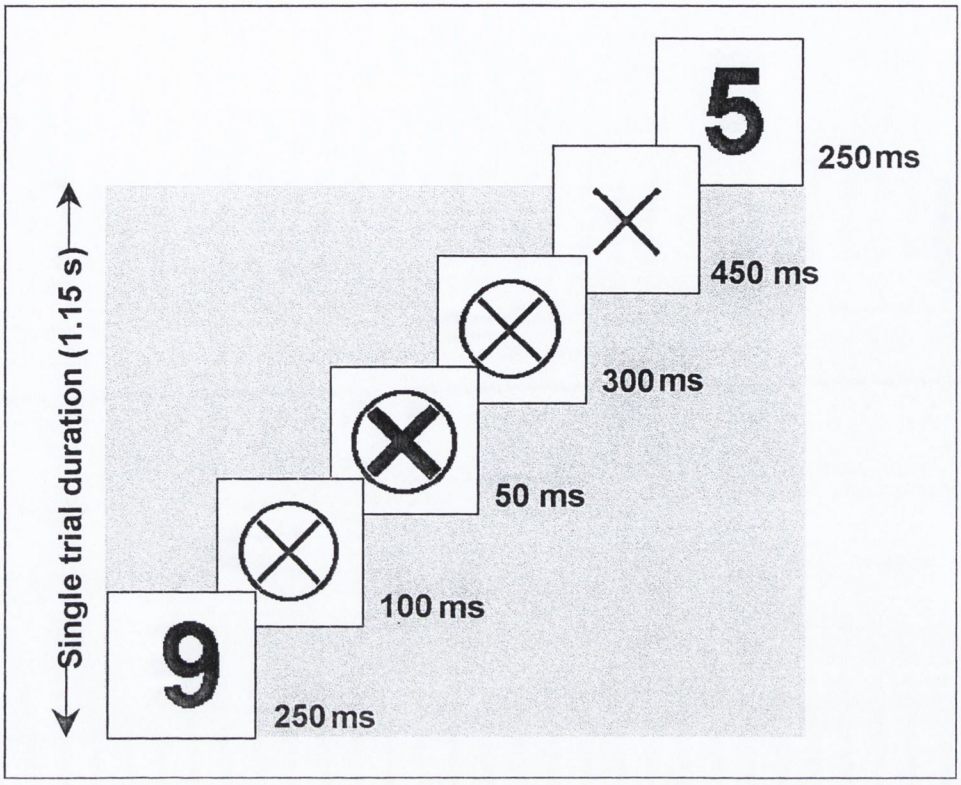

Figure 7.2: Mask sequence.

7.4.2 Results

Mean errors of commission were 5.61 (S.D. = 6.96) for the older participants and 2.58 (S.D. = 2.47) for the younger participants. An independent t-test was carried out on the data but and the between-groups difference was found to be statistically significant ($t = 2.54$, $df = 45.76$, $p < 0.05$; see Figure 7.3). An association between errors and RT to Go trials has been demonstrated in the past (Manly et al., 2000b) so to determine if RT was a factor in this difference between groups, an independent t-test was conducted on participants' RT to Go trials. The young group's mean RT to Go trials was 496.21 (S.D. = 95.31) and the old group's mean RT to Go trials was 506.33 (S.D. = 135.40). There was no group difference in RT to Go trials ($t = 0.38$, $df = 66.13$, $p > 0.05$).

Descriptive statistics (means and standard deviations) for errors of commission and RT on the $SART_{fixed}$ are displayed in Table 7.4 below.

Table 7.4: Errors of commission and RT (ms) for the $SART_{fixed}$.

SART	$SART_{fixed}$ (42 NoGo)			
Group	*Old*		*Young*	
	Mean	S.D.	Mean	S.D.
Errors	5.61	6.96	2.58	2.47
RT to Go (ms)	506.33	135.40	496.21	95.31

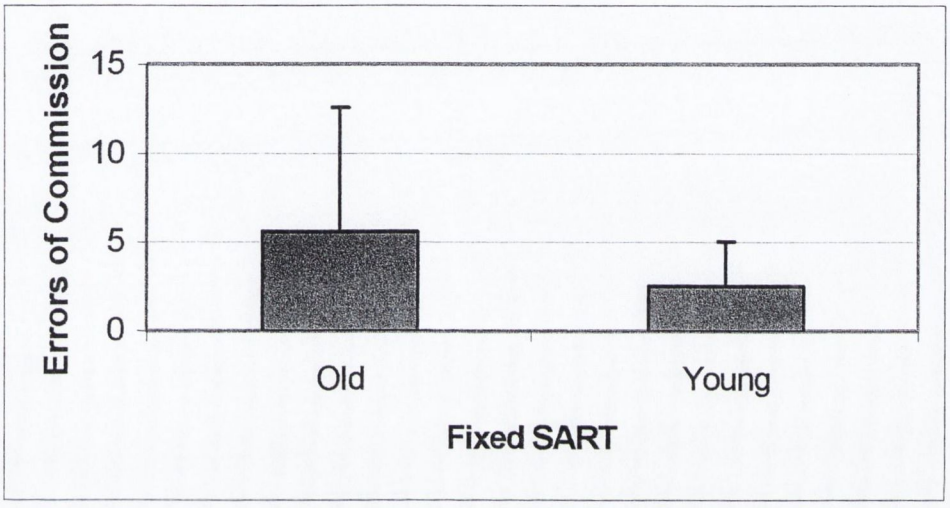

Figure 7.3: Group differences in errors of commission made on the $SART_{fixed}$.

Cognitive Failures Questionnaire (CFQ)

Two Pearson correlations were conducted to see if there was any relationship between CFQ scores and errors of commission on the $SART_{fixed}$ in the young ($r = -0.31$, $n = 40$, $p > 0.05$) and the elderly ($r = 0.23$, $n = 38$, $p > 0.05$). No significant correlations were found.

7.4.3 Discussion of Experiment 2

An age-related deficit in sustained attention as measured by the $SART_{fixed}$ was found in Experiment 2. The old group made significantly more errors of commission on this version of the SART than the young group. This result is consistent with a number of studies that suggested that the $SART_{fixed}$ was a more sensitive measure in terms of a

sustained attention deficit than the $SART_{random}$ (Manly et al., 2003; McAvinue et al., in press).

7.5 General Discussion

The results of Experiment 1 showed that the $SART_{random}$ was not sensitive to an age-related deficit in sustained attention. Furthermore, despite the elderly rating their memory as worse than the average individual's and slower than it used to be on the MAC-S global items, there was no significant difference between the elderly and the young in self-reported failures as measured by the CFQ or indeed the MAC-S total score, ability to remember, or frequency of occurrence subscales. The use of the $SART_{fixed}$ in Experiment 2 was successful in demonstrating an age-related deficit in sustained attention. On this version of the SART, the elderly participants made significantly more errors of commission than their young counterparts.

7.5.1 Performance on the SART

The SART has shown itself to be sensitive to an age-related decline in performance. This performance deficit is most reasonably explained in terms of sustained attention capacity; the elderly demonstrated more lapses of attention than the young. Could this difference be attributable to anything other than sustained attention? The nature of the task - a Go-NoGo task - lends itself to two other possibilities. The first is that the performance deficit displayed by the elderly was due to a general cognitive slowing manifested in RT. Indeed, speed has been proposed as a primary factor in ageing cognition (e.g., Salthouse, 1985b). On the SART, it is generally decreased RT that is associated with a performance deficit. Manly, Davison, Heutink, Galloway and Robertson (2000b) tested 109 adults on the SART and found a significant relationship between errors of commission and RT to Go trials. Individuals who responded more quickly were more likely to make more errors of commission. However, in the current study, the effect of RT was controlled for in the version of the SART that showed a performance difference. Participants were instructed to respond as close as possible to the 'blip' in the mask. That this manipulation was successful shows in the RT data; there was no significant difference between groups on Go trials. It would seem then that

a difference in performance speed couldn't account for the finding in Experiment 1. The second possibility relates to response inhibition. After all, response inhibition is a capacity believed to decline with age (see, for example, Christ et al., 2001). Is that what is going on here? The fact that an age-related effect was found on the $SART_{fixed}$ and not on the $SART_{random}$ argues against this possibility. The $SART_{random}$ has a much greater response inhibition component than the $SART_{fixed}$ because the presentation of the NoGo trial in the former is entirely unpredictable, giving the participant no warning that he or she will shortly be required to withhold a response.

7.5.2 An age-related sustained attention deficit

The results of Experiment 1 in the current study have important implications for the interpretation of previous studies of sustained attention and how this capacity changes with age. There were several reasons why such a result was expected. Theoretically, the FLH suggested that there should be an age-related sustained attention deficit. This theory of cognitive ageing may need refinement (West, 2000), but there is substantial neuropsychological and neurobiological evidence supporting its main ideas. Sustained attention function has repeatedly been associated with right dorsolateral prefrontal cortex (Cohen et al., 1988; Coull et al., 1996; Koski & Petrides, 2001, etc.) and if, as the FLH maintains, functions associated with frontal areas in the brain decline earlier and to a greater extent than functions associated with nonfrontal areas then sustained attention should be susceptible to age-related decline. Phillips and Della Sala (1998) pointed specifically to the dorsolateral prefrontal cortex as being impaired with old age. Even supposing that critics of the FLH such as Greenwood (2000a) are correct, and age-related decline is apparent as early and as much in nonfrontal areas and associated functions, that does not necessarily mean that there is no age-related sustained attention deficit. After all, decline in the frontal areas of the brain does still exist.

Another reason why an age-related deficit in sustained attention was expected was evidence for a sustained attention deficit in TBI patients. It is thought that both ageing and TBI have similar effects on brain function and behaviour (Stuss et al., 1989b). Not only are attention deficits among the most commonly reported cognitive sequelae of TBI (Auerbach, 1986; van Zomeren & Brouwer, 1987; van Zomeren et al., 1984;

Whyte & Rosenthal, 1993), but Robertson et al. (1997) showed a performance deficit in a group of TBI patients compared to a control group. The former made significantly more errors of commission on the SART than the latter.

However, as with the TBI literature (Brouwer & Wolffelaar, 1985; Loken et al., 1995; Parasuraman et al., 1991; Whyte et al., 1995), findings related to sustained attention function in the elderly have not always been consistent (Berardi et al., 2001; Giambra, 1997; Giambra & Quilter, 1988; Parasuraman & Giambra, 1991; Parasuraman et al., 1989). This is arguably mainly due to task differences and the definition of sustained attention on which they are based. Giambra (1997) described a sustained attention task as requiring the individual "to attend continuously to a stream of events for an extended period of time and to react when a particular event occurs" (p. 145). Sustained attention as measured by the SART can be recorded in a relatively short period of time and requires participants to react to the "stream of events" (Go trials) and *not react* to a "particular event" (NoGo trial). This means that participants must self-maintain attention to task in a conscious, controlled fashion in order to avoid an action slip. Previous measures of sustained attention were susceptible to ceiling effects and required additional manipulations to produce any effect at all. For example, Berardi et al. (2001) used perceptually degraded digits in their sustained attention task. The SART, especially the fixed sequence version, is arguably a more straightforward, 'purer' measure of sustained attention. Robertson et al. (1997) found a much stronger relationship between the SART and sustained attention measures than with other attentional tasks including the Stroop (Trenerry et al., 1989). In contrast, Berardi and colleagues failed to find a sustained attention difference between their old and young groups but they did find a performance difference on other attentional measures, including the Stroop.

7.5.3 Associated memory and other cognitive failures

The four global items on the MAC-S ask the participant to rate their memory in comparison to others, in comparison to the best it has ever been, in terms of speed of recall and also as to how much it concerns them. In the current study (specifically, Experiment 1), the elderly scored significantly higher than the young on two of these

items. Firstly, compared to the average individual, the elderly described their memory as average whereas the young described their memory as good. Secondly, compared to the best their memory had ever been, the elderly described the speed with which they remembered things as a little slower whereas the young described it as about the same. This finding is in keeping with the idea that the elderly complain of memory problems (Lowenthal et al., 1967) and with the apparent age-related deficit in SART performance, a task that has been associated with absent-mindedness. However, the main findings in regard to memory and other cognitive failures were non-significant ones. Elderly and young groups did not differ significantly on either the self-report CFQ or MAC-S. This was not entirely unexpected and both the lack of a significant finding on the self-report CFQ and the direction of the results on the informant-report CFQ were consistent with previous research (Mahoney et al., 1998; Martin, 1986; Rabbitt & Abson, 1990). Interestingly, the MAC-S Frequency of Occurrence (of memory problems) subscale approached significance but in the opposite direction from that of the informant-report CFQ in the current study and self-report CFQ in earlier studies. In other words, the elderly reported themselves as experiencing memory problems more often than the young did. It may be that the MAC-S is a more suitable questionnaire for testing the elderly than the CFQ. At the same time, it was not sufficiently sensitive to an age-related decline to yield a significant difference between groups.

The CFQ and MAC-S findings could be explained by one or more of the problems outlined by Rabbitt and Abson (see also Maylor, 1993; 1990). These problems included (1) failure to remember memory failures, (2) influence of self-image, (3) individual differences in life-style and (4) response biases. The first problem is particularly difficult to test. However, if an individual's memory was so poor that they could not remember their memory failures then surely a discrepancy between the frequency of their memory failures as self-reported and reported by their relatives/friends would be apparent. In the current study there was no such discrepancy; the direction of the results in the self- and informant-report CFQ were the same, if significant only in the latter. In regard to the second problem, Maylor (1993) noted that the older participants' ratings may be more influenced by their self-image than by their actual memory ability. Rabbitt and Abson (1990) found a significant correlation between CFQ scores and depression in the over-50s and made the suggestion that self-ratings reflect feelings of depression, inadequacy and poor self-regard. The findings of the current study do not support this

particular assertion given that there was no between-groups difference on either anxiety or depression as measured by the HADS. Of greater relevance to the current study, perhaps, are life-style differences and response biases. The third listed problem, life-style differences, could very easily distort results in a comparison of undergraduate students and retired elderly. It seems likely that the elderly lead a less demanding lifestyle than the young. Rabbitt and Abson (1990) argued that, "busy 50-year-olds who still lead demanding lives will, inevitably, often make lapses...in contrast, people in their 60s and 70s may increasingly move into undemanding life-patterns" (p. 14). In this instance, the young participants' lifestyles may well be comparable to that of Rabbitt and Abson's 50-year-olds. This relates to the fourth problem of response biases in questionnaire measures, in particular the use of memory aids. Karl, Schmitter-Edgecombe and Simpson (1998) asked older and younger adults to fill in 'memory diaries' each night for one week. These diaries included a memory problems and activities checklist. They found that although there was no overall between-groups difference in memory lapses, the results suggested that the older adults were using compensatory strategies (e.g., calendars) to avoid memory failures. It could be the case in the current study that fewer cognitive failures were reported, not because of a better memory but rather as a result of such compensatory strategies or memory aids.

Some of the arguments made by Rabbitt and Abson (1990) were strengthened by the findings of a subsequent study by the same authors (Rabbitt & Abson, 1991). They conducted a study with the aim of finding out whether the efficiency of older adults' metamemory was independent from an age-related decline in their more "fluid" memory abilities. Metamemory refers to people's knowledge about the limits and characteristics of their memory (Flavell, 1977; 1981; Flavell & Wellman, 1977). If metamemory skills are learned through life experience, Rabbitt and Abson argued that they might therefore be expected to be similar to information about the world, skills and procedural knowledge in being described as "crystallised knowledge". Crystallised knowledge has been shown to be relatively resistant to the effects of age in comparison to more "fluid" intellectual resources (Horn, 1998; see also section 3.6 in chapter 3). Rabbitt and Abson (1991) asked 320 people aged from 50 to 79 years to predict their performance on four simple memory tasks (including Recognition Memory, Digit Span, Cumulative Learning, and Free Recall) having had the tasks and the scoring system for each task carefully explained to them. The participants then completed the various tasks

and their predictions were compared with their actual performance. All participants were screened on pencil-and-paper tests of fluid intelligence (the AH 4 IQ test, parts 1 and 2; Heim, Watts, & Simmonds, 1970) and of crystallised intelligence (the Mill Hill vocabulary tests, parts A and B). The CFQ and a version of a Memory Failures Questionnaire (MQ; Sunderland, Harris, & Gleave, 1984) were also given to the participants to assess their subjective knowledge of their efficiency in everyday life. In addition, the participants completed the Beck Depression Inventory (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961).

As expected, Rabbitt and Abson (1991) found that scores on the test of fluid intelligence (the AH 4 IQ test) did decline with age whereas those on the test of crystallised intelligence (Mill Hill vocabulary test) did not. Scores on both of these tests predicted performance on the four memory tasks but the subjective ratings of everyday memory and cognitive efficiency as measured by the CFQ and MQ failed to do so. Rabbitt and Abson (1991) came to the conclusion that "neither are very good at picking up 'metamemorial' insights or personality of emotional factors that determine people's degrees of optimism about their memory abilities or the accuracy with which they can predict their performance" (p. 148). Replicating Rabbitt and Abson's (1990) findings, CFQ scores correlated positively and significantly with the Beck scores suggesting that age changes in people's subjective knowledge of their efficiency in everyday life may be partly due to personality and emotional rather than cognitive differences between older and younger adults. Furthermore, Rabbitt and Abson (1991) observed that while the CFQ and MQ correlate modestly with each other (e.g., at 0.27 in their study), they show quite different degrees of common variance with measures of personality and emotional factors. They give the example that in each of five randomly selected subgroups of individuals aged over 50 years and 96 individuals being investigated by the University of Manchester Age and Cognitive Performance Research Centre at that time correlations between scores on the CFQ and on the Beck are in excess of $r = 0.30$ ($p < 0.001$). In contrast, no significant relationship was ever found between the MQ and the Beck. This leads to the conclusion that not only can scores on self-report questionnaires such as the CFQ and the MQ be influenced by many different personality and emotional variables (e.g., depression) but that different questionnaires may or may not pick up the same emotional and personality variables. This has ramifications for the use of questionnaires in ageing research in regard to interpreting

the self-ratings in a purely cognitive sense. It may be that the extent to which these emotional and personality variables affects the questionnaire in use should be determined before any conclusions can be reached. Perhaps, as Rabbitt and Abson (1991) suggested, self-report questionnaires such as the CFQ and MQ should be used in conjunction with personality tests or otherwise the data "is of very limited interest" (p. 150).

Another consideration for the researcher using questionnaires in ageing studies is the response process itself. Much of our knowledge about age-related differences in behaviour is based on self-reports obtained from older and younger respondents. However, while the cognitive and communicative processes underlying the response process have been relatively well researched (see Sudman, Bradburn, & Schwarz, 1996 for a review), "we know little about the impact of age-related changes in cognitive and communicative functioning on the question answering process" (Schwarz & Knäuper, 2000, p. 249). Recent research has indeed shown that older and younger respondents are differentially influenced by features of the research instrument (Schwarz and Knäuper suggest seeing the contributions in Schwarz, Park, Knäuper, & Sudman, 1999 for reviews).

Schwarz and Knäuper (2000) looked at what was involved in answering a question in a research setting from a cognitive perspective. It is as if the respondent has to solve a number of tasks, including: question comprehension, recalling or computing a judgement, formatting the response and editing the response. In terms of understanding the question, the respondent needs to understand what the question refers to and which behaviour they are meant to be reporting on. It is important that their understanding of the question matches what the researcher had in mind. Once the respondent thinks that they have understood the question, they must then recall or reconstruct relevant instances of this behaviour from memory. Furthermore, they must determine if these remembered instances occurred in the requested reference period or not. For example, in the CFQ respondents are asked to remember how often they have failed to notice signposts on the road in the last six months. Finally, the respondent must make an estimate, perhaps mapped onto a response scale (such as the CFQ's five-point scale ranging from very often to never). Sometimes, the respondent may want to edit their response before communicating it for reasons of social desirability. This last point is

more pertinent to face-to-face interviews than self-administered questionnaires (DeMaio, 1984).

Not all of these aspects of answering a question in a research setting have been studied in the context of age-related changes in cognitive and communicative functioning. In fact, as Schwarz and Knäuper (2000) observed, very little is known about how changes in these processes with age affect self-reports. They argued that given older respondents age-related decline in cognitive resources (see Park, 2000 and the chapter on ageing cognition, chapter 3), they might be less likely to understand a question and relate it to the accompanying response alternatives. These behaviours could require considerable cognitive resources. In regard to formatting the response, it has been recorded in the very old – that is, in respondents of 80 years and older – that they do discriminate less between different categories of response scales. This would, of course, reduce the predictive power of their ratings (Knäuper & Seibt, 1999). There may also be age-related differences in the last task involved in answering a question a research setting, i.e., editing the response. Older respondents have been shown to score higher on social desirability scales (e.g., Gove & Geerken, 1977; Lewinsohn, Rohde, Seeley, & Fischer, 1993) that, Schwarz and Knäuper suggested, may result in an increase in socially desirable responding with age.

Where does that leave us in regard to the SART's relationship to everyday absent-mindedness? Previous studies have established the link between sustained attention and cognitive failures (e.g., Robertson et al., 1997, see also chapter 4) in a young population. While this relationship may exist in the elderly population also, the age-related confounds of the self-report questionnaire make it difficult to expose it. There is also the question of the version of the SART that showed a performance difference between old and young participants, the $SART_{fixed}$, and its relationship with the CFQ. The exact nature of this relationship has yet to be established; in part because it has not been used as much as the random sequence version and in part because it tends not to yield as many errors, making it difficult to test statistically.

The CFQ may have failed to detect age differences in cognitive failures (including memory failures) but the elderly participants did show a deficit on at least one other measure of memory ability, the Associate Learning Subtest of the Wechsler Memory

Scale. "One of the longest and richest literatures regarding ageing and cognition concerns age differences in associative learning" (Rogers et al., 2000, p. 363) and the direction of the difference in the current study is consistent with earlier studies (see Botwinick, 1984; Kausler, 1994 for reviews). Could the age-related deficit in sustained attention as measured by the $SART_{fixed}$ be related to this memory impairment? The absence of any correlation between each group's errors of commission on the $SART_{fixed}$ and scores on the Associate Learning Subtest would suggest that this was not the case. In this group at least, these two measures were independent of each other. However, the finding of an associate learning deficit, consistent with previous research, does suggest that the young and elderly participants in the current study were relatively normal in respect to this aspect of cognition.

7.5.5 Concluding remarks

Experiment 2 in the current study provided evidence for the existence of a sustained attention deficit in the able elderly. Older participants made more mistakes on the SART than their younger counterparts. In general, this difference was not reflected in the questionnaire data relating to memory and other cognitive failures collected in Experiment 1. However, this finding may be due to the unsuitability of questionnaire measures for ageing research. The next step is to examine the brain activity underlying the sustained attention difference between young and old using ERPs. Chapter 8 outlines an experiment in which electrophysiological activity is recorded from young and old participants during SART performance.

8. Sustained attention capacity in the young and able elderly: An ERP study

8.1 Overview

The study described in this chapter represents the culmination of all the experimental work outlined in this thesis so far. Firstly, the SART was selected as a sustained attention task sensitive to a range of performance within a normal, healthy population and also to everyday absent-mindedness. Secondly, two experiments were conducted using different brain mapping techniques - TMS and ERPs - to establish which method was more suited to studying the brain activity underlying SART performance. ERPs was deemed the better choice because of its safety and excellent temporal resolution. ERPs revealed that differences in sustained attention capacity could be indexed by the P300 component. Thirdly, a sustained attention deficit was discovered in an elderly group. Older participants made more errors of commission on the SART than their younger counterparts. The purpose of the experiment described in this chapter was to use the SART, the task shown to be sensitive to an age-related increase in attentional lapses, with the best method to examine participants' brain activity while performing the task and investigate any differences between young and older adults. In this way, one of the main tasks of cognitive gerontology was attempted: "to describe how mental abilities change with age and to relate these observations to the ageing of the brain and central nervous system" (Lowe & Rabbitt, 1997, p. 39).

Young and old adults performed the $SART_{fixed}$ while having their ERPs recorded. No behavioural effect was found but a trend towards the elderly making more errors than the young was apparent. In regard to the ERPs, Go trials (excluding the two Go trials subsequent to a NoGo trial to remove the effect of an error of commission or a correct withhold) were submitted to analysis. Statistically significant effects were found in both

frontal and parietal sites. In brief, the young group displayed greater amplitude and latency in the P200 component at fronto-central sites than the old group. At parietal sites, the young displayed greater amplitude in the P300 component than the old group. These findings are discussed in the context of ageing and ERPs.

8.2 Introduction

8.2.1 Ageing sustained attention

As mentioned, the last study found an age-related deficit in sustained attention capacity. However, a review of the literature on sustained attention and ageing revealed that this is not a consistent finding. Davies and Parasuraman (1982) reviewed 13 studies that investigated age-related effects on vigilance and found a significant effect of age in approximately half of them. This pattern has repeated itself in the last 20 years, with some researchers finding a deficit (Parasuraman & Giambra, 1991; Parasuraman et al., 1989) and others not finding one (Berardi et al., 2001; Giambra, 1997; Giambra & Quilter, 1988). One possible explanation for this discrepancy lies in the type of tasks used. If a task is more demanding (e.g., with perceptually degraded stimuli) then it seems the researcher is more likely to find a deficit. However, this raises an important question: if age effects are found on such a task, are they a function of the sustained attention components of the task or the non-sustained attention components?

Chapter 7 of this thesis described an experiment in which young and able elderly participants were tested for sustained attention deficits using the SART (Robertson et al., 1997). This task differed from those previously used to test sustained attention, the main difference being that it required participants to respond to a series of non-targets (Go trials) and withhold a response on targets (NoGo trials) rather than the other way around. In comparison, the traditional sustained attention task has been described as requiring the participant "to attend continuously to a stream of events for an extended period of time and to react when a particular event occurs" (Giambra, 1997, p. 145). There was a significant age-related effect on SART performance. Overall reaction times between groups were the same and so the performance difference would seem to reflect a distinctly cognitive, sustained attention deficit in the old participants. In addition, the

deficit was only apparent on the $SART_{fixed}$, rather than the standard, $SART_{random}$. There is a much higher inhibition of response demand in the $SART_{random}$ because the NoGo trials are entirely unpredictable, in direct contrast to the $SART_{fixed}$ where it is known exactly when the NoGo trials are coming. This reduces the possibility that the deficit is due to an inhibitory rather than sustained attention failure.

Having established a sustained attention deficit in the elderly, the next step was to see if this deficit manifested itself electrophysiologically. There are some issues, however, that need to be considered in an ERPs study of ageing. To this end, age differences and ERPs and the issues emerging from such a combination will now be reviewed.

8.2.2 Ageing ERPs

The alteration of ERPs as a function of ageing is an area of research in itself. For the most part, the literature consists of chronometric studies using mainly oddball tasks to ascertain the effects of age on various components of the ERP, with a definite emphasis on the P300. Friedman (1995) observed that it is only recently that ERP studies of performance on well-known cognitive paradigms has appeared. For in-depth coverage of age-related changes in mental processes as indexed by ERPs, the reader is referred to Bashore (1990).

Early studies used auditory oddball tasks. An oddball task by definition is a paradigm in which a participant "detects occasional target signals randomly interspersed among more frequent standard stimuli" (Picton, 1992, p. 456). Most of the studies replicated the findings of Goodin, Squires, Henderson and Starr (1978), who tested normal, healthy participants ranging in age from 6 to 76 on an auditory oddball count task. They found that after the age of 15 years the latencies of the P200, N200 and P300 declined linearly. Amplitude reductions were also observed in the P200 and P300 (the N100 was not measured).

According to Bashore (1990), there has been only one visual oddball study with a broad age range that used the conventional visual oddball count task with simple, non-semantic stimuli: Picton, Stuss, Champagne and Nelson (1984). In this task the non-

target was a green light and the target a red light. They examined the P300 for age effects and got similar results to those achieved with an auditory oddball paradigm: increased latency and reduced amplitude with increasing age.

Dujardin, Derambure, Bourriez, Jacquesson and Guieu (1993) used modified visual and auditory oddball tasks in which the participants (young and old) had to respond to both frequent and infrequent stimuli. The purpose of this adapted oddball paradigm was to control the event probability effect and its modifications with age. They found that both the amplitude and latency of the P300 component were affected by ageing. A higher and later P300 was recorded for the visual, compared to the auditory, version of the task.

It would appear, in the area of ageing cognition and ERPs, that the bulk of the research has involved simple mental processing. Bashore (1990) noted that only a handful of studies have looked at more complex mental processing and of those, most of the studies focused on memory. In Friedman's (1995) review of ERPs and cognition in the elderly, for example, he mentioned studies that his own laboratory had conducted on implicit and explicit memory (e.g., Friedman, Hamberger, & Ritter, 1993). In relation to attentional processes, Friedman mentioned some data on the mismatch negativity (MMN) and the processing negativity in the context of selective attention (e.g., Woods, 1992). However, to this author's knowledge, there have been no ERP studies conducted on vigilance or sustained attention in relation to ageing. Kügler, Petter and Platt (1996) tested participants (ranging in age from 18-98 years) on two measures that they termed "transient attention" (passive condition) and "selective attention" (active condition). In the transient attention condition, participants were asked to look at a sequence of checkerboard stimuli. In the selective attention condition, the infrequent checkerboard stimuli were defined as targets and the participants were required to count only those stimuli. ERPs recorded during performance on both measures revealed increased N250 and P300 latencies with age and a slight age-related reduction in P300 amplitude. The P300 latency differences were greater in the selective attention condition than the transient attention condition.

8.2.3 Complications

It is well to be aware that there are a number of concerns complicating the interpretation of ageing effects on ERPs. One such concern relates to the scalp distribution of the P300. It does appear to change with age (Picton, 1992) but not consistently: "some subjects have the classic young adult distribution, some have a central orientation, some a frontal orientation, some an equipotential distribution" (Bashore, 1990, p.269). This may have an effect on P300 amplitude. For example, the negative slow wave on which the P300 is superimposed decreases with increasing age, especially frontally. This could account for the observed P300 amplitude increase at frontal sites in the elderly (Pfefferbaum, Ford, Wenegrat, Roth, & Kopell, 1984). Another problem lies in managing the within- and between-subject variability among older participants. This variability likely originates in the nervous system. Bashore (1990) suggested that sufficient practice on the task in question could solve this particular problem by increasing performance stability and consequently P300 latency. There is also the relationship among the P300, RT and age to consider. This relationship is very complex (Picton, 1992). In simple tasks, the P300 latency is more affected by age than RT and the reverse is true for complex tasks. Finally, sex differences in P300 amplitude are also an issue. In Kügler et al.'s (1996) study described above, females showed a greater, and possibly earlier, P300 latency increase during ageing than males. Also, females had significantly greater P300 amplitudes in the selective attention or active condition than males. However, the reliability of such a finding is questionable. In contrast to Kügler's group, Hegerl, Klotz and Ulrich (1985) found a greater latency increase in P300 with age for males in comparison to females using an auditory oddball paradigm. Either way, putting the direction of the difference aside, these age-related differences in P300 measurements between males and females should be taken into account.

8.2.4 Current study

The current study took these issues into account in so far as was practicable. In regard to sex differences, for example, the selected sample was entirely female. Females were chosen rather than males because of increased availability on their part. Participants had their ERPs recorded while doing the $SART_{fixed}$. This version of the SART was selected

because it showed an age effect in the last experiment (chapter 7) where the random sequence version didn't. Prior to ERP testing, participants were assessed on measures of cognitive failures, anxiety and depression and memory to confirm the findings of the last study. A group difference was consequently expected on paired-associate learning but not anxiety or depression or indeed cognitive failures.

In addition to ERPs and behavioural measures, participants' skin conductance response (SCR) was recorded during task performance. SCR describes phasic electrodermal activity or, in other words, the electrical activity of the skin in response to a stimulus. The purpose of this measure was to gauge participants' arousal levels within 1 to 4 s after an error of commission and a correct withhold. The question of arousal's contribution to SART performance was raised in the ERP study of high and low sustained attention capacity (see chapter 6). It was unclear in that study whether poor performance on the SART was due to over- or under-arousal. The inclusion of this measure in the current study was exploratory: would the poor performers display more or less arousal than the good performers?

8.3 Methods

8.3.1 Participants

There were 12 young (mean age = 21.01, S.D. = 1.16 years) and 12 elderly (mean age = 72.49, S.D. = 4.55 years) participants in this study. All were female, right-handed and had normal or corrected-to-normal vision. History of head injury, epilepsy or other neurological condition, drug or alcohol problems, and/or major psychiatric disorder resulted in exclusion from the study. Young and elderly groups were participants in a previous study and were matched on their IQ (predicted from the number of errors made on the NART). Participants gave informed consent and were debriefed at the end of the study. All participants were paid a nominal sum of €20 per testing session.

8.3.2 Behavioural measures

SART$_{fixed}$

945 single digits from 1-9 (105 of each of the 9 digits) were presented over an 18.11-minute period. Each digit was presented for 250 ms followed by a 900 ms mask. The mask was divided into four components that, when presented in sequence, gave the impression of a 'blip' in the mask. Participants were instructed to respond upon seeing this 'blip' unless it followed the digit 3. Participants responded with a button press. In this version of the SART, digits were presented successively in the conventional, ascending order. Participants were instructed to place equal emphasis on speed and accuracy.

Cognitive Failures Questionnaire (CFQ)

The CFQ is a 25-item self-report questionnaire designed to assess the frequency (over the last 3 months) of everyday slips and errors. Each item refers to a particular type of mistake (e.g., bumping into people, forgetting names), and participants are asked to indicate, on a five-point scale, how often they commit that particular error.

Hospital Anxiety and Depression Scale (HADS) (Zigmond & Snaith, 1983)

The HADS is a 14-item self-report measure of anxiety and depression. A separate score is given for each and pre-determined cut-off points indicate when a participant is within the normal range, or in a mildly, moderately or severely disordered state.

Wechsler Memory Scale (Associate Learning Subtest) (Wechsler, 1974)

This subtest of the Wechsler Memory Scale measures associate learning as part of a battery to assess adult (16-89 years) memory ability.

8.3.3 EEG recording

EEG data was recorded in a.c. mode (gain 500, band pass 0.15-30 Hz). The A/D conversion rate was 500 Hz and the range was 11 mV. Participants were fitted with a 32-channel Quikcap (Ag/AgCl electrodes) connected to the Neuroscan Synamps (Scan 4.1) ERP recording system (Medtech Systems, Horsham, UK). Linked ear reference

electrodes and an anterior scalp reference site (AFz) were used. The electrode array consisted of 12 frontal, 15 central/temporal/parietal and three occipital electrodes conforming to the International 10-20 System (Society, 1994). Vertical and horizontal eye movements were recorded with two VEOG and HEOG electrodes placed above and below the eye, and at the outer canthus of each eye, respectively. Recording commenced upon reducing the electrical impedance to less than 15 kΩ.

EEG measurements

All NoGo trials and the subsequent two Go trials following NoGo trials were excluded from the analysis. Trials were epoched around the stimulus: 200 ms pre-stimulus to 950 ms post-stimulus. All sweeps were baseline corrected using the 100 ms pre-stimulus interval as the baseline. Epochs were subjected to ocular artifact reduction to remove artifactual scalp potentials caused by eye-blinks. Trials that were still contaminated were rejected according to a cut-off threshold of ±70 μV. Remaining epochs were averaged for each individual and then combined into a grand average for each group.

8.3.4 Skin conductance response

Electrodermal activity was acquired using Biopac Student Lab™ version 3.6.7. Skin conductance was measured from the fingertips of the index and middle fingers of the non-dominant hand (all participants were right-handed) using two Ag-AgCl electrodes shielded within individual housings to minimise noise interference. These were attached to the fingertips with Velcro straps. The electrodes had a 6 mm contact area with a 1.6 mm cavity for accommodating conductive gel (Signa gel was used as the electrolyte).

Recording

Skin conductance signals were digitally converted in a.c. mode and amplified 5000 times via a Biopac MP30™ data acquisition unit.

Data analysis

Responses were categorised into errors of commission (making a response on a NoGo trial) and correct withholds (successfully withholding a response on a NoGo trial). For each category, a latency window of 1-4 ms post-stimulus was selected. Within each

window, the amplitude of the largest Skin Conductance Response (SCR) was measured and recorded. SCRs starting within the 1-4 ms window that ended outside the window were included in the analysis. The criterion for the smallest SCR was set at 0.01 μS. Mean SCR amplitude was calculated for each category of response for each participant. These means contributed to a grand average for each group (old and young). Averages were based on all available responses (i.e. non-responses were scored as zero-amplitude SCR in accordance with Tranel & Damasio, 1994).

8.3.5 General procedure

Both groups were tested in one session lasting approximately two hours. Participants completed the paper-and-pen measures before fitting the ERP cap and running the $SART_{fixed}$.

8.4 Results

8.4.1 Behavioural

Computer task

One participant in the young group displayed excessive drowsiness and was excluded from both the behavioural and ERP analysis of the data. Mean errors of commission were 9.67 (S.D. = 10.60) for the old group; 5.09 (S.D. = 3.65) for the young group. This difference was not significant ($t = 1.41$, $df = 13.77$, $p > 0.05$; see Figure 8.1). In making these errors of commission, the young group were significantly faster (mean = 51.05, S.D. = 58.55 ms) than the old group (mean = 9.91, S.D. = 4.37 ms) in their key press ($t = 2.43$, $df = 11$, $p < 0.05$). Mean reaction times for the Go trials between groups (old: mean = 474.23, S.D. = 106.32 ms, young: mean = 427.03, S.D. = 85.93) were not significantly different ($t = 1.16$, $df = 21$, $p > 0.05$). Descriptive statistics for reaction times are displayed in Table 8.1 below.

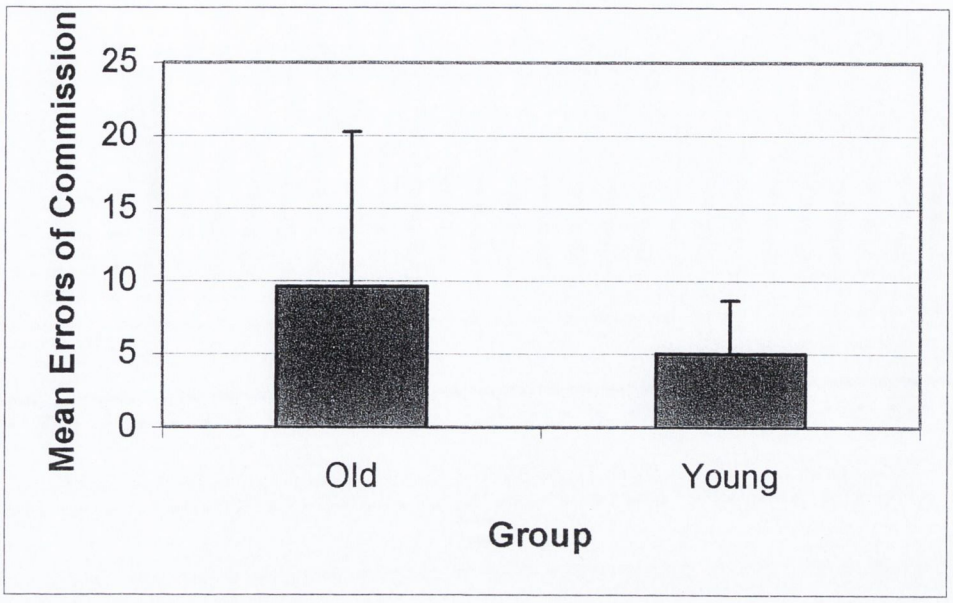

Figure 8.1: Mean errors of commission on the $SART_{fixed}$ (ns).

Table 8.1: Descriptive statistics for reaction times on Go and NoGo (Error) trials.

	RT (ms)			
Trial	Old		Young	
	Mean	*S.D.*	*Mean*	*S.D.*
Go	474.23	106.32	427.03	85.93
NoGo (Error)	51.05	58.55	9.91	4.37

Paper-and-pen measures

An independent t-test revealed no significant difference in self-reported cognitive failures ($t = -0.79$, $df = 21$, $p > 0.05$). Analysis of the HADS showed a group difference in anxiety ($t = -2.26$, $df = 21$, $p < 0.05$) but not in depression ($t = 1.45$, $df = 21$, $p > 0.05$). The young scored higher on anxiety than the elderly. The Associate Learning Subtest of the Wechsler Memory Scale revealed a significant difference between old and young ($t = -4.33$, $df = 12.75$, $p < 0.01$): the old participants performed worse than the young participants. There was no difference between groups in predicted IQ as measured by the NART ($t = 0.13$, $df = 21$, $p > 0.05$).

Table 8.2: Descriptive statistics for the paper-and-pen measures.

Measure	**Max. score**	**Old**		**Young**		**Sig.**
		Mean	*S.D.*	*Mean*	*S.D.*	*p*
CFQ	100[+]	33.08	11.68	36.27	6.75	0.44
HADS Anxiety	21[+]	4.50	2.78	7.09	2.70	0.03*
HADS Depression	21[+]	2.42	1.62	1.55	1.21	0.16
Associate Learning	21	13.83	4.63	19.85	1.20	0.00**
NART	131	114.17	9.38	113.73	6.31	0.90

[+] Poor performance

* $p < 0.05$, ** $p < 0.01$

8.4.2 ERP

Visual inspection of the data revealed a positive deflection at about 160-330 ms with a fronto-central maximum. This component was labelled P200. At a latency of 350-700 ms a second positive deflection was apparent. This was labelled P300. A MANOVA was conducted to make a group comparison (old vs. young) on P200 and P300 amplitude and latency for all Go trials (excluding the two trials subsequent to a NoGo trial). Cases were weighted by the number of trials contributing to the group average.

P200 component

The fronto-central P200 had a larger amplitude in the young as compared to the old (**C4**, $F(1,20) = 5.94$, $p < 0.05$; **CZ**, $F(1,20) = 5.93$, $p < 0.05$); **F4**, $F(1,20) = 4.56$, $p < 0.05$; **FC4**, $F(1,20) = 4.42$, $p < 0.05$); and also a longer latency in the same direction (**C4**, $F(1,20) = 17.80$, $p < 0.001$; **CP4**, $F(1,20) = 5.22$, $p < 0.05$; **CZ**, $F(1,20) = 5.46$, $p < 0.05$). Descriptive statistics for these measures are displayed in Table 8.3 and grand average ERPs for the 32 scalp locations are shown in Figure 8.2.

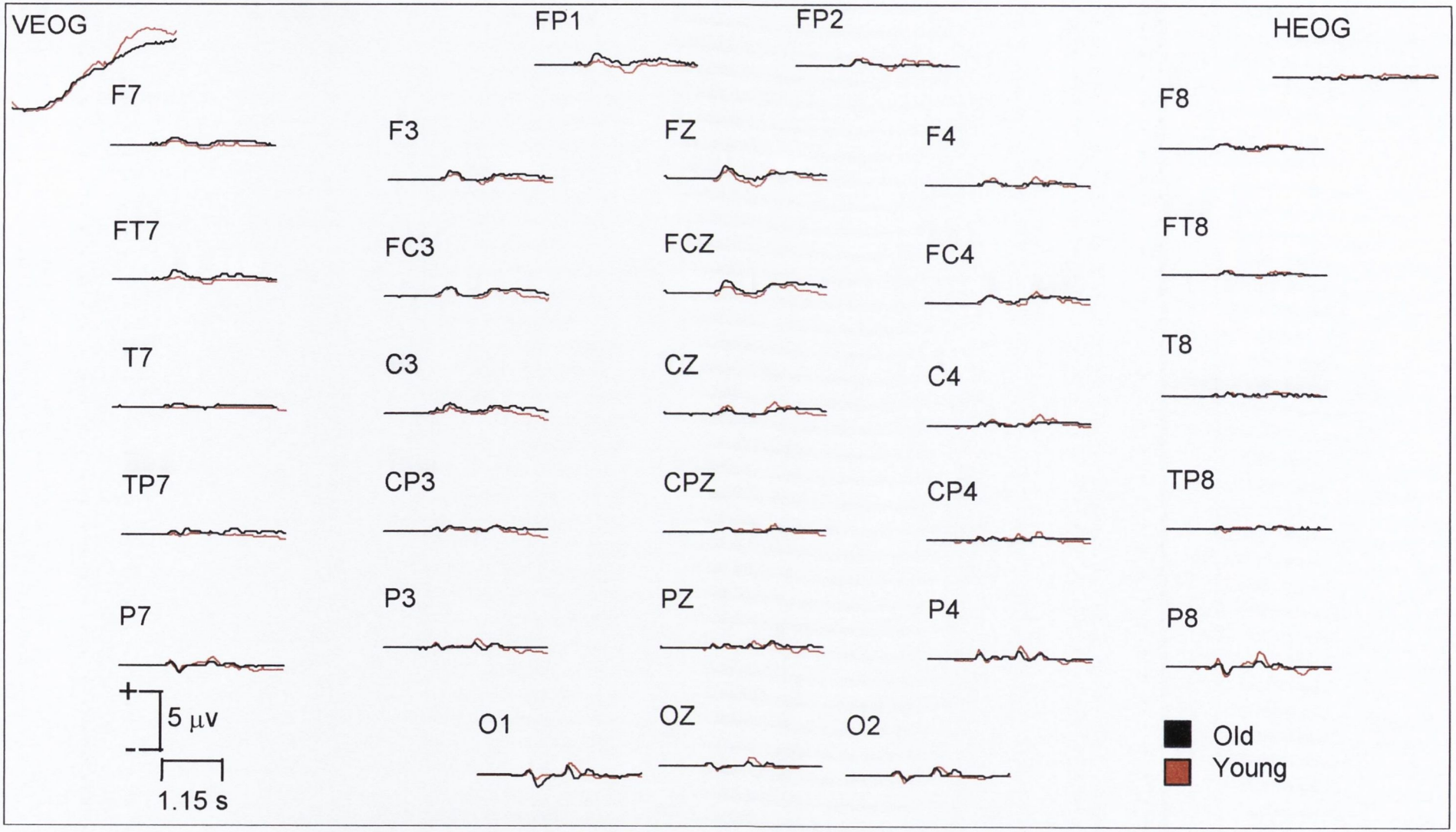

Figure 8.2: Grand average ERPs for the 32 scalp locations. Superimposed are ERPs for the old and the young group.

Table 8.3: Descriptive statistics for amplitude and latency differences in P200.

		Old		Young	
Channel	Measure	Mean	S.D.	Mean	S.D.
C4	**Amplitude** μV	0.89	1.03	1.59	1.05
CZ		1.03	1.06	1.75	1.12
F4		0.96	1.32	1.44	1.23
FC4		1.36	1.44	1.77	1.19
C4	**Latency** ms	207.51	31.51	258.20	39.16
CP4		206.76	39.48	234.39	49.23
CZ		215.61	33.38	254.08	33.74

P300 component

Examination of the P300 component revealed group differences at frontal and parietal sites. However, at frontal sites this difference was not a straightforward one. A P300 component was clearly discernible in the waveform of the young group but not the old group. This meant that the data was not suitable for peak detection and comparison. So saying, the effect is of note. The parietal P300 was larger in amplitude for the young as compared to the old at **P8** ($F(1,20) = 4.64$, $p < 0.05$). This difference was also observed at **P4** but it did not reach statistical significance ($p = 0.06$). Descriptive statistics for these two channels are displayed in Table 8.4.

Table 8.4: Descriptive statistics for amplitude differences in P300. Significant only at P8.

		Old		Young	
Channel	Measure	Mean	S.D.	Mean	S.D.
P8	**Amplitude** μv	1.36	1.42	2.79	2.48
P4		1.62	1.63	2.67	2.20

8.4.3 SCR

A repeated measures ANOVA was carried out on the data with response type (errors of commission and correct withholds) as the within-subjects factor and group (young and old) as the between-groups factor. There was a significant effect of response type ($F(1,17) = 18.79$, $p < 0.001$; see Figure 8.3), with mean amplitude SCR being greater following an error of commission than a correct withhold. See Table 8.5 for means and standard deviations for each group for each response type.

Table 8.5: Descriptive statistics for SCR amplitude following an error of commission and a correct withhold.

Response type	Amplitude SCR	Old	Young
Error of commission	Mean	0.65	1.28
	S.D.	0.69	0.97
Correct withhold	Mean	0.29	0.31
	S.D.	0.37	0.25

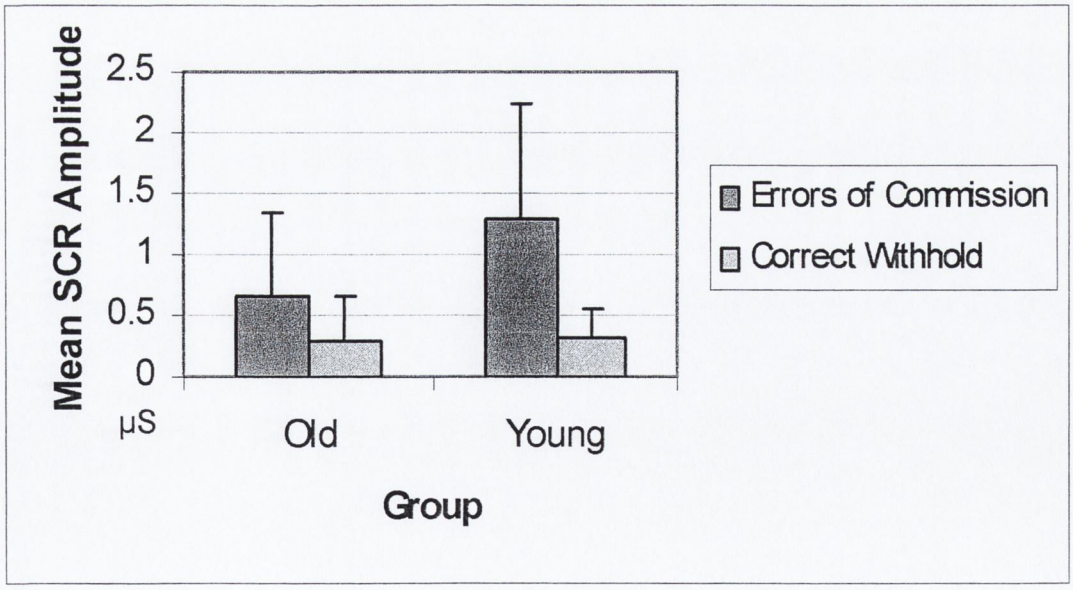

Figure 8.3: Significant effect of response type on mean SCR amplitude (µS).

8.5 Discussion

8.5.1 Behavioural effects

There was no significant group difference in errors of commission or reaction times to Go trials on the $SART_{fixed}$. However, there was a trend for the older adults to make more errors or absent-minded slips than the younger adults. When making these errors of commission, the young were faster than the old. Groups did not differ on self-reported cognitive failures, depression or NART IQ. A significant difference was found between old and young participants on anxiety and associate learning. The young reported themselves as being more anxious on average compared to the old. Finally, in regard to associate learning, the old participants performed worse than their young counterparts.

The age-related sustained attention deficit demonstrated in the last study (chapter 7) was not replicated here. Why? There are a number of possibilities. The first possibility is that the sample size was too small to show an effect. The time-consuming nature of an ERPs experiment is somewhat restrictive in this way. However, the fact that there was a trend for old participants to make more errors of commission than the young participants indicates that with a larger sample size the finding would have been consistent with that of the previous study.

Yet another possibility relates to the influence of increased anxiety on the part of the young participants. Perhaps this affected their performance, closing the gap between them and the older participants? Electrodermal activity - e.g., sweaty palms - is a somatic-physiological symptom commonly reported with anxiety (Lau, Edelstein, & Larkin, 2001). The SCR results support this idea in that there was a trend for young participants to display a larger SCR following an error of commission than the old participants. Berardi et al. (2001) suggested arousal as a possible cause for their inability to find an age-related difference in vigilance performance between groups. Indeed, overall vigilance can be affected by factors that affect arousal (Davies & Parasuraman, 1982). However, measures of arousal in the elderly must be interpreted

with caution because of age-related changes in physiology. Eccrine sweat glands* are particularly important for electrodermal activity (Stern, Ray, & Quigley, 2001) and they decrease in number with age. In addition, there is a reduction in the density of sweat glands and those that are active produce a smaller amount of sweat over the age of 65 (Catania, Thompson, Miachalewski, & Bowman, 1980; Montagna, 1965; Porges & Fox, 1986).

Young participants scored significantly higher on the Associate Learning Subtest of the Wechsler Memory Scale than old participants. This is consistent with earlier findings (see chapter 7) and those of other researchers (e.g., Rogers & Gilbert, 1997; Rogers et al., 2000). One possible reason for this age difference is strategy choice. Older adults have been shown to use the less effective mnemonic technique of rote rehearsal for paired-associate learning whereas younger adults use effective techniques such as visual imagery and sentence formation (Brigham & M., 1988; Rogers et al., 2000). The fact that a group difference was found on this measure and not on the SART may indicate their independence from each other. Moreover, these measures failed to correlate with each other in the last study. However, the fact that an age-related associate learning deficit is a common finding suggests that the elderly in the current study were relatively representative of an elderly population. Also consistent with the last study, the measure that SART performance has traditionally been associated with - the CFQ - also showed no difference between groups (again, see chapter 7 for further discussion on this point).

8.5.2 ERP effects

ERP differences between young and old groups were observed. The P200 component was larger for the young as compared to the old at fronto-central sites and also displayed a longer latency in the same direction. The young exhibited a definite P300 at frontal sites but this component appeared to be absent in the old. At parietal sites, however, the P300 was present and significantly reduced for the old compared to the young.

P200 component

* A special type of sweat gland concentrated in the palms of the hands and the soles of the feet.

What do we know about the P200? It is a long-latency exogenous component that occurs between 100 ms and 200-300 ms and is thought to reflect the first neural processing of the physical characteristics of a stimulus (Hugdahl, 1995). The magnitude of the P200, unlike the P300, is not dependent on the cognitive processing of the stimulus. In other words, it is not one of the components known to be modulated by cognition (including attention).

Age-related effects on this component have been observed before. Goodin et al. (1978), for example, found an increased latency and reduced amplitude P200 when they looked at age effects on an auditory oddball paradigm. These latency differences were subsequently replicated but the amplitude differences less consistently (Bashore, 1990). Taking the longer latency and greater amplitude of the younger compared to the older participants in this study, what can we conclude? The larger amplitude is relatively in keeping with the literature but the longer latency is not. Perhaps the most feasible explanation is that the young participants devoted more basic processing resources for longer to the stimuli than the old participants.

P300 component

In contrast to the P200, the P300 is an endogenous component of the ERP that occurs between 200 and 250 ms and some later time. Amplitude and latency of the P300 are closely related to the quality of attention (Dujardin et al., 1993). The findings of the current study regarding this component are in agreement with the ageing and cognition literature. A reduced amplitude P300 for the old relative to the young group is consistent with the findings of most of the research in the field (see also Bashore, 1990; Dujardin et al., 1993; Goodin et al., 1978; Iragui, Kutas, Mitchiner, & Hillyard, 1993; Picton et al., 1984).

A reduced P300 amplitude for old relative to young participants may be a fairly common finding but in this case, the P300 observed in the young at frontal sites seemed to be not so much reduced but absent altogether in the old. This invalidated a statistical comparison of peak differences between groups (the elderly had no peak) and made functional interpretation more difficult. If the P300 increases when a stimulus is attended to, does that mean that the elderly simply weren't paying attention to the Go trials? The answer is likely not that straightforward. The sites at which the P300 was

absent in the elderly were, as mentioned, frontal. A mere reduction in amplitude of the component was apparent at parietal sites. This could be interpreted as different elements of the P300 complex. A P300 at frontal sites is often considered to be P3a whereas one at parietal sites, P3b. These two components are often associated with different functions. P3a is thought to be unaffected by whether the participant is attending to the stimuli, whereas the P3b is larger with attention (Picton, 1992). So saying, while the location of the P300 in this study is frontal, it could be argued that it occurs a little too late to be P3a. Also, the scalp distribution of this component is known to change with age and moreover inconsistently (Bashore, 1990), making interpretation based on topography undependable. It may be sensible to describe the P300 in this case as simply a marker of attention.

8.5.3 Conclusions

If we pull the different strands - behaviour and electrophysiology - of this experiment together, what do we have? Firstly, it would appear that the ability to sustain attention changes with age. The last experiment provided evidence in that direction as does the current experiment, albeit not significantly. Secondly, the P300 component of the ERP presents itself as a good candidate for the manifestation of sustained attention electrophysiologically. Thirdly, in this comparison of elderly and young groups, changes in the P300 are complemented by changes in the P200. The P200 is considered an index of automatic processes, related to the physical properties of the stimulus (Hugdahl, 1995). The increased amplitude of the P200 in the young relative to the old group can be interpreted as the former putting greater processing resources into the perception of the stimulus. In regard to the P300, it could be argued that the frontal P300 represents something other than attention but the parietal P300 strongly suggests that it is indeed an index of the participants' paying attention. The P300 has long been associated with the capacity of attention and this experiment is no exception. Lowe (1997) identified one of the main tasks of cognitive gerontology as describing age-related changes in cognition and the concomitant changes of the brain. The current experiment attempted that task and has provided evidence for an age-related change in sustained attention manifested in the brain's electrophysiology in the shape of the P300.

9. Quantitative EEG

9.1 Overview

This chapter consists of two quantitative EEG (qEEG) analyses of previously gathered data: (1) high and low sustained attention capacity (SAC) and (2) sustained attention in the young and able elderly. Both of these studies used the SART to measure sustained attention, a task that has been shown to correlate with measures of memory and other cognitive failures (Robertson et al., 1997, see also chapters 2 and 4). The SART has shown itself to be sensitive to a range of performance in a normal, healthy population and moreover, to an age-related sustained attention deficit (chapters 4 and 7). When ERPs were recorded during young and elderly participants' performance on the SART, the P300 component was revealed as indexing that performance (chapters 6 and 8). An analysis of the background EEG added more detail to the picture, revealing group differences in slow-wave activity in both data sets. In the high and low SAC comparison, these differences can be interpreted as differences in cortical arousal consistent with qEEG findings in children with attention deficit (Chabot & Serfontein, 1996; Clarke, Barry, McCarthy, Selikowitz, & Brown, 2002; Mann, Lubar, Zimmerman, Miller, & Muenchen, 1992; Monastra, Lubar, & Linden, 2001). The differences in the young and elderly comparison are more difficult to interpret, taking into consideration the possibility of task-related slow-wave activity (Gevins & Smith, 2000; Klimesch, 1999). This issue will be addressed in the discussion.

9.2 Introduction

9.2.1 What is qEEG?

This chapter makes use of the qEEG procedure in the form of power spectral analysis. EEG power is a measure that, "reflects the number of neurons that discharge synchronously" (Klimesch, 1999, p. 170). The EEG is made up of oscillations that can be classified according to the 'natural frequencies' of the brain (Basar, Basar-Eroglu, Karakas, & Schürmann, 1999): delta, theta, alpha, beta and gamma. Different frequencies are associated with different states of arousal. Alert attentiveness is reflected in fast-wave beta activity, whereas relaxed wakefulness is associated with slower alpha activity and activity in slow-wave delta and theta bands is thought to indicate drowsiness (Parasuraman et al., 1998). In addition, examining how EEG power changes within these natural frequencies - how it increases (synchronises) and decreases (desynchronises) - provides information about the capacity or performance of cortical information processing (Klimesch, 1999). The various oscillations and the cognitive processes associated with them are described below:

Delta (0-4 Hz*)

As well as being associated with drowsiness (Parasuraman et al., 1998), delta oscillations are related to cognitive processing (Basar et al., 1999). During oddball experiments the delta response is greatly increased and consequently it has been associated with signal detection and decision making. For example, Schürmann, Başar-Eroglu, Kolev and Başar (2001) recorded EEG during an oddball paradigm using checkerboard-type stimuli in which participants were asked to pay attention to the targets (checkerboard reversal with horizontal and vertical displacement – 25% probability) and ignore the non-targets (checkerboard reversal – 75% probability). Responses to targets were characterised by an increase in delta leading the authors to suggest that activity in this band is "mostly involved with the signal matching and decision making following a novel or unexpected signal and/or partial surprise" (p. 236). Makeig and Inlow (1993) established a link between delta and the vigilance

* Excluding gamma, the ranges given represent the 'classic' frequency bands (Nuwer, 1988).

decrement using a 28-minute auditory detection task. Participants had their eyes closed and were required to detect noise burst targets presented against a white noise background. They then calculated local error rate which they defined as the fraction of targets detected in a 33-second moving window. This local error rate fluctuated widely and increased over time on the task. This decline in performance was accompanied by an increase in delta (and theta activity).

Theta (5-7 Hz)

Theta oscillations are associated with functions similar to delta (Basar et al., 1999). Klimesch (1999) posits synchronisation in the theta band as reflecting episodic memory and the encoding of new information. Theta has also been associated with selective attention. Event-related theta oscillations are prolonged subsequent to the target stimulus in oddball tasks. This prolongation is interpreted as being related to selective attention. Theta has also been associated with 'orienting', "a coordinated response indicating alertness, arousal or readiness" (Basar et al., 1999, p.167). Recent studies have shown that theta is increased in tasks with greater working memory demands (Gevins et al., 1998; Gevins & Zeitlin, 1977). McEvoy, Pellouchoud, Smith and Gevins (2001) found increased theta in young and middle-aged adults with increased task difficulty on a spatial working memory task. There was an easy and a difficult version of the task. In the easy version participants were required to compare the location of the current stimulus with the location of the very first stimulus in the block. In the difficult version, participants had to compare the location of the current stimulus with the location of the stimulus presented two trials previously. Smith, McEvoy and Gevins (1999) finding of increased theta with time on a similar working memory task, offers an interesting alternative interpretation to Makeig and his colleagues (1993, 1995) in respect to performance decrement. The latter provided an arousal interpretation for their observation of increased delta and theta over time on task, related to the increase in local error rate. In contrast, Gevins and Smith suggested that the theta increases they observed reflected were task-related rather than drowsiness-related. They based their argument on the fact that their theta was later and more frontal than the drowsiness theta and that this activity has been related to mental activities before, such as working memory.

Alpha (8-13 Hz)

Alpha is the dominant frequency in the human EEG (Klimesch, 1999). It can be broken down into different bands, the exact number of bands and their ranges depends on the individual researcher and their aims. Klimesch, Doppelmayr, Russegger, Pachinger and Schwaiger (1998) split alpha into a lower, intermediate and upper band to tease apart the relationship between alpha and attention. EEG was recorded during a visual oddball task in which a warning signal preceded a target or non-target. Participants were required to count the targets. A significant response was defined as a decrease in band power. This was apparent in the lower alpha band when the warning signal preceded a target, indicating that this band represented phasic alertness. A significant response in the intermediate alpha band was observed before a target and a non-target. The authors interpreted this as an index of expectancy. Finally, a reduction in upper alpha was apparent only after a target was presented suggesting its involvement in task performance (i.e., counting the targets). Thus, only the slower frequencies were seen to relate to attentional demands such as alertness and expectancy. Klimesch (1999) differentiated between lower and upper alpha, not only by their functional correlates, but topographically. The lower band (6-10 Hz) which reflects "a variety of non-task and non-stimulus specific factors which may be best subsumed under the term 'attention'" (p. 183) is topographically widespread across the scalp. Upper band alpha (10-12 Hz) is topographically restricted and is associated with the processing of sensory-semantic information.

14 Hz plus: beta and gamma activity

At the faster end of the EEG spectrum is beta and gamma activity. As mentioned before, beta is associated with an alert, attentive state (Parasuraman et al., 1998). It is known to increase during both physical and mental activities (Ackerman, Dykman, Oglesby, & Newton, 1994; Ackerman, Dykman, Oglesby, & Newton, 1995; Andreassi, 1995). Williamson (1990) found that cognitive performance correlated positively with beta activity even after controlling for age, education, occupation and medication. Gamma activity has a number of functional correlates including perceptual feature binding, memory and attentional processes (Gray, Konig, Engel, & Singer, 1989; Muller, Gruber, & Keil, 2000; Tallon-Baudry, Bertrand, Peronnet, & Pernier, 1998). Miltner, Braun, Arnold, Witte and Taub (1999) demonstrated that increased gamma activity was involved in associative learning and furthermore, that increased gamma

coherence between two regions of the brain that received two classes of stimuli in an associative learning procedure in humans. In a classical conditioning paradigm, participants learned to associate one colour (red or green) with an electric shock to the finger (CS^+). These CS^+ trials, 60 in total, were randomly interspersed with 60 trials in which the alternate colour was presented without the electric shock (CS^-). Gamma band activity increased for the first 2 s of each 3s trial at all occipital and parietal electrode sites and remained elevated for the last second. This increase in activity in the gamma band was significantly greater in CS^+ than CS^-. In regard to gamma coherence, it was significantly greater during CS^+ trials than during CS^- trials just before the shock. When the shock was delivered to the non-dominant (left) hand four electrode pairs spanning primary and association visual cortices, which would have received visual input concerning CS^+ and CS^-, and the contralateral (right) or midline pericentral cortex, which would have received input from the finger that was shocked, showed greater gamma coherence during CS^+ than CS^-. This effect was also apparent in two electrode pairs connecting the visual cortex with the contralateral posterior parietal somatosensory association area. When the shock was delivered to the dominant (right) hand, the laterality of increased coherence was reversed.

9.2.2 Abnormal EEG and attention deficit

The most comprehensive analysis of EEG and attention deficit can be found in the ADHD (attention deficit hyperactivity disorder) literature. The class of disorders that comprises ADHD display "behavioural symptoms of hyperactivity, inattention, and/or impulsivity" (Chabot & Serfontein, 1996, p. 951). The diagnostic and statistical manual of mental disorders (DSM) describes ADHD as a two-dimensional disorder with three types: inattentive, hyperactive/impulsive and combined (American Psychiatric Association, 1994). These types are differentiated by behaviour but there is a growing body of evidence to suggest that ADHD would be better classified by patients' underlying central nervous system (CNS) dysfunction. The efforts to better conceptualise ADHD have resulted in a wealth of information about attention deficit and associated EEG. There appears to be two lines of research. One investigates ADHD subtypes differentiated by their EEG within the traditional types of ADHD, ADHDcom and ADHDin (Chabot & Serfontein, 1996; Clarke et al., 2002). The other works on

comparing ADHD and normal, healthy children (Lubar, 1991; Mann et al., 1992; Monastra et al., 2001; Monastra et al., 1999).

The pattern of EEG activity displayed by children with ADHD is different from children without the disorder. ADHD children show increased slow wave activity (delta and theta) and decreased fast wave activity (alpha and beta) (Clarke et al., 2002). Monastra and colleagues (Monastra et al., 2001; Monastra et al., 1999) proposed the EEG procedure as a reliable and valid laboratory test of ADHD. Existing diagnostic tools are unsatisfactory. For example, interview and rating scales are subject to rater bias (Barkley & Murphy, 1998; Cantwell, 1996). EEG examination of the prefrontal and frontal cortex has consistently shown electrophysiological differences between ADHD children and controls (Chabot & Serfontein, 1996; Clarke et al., 2002; Mann et al., 1992; Monastra et al., 2001; Monastra et al., 1999). Mann et al. (1992) compared the EEG of 25 boys with ADHD with 27 boys without the disorder during reading, drawing and rest and found increased theta and decreased beta in the ADHD group. When they looked at the topography of the EEG, the increase in theta was predominantly frontal (F3 and F4), while the decrease in beta was more temporal. Lubar and colleagues (Lubar, 1995; Lubar, Swartwood, Swartwood, & Timmerman, 1996) recorded EEG from ADHD children and controls during two baseline conditions (eyes open and eyes closed), reading silently, doing visuomotor tasks and listening. They calculated a theta-beta power ratio by dividing the electrophysiological output produced in the theta frequency band (slow-wave) by the output produced in the beta frequency band (fast-wave). ADHD participants showed a higher theta-beta ratio than controls at multiple sites, but particularly at CZ and FZ. Monastra et al. (Monastra et al., 2001; Monastra et al., 1999) in testing the quantitative EEG procedure, replicated these findings in large samples. The initial validation study had a sample size of 482 participants (6-30 years old) and the follow-up study, to test validity further and reliability, consisted of 469 participants (6-20 years old). Recordings were obtained from a single channel (CZ) while participants were engaged in cognitive tasks such as reading, listening and drawing. Like Lubar and colleagues, Monastra et al. found that the ADHD children exhibited significantly higher theta-beta power ratios than their peers without any disorder. All of the above-named authors including Lubar and Monastra agree that this pattern of activity - increased slow-wave activity with decreased fast-wave activity - is electrophysiological evidence of cortical slowing.

Clarke and colleagues (Clarke, Barry, McCarthy, & Selikowitz, 2001; Clarke et al., 2002) have described two types of EEG pattern that can be found within both ADHDcom (combined) and ADHDin (inattentive). They recorded EEG from 21 sites during an eyes-closed resting condition. The first EEG-defined cluster displayed increased theta activity with a reciprocal decrease in beta activity. This pattern of activity was interpreted as *under-arousal*. The second cluster presented a more general increase in slow wave activity and a decrease in fast wave activity. Clarke and colleagues believed that this cluster of ADHD children was showing a *maturational lag*. A third cluster defined by EEG was found in the ADHDcom children characterised by *over-arousal* with excess beta activity. These findings were comparable to the results of Chabot and Serfontein (1996) in which they recorded EEG from 19 sites during a 20- to 30-minute eyes-closed condition. They also identified two main subtypes defined by EEG in ADHDcom and ADHDin. 46% of children displayed a pattern indicative of over-arousal and 30% under-arousal or slowing. These subtypes were also apparent in a third group consisting of children with attention problems who did not reach the ADHD criteria of the DSM. These subtypes support the idea that CNS arousal can be abnormally low or high in children with attention problems (Frank, 1993). Chabot and Serfontein (1996) neatly summarised their findings as "...a generalised theta excess with greater involvement of frontal regions was the most common abnormality found" (p. 960).

9.2.3 Adults with attention deficit

As many as 60-70% of children with ADHD continue to show symptoms of the disorder as adults (Wender, 1998). Some of these symptoms include organisational and concentration difficulties, being regarded as rude and impolite and underachieving in academic and vocational areas (Weiss & Hechtman, 1986). Adults with ADHD are also more likely to be of lower socio-economic status, change jobs more frequently, move residence and have more part-time employment (Barkley, 1990). A study by Bresnahan, Anderson and Barry (1999) examined electrophysiological measures in children, adolescents and adults with ADHD and found that: (1) these groups showed elevated slow-wave power (delta and theta) and (2) the children and adolescents with ADHD

showed reduced beta power compared with their respective normal, control groups but that this difference reduced at Fz and Cz by adulthood. The latter result suggested that beta power in adults with ADHD resembles that of adults without the disorder. Bresnahan et al.'s findings were consistent with the research on children and adolescents with ADHD (as outlined above). It was suggested that the qEEG differences might be connected to the symptomatology of the disorder. Clinical observation of ADHD in adults suggests that the early hyperactivity is reduced while impulsive-type behaviours stay the same. In this way, the elevated slow-wave power reflected their continuing high levels of impulsive-type behaviour, and the apparent normalisation of beta power was associated with a reduction in the level of hyperactivity. In a second study, Bresnahan and Barry (2002) tested the hypothesis that elevated slow-wave power was the predominant EEG difference between adults with ADHD and normal, control participants. They also compared these groups to a group of non-ADHD participants who presented for ADHD assessment but failed to meet the diagnostic criteria. Consistent with the earlier study, Bresnahan and Barry found that the ADHD group differed significantly from both the non-ADHD and control groups on the basis of elevated theta activity. The ADHD group also produced more delta than the control group. The ADHD and control groups did not differ in beta activity, but activity in this band was elevated in the non-ADHD group compared to the two other groups. The authors suggested that this elevated beta power may have reflected some of the clinical symptoms in the non-ADHD group that were not found in the ADHD group.

9.2.4 Age-related changes in the EEG

The pattern of activity observed in ADHD is comparable to that of old age. As people get older they show more slow-wave activity and less fast-wave activity (Klimesch, 1999). In a study of 120 participants (ten males and ten females per decade), Polich (1997) recorded EEG in an auditory and visual condition and with eyes open and closed. A simple discrimination task was used in both conditions. He found that with increasing age, delta and theta activity increased and alpha activity decreased. Indeed, a variety of studies have found age-related changes in EEG power and most of these studies showed a general slowing of the EEG with a pronounced increase slow-wave activity and decrease in fast-wave activity (Böttger, Herrmann, & von Cramon, 2002;

Markand, 1990; Obrist, 1954; Obrist et al., 1963). "It is a well documented fact that alpha frequency changes with age"; it increases from early childhood up until puberty and then decreases from then on (Klimesch, 1999, p. 175). These changes in alpha (and indeed theta) may, however, be due to age-related neurological diseases rather than age per se (Hartikainen, Soininen, Partanen, Helkala, & Riekkinen, 1992; Hubbard, Sunde, & Goldensohn, 1976). There is also the risk of confusing alpha and theta activity because in participants from 60 to 70 years and older, alpha frequency lies between 8.5 and 9 Hz rather than the traditional 7.5 and 12.5 Hz. Theta (4 to 7.5 Hz) can actually reflect slowed alpha activity. This can often happen in studies that use a broad band analyses within fixed frequency windows.

The relationship between EEG slowing and dysfunction in attention and cognition described in regard to ADHD can also be seen in ageing (Chabot & Serfontein, 1996). It has been suggested that age-related changes in alpha frequency are indicative of cognition and memory performance, manifested in speed of response (Klimesch, 1999). Alpha frequency has been found to correlate significantly with information processing as measured by reaction times; high alpha frequency is associated with fast reaction times and low alpha frequency is associated with slow reaction times (Surwillo, 1961; 1963a; 1963b; 1964a; 1964b; 1971). Similar results were found more recently by Klimesch, Doppelmayr, Schimke and Pachinger (1996). The link to memory performance comes from a variety of experiments conducted in Klimesch and colleagues' laboratory, showing that alpha frequency of good memory performers was about 1 Hz higher than that of age-matched samples of bad performers (Klimesch, 1996; 1997; Klimesch, Pfurtscheller, & Schimke, 1993a; Klimesch, Schimke, Ladurner, & Pfurtscheller, 1990a; Klimesch, Schimke, & Pfurtscheller, 1990b; Klimesch, Schimke, & Pfurtscheller, 1993b).

9.2.5 EEG and ERPs

"Even though the exact origins of ERP variability are not known, it is reasonable to suppose that background electroencephalographic (EEG) activity may contribute to variation in ERP values" (Polich, 1997, p. 300). There have been two approaches to understanding the relationship between EEG and ERPs: (1) group comparisons in

which participants' EEG variability affects EP (evoked potential) amplitude and latency between subjects and (2) within subjects comparisons in which the relationship between pre- and post-stimulus EEG and post-stimulus EP is examined. Despite wide variation in recording techniques and experimental methodology, the first approach has generally found that variation of background EEG does influence sensory EP measures. The second approach has yielded a lot of information about the relationship between EEG power and the amplitude of the P300. For example, Polich (1997) recorded EEG and ERP from Fz, Cz and Pz electrode sites during an auditory oddball paradigm and found a strong association between P300 amplitude and activity in the delta, theta and alpha bands. Generally, this association took the form of a positive correlation. Schürmann, Başar-Eroglu, Kolev and Başar (2001) used a visual oddball task to demonstrate that some features of the P300 were dependent on delta, hinting at a cognitive role for that frequency band. Schürmann et al. studied single trials and found delta responses that closely resembled the unfiltered P300 response and furthermore, that averages of subsets of trials with differences between the delta responses showed different P300 responses. Delta responses could be used to classify trials without knowing what type of target they were. Schürmann et al. noted that the delta response was only one of the determinants of the P300 response; the role of the theta response preceding the P300 wave has also been addressed (Yordanova & Kolev, 1996). Yordanova and Kolev tested 50 children (6-11 years old) on an oddball task and analysed the data in both time and frequency domains. Theta response latency at Cz and Pz decreased with increasing age and entirely predicted the developmental latency reduction of the parietal P300 component. It can be concluded, therefore, that there is a relationship between EEG and ERPs. However, it does not appear to be very clearly delineated or have moved beyond the P300.

9.2.6 The current study

Spectral analysis of the high/low SAC and old/young group data was conducted in an exploratory manner. Both of these comparison studies were designed with ERPs in mind but their design, methodology and data structure made them equally amenable to qEEG analysis. However, in contrast to the ERPs, there appeared to be somewhat of a dearth of literature on qEEG analysis. Activity in the alpha band of the EEG has

received the most attention, whereas activity in the delta band has received very little. Also, research in this area appears to have been conducted in distinct subject groups with little crossover. For example, no connection has been made between the ADHD literature (Chabot & Serfontein, 1996; Clarke et al., 2001; Clarke et al., 2002; Lubar, 1991; Mann et al., 1992; Monastra et al., 2001; Monastra et al., 1999) and researchers working on the cognitive processes associated with the various oscillations (Basar et al., 1999; Basar-Eroglu, Basar, Demiralp, & Schürmann, 1992; Schürmann et al., 2001). This has resulted in relatively poor definition of EEG activity. Delta, for example, has been associated with drowsiness (Parasuraman et al., 1998) on the one hand and signal detection and decision-making (e.g., Schürmann et al., 2001) on the other.

It was therefore difficult, and perhaps unwise, to make precise predictions about our two data-sets and what applying the qEEG procedure would result in. On an electrophysiological level (functional interpretations aside), the fact that the P300 has been positively correlated with delta, theta and alpha oscillations of the background EEG (Polich, 1997) meant that group differences in any of these bands were likely to be in the same direction as the P300 differences. In other words, those groups that displayed an increased P300 were likely to display increased activity in delta, theta and alpha bands if activity in those bands was apparent.

9.3 Methods

The methods for both data-sets - high/low SAC and old/young - have been described previously in chapters 6 and 8 respectively. The only addition related to the spectral analysis and this will now be described.

9.3.1 Spectral analysis

Artifact-free EEG from all participants was converted into the frequency domain using an FFT function. The data from the high/low SAC study was averaged (1) for each individual across four blocks of the $SART_{random}$ and (2) for each group. Peformance on the $SART_{fixed}$ for the old/young study was continuous and the corresponding EEG data was simply averaged across groups. Activity in the delta, theta, alpha and beta bands of

the EEG was measured at all sites as per the fixed frequency bands in Scan 4.2 (Medtech Systems, Horsham, UK): delta (0-4), theta (4-8), alpha (8-12) and beta (12-30).

9.4 Results

9.4.1 High vs Low Sustained Attention Capacity

Group differences in delta activity were observed at frontal sites. A MANOVA was carried out on each channel with delta, theta, alpha and beta as the dependent variables and group as the independent variable with two levels (high SAC and low SAC). Cases contributing to the analysis were weighted by the number of trials that made up their individual average (to account for the inter-subject variation). Tests of between-subjects effects revealed that the observed delta differences were significant at F3 ($F(1,16) = 5.52$, $p < 0.05$). Mean delta amplitude for the high SAC group was 11.39 μV (S.D. = 8.26) as compared to 13.66 μV (S.D. = 5.32) for the low SAC group. This difference is displayed graphically in Figure 9.1.

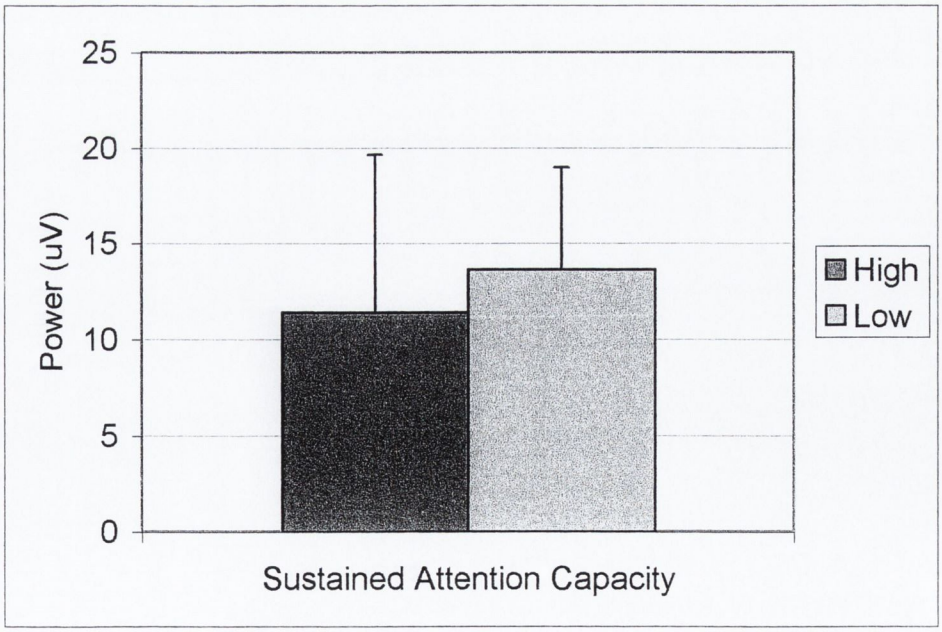

Figure 9.1: Group differences in mean delta amplitude at F3.

9.4.2 Old vs Young Comparison

Spectral analysis of the old/young data revealed widespread differences in delta and theta activity. A MANOVA was carried out on each channel with delta, theta, alpha and beta as the dependent variables and group as the independent variable with two levels (old and young). Cases contributing to the analysis were weighted by the number of trials that made up their individual average (to account for the inter-subject variation). Tests of between-subjects effects revealed that the observed delta and theta differences were significant at several sites: unweighted means, standard deviations, F statistics and significance level for delta and theta at each channel are displayed in Tables 9.1 and 9.2 below. To illustrate group differences in these oscillations, Figure 9.2 shows the mean power and standard deviations for delta and theta at FC4.

Table 9.1: Significant group differences in delta (descriptive and test statistics).

Channel	Group	Mean	S.D.	F	Sig.
F4	Old	0.87	1.03	8.05	0.01
	Young	2.54	2.38		
FC3	Old	1.87	2.56	4.68	0.04
	Young	2.58	1.90		
FC4	Old	1.27	1.83	8.74	0.01
	Young	2.91	2.19		
FT8	Old	0.84	0.82	5.68	0.03
	Young	2.47	2.95		
C4	Old	1.26	1.16	5.52	0.03
	Young	3.11	2.30		
CP3	Old	1.10	0.98	4.61	0.04
	Young	2.67	2.30		
CP4	Old	1.47	1.82	5.29	0.03
	Young	2.79	2.32		

Table 9.2: Significant group differences in theta (descriptive and test statistics).

Channel	Group	Mean	S.D.	F	Sig.
F4	Old	0.21	0.30	5.37	0.03
	Young	1.11	1.49		
FC4	Old	0.31	0.50	6.59	0.02
	Young	1.05	1.11		
FT8	Old	0.15	0.15	5.58	0.03
	Young	0.41	0.44		
CZ	Old	0.40	0.39	4.87	0.04
	Young	1.26	1.28		
C4	Old	0.22	0.22	6.58	0.02
	Young	0.99	0.95		
CP3	Old	0.24	0.21	5.67	0.03
	Young	0.81	0.79		
CP4	Old	0.33	0.43	5.08	0.04
	Young	0.89	0.98		
T8	Old	0.19	0.17	5.87	0.03
	Young	0.45	0.43		
TP8	Old	0.17	0.18	5.37	0.03
	Young	0.46	0.46		
P3	Old	0.29	0.28	4.65	0.04
	Young	0.75	0.89		
P4	Old	0.30	0.27	4.87	0.04
	Young	0.96	1.11		

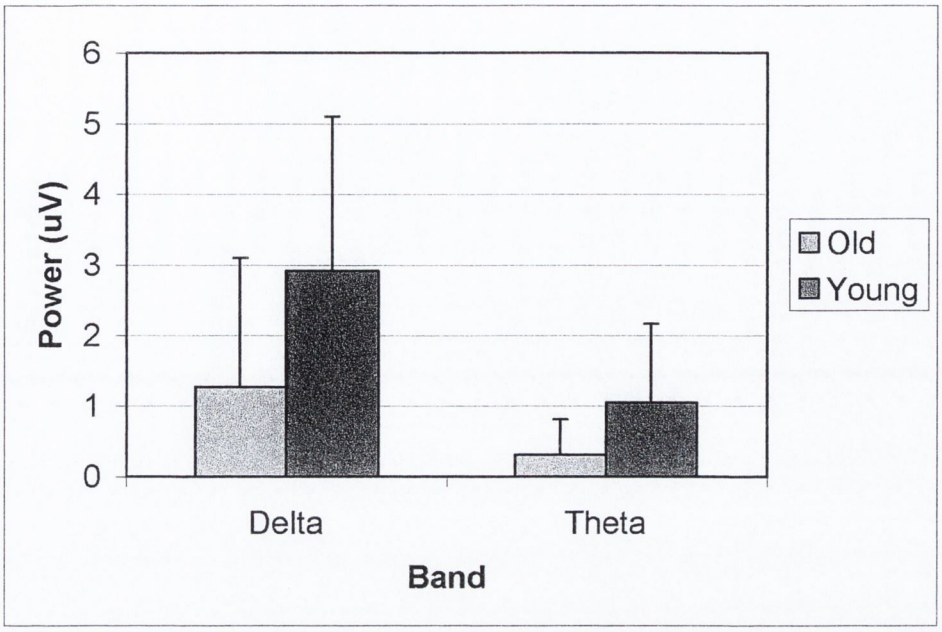

Figure 9.2: Group differences in mean delta and theta power at FC4.

9.5 Discussion

Increased slow-wave activity was observed in both (1) low compared to high sustained attention capacity and (2) young compared to able elderly. Differences in delta were observed at frontal sites in the first comparison. Similarly, in the second comparison, delta differences were apparent at frontal and central sites. Topographically widespread differences in theta were also apparent. These results will now be discussed with respect to the existing literature and the earlier behavioural and ERP results in each case.

9.5.1 Delta differences between high and low SAC groups

The direction of the difference between high and low SAC groups in delta activity was as expected when the relationship between delta and the P300 component of the ERP was considered. The ERP study reported in chapter 6 showed a group difference in P300 amplitude and this difference was greatest at the same site as the significant delta difference in the current study, i.e., F3. A number of researchers have shown that background EEG relates to ERP activity (e.g., Polich, 1997). Polich showed that the amplitude of the P300 and activity in the delta, theta and alpha bands of the EEG were

positively correlated. Furthermore, Schürmann et al. (2001) demonstrated a link between delta specifically and the P300 using a visual oddball task.

9.5.2 Slow-wave activity and attention-deficit

The behavioural results for the high and low SAC study showed a trend for the latter to score higher on the Brown Attention-Deficit Disorder (ADD) Scales (Brown, 1996) than the former. Moreover, five out of nine low sustainers fell into the "ADD probable but not certain range" compared to one out of nine good sustainers. Scoring in this range suggested that there was a significant possibility that these participants would meet diagnostic criteria for ADD. Without comprehensive evaluation by a clinician using a variety of measures, of course, it cannot be said with any certainty that this is the case. However, this finding would suggest that the majority of the low SAC participants had a high level of inattention and suffered ADD-related symptoms on a relatively regular basis in the six months prior to testing.

Both the behavioural and qEEG results for these groups were therefore consistent with the qEEG literature on ADHD in children. The low SAC group did not show decreased fast-wave activity but they did show increased slow-wave activity in the delta band, compared to the high SAC group. The qEEG procedure has shown itself to be a valid and reliable tool in the assessment of ADHD (Monastra et al., 2001; Monastra et al., 1999) and it did seem to pick up an EEG pattern indicative of an attention-deficit in the low SAC group. The topography of the difference between the high and low SAC groups (frontal F3) further supports this idea. EEG differences between ADHD children and controls have been consistently observed at prefrontal and frontal regions (Barkley & Murphy, 1998; Chabot & Serfontein, 1996). More specifically, Mann et al. (1992) found increased slow-wave activity (albeit theta activity not delta) in their ADHD participants at F3 and F4.

The results were also consistent with Bresnahan and colleagues' (Bresnahan et al., 1999; Bresnahan & Barry, 2002) research into ADHD in adulthood. Adults with the disorder show increased slow-wave activity like children with ADHD. However, the results of the comparison between high and low SAC groups were consistent with

Bresnahan and colleague's research on one other point too. In both the 1999 and 2002 studies, they observed that while children, adolescents and adults with ADHD showed the increase in slow-wave activity compared to normal, healthy controls, the reduced beta activity between ADHD groups and controls was only apparent in childhood and adolescence. The beta difference at Fz and Cz was reduced by adulthood. This observation is strikingly similar to the current study's findings; increased slow-wave activity but no difference in fast-wave (i.e., beta) activity between groups. Bresnahan and colleagues interpreted the qEEG differences between children and adults with ADHD as connected to the symptomatology of the disorder. Basically, they believed that the increased slow-wave activity represented persistent impulsive-type behaviours and the normalisation of beta activity, a reduction in the level of hyperactivity. This was considered consistent with the clinical observation of ADHD in adults.

There is a tie-in here with memory and other cognitive failures too. Significant driving problems have been associated with ADHD (Barkley, Guevremont, Anastopoulos, DuPaul, & Shelton, 1993; Barkley & Murphy, 1998). Barkley and colleagues found that, compared to controls, adults with ADHD self-reported significantly more traffic citations, vehicular crashes and license suspensions. Most of these differences were corroborated by the official DMV records. Not only did the low SAC group in the current study score highly on the Brown ADD Scales but they also scored highly on the CFQ. Cognitive failures as measured by the CFQ have previously been associated with driving problems also. Larson and Merritt (1991) found that scores on the CFQ differentiated between participants who had been cited for causing an accident and those who had not.

On a number of levels, then, the low SAC group appeared to show symptoms similar to that of adults with ADHD. However, it must be remembered that the Brown ADD Scales total score failed to distinguish between the low SAC group and the high SAC group so it is unlikely that these students actually had the disorder. It seems more likely that they were simply highly inattentive and susceptible to absent-minded slips. This idea is supported by the fact that the Brown ADD subscale on which the two groups differed most was the one related to everyday forgetfulness.

9.5.3 Effort or distractibility?

Two hypotheses were proposed in chapter 6 to explain the ERP findings. The first argued that the larger amplitude P300 displayed by the low SAC group reflected effort, perhaps too much attention. The second presented the P300 as an index of distractibility or too little attention. Do the results of the qEEG analysis support one of these hypotheses more than the other?

In this study, the group that showed more electrophysiological activity - both in regard to ERPs and background EEG - performed more poorly on the sustained attention task. The greater P300 amplitude and delta power may have been indices, therefore, of poorly maintained attention. This idea is supported by the increased slow-wave activity evidenced by a patient group defined by their lack of attention, ADHD. In the context of ADHD, increased slow-wave activity is interpreted as under-arousal (e.g., Clarke et al., 2002).

If the low SAC group were considered to be under-aroused then the results of the qEEG analysis would seem to support the 'effort hypothesis'. It could be argued that these participants were under-aroused and found the task more taxing as a result. The cognitive effort required to counteract this lack of arousal was reflected in the P300. An increased P300 has also been observed in a clinical population characterised by drowsiness, narcoleptics (Naumann et al., 2001). Then again, the pattern of activity demonstrated by Naumann et al.'s (2001) narcolepsy group supported the 'distractibility hypothesis'. Increased P300 (or more specifically P3a) amplitude has been cited as an index of distractibility (Escera et al., 2000; Gumenyuk et al., 2001; Kilpelainen et al., 1999a; Kilpelainen et al., 1999b), arguably a feature of ADHD also.

The cognitive interpretation of delta activity provided by Başar and his colleagues (Basar et al., 1999; Schürmann et al., 2001) - signal detection and decision-making - is unfortunately not very helpful. Apart from anything else, the increase in delta activity observed by this research group was associated with target stimuli, rather than non-target stimuli (as is the case here). It would seem that the work on the cognitive

correlates of delta is in its infancy and further research in this area is required to reach any definitive answer.

9.5.4 Age-related differences in delta and theta

As with the first study, comparing high and low SAC, the second study revealed differences in slow-wave activity in a direction not unexpected. The amplitude of the P300 has been shown to correlate positively with theta as well as delta (Polich, 1997). Since the young displayed a larger P300 component than the elderly, more delta and theta activity would have been expected.

How can the group differences found in the current study be interpreted? The young group displayed more slow-wave activity than the elderly group at topographically widespread sites. There are a number of possibilities: (1) increased slow-wave activity reflects good performance, (2) increased slow-wave activity reflects poor performance or (3) the group difference found between the young and the elderly was independent of sustained attention, and was simply a marker of old age.

9.5.5 Young as poor performers

Is there evidence to support the idea that increased slow-wave activity (in this case delta and theta) in one group over another reflects poor performance? It is possible that the background EEG of the young participants hints at why a behavioural difference wasn't found in the current study, contrary to previous findings (see chapter 7). We know that in ADHD children, their EEG differs from normal, healthy children in that they demonstrate more slow-wave activity and less fast-wave activity and that this has been interpreted as under-arousal (Chabot & Serfontein, 1996; Clarke et al., 2002; Lubar, 1991; Mann et al., 1992; Monastra et al., 2001). Delta and theta have been described in terms of drowsiness (Parasuraman et al., 1998). In fact, consistent with the high/low SAC comparison study, the participants with poor sustained attention capacity showed greater activity in the delta band than the good sustainers. The age-related sustained attention deficit may have been absent in the current study because the young

participants were disproportionately sampled from the poorer performing end of the sustained attention capacity distribution. Or that they were a particularly under-aroused group, adversely affecting their sustained attention.

9.5.6 Young as good performers

On the other hand, the young participants' performance was not that poor. They made an average of 5.09 (S.D. = 3.65) errors of commission out of a potential 105. While the group difference was not statistically significant, there was a trend for the older participants to make more errors on the SART (mean = 9.67, S.D. = 10.60). The common perception of delta and theta is that activity in these bands reflects drowsiness and a lack of alertness. This very issue is addressed by Smith et al. (1999) in the context of practice effects. They found that theta increased at frontal midline sites with time on task. Initially, in keeping with the traditional interpretation, they thought that this change in theta represented an increase in fatigue or decrease in alertness from the beginning to the end of the session. However, there was other evidence to suggest that this wasn't the case. Firstly, there was no within-session performance decrement. Secondly, theta activity associated with drowsiness has a lower characteristic frequency and thirdly, their theta activity was localised to frontal midline regions. Drowsiness-related theta tends to be most prominent at posterior sites (Gevins & Zeitlin, 1977; Makeig & Jung, 1995; Matousek & Petersen, 1983). Equally, there was no performance difference to suggest that the young participants were in fact drowsy or fatigued. Also, our theta activity, though widespread, is not focussed at posterior sites. It could be argued that it was predominantly fronto-central. However, the findings of the current study were not entirely consistent with the findings of Smith et al. (1999) because delta increases were found in the young participants as well as theta. The observed activity spanned the slow-wave spectrum. However, this does not entirely debunk the task-related slow-wave activity notion. Delta, as well as theta activity, has been associated with cognitive processing (Basar et al., 1999; Schürmann et al., 2001). Smith et al. (1999) concluded that the increases in theta activity that they observed reflect "the conscious control over attention associated with maintenance of task-appropriate mental set" (p. 389). It seems likely that that is what our increase in slow-wave activity is expressing in the young participants, at least in relation to theta. As with the high/low

SAC study, there is not enough research on delta activity in this context to supply a definite answer.

9.5.7 Ageing effects

How do we know that the between-group difference in EEG activity is not simply a general age effect rather than anything task-related? Although there was a trend, no significant difference was found in task performance. The greatest support for the EEG findings being a function of an age-related deficit in sustained attention (and not just age per se) is that EEG activity considered typical of ageing is not what was observed here. In the current study, younger adults displayed greater levels of slow-wave activity than older adults. Usually, as people age they demonstrate more slow wave activity and less fast-wave activity (Klimesch, 1999). Polich (1997), for example, found that delta and theta activity increased with age and alpha activity decreased. It has been suggested that these age-related changes in EEG activity are due to neurological diseases and not just age (Hartikainen et al., 1992; Hubbard et al., 1976). Perhaps the elderly participants in this study were a particularly healthy group and that is why the age-related EEG usually recorded in older people was not observed here. The majority of elderly participants were recruited from active retirement groups and this may have biased our sample in this way.

9.5.8 Conclusion

Başar et al. (1999) observed that "it is impossible to assign a single function to a given type of oscillatory activity" (p. 167). Activity in the theta band, for example, has been associated with episodic memory and the encoding of new information (Klimesch, 1999), selective attention and orienting (Basar et al., 1999), working memory (Gevins et al., 1998; Gevins, Smith, McEvoy, & Yu, 1997; McEvoy et al., 2001) and drowsiness (Parasuraman et al., 1998). This prevents a straightforward explanation of the findings of both the high/low and old/young data-sets. Further confusing the issue is the apparently contradictory findings in regard to slow-wave activity, along two dimensions: (1) good and poor performance and (2) task- and drowsiness-related EEG.

This is likely due to a variety of factors that affect power measurements in addition to information-processing. These range from unspecific factors such as skull thickness to methodological and technical factors (e.g., interelectrode distance) to specific factors such as arousal (Klimesch, 1999).

So saying, the qEEG analyses described in this chapter do add more information to our existing knowledge about sustained attention capacity within a normal, healthy population and in relation to ageing. The increased delta activity displayed by the low SAC group seemed to index poor sustained attention performance, comparable to the increased slow-wave activity associated with ADHD. In this context, the increased slow-wave activity suggested under-arousal. In considering the age-related differences in slow-wave activity, the young participants demonstrated a pattern of activity in keeping with task-related theta and, it is tentatively assumed, task-related delta. Slow-wave activity has been associated with good performance in this way before (Gevins & Smith, 2000; Klimesch, 1999). Albeit preliminary, these must be our conclusions until the issues mentioned above are resolved.

10. General Discussion

10.1 Overview

This final chapter contains a discussion of the issues raised by the studies previously described. Firstly, the introductory chapters and the results for each of the five experiments will be summarised. Secondly, the results will be discussed in relation to the tools and techniques used, theory and the target populations - young and able elderly. Finally, some suggestions for future research will be made before reaching conclusions.

10.2 Summary

10.2.1 Introductory chapters

Chapters 1-3

Attention is a familiar cognitive process. However, it is somewhat difficult to define. In psychological terms, its meaning changes depending on the theory behind it, the task used to measure it and/or perhaps its practical application, such as rehabilitation. However, it is believed that the attention system can be divided into at least three subsystems: selective, sustained and executive attention (Parasuraman, 1998; Posner & Petersen, 1990). These three subsystems are independent of each other and yet interactive. This has been demonstrated anatomically, physiologically and neuropsychologically (see, e.g., Coull, 1998; Fan et al., 2002; Fernandez-Duque & Posner, 2001; Mesulam, 1990; Posner & Fan, in press; Posner & Petersen, 1990). In its current manifestation, Posner and Fan (in press) present this model of attention as an

organ system with its own functional anatomy, circuitry and cellular structure. Viewing attention as an organ system helps answer many questions raised in cognitive psychology, psychiatry and neurology. Recent studies have successfully implemented rehabilitation techniques that centre on specific attentional networks (Robertson et al., 1995; Sohlberg et al., 2000; Sturm et al., 1993; Sturm et al., 1997).

One of these networks – the sustained attention network – is the primary focus of this thesis. The study of sustained attention has many practical applications. Not only is it necessary for most everyday activities but a *lack* of this type of attention can result in minor and major mistakes. Deficits in sustained attention are apparent in several clinical disorders including brain injury (Robertson et al., 1997; Rueckert & Grafman, 1996; Rueckert & Grafman, 1998; Whyte et al., 1995; Whyte et al., 2000; Wilkins et al., 1987) and attention-deficit disorder (DSM-IV, 1994; Swanson et al., 1998). A better understanding of sustained attention can inform the diagnosis and treatment of such disorders.

Lesion (Koski & Petrides, 2001; Rueckert & Grafman, 1996; Wilkins et al., 1987) and imaging studies using PET (Cohen et al., 1988; Coull et al., 1996; Pardo et al., 1991) and fMRI (Lewin et al., 1996) have provided evidence for a fronto-parietal network specialised for sustained attention, predominantly in the right hemisphere. Another source of evidence comes from transmitter studies. At least two cortical neurotransmitters - norepinephrine (NE; Aston-Jones et al., 1994; Coull et al., 1995; Marrocco & Davidson, 1998; Smith & Nutt, 1996; Witte & Marrocco, 1997) and acetylcholine (ACh; McGaughy & Sarter, 1995; Moore et al., 1992; Wesnes & Revell, 1984; Wesnes & Warburton, 1984) - appear to be involved in sustained attention functioning.

This evidence for a fronto-parietal sustained attention network was gathered by combining neuroscientific techniques with vigilance tasks and methodology. These tasks were long and boring, with low target probability. Many tasks were designed with a particular clinical population in mind, e.g., the multiple vigilance test (MVT; Hirshkowitz et al., 1993) for patients with obstructive sleep apnoea. The problem was that performance on such tasks did not correlate with self, clinician and family reports. In the case of the MVT, performance did not correlate with patients' self-reported

sleepiness. This lack of a relationship between the laboratory and real-life was also found in traumatic brain injury (TBI) studies. Attention disorders are among the most commonly reported cognitive sequelae of this injury (Auerbach, 1986; van Zomeren & Brouwer, 1987; van Zomeren et al., 1984; Whyte & Rosenthal, 1993). A sustained attention deficit specifically would be expected because TBI affects brain areas that have been associated with maintenance of the alert state (including Wilkins et al., 1987 and others above). However, studies of sustained attention in TBI patients produced inconsistent results. Whyte et al. (1995) attributed this inconsistency to the confounds inherent in vigilance tasks and designed their own paradigm to counteract them. The stimuli used in Whyte et al.'s task were pairs of lines, presented simultaneously and vertically along the midline. In this way, Whyte et al. aimed to minimise perceptual and memory demands and to account for the possibility of hemi-spatial neglect. Even this task, however, failed to find a difference between patients and controls in accuracy and performance was not related in any way to available measures of injury severity. Robertson, Manly, Andrade, Baddeley and Yiend (1997) designed a sustained attention task that managed to bridge the gap between laboratory measurement and real-life observation of lapses of attention. The task - the Sustained Attention to Response Task (SART) - differed from the typical task used to measure sustained attention in that it required participants to respond with a key press to the target rather than the non-targets. Accuracy on the SART correlated significantly with self- and informant-reported cognitive failures in normal, healthy controls, whereas a more conventional task, the Triplets Test, did not. Performance on the SART was also found to discriminate between controls and TBI patients and was associated with injury severity in the form of coma severity as measured by the Glasgow Coma Scale (GCS).

The SART provided an opportunity to study sustained attention and its relationship to everyday cognitive failures or absent-minded mistakes not only in TBI but in other populations too. The elderly are one such population. With a rapidly ageing population throughout the developed world, it is important to understand ageing and the common cognitive problems associated with it. This thesis was concerned with the inattentiveness component of absent-mindedness, a lack of sustained attention and the range of normal human performance in this capacity including healthy young and old adults. To this end, the final introductory chapter reviewed the ageing cognition literature and addressed the question: is there an age-related sustained attention deficit?

One of the most influential theories of ageing cognition would suggest that there is such a deficit in sustained attention. The frontal lobe hypothesis (FLH) posits that due to differential decline in the frontal lobes of the brain, cognitive functions most associated with this area are more susceptible to the effects of age. The neurobiological and neuropsychological evidence that support the FLH make it better grounded than earlier theories such as processing speed theory, which proposes that a reduction in the speed with which cognitive operations can be executed is a major factor in age-related cognitive decline (Salthouse, 1985b; Salthouse, 1996b). As has been shown by various lesion and imaging studies (see above), sustained attention is associated with right dorsolateral prefrontal cortex. If age-related declines in cognitive processes supported by the prefrontal cortex emerge at an earlier age and in greater magnitude than declines in processes supported by nonfrontal regions, as the FLH suggests (West, 2000), then sustained attention is a prime candidate for a decline with age. However, previous empirical research has not provided an answer to the question of the existence of an age-related sustained attention deficit. Some studies have found a deficit (Parasuraman & Giambra, 1991; Parasuraman et al., 1989) but yet more have not found one (Berardi et al., 2001; Giambra, 1997; Giambra & Quilter, 1988). Davies and Parasuraman (1982) - in reviewing 13 studies of sustained attention in ageing, found a deficit in about half of them. This inconsistency may be the product of task; a deficit is often only demonstrated on more demanding tasks (e.g., Parasuraman et al., 1989). However, making the task more demanding may result in effects due more to the non-sustained attention components of the task such as perceptual and information-processing components rather than sustained attention. Robertson et al.'s (1997) SART aimed to remedy some of these problems. The SART is a simple measure, sensitive to sustained attention deficits in TBI patients and related to a real-life measure, absent-mindedness. Given these attributes, it seemed a useful tool to test sustained attention performance in the able elderly. Before doing so, however, its relationship to cognitive failures and absent-minded slips needed to be explored further and this was the aim of the first experimental chapter.

10.2.2 Experimental chapters

Chapter 4

The first experiment consisted of two parts. The first part was a correlational study, conducted to replicate Robertson et al.'s (1997) finding of a significant relationship between sustained attention as measured by the SART and everyday absent-mindedness as measured by the Cognitive Failures Questionnaire (CFQ, Broadbent et al., 1982). Consistent with Robertson et al.'s study, a significant positive correlation ($r = 0.27$) was found between errors of commission on the $SART_{random}$ and scores on the CFQ.

The second part of the experiment involved factor analysing the CFQ to determine if the questionnaire was unidimensional or multidimensional. The data was submitted to a PCA (principal components analysis) and then a principal axis factoring analysis was run on the number of factors extracted by the PCA. Factors were orthogonally rotated to the normalised varimax criterion. An eight-factor solution emerged accounting for 62 per cent of the variance. Factors were labelled according to their item content as follows: 1 = Forgetfulness, 2 = Use of language, 3 = Names, 4 = Clumsiness, 5 = Social, 6 = Distractibility, 7 = Spatial, and 8 = Item 6. Two of these factors – 2 and 6 – correlated significantly with performance on the $SART_{random}$. In determining that the CFQ was multidimensional, the aim of this part of the experiment was achieved. However, it was concluded that it was no more useful to use the component factors of the CFQ than the CFQ total score in relation to the SART.

Chapter 5

A pilot study was conducted to explore the use of the transcranial magnetic stimulation (TMS) technique with the SART. The intention was to further establish the link between sustained attention performance and right fronto-parietal areas of the brain. It was hypothesised that the application of TMS to the right posterior parietal cortex would disrupt functioning in that area, thereby interrupting sustained attention. This interruption would in turn manifest itself in increased errors of commission on the SART. On the one hand, there was no difference in either errors of commission or omission across the three conditions of (1) no TMS applied, (2) TMS applied to the left

parietal cortex and (3) TMS applied to the right parietal cortex. Reaction times (RT), on the other hand, were significantly faster in the no TMS condition compared to the other two conditions. Interpretation of these results was hindered by a number of confounding factors involving the technique (e.g., the cueing and/or alerting effect of the pulse) and its use with the SART and it was therefore concluded that TMS was not suitable to study sustained attention as measured by the SART and that an alternative technique must be found.

Chapter 6

An alternative technique to study the brain activity underlying sustained attention performance was found in event-related potentials (ERPs). The experiment reported in chapter 6 looked at the electrophysiology of the brain during performance on the $SART_{random}$, specifically on the Go trials. Two groups – distinguished by having high and low sustained attention capacity (SAC) – were compared. These groups were selected on the basis of their performance on the $SART_{random}$ in a previous experiment.

In the current experiment, the two groups were again tested on the $SART_{random}$ and the difference between them was found to be reliable. Furthermore, these two groups differed significantly on the CFQ and the Memory Assessment Clinics Self-Rating Scale (MAC-S; Winterling et al., 1986). The low SAC group reported significantly more memory and other cognitive failures than the high SAC group. There was no group difference in scores on the Brown ADD Scales but there was a trend for the low SAC group to report more symptoms of ADD than the high SAC group, especially on the subscale related to forgetfulness in daily routines and problems in recall of learned material. Several of the low SAC group scored highly enough on the Brown Scales to qualify as ADD probable. ERPs revealed significant P300 amplitude differences at several fronto-central sites. The low SAC group displayed a greater amplitude in this component compared to the high SAC group. The most likely explanation for these electrophysiological results was that the P300 reflected effort with the low SAC group expending more effort on the task than the high SAC group.

Chapter 7

The experiment reported in chapter 7 tested sustained attention capacity in the young and able elderly. The elderly did display a sustained attention deficit; they made more errors of commission on the $SART_{fixed}$ than their younger counterparts. In comparing their memory to the average individual, the elderly rated themselves worse than the young did on the MAC-S Global item 1. Furthermore, the elderly rated their speed of remembering as slightly slower than it had ever been whereas the young rated it as about the same (MAC-S Global item 3). On the MAC-S again, there was a trend for the elderly to report themselves as experiencing more frequent memory failures than the young but this difference between the groups was not significant. However, on the MAC-S Ability to Remember subscale and the CFQ questionnaire there was no difference in scores between groups.

Chapter 8

The information gathered from the experiments already described was used to design an ERP study of sustained attention in the young and able elderly. The task found to be sensitive to attentional lapses in the elderly (the $SART_{fixed}$) was used together with the best method to examine participants' brain activity while doing this task. In this experiment, there was a trend for the elderly to make more errors of commission on the SART than the young but this difference was not significant. The lack of a significant finding was attributed to the small sample size and/or sampling bias. The P200 component of the ERP was greater in amplitude for the young compared to the elderly at fronto-central sites and also displayed a longer latency in the same direction. This was explained as the young devoting more basic processing resources for longer to the stimuli than the elderly. Group differences were also found in the P300 component. At frontal sites this component was absent in the elderly. At parietal sites, there was a reduction in amplitude of the P300 for the elderly compared to the young. This finding was interpreted as the electrophysiological correlate of poor sustained attention performance in the elderly, compared to the young.

Chapter 9

The final experimental chapter consisted of two quantitative EEG (qEEG) analyses of previously gathered data:

(1) High and low sustained attention capacity in the young

Group differences in delta activity were observed at frontal sites. However, this difference was only significant at F3 with the low SAC group displaying more delta activity than the high SAC group. This finding was consistent with the qEEG literature on ADHD in children (Lubar, 1995; Lubar et al., 1996; Mann et al., 1992; Monastra et al., 2001; Monastra et al., 1999) and adults (Bresnahan et al., 1999; Bresnahan & Barry, 2002); increased slow-wave activity at prefrontal and frontal regions. That the brain activity of the low SAC group was comparable to that of children and adults with ADHD was consistent with the low SAC group's scores on the Brown ADD Scales (see chapter 6).

(2) Sustained attention in the young and able elderly

Analysis of this data showed group differences in delta and theta activity. These differences were topographically widespread. The young showed more slow-wave activity than the elderly, a finding in keeping with a task-related interpretation of delta and theta. The most probable explanation of this data was that increased activity represented good performance, as has been shown by Gevins et al. (2000) and Klimesch (1999).

10.3 Discussion

The aim of this project was to provide more information on sustained attention and related memory and other cognitive failures in the young and able elderly. Implicit in this aim was a test of the theory, tasks and techniques that have been used previously in sustained attention research. The findings of previous studies contained a number of contradictions. For example, directly relevant to this thesis, was the apparent contradiction among the theory, tests and neuroanatomy of sustained attention in the young compared to the elderly. The FLH maintains that functions associated with the frontal lobes of the brain are more susceptible to age-related decline than functions

associated with nonfrontal areas. Since the function of sustained attention has been repeatedly localised to the frontal lobes (Cohen et al., 1988; Coull et al., 1996; Koski & Petrides, 2001; Lewin et al., 1996; Pardo et al., 1991; Rueckert & Grafman, 1996; Wilkins et al., 1987), it would therefore be expected that the elderly would display a sustained attention deficit in comparison to the young. However, findings in this regard have been inconclusive (Berardi et al., 2001; Davies & Parasuraman, 1982; Giambra, 1997; Giambra & Quilter, 1988; Parasuraman & Giambra, 1991; Parasuraman et al., 1989). This project attempted to address these inconsistencies by using a relatively new task – the SART – in conjunction with electrophysiological measures, including ERPs, qEEG and skin conductance response (SCR). In addition, performance in the laboratory was related to a real-life measure of memory and other cognitive failures. Consequently, the discussion begins with an analysis of the tools used in the research reported in this thesis.

10.3.1 Tools

The SART

The design of the SART was fundamentally different from other measures of sustained attention in that participants responded to the non-targets and withheld on the targets, rather than vice versa. This meant that the participants were required to actively maintain attention to their responses if they were to avoid a key press to the target. Also, the task lasted only 4.3 minutes. In this way, not only was the SART's design different but the definition of sustained attention that the task was based on was different too. Sustained attention or vigilance tasks typically last for long periods and decrements only become apparent after several tens of minutes (Mackworth, 1968) and the performance decrement over time is considered a more important measure than accuracy. However, imaging studies have shown that the right fronto-parietal sustained attention system was active over periods as short as 40 seconds (Pardo et al., 1991). This meant that local fluctuations or lapses of attention could occur over a few seconds. Robertson and colleagues (1997) argued that these lapses gave a better account of poor performance. Accuracy and not the performance decrement over time was shown to be sensitive to sustained attention deficit in a comparison between TBI patients and

controls. Previous attempts to test sustained attention capacity in TBI had failed. For example, Whyte et al. (1995) found no group difference in accuracy between patients and controls on their vigilance task in which half the stimuli were targets and half non-targets. Participants were given up to three seconds to respond to the targets. In addition to the lack of a TBI-related deficit no relationship was found between performance on the task and measures of injury severity. However, there were many reasons to expect a sustained attention deficit in TBI, including family and clinician reports and the neuroanatomical bases of the injury. The SART succeeded in discriminating between patients and healthy controls, with the patients making more errors of commission than the controls. Performance was also associated with injury severity in the form of coma severity as measured by the Glasgow Coma Scale (GCS). The SART's sensitivity to sustained attention deficit was again demonstrated in this thesis, except this time in an elderly population (chapter 7). The state of research in regard to sustained attention in the elderly was similar to that in TBI; a deficit was expected but not consistently demonstrated in the laboratory. In this case, the $SART_{fixed}$ was used to show an age-related deficit in sustained attention with the elderly making more errors of commission than the young. However, no difference was found in performance on the standard $SART_{random}$ as was used in testing the TBI population. This discrepancy will be addressed at a later point in the discussion.

The SART and the CFQ

Another success of the SART was its association with a non-laboratory, real-life measure – self-reported cognitive failures. The lack of a relationship between self, clinician and family reports and lab measures was a common finding in sustained attention research. For example, Hirshkowitz, De La Cueva and Herman's (1993) multiple vigilance test (MVT) was designed to measure manifest sleepiness in patients with a disorder of excessive daytime sleepiness and yet despite the patients' poor performance on the task, it did not correlate with their self-reported sleepiness. Robertson and colleagues (1997) found that accuracy on the SART (but not the more typical Triplets test of sustained attention) positively correlated with everyday cognitive failures as reported by the participants themselves and the reports of their relatives and friends. Cognitive failures were measured by the CFQ; a questionnaire measure intended to be a measure of cognitive failures as typified by perception, memory and

action failures in everyday life. Experimental research reported in this thesis supported this relationship between the SART and the CFQ (see chapter 4).

However, this relationship was not found in the elderly group (chapter 7). The elderly's performance on the SART may have been worse than the young, but there was no significant difference between these two groups on cognitive failures as measured by the CFQ. In fact, there was a trend for the elderly to report *less* everyday cognitive failures than the young. This was despite the elderly rating their memory as worse than the young did on two Global items of the MAC-S (comparing their memory to the average individual's memory and comparing their speed of remembering to the best it had ever been). Also, there was a trend for the elderly to report more frequent memory failures on the MAC-S Frequency of Occurrence subscale. Perhaps the elderly's scores on the CFQ were comparable to Robertson and colleagues' TBI patients (1997)? Unlike in the normal, healthy group, performance in the TBI group did not correlate with self-reported cognitive failures. However, it did correlate with informant-reported failures (i.e., those of their family and friends). This was interpreted as a lack of awareness on the part of the patients. However, a statistical analysis of the informant- and self-reported failures in the elderly showed that the two measures were in fact strongly correlated. Rather than a lack of awareness, it may just have been that a questionnaire measure such as the CFQ was not suitable for the elderly. Several problems have been identified with using questionnaires as a tool in the study of ageing, including failure to remember memory failures, influence of self-image, individual differences in life-style and response biases (Rabbitt & Abson, 1990).

$SART_{random}$ and $SART_{fixed}$: Different versions, same task?

There was, however, another consideration in interpreting the relationship (or lack thereof) between SART performance and CFQ scores in the elderly: the version of the task used. This thesis employed two versions of the SART (the $SART_{random}$ and the $SART_{fixed}$). The design of these two versions differed only in the sequence or order of the digits. In the $SART_{random}$ the occurrence of the target was unpredictable whereas in the $SART_{fixed}$ it was entirely predictable. However, the findings of the various studies reported herein revealed several differences between the $SART_{random}$ and the $SART_{fixed}$ and these must be addressed. The results in this regard may be summarised as follows.

Firstly, the significant positive relationship between the CFQ and the SART was originally found using the $SART_{random}$ (Robertson et al., 1997). This finding was then replicated in the study reported in chapter 4. However, the participants in that same study also performed the $SART_{fixed}$. No relationship was found between the $SART_{fixed}$ and participants' scores on the CFQ. Secondly, performance on the $SART_{fixed}$ discriminated between elderly and young groups but performance on the $SART_{random}$ did not. Thirdly, the ERP results reported in chapters 6 and 8 suggested that there may be a difference in the brain areas activated by these two tasks. In comparing the high sustained attention capacity (SAC) group with the low SAC group, P300 amplitude differences were found at fronto-central sites. In comparing the elderly with the young, P200 and P300 differences were found at frontal, central and parietal sites. The high/low participants were tested using the $SART_{random}$; the elderly/young, the $SART_{fixed}$. Finally, the electrophysiological correlates of performance on the SART differed between versions. In the random SART, P300 and delta differences were found. In the fixed SART, in addition to these two components, P200 and theta differences were found. Of course, these findings come from two separate studies and are therefore not directly comparable but their differences are noteworthy.

How can these differences be interpreted? The design of the $SART_{random}$ is so similar to that of the $SART_{fixed}$ that they are probably measuring the same thing, just to a different degree. Evidence presented in this thesis and provided by previous studies (e.g., Manly et al., 2001) suggests that the $SART_{random}$ is less taxing on a self-sustained attention system than the $SART_{fixed}$. Perhaps this is because the response inhibition component of the task is more manifest in the $SART_{random}$. That response inhibition *is* a component of the task was confirmed by Moores and Andrade (2000) who found a strong relationship between performance on the $SART_{random}$ and the go-gap-stop test (GGST) of response inhibition. For the normal, healthy participants, response inhibition failures on the GGST correlated strongly with SART errors of commission even after SART response times had been partialled out. That response inhibition is more a component of the $SART_{random}$ than the $SART_{fixed}$ was evidenced by a recent fMRI study comparing performance on the two tasks. When Fassbender and colleagues (2004) looked at correct inhibitions, they found two separate networks for the random and fixed SART. During correct inhibitions on the $SART_{random}$ activation was observed in the right ventral prefrontal cortex, right inferior parietal lobule, left dorsolateral prefrontal cortex

and the left putamen. These activations are consistent with previous findings in regard to response inhibition (Braver, Barch, Gray, Molfese, & Snyder, 2001a; Garavan, Ross, & Stein, 1999; Iverson & Mishkin, 1970; Kawashima et al., 1996; Konishi et al., 1999; Konishi, Nakajima, Uchida, Sekihara, & Miyashita, 1998; Peterson et al., 2002). In contrast, the areas activated for correct inhibitions on the $SART_{fixed}$ were more left-lateralised: left inferior frontal gyrus, right angular gyrus, left insula and left middle frontal gyrus. Fassbender and colleagues argued that this suggested that correct inhibitions on the $SART_{random}$ were more associated with inhibitory processes than the $SART_{fixed}$. This was also reflected in response times to NoGo and Go trials. A common finding on Go-NoGo tasks such as the SART is that errors of commission on NoGo trials are made faster than correct presses on Go trials, suggesting that participants have insufficient time to inhibit the prepotent Go response (Logan & Cowan, 1984). In Fassbender and colleagues' study, this was observed for reaction times on the $SART_{random}$ but not the $SART_{fixed}$. There was no difference in response times for the NoGo and Go trials on the latter, suggesting that errors that are made on the $SART_{fixed}$ are due more to failed attention than failed inhibition. In the $SART_{fixed}$ participants are not paying enough attention to notice that a target has been presented whereas in the $SART_{random}$, they do notice but are too late to withhold a response.

Moores and Andrade (2000) observed that the response inhibition component of the SART was only important when the stimuli were recognised automatically. They designed a squiggle version of the SART (in which digits were replaced with squiggles) that made recognising the stimuli more difficult, requiring learning and therefore more controlled processing. In this way, the $SART_{fixed}$, like the squiggle SART, may require more controlled processing than the $SART_{random}$. This is not because of the stimuli per se, but rather how difficult the task seems. The $SART_{random}$ may be subjectively more difficult but that very perception keeps the attention system active. The participants are aware that a target could be presented at any time and are consequently more alert. This is less taxing on the self-sustained attention system than the $SART_{fixed}$: the presentation of the target is entirely predictable and consequently it seems easier. However, the $SART_{fixed}$ is also more boring and so more demanding on participants' endogenously maintained attention. This is apparent in higher rCBF levels (Manly et al., 2001), more electrophysiological activity and greater sensitivity in groups with a suspected sustained attention deficit (i.e., TBI patients and the elderly).

These differences have implications for the SART's use as a tool in testing sustained attention. McAvinue, O'Keefe, McMackin and Robertson (in press) suggested that the $SART_{fixed}$ is more suited to measuring deficit and the $SART_{random}$, normal, healthy capacity. They administered the two versions of the SART to TBI and control participants and found that the $SART_{fixed}$ was more sensitive than the $SART_{random}$ in discriminating between the groups. This is consistent with the findings in this thesis in comparing the young and the elderly. However, in normal, healthy participants the $SART_{fixed}$ can be vulnerable to ceiling effects so, as McAvinue and colleagues proposed, it may be more useful in studying populations susceptible to deficit.

The CFQ: further considerations

Rabbitt (1995) described the CFQ as "an exceptionally well designed and standardised self-assessment questionnaire" (p. S127). However, he also wrote that the interpretation of self-assessment questionnaires such as the CFQ could be difficult because people's answers can be telling the researcher several different things. This observation begs the question: what do people's answers on the CFQ tell us?

Broadbent et al. (1982) intended the CFQ to give an indication of people's susceptibility to absent-minded mistakes. It was inspired by the work of James Reason (1977, 1979) who studied absent-mindedness in all its forms from a number of different sources including diaries and questionnaire measures. The CFQ represented a departure from earlier absent-mindedness measures (e.g., Herrmann and Neisser's (1978) Short Inventory of Memory Experiences), however, because it went beyond memory failures and assessed perceptual and action failures as well. These three types of failures were grouped together as a common cognitive failures factor.

One of the CFQ's strengths was its numerous practical applications. One of the best examples of how the CFQ addressed real-life errors (as opposed to just ones tested in the laboratory) was Larson and Merritt's (1991) study of susceptibility to absent-minded slips and traffic accidents. Young male respondents' scores on the CFQ differentiated between those who had been cited for causing an accident and those who had not. The CFQ has also been used to study absent-mindedness in shops and

shoplifting (Reason & Lucas, 1984). Reason and Lucas found a significant correlation between the CFQ and the Absent-mindedness in Shops Questionnaire. They used these two questionnaires to determine if shoplifting was the result of absent-mindedness or wilful intent. From the participants' answers they realised that most shoppers knew what they were doing and were well aware of the consequences of lapses, especially risky lapses.

Broadbent et al. (1982) wanted the CFQ to have a definite clinical usefulness. However, it has been suggested that more investigation is needed before it can be used as a standard measure in clinical practice (Wagle et al., 1999). Indeed, studies looking at the CFQ's usefulness in this regard have returned mixed results. Studies of daily stress and anxiety (Mahoney et al., 1998), diseases such as Alzheimer's, frontal lobe dementia, anxiety, and depression (Wagle et al., 1999), and brain-injured patients (Robertson et al., 1997) have cited evidence in support of the CFQ's efficacy in a clinical setting. So saying, some of this evidence was questionable. Wagle, Berrios and Ho's study, in particular, suffered from a number of serious methodological problems. Furthermore, in direct contrast to the other studies, Miotto, Feigenbaum, and Morris (2000) conducted a study in which they administered the CFQ to patients with focal frontal and temporal lesions and they failed to find a difference in scores either among the patient groups or in comparison with healthy controls. As mentioned above, the picture in relation to the CFQ and ageing is not clear either. It seems as though it has yet to be determined whether the questionnaire's clinical applications can be considered strength or weakness.

What of performance correlates of the CFQ? Since Broadbent et al.'s (1982) original study of the CFQ, there has been a search for some test more objective than a self-report scale for assessing cognitive failures. However, as Broadbent et al. themselves acknowledged, "the difficulty is to identify the right objective function to test" (p. 12). An early study by Martin (1986) did suggest that cognitive failures were related to everyday memory more than attention. She found a significant correlation between the CFQ and the Everyday Memory Questionnaire but not between the CFQ and the Everyday Attention Questionnaire. However, Broadbent et al. failed to find a significant relationship between the CFQ and several memory measures including immediate memory for nine-item lists, longer-term memory for categorised material, and the

Williams delayed recall test. More research finds in favour of attention than memory. Exactly what type of attention is related to cognitive failures as measured by the CFQ is less clear. Relationships have been found between the CFQ and measures of divided attention (Harris & Wilkins, 1981; Martin & Jones, 1983), selective attention (Meiran et al., 1994; Tipper & Baylis, 1987; Vom Hofe et al., 1998), and sustained attention (Robertson et al., 1997; see also Chapter 4 in this thesis). It may be the case that people who are susceptible to absent-minded slips may be deficient in some or all of these types of attention and related response inhibition. Vom Hofe et al. concluded that the CFQ was associated with "some fairly general trait related to the ability to attend to focal stimuli while simultaneously ignoring task-irrelevant distractions" (p. 53).

The influence of personality and emotional factors is a further consideration in evaluating the CFQ and determining what people's answers on the questionnaire really mean. Rabbitt (1995) suggested that answers on self-assessment questionnaires such as the CFQ may mainly reflect individual difference in personality, depression, anxiety, and motivation or even maybe in competence brought about by these states and traits. There is good evidence to support this opinion, particularly in an older population. In a group of 442 participants aged from 50 to 80 years, Rabbitt and Abson (1990) found a significant correlation between CFQ scores and scores on the Beck depression inventory (Beck et al., 1961). Similarly, McInnes and Rabbitt (unpublished data cited in Rabbitt, 1995) found a significant relationship between these two measures in a group of 1000 participants aged from 50 to 86 years. It's possible that people with depression and other personality characteristics (e.g., neuroticism as measured by the Eysenck Personality Questionnaire; Broadbent et al., 1982) make more absent-minded slips. However, it's also a possibility that they only complain of making them. Another alternative is that people who suffer from anxiety and depression may be more vulnerable to the effects of stress and consequently cognitive failures (see Mahoney et al., 1998). In fact, Rabbitt argued that this last might be the most valuable application of the CFQ and other self-assessment questionnaires to cognitive gerontology.

In all, it could be argued that the CFQ's strengths outweigh its weaknesses. It has both practical and clinical applications (although more research is required on the latter to determine exactly how useful the questionnaire is in this regard). People's answers on the CFQ give an indication of their susceptibility to absent-minded slips and while these

answers may be influenced by personality and emotional factors, it may be possible to partial them out. Whether the questionnaire is still associated with performance correlates such as attention when this has happened remains to be seen.

10.3.2 Theory

Sustained attention network

Sustained attention is currently viewed as an independent but interactive network of the attention system (Fan et al., 2002; Posner & Fan, in press; Posner & Petersen, 1990). In regard to the neuroanatomical correlates of sustained attention, the results reported in this thesis were consistent with this view. The ERP findings showed up in areas of the brain previously associated with sustained attention, namely frontal and parietal cortex (Cohen et al., 1988; Coull et al., 1996; Koski & Petrides, 2001; Pardo et al., 1991; Rueckert & Grafman, 1996; Wilkins et al., 1987). However, the use of ERPs limits any attempts at further localisation. It is even difficult to say whether or not the ERP findings were lateralised to one hemisphere or the other. As a technique, it has very poor spatial resolution. The TMS experiment, unfortunately, had too many confounding factors to provide an answer either way. The strength of the ERP experiment lies in its temporal resolution and it is from that direction further information about sustained attention was learned.

It has been mentioned that the definition of sustained attention on which the SART was based comes from the observation that sustained attention effects can be observed in as short a time span as 40 seconds (Pardo et al., 1991). This definition was strongly supported by the first ERP experiment, in particular (chapter 6). In that experiment there were two groups who occupied the higher and lower end of a sustained attention performance scale. The groups differed significantly on their ability to maintain attention and avoid errors of commission on the $SART_{random}$. Furthermore, the high and low SAC groups differed significantly on measures of memory and other cognitive failures, including the CFQ and the Memory Assessment Clinics Self-Rating Scale. Most importantly, electrophysiological differences between these two groups were apparent in a time window of no more than 1.15 seconds.

This highlights the value of an electrophysiological analysis of sustained attention, which is, after all, attention maintained over time. The majority of studies that have contributed to the concept of a sustained attention network have been lesion- or imaging-based and yet ERPs can make an important contribution. While a lot of information has been gathered about the network's behavioural, anatomical and psychopharmacological bases, relatively little is known about its electrophysiology. Moreover, research conducted into sustained attention using ERPs in the past was of the "low-target-rate, long-watch-period" (Paus et al., 1997, p. 393) vigilance version of sustained attention.

From the current studies, the late positive component or P300 has emerged as a contender for the electrophysiological correlate of sustained attention. The P300 has often been associated with attention (Hillyard et al., 1973; Picton, 1992; Polich & Kok, 1995) but the studies reported in this thesis demonstrated that the electrophysiology is as complicated as the term sustained attention itself and what it represents. The direction of the results were contrary to expectations. If the amplitude of the P300 varies according to the amount of conscious attention paid to a stimulus (Picton, 1992), then the high SAC group should have shown a greater mean amplitude P300 than the low SAC group. However, the opposite occurred; the low SAC group displayed a larger P300 than their high SAC counterparts. This may have represented too much or too little attention on the part of the former. However, taking into account the conclusions reached earlier in regard to the $SART_{random}$, the most likely explanation is that the larger P300 reflected too much attention or at least increased effort on the part of the low SAC group. Moores and Andrade (2000) suggested that their dyslexic teenagers' poor performance on the $SART_{random}$ was due to a difficulty with automatic responding. If the low SAC group's poor performance was due to an over-emphasis on controlled processing on the Go trials (i.e., non-target trials) then that would be consistent with the P300's association with controlled over automatic processing (Hoffman, 1990).

Attention system

In Posner and colleagues' representation of the attention system (Fan et al., 2002; Fernandez-Duque & Posner, 2001; Posner & Fan, in press; Posner & Petersen, 1990),

sustained attention is not the only network. It may be independent but it interacts with at least two other networks: selective and executive attention. The research in this thesis may provide evidence consistent with what has already been found out about the sustained attention network (and added to it with the ERPs) but unfortunately, it doesn't demonstrate the network's independence. Indeed, in general, this has been somewhat difficult to demonstrate. Neuropsychologically and psychopharmacologically there have been overlaps. For example, the parietal cortex seems to play a role in both sustained and selective attention (Corbetta, 1998; Corbetta et al., 2000; Coull et al., 1998; Coull, Frith, Buchel, & Nobre, 2000; Coull et al., 1996; Manly et al., 2001). Behaviourally, Fan, McCandliss, Sommer, Raz and Posner (2002) successfully separated the three networks with the Attention Network Test (ANT). They found no correlation between any combination of alerting, orienting and conflict resolution (executive) as measured by this test. Even so, there was some interaction between alerting and orienting, suggesting that these networks may not be independent in all studies.

Cognitive ageing

The FLH of cognitive ageing would predict an age-related decline in sustained attention for reasons already outlined (see chapters 3 and 7). The processing speed theory proposed by Salthouse and others (Birren, 1965; Birren, 1974; Cerella, 1985; Cerella, 1990; Myerson et al., 1990) offers an account of this age-related decline but experimentation (Salthouse, 1985a; Stuss et al., 1989b; Welford, 1977; Welford, 1980) has shown that the main tenet of this theory is incorrect. In other words, processing speed is not the primary cause of age-related cognitive decline. Stuss and colleagues (1989b) suggested that the deficit may be due to a more specific impairment in attentional control processes, as conceptualised by the FLH. At any rate, there was no difference between the RT of the elderly and the young group in the study reported in chapter 7, arguing against a simple age-related cognitive decline in speed of processing.

The FLH is supported by a large body of evidence, mostly neurobiological in nature. There is a reduction in gross brain volume with age (Coffey et al., 1992; Haug et al., 1983; Haug & Eggers, 1991; Raz, 1996) due to a decrease in neuron size (Haug & Eggers, 1991), due in turn to a loss of connective processes such as dendritic extensions and numbers of synapses (Gibson, 1983; Huttenlocher, 1979; Uylings & de Brabander,

2002). In addition, there are age-related declines for some neurotransmitters (West, 1996) and increases in the number of pathological structures (Kubanis & Zornetzer, 1981). However, this list of age-related neuropathological changes does not mean that there are concomitant changes in performance. In this instance, though, a change in performance was observed. A refinement of the FLH may be called for (Garavan et al., 1999; Greenwood, 2000a; Greenwood, 2000b; West, 2000) but it nicely predicted the sustained attention deficit. It was also supported by the accompanying electrophysiological changes.

10.3.3 Target population

Sustained attention in the able elderly

One of the primary goals of this thesis was to tackle the question of whether there is a difference between the young and the able elderly in their sustained attention capacity? The finding of a performance difference on the $SART_{fixed}$ would certainly suggest that there is. The $SART_{fixed}$, even more so than the $SART_{random}$, is a simple, straightforward measure of self-maintained attention that places minimal demands on perceptual, motor or other cognitive processes. When a deficit has been demonstrated before, it has generally been on more demanding tasks such as Parasuraman, Nestor and Greenwood's (Parasuraman et al., 1989) perceptually demanding task (West, 1996). Furthermore, this behavioural difference on the SART was associated with a specific pattern of brain activity. The young participants displayed larger P200 and P300 components at fronto-central and parietal sites, respectively. Also, the young showed a definite P300 at frontal sites but this appeared to be absent altogether in the elderly. The P200 is not dependent on the cognitive processing of the stimulus but it could be interpreted as the young participants devoting more basic processing resources for longer to the SART stimuli than the elderly participants. More interesting perhaps is the P300. Its absence at frontal sites in the elderly may be relevant to earlier discussion of SART performance. A frontal P300 is more associated with automatic processing and a parietal P300, controlled processing. Could the elderly participants be over-emphasising the effortful, controlled processing comparable to the low SAC group (chapter 6) and the dyslexic teenagers (Moores & Andrade, 2000)? In addition to the ERP effects, data

from this experiment was submitted to qEEG analysis to look at the background EEG. The young group displayed more slow-wave activity than the elderly group. The explanation most consistent with the behavioural findings is that the delta and theta differences represent poor and good performance for the elderly and young respectively.

Confounds in the study of ageing cognition

No matter what the results, however, ageing studies by their very nature carry with them a number of confounding factors. For example, it may be that many of the age-related declines found in research are due to age-related ill-health rather than cognitive processes. Berardi et al. (2001) attributed the age-related sustained attention deficits that previous studies had found to poorly screened participants. They thoroughly checked all their elderly participants and found no difference between them and the young participants on either overall vigilance or the vigilance decrement. However, in the old/young comparison described in chapter 7 participants were also carefully checked. All participants had normal or corrected-to-normal vision. History of head injury, epilepsy or other neurological condition, drug or alcohol problems, or major psychiatric disorder resulted in exclusion from the study. Screening was limited, however, to self-report. There may have been conditions that the participants were either unaware of or reluctant to disclose. Another aspect of health that was not considered was fitness levels. Fitness has been shown to influence cognitive and motor processes (Hillman, Weiss, Hagberg, & Hatfield, 2002). A meta-analytic study of eighteen intervention studies published between 1966 and 2001 showed that fitness training has robust but selective benefits for cognition, with the largest fitness-induced benefits occurring for executive-control processes (Colcombe & Kramer, 2003). Hawkins, Kramer and Capaldi (1992) investigated the effects of aerobic exercise on two attentional tasks, a time-sharing task and an attentional flexibility task. Young adults time-shared the processing of two tasks more efficiently and alternated attention between two sequenced tasks more rapidly than older adults. Hawkins et al. found, however, that after a 10-week exercise program older exercisers showed substantially more improvement in alternation speed and time-sharing efficiency than older controls, indicating that aerobic exercise can have a beneficial effect on at least two different attentional processes. In regard to sustained attention specifically, physical fitness has

been found to moderate age variation in performance on a vigilance task (Bunce, 2001). In both the 2001 study and an earlier one in 1996 (Bunce, Morris, & Barrowclough, 1996), Bunce and colleagues used Nuechterlein, Parasuraman and Jiang's (1983) vigilance task in which continuous degraded stimuli are presented. Participants are required to respond to a target stimulus, presented with a probability of 0.25. Bunce et al. (1996) found that older less fit participants consistently underperformed other participants, responding significantly slower and less able to detect targets. Bunce (2001) manipulated task demands by degrading stimuli by different amounts and found that age differences in performance were greater in situations of higher task demands. Performance was more variable among older adults as stimulus degradation increased and as time progressed on the task. Fitness appeared to attenuate age differences in performance in conditions placing greater demand on attentional capacity (i.e., in conditions of higher stimulus degradation and with time-on-task).

Sustained attention as an executive function

It is in considering this capacity in the context of ageing cognition, that the discussion must be directed towards executive attention. It may be that the sustained attention deficit found in the elderly participants when they were compared with the young participants is better described as a deficit in executive control. Executive control influences behaviour across a wide range of cognitive domains and furthermore it is thought to be affected by age (Braver & Barch, 2002). It has been proposed that executive control fluctuates in efficiency over time and that the elderly are more susceptible to these fluctuations (West, Murphy, Armilio, Craik, & Stuss, 2002). This is apparent in increased lapses of intention (i.e., when our actions become dissociated from our intentions; Reason, 1979) and increased performance variability with age. West et al. (2002) showed that age-related increases in performance variability were greater in a task that required more executive control. They also listed evidence supporting the role of the prefrontal cortex in maintaining optimal levels of executive control, including TBI studies demonstrating increased performance variability (Stuss, Pogue, Buckle, & Bonder, 1994; Stuss et al., 1989a), goal neglect (Duncan, Emslie, Williams, Johnson, & Freer, 1996) and prospective memory (Shum, Valentine, & Cutmore, 1999). Robertson et al.'s (1997) original paper on the SART was also cited. If these two aspects of executive control are taken together - the manner in which it

fluctuates over time and its links to prefrontal cortex - it is not difficult to see how poor performance on the SART could be interpreted as an executive rather than an attentive deficit. However, the two are not mutually exclusive. It may very well be that sustained attention is simply one of a number of executive processes, as suggested by Stuss, Shallice, Alexander and Picton (1995). They described sustained attention in terms of the Supervisory System model (Norman & Shallice, 1986). This means that in a sustained attention task such as the SART - repetitive and perceptually undemanding with rare targets to watch out for - the well-learned, routine response (schema) to the non-targets or Go trials becomes vulnerable to competition from task-irrelevant schema. These irrelevant schema may be triggered by environmental or internal events. Overcoming this vulnerability requires supervisory or executive control.

10.4 Future directions

10.4.1 Sustained attention training: auditory cues

Perhaps the most obvious direction for future research to go in is that of training. It has been ascertained that there is an age-related deficit in sustained attention, is there anything that can be done about it? One way would be to apply the approach Manly et al. (2004) took with seven right-hemisphere stroke patients with a problem maintaining attention. In a series of three experiments they showed that: (1) periodic auditory cues associated with a goal improved accuracy, (2) this improvement was due to a 'transient hiatus' allowing automatic responding to be superseded by more controlled, attentive responding and (3) the disruption of automatic responding was greater in a task that encouraged 'unsupervised' action. Although there was some doubt about the mechanisms - alerting, arousing or executive function - underlying the cued improvements, the improvements did exist. The potential role of such cueing could be explored in the context of an elderly population.

10.4.2 Sustained attention training: providing feedback

Providing feedback when participants make errors is another alternative. Research has shown that participants slow down on the trial following an error (Rabbitt, 1981) including during performance on the SART (Manly et al., 2000). This indicates that the participants are aware of the success or failure of their performance. In a population associated with reduced levels of awareness – closed head injury (CHI) patients – feedback, in the form of a tone following an error, was found to significantly improve performance on the SART (McAvinue et al., in press). Feedback acts as a mechanism of response monitoring, activating the cingulate area of the brain which is part of the executive attention system (Badgaiyan & Posner, 1998). If it is assumed (as McAvinue and colleagues do) that sustained attention is a part of that same executive attention system then feedback on the SART may aid performance in another population with a sustained attention deficit, e.g., the elderly. However, this assumes that the elderly are unaware of their errors on a level comparable to the CHI patients. More study is required to ascertain if this is in fact the case, but observations made in the course of this project would suggest that they are no less aware than their younger counterparts. In regard to everyday absent-minded slips as measured by the CFQ, the self-report scores of the elderly correlated highly with the reports of their family and friends. Rabbitt and Abson (1990) suggested that older people forget that they forget but if this was the case, then surely there would be no such correlation. In support of this idea, there was no correlation between TBI patients' self- and informant-report scores on the CFQ. If anything, the elderly may be unduly over-aware of their failings, both in the everyday sense and in the laboratory. Memory successes are seen as less typical in older adults and their failures are attributed to lack of ability, and are considered more worrisome and less controllable than in their younger counterparts (Bieman-Copland & Ryan, 1998). In filling in the MAC-S, the elderly rated themselves worse than the young in comparing their memory to the average individual and rated their speed of remembering as slightly slower than it had ever been. Then again, it may be that the performance improvements that McAvinue and colleagues observed in the CHI patients were mediated by alerting rather than awareness. Manly et al. (2002) demonstrated the effectiveness of task-irrelevant tones presented intermittently during task performance and the improvement in performance was attributed to the alerting effect of the tones,

reminding participants of their goal. In this case, feedback on errors may prove effective in the elderly too.

10.4.3 The role of arousal

It may be that more research needs to go into how improvements in sustained attention come about. After all, in addition to awareness and alerting, improvement could also be mediated by arousal. In both of the studies reported in chapters 7 and 8 the elderly participants showed impaired associative learning compared to the young participants. Fisk and Warr (1996) demonstrated that age-related differences in performance on an associative learning task were attenuated following control for changes in arousal. If arousal can have such an effect on learning, could it affect sustained attention performance as measured by the SART? Could the elderly's deficit in this capacity be mediated by arousal? While no measure of arousal was taken in the first experiment (chapter 7) comparing the elderly and the young, SCR was recorded in conjunction with ERPs in the next one (chapter 8). Following an error of commission, there was a trend for the elderly to exhibit less arousal than the young. However, research has shown that developmental changes occur in the electrodermal system (Porges & Fox, 1986) and that there is a decrease in the density of sweat glands, a reduction in the number of eccrine sweat glands and in the amount of sweat produced as a person ages (Catania et al., 1980; Montagna, 1965; Porges & Fox, 1986) so these results must be interpreted with caution.

10.4.4 Improving performance in the young and elderly

The obvious target group for these training methods is the elderly. However, the study reported in chapter 6 showed that at least some younger adults are susceptible to lapses of attention both in the laboratory and in everyday situations as measured by the CFQ. This has important practical applications for students who spend a large proportion of their time either in lectures or studying – both occupations that require maintaining attention to task. It would be interesting to see if, in a carefully controlled situation, students trained in sustained attention performance actually learned more and

performed comparably better in a test. The young participants could also learn something from their elderly counterparts. One of the suggested reasons for a lower reported incidence of cognitive failures in the elderly compared to the young is their use of memory aids such as diaries and lists (Maylor, 1993). This may cause problems in regard to accurately assessing memory but that does not diminish their usefulness. Encouraging the use of memory aids in younger adults could both improve their performance in the present and form a habit that would help in their future. Individual differences - for example, the use of memory aids - could well be important in determining a person's performance in later life. Recent research has shown that whereas some elderly display significant cognitive deficits, others do not. In fact, they do as well as their younger counterparts (Christensen et al., 1999). In regard to memory, this behavioural difference within an elderly population is reflected in differential prefrontal cortex activity. Activity in this brain area tends to be less asymmetric in the elderly compared to the young (Hemispheric Asymmetry Reduction in Old Adults or HAROLD; Cabeza, 2002). However, Cabeza, Anderson, Locantore, McIntosh (2002) showed that bilateral activity in prefrontal cortex during a source memory task was compensatory. In other words, activity was adapted to counteract age-related cognitive decline. This was not the case for all their elderly participants though. Low-performing old adults recruited similar right prefrontal cortex regions as the young adults but used it inefficiently. Cabeza and colleagues concluded their study by suggesting ways in which age-related asymmetry reductions could be used to attenuate age-related cognitive decline. It may be, however, that intervention is not the answer. Determining what causes this effect in some elderly and not others might offer a way to prevent the deficit. Memory training has been only modestly successful (Tabor Connor, 2001). When older adults were trained by drill and by teaching mnemonic techniques their performance was improved but only temporarily. Soon after the training ended, participants went back to remembering things the way they always did. For the older adults, these techniques were less effective but also less effortful (Hill, Yesavage, Sheikh, & Friedman, 1989; Schmidt, Dijkstra, Berg, & Deelman, 1999). It seems likely that any training technique - whether it is for memory or sustained attention - will be more effortful than whatever the participant is used to. Perhaps the answer is in associating deficit with determining factors: why does one person decline and not another? What caused one group of elderly participants in Cabeza and colleagues' study to recruit different brain regions to the other group? Perhaps something as simple as

fitness - a factor known to influence cognition (Colcombe & Kramer, 2003) and sustained attention specifically (Bunce, 2001; Bunce et al., 1996) - could be effective.

10.5 Concluding remarks

This project examined sustained attention in the context of absent-minded memory and other cognitive failures. The most significant finding reported in this thesis was the discovery of a sustained attention deficit in the elderly. Not only was a behavioural difference found between the young and the elderly but also an electrophysiological difference. These findings were consistent with current theories of attention and sustained attention specifically and the FLH of age-related cognitive decline. That such findings were possible can be attributed to the tools used to test sustained attention and its associated brain activity, the SART and ERPs. The SART would appear to be an appropriate measure for sustained attention as it is now viewed, i.e., the self-sustained maintenance of attention over short periods of time associated with activity in fronto-parietal areas of the brain. The use of ERPs as a technique meant that the brain activity associated with sustained attention could be characterised temporally as well as spatially. The P300 component would appear to be a good candidate for an electrophysiological correlate of sustained attention capacity.

However, the exact nature of the relationship between sustained attention and the P300 needs to be explored further. The direction of the P300 amplitude differences both within the young population and between the young and the elderly were not entirely as expected. It may be that these differences can be explained to a certain extent by the P300 component's association with effortful, controlled processing but this explanation could be refined by further research. Equally, further research could be done to elaborate on the relationship between sustained attention and cognitive failures. A relationship between the $SART_{random}$ and the self-report CFQ has been reliably shown. However, no such relationship has yet been demonstrated between the $SART_{fixed}$ and the same questionnaire. Furthermore, the CFQ failed where the $SART_{fixed}$ succeeded in differentiating between the elderly and their younger counterparts. This may be due to the differences between the $SART_{random}$ and the $SART_{fixed}$ or any one of several possibilities related to the use of questionnaire measures in testing the elderly.

Another direction for future research is in improving sustained attention performance both in the young and able elderly. The use of auditory cues and/or providing feedback during performance are possibilities. These methods have been shown to improve sustained attention performance in clinical populations such as stroke and TBI patients. However, it is not precisely clear what mechanisms are underlying patients' improved performance. An alternative route to training might be in associating deficit with determining factors. Not every elderly person experiences age-related cognitive decline, at least not in memory. There may be factors that determine why one person declines and not another and preventative measures could be implemented before the damage is done. Fitness, for example, has been shown to influence sustained attention specifically.

It is important that the problems faced by the elderly, such as sustained attention and associated absent-mindedness, are identified. These problems have an impact not just on the elderly and their everyday lives but also on the people who take care of them. With an ageing population in the developed world, it becomes increasingly pressing not only to identify these problems but to treat and hopefully improve them to some degree. This thesis has taken a step towards identifying a sustained attention deficit in the elderly, behaviourally and electrophysiologically, and suggests tools and techniques that could be used with some success in future research.

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Self-Report CFQ

Name.....

Date of Birth.....

Sex (please circle) **m / f**

ID.....

The following questions are about minor mistakes which everyone makes from time to time, but some of which happen more often than others. We want to know how often these things have happened to you in the last six months. Please circle the appropriate number.

	Very often	**Quite often**	**Occasio -nally**	**Very rarely**	**Never**
Do you read something and find you haven't been thinking about it and must read it again?	4	3	2	1	0
Do you find you forget why you went from one part of the house to the other?	4	3	2	1	0
Do you fail to notice signposts on the road?	4	3	2	1	0
Do you find you confuse right and left when giving directions?	4	3	2	1	0
Do you bump into people?	4	3	2	1	0
Do you find you forget whether you've turned off a light or a fire or locked the door?	4	3	2	1	0
Do you fail to listen to people's names when you are meeting them?	4	3	2	1	0

	Very often	Quite often	Occasio -nally	Very rarely	Never
Do you fail to hear people speaking to you when you are doing something else?	4	3	2	1	0
Do you lose your temper and regret it?	4	3	2	1	0
Do you leave important letters unanswered for days?	4	3	2	1	0
Do you find you forget which way to turn on a road you know well but rarely use?	4	3	2	1	0
Do you fail to see what you want in a supermarket (although it's there)?	4	3	2	1	0
Do you find yourself suddenly wondering whether you've used a word correctly?	4	3	2	1	0
Do you have trouble making up your mind?	4	3	2	1	0
Do you find you forget appointments?	4	3	2	1	0
Do you forget where you put something like a newspaper or a book?	4	3	2	1	0
Do you find you accidentally throw away the thing you want and keep what you meant to throw away as in the example of throwing away the matchbox and putting the used match in your pocket?	4	3	2	1	0
Do you daydream when you ought to be listening to something?	4	3	2	1	0

	Very often	Quite often	Occasio -nally	Very rarely	Never
Do you start doing one thing at home and get distracted into doing something else (unintentionally)?	4	3	2	1	0
Do you find you can't quite remember something although it's 'on the tip of your tongue'?	4	3	2	1	0
Do you find you forget what you came to the shops to buy?	4	3	2	1	0
Do you drop things?	4	3	2	1	0
Do you find you can't think of anything to say?	4	3	2	1	0

Tabulated summary of the CFQ factor analyses.

Study	n	CFQ mean, S.D.	Factor solution	% variance	Factor	Items
Matthews 1990	475	-	**Seven**	37	1 physical clumsiness	3, 4, 5, 6, 22, 24
					2 people's names	7, 20
					3 planned social interaction	11, 15, 16
					4 item 12	12
					5 use of language	8, 10, 14, 22, 25
					6 lack of concentration	1, 13, 15, 19, 21, 22
					7 absent-mindedness	2, 3, 6, 17, 18, 22, 23, 24
Pollina 1992	387	19.1, -	**Five**	49	1 distractibility	1, 2, 14, 15, 19, 21, 22, 25
					2 misdirected actions	9, 12, 13, 14, 16, 17, 18, 23
					3 spatial/kinaesthetic memory	3, 4, 5, 6, 18, 24
					4 memory for names	7, 20
					5 interpersonal intelligence	8, 10, 11
Larson 1997	2379	33.6, 12.8	**Three**	44	1 general	2, 4, 5, 6, 12, 13, 14, 16, 17, 23, 24, 25
					2 general	8, 9, 10, 11, 19, 21
					3 names	7, 20

Study	n	CFQ mean, S.D.	Factor solution	% variance	Factor	Items
Wallace 2002	335	43.46, 17.02	**Four**	54	1 memory	3, 6, 12, 13, 16, 17, 18, 23
					2 distractibility	1, 2, 3, 4, 15, 19, 21, 22, 25
					3 blunders	5, 8, 9, 10, 11, 14, 24
					4 names	7, 20
Current study	225	43.95, 12.77	**Eight**	62	1 forgetfulness	2, 17, 18, 23
					2 use of language	14, 15, 22, 23, 25
					3 names	7, 20
					4 clumsiness	5, 24
					5 social	11, 16, 17
					6 distractibility	1, 19
					7 spatial	3, 4
					8 item 6	6

The Memory Assessment Clinics Self-Rating Scale

Please read the following questions and answer them as truthfully as possible by circling the response that best describes how you feel.

1	In general, as compared to the average individual, how would you describe you memory?	Very poor	Poor	Average	Good	Very good
2	How would you describe you memory, on the whole, compared to the best it has ever been?	Much worse	A little worse	About the same	A little better	Much better
3	Compared to the best your memory has ever been, how would you describe the speed with which you now remember things?	Much slower	A little slower	About the same	A little faster	Much faster
4	How much concern or distress do you feel about your memory at this time?	Very serious concern	Serious concern	Concerned	Not very concerned	No concern

How well would you describe your ability to remember the following:

5	Gifts you have received at holidays during the past year?	Very poor	Poor	Average	Good	Very good
6	Details of holidays or special occasions of your childhood?	Very poor	Poor	Average	Good	Very good
7	Details of family events that occurred during the past year?	Very poor	Poor	Average	Good	Very good
8	Who was with you at events attended weeks or months ago?	Very poor	Poor	Average	Good	Very good
9	The name of the person just introduced to you?	Very poor	Poor	Average	Good	Very good

10	Telephone numbers that you use on a daily basis?	Very poor	Poor	Average	Good	Very good
11	Addresses of close family members, friends or associates?	Very poor	Poor	Average	Good	Very good
12	Telephone numbers that you use on a monthly basis or less often?	Very poor	Poor	Average	Good	Very good
13	To turn out lights, turn off appliances, and lock doors when leaving home?	Very poor	Poor	Average	Good	Very good
14	To write letters you intend to write or make telephone calls you intend to make?	Very poor	Poor	Average	Good	Very good
15	To take along, when leaving the home or office, any items that you intended to take (for instance an umbrella or a letter to post)?	Very poor	Poor	Average	Good	Very good
16	Where you have put objects (such as keys) in the home or office?	Very poor	Poor	Average	Good	Very good
17	Specific facts from a newspaper or magazine article you have just finished reading?	Very poor	Poor	Average	Good	Very good
18	Meanings of words that you use only rarely?	Very poor	Poor	Average	Good	Very good
19	Meanings of words that you once knew very well?	Very poor	Poor	Average	Good	Very good
20	Verbal directions to a geographic location given minutes earlier?	Very poor	Poor	Average	Good	Very good
21	Which door you entered when shopping in a large department store or shopping centre?	Very poor	Poor	Average	Good	Very good
22	How to reach a geographic location you have visited once or twice?	Very poor	Poor	Average	Good	Very good

23	The date and day of the week?	Very poor	Poor	Average	Good	Very good
24	Facts that must be recalled very quickly as in a game or a television show?	Very poor	Poor	Average	Good	Very good
25	What you read in the newspaper one day ago?	Very poor	Poor	Average	Good	Very good

How often do you:

26	Have difficulty recalling a word you wish to use?	Very often	Often	Occasionally	Rarely	Very rarely
27	Feel that a word or name you want to remember is 'on the tip of your tongue' but cannot be recalled?	Very often	Often	Occasionally	Rarely	Very rarely
28	Forget the name of a familiar object?	Very often	Often	Occasionally	Rarely	Very rarely
29	Fail to remember a name or word when trying, but recall it later?	Very often	Often	Occasionally	Rarely	Very rarely
30	Take a surprisingly long time to recall a fact that you know quite well (and do eventually remember)?	Very often	Often	Occasionally	Rarely	Very rarely
31	Miss the point someone else is making during a conversation?	Very often	Often	Occasionally	Rarely	Very rarely
32	Have difficulty following a conversation when there are distractions in the environment such as noise from a TV or radio?	Very often	Often	Occasionally	Rarely	Very rarely
33	Have to re-read earlier paragraphs from a newspaper or magazine story to understand the point?	Very often	Often	Occasionally	Rarely	Very rarely
34	Have trouble finding your place again when interrupted in reading?	Very often	Often	Occasionally	Rarely	Very rarely

35	Confuse one word with another when they sound the same?	Very often	Often	Occasionally	Rarely	Very rarely
36	Go into a room to get something and forget what you are after?	Very often	Often	Occasionally	Rarely	Very rarely
37	Forget to bring up an important point you had intended to mention during a conversation?	Very often	Often	Occasionally	Rarely	Very rarely
38	Arrive at a shop and forget what you intended to buy?	Very often	Often	Occasionally	Rarely	Very rarely
39	Store an important item in a place where it will be safe and then forget where it is?	Very often	Often	Occasionally	Rarely	Very rarely
40	Have to stop and think when distinguishing right from left?	Very often	Often	Occasionally	Rarely	Very rarely
41	Dial a number and forget whom you were calling before the phone is answered?	Very often	Often	Occasionally	Rarely	Very rarely
42	Forget an appointment or other event that is very important to you?	Very often	Often	Occasionally	Rarely	Very rarely
43	Forget which waiter took your order in a restaurant?	Very often	Often	Occasionally	Rarely	Very rarely
44	Fail to recognise people who recognise you?	Very often	Often	Occasionally	Rarely	Very rarely
45	Meet people who seem familiar but can't remember where you met them?	Very often	Often	Occasionally	Rarely	Very rarely
46	Forget that you have told someone something and tell that person the same thing again?	Very often	Often	Occasionally	Rarely	Very rarely
47	Forget an entire event, such as attending a party or having a visitor?	Very often	Often	Occasionally	Rarely	Very rarely

48	Call someone you recently met by the wrong name?	Very often	Often	Occasionally	Rarely	Very rarely
49	Pass the point where you intended to exit while driving a car or taking public transportation?	Very often	Often	Occasionally	Rarely	Very rarely

Ready Score® Answer Document

Adult

Adult's Name: _____ ID: _____ Age: ____ Highest Grade Completed: ____

Occupation: _____ Examiner: _____ Date: ___/___/_

Instructions to Examiner: Item by item, read to the client each symptom listed, and circle the color number beneath the words that tell how much the client believes that feeling or behavior has been a problem in the past 6 months. (Optional: Obtain a collateral's rating of the client only after obtaining the client's self-rating. Record by circling the black number.)
See *Note* on page 2.

		Never	Once a Week or Less	Twice a Week	Almost Daily
1.	Listens and tries to pay attention (e.g., in a meeting, lecture, or conversation) but mind often drifts; misses out on desired information.	0 0	1 1	2 2	3 3
2.	Experiences excessive difficulty getting started on tasks (e.g., doing paperwork or contacting people).	0 0	1 1	2 2	3 3
3.	Feels excessively stressed or overwhelmed by tasks that should be manageable (e.g., "no way I can do all this now; this is way too much" though it really isn't all that bad).	0 0	1 1	2 2	3 3
4.	"Spaces out" involuntarily and frequently when doing required reading; keeps thinking of things that have nothing to do with what is being read.	0 0	1 1	2 2	3 3
5.	Is easily sidetracked; starts a task then switches to doing something less important.	0 0	1 1	2 2	3 3
6.	Loses track in required reading of what has just been read and needs to read it again; understands the words, but what was read "just doesn't stick."	0 0	1 1	2 2	3 3
7.	Is excessively forgetful about what has been said, done, or heard in the past 24 hours.	0 0	1 1	2 2	3 3
8.	Remembers some of the details in required reading but has difficulty grasping the main idea.	0 0	1 1	2 2	3 3
9.	Is easily frustrated and excessively impatient.	0 0	1 1	2 2	3 3
10.	Bogs down when presented with many things to do; has difficulty setting priorities, getting organized, and then getting started.	0 0	1 1	2 2	3 3
11.	Procrastinates excessively; keeps putting things off: "I'll do it later," or "I'll do it tomorrow."	0 0	1 1	2 2	3 3
12.	Feels sleepy or tired during the day, even after a decent sleep the night before.	0 0	1 1	2 2	3 3
13.	Is disorganized; has excessive difficulty keeping track of plans, money, or time.	0 0	1 1	2 2	3 3
14.	Cannot complete tasks in the allotted time; needs extra time to finish satisfactorily.	0 0	1 1	2 2	3 3
15.	Intends to do things but forgets (e.g., turn off appliances, get things from store, return phone calls, keep appointments, pay bills, do assignments).	0 0	1 1	2 2	3 3
16.	Is criticized by self or others for being lazy.	0 0	1 1	2 2	3 3
17.	Produces inconsistent quality of work; performance quite variable—slacks off unless "pressure" is on.	0 0	1 1	2 2	3 3
18.	Is sensitive to criticism from others; feels it deeply or for a long time; gets overly defensive.	0 0	1 1	2 2	3 3
19.	Tends to be slow to react or to get started; sluggish or slow-moving; doesn't jump right into things; slow to answer questions or to get ready to do something.	0 0	1 1	2 2	3 3
20.	Becomes irritated easily; "short-fused" with sudden outbursts of anger.	0 0	1 1	2 2	3 3

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BROWN ADD SCALES™

Ready Score® Answer Document

Adult

	Never	Once a Week or Less	Twice a Week	Almost Daily
21. Is excessively rigid or is a perfectionist (has to get things just so, "picky, picky, picky").	0 0	1 1	2 2	3 3
22. Receives criticism for not working up to potential (e.g., "could do so much better if only . . . would try harder or work more consistently").	0 0	1 1	2 2	3 3
23. Gets lost in daydreaming or is preoccupied with own thoughts.	0 0	1 1	2 2	3 3
24. Has difficulty expressing anger appropriately to others; doesn't stand up for self.	0 0	1 1	2 2	3 3
25. "Runs out of steam" and doesn't follow through; effort fades quickly.	0 0	1 1	2 2	3 3
26. Is easily distracted from tasks by background noises or activities; needs to check out whatever else is going on.	0 0	1 1	2 2	3 3
27. Has a hard time waking up in the morning; finds it very difficult to get out of bed and to get going.	0 0	1 1	2 2	3 3
28. In writing, must repeatedly erase, scratch out, or start over because of minor mistakes.	0 0	1 1	2 2	3 3
29. Frequently feels discouraged, depressed, sad, or down.	0 0	1 1	2 2	3 3
30. Tends to be a loner among peers, keeps to self, and is shy; doesn't associate much with friends of same age.	0 0	1 1	2 2	3 3
31. Appears apathetic or unmotivated (others think he/she doesn't care at all about his/her work).	0 0	1 1	2 2	3 3
32. Stares off into space; seems "out of it."	0 0	1 1	2 2	3 3
33. Often leaves out words or letters in writing.	0 0	1 1	2 2	3 3
34. Has sloppy, hard-to-read penmanship.	0 0	1 1	2 2	3 3
35. Forgets to bring—or loses track of—needed items such as keys, pencils, bills, and paperwork ("I know it's here someplace; I just can't find it right now . . . ").	0 0	1 1	2 2	3 3
36. Doesn't seem to be listening and gets complaints from others about it.	0 0	1 1	2 2	3 3
37. Needs to be reminded by others to get started or to keep working on tasks that need to be done.	0 0	1 1	2 2	3 3
38. Has difficulty memorizing (e.g., names, dates, information at work).	0 0	1 1	2 2	3 3
39. Misunderstands directions for assignments, completion of forms, etc.	0 0	1 1	2 2	3 3
40. Starts tasks (e.g., paperwork, chores) but doesn't complete them.	0 0	1 1	2 2	3 3

Note. Collateral responses are collected only for the clinical value of the information and are not used for diagnostic purposes.

Total the black numbers for Items 1–40 to obtain the collateral score: _____

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Informant-Report CFQ

The questions given below are about mistakes and difficulties which everybody has from time to time. We would like you to think of a recent two-month period when _____ has shown any of these difficulties. After each question please tick only one of five possible answers. Please make sure you read them carefully.

During the last two months has _____ seemed to be:

1. Absentminded, that is making mistakes in what he/she is doing because he/she is thinking of something else?

Very Often	Quite Often	Occasio-nally	Very rarely	Never
4	3	2	1	0

2. Finding it difficult to concentrate on anything because his/her attention tends to wander from one thing to another?

Very Often	Quite Often	Occasio-nally	Very rarely	Never
4	3	2	1	0

3. Forgetful, such as forgetting where he/she has put things, or about appointments, or about what he/she has done?

Very Often	Quite Often	Occasio-nally	Very rarely	Never
4	3	2	1	0

4. Busy thinking about his/her own affairs and so not noticing what is going on around him/her?

Very Often	Quite Often	Occasio-nally	Very rarely	Never
4	3	2	1	0

5. Clumsy, for example, dropping things or bumping into people?

Very Often	Quite Often	Occasio-nally	Very rarely	Never
4	3	2	1	0

6. Having difficulty in making up his/her mind?

Very Often	Quite Often	Occasio-nally	Very rarely	Never
4	3	2	1	0

7. Disorganised, that is, getting into a muddle when doing something because of lack of planning or concentration?

Very Often	Quite Often	Occasio-nally	Very rarely	Never
4	3	2	1	0

8. Getting unduly cross about minor matters?

Very Often	Quite Often	Occasio-nally	Very rarely	Never
4	3	2	1	0

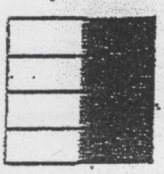
HAD Scale

Name: Date:

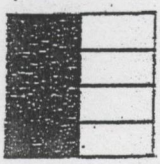
Read each item and place a firm tick in the box opposite the reply which comes closest to how you have been feeling in the past week.
Don't take too long over your replies; your immediate reaction to each item will probably be more accurate than a long thought-out response.

Tick only one box in each section

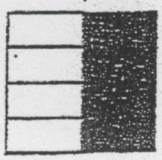
I feel tense or 'wound up':
- Most of the time
- A lot of the time
- Time to time, Occasionally
- Not at all



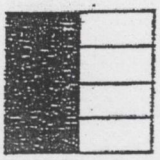
I still enjoy the things I used to enjoy:
- Definitely as much
- Not quite so much
- Only a little
- Hardly at all



I get a sort of frightened feeling as if something awful is about to happen:
- Very definitely and quite badly
- Yes, but not too badly
- A little, but it doesn't worry me
- Not at all

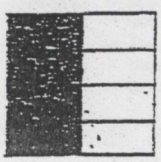


I can laugh and see the funny side of things:
- As much as I always could
- Not quite so much now
- Definitely not so much now
- Not at all

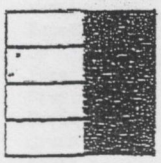


Worrying thoughts go through my mind:
- A great deal of the time
- A lot of the time
- From time to time but not too often
- Only occasionally

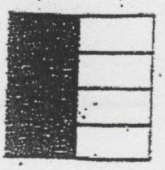
I feel cheerful:
- Not at all
- Not often
- Sometimes
- Most of the time



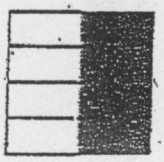
I can sit at ease and feel relaxed:
- Definitely
- Usually
- Not often
- Not at all



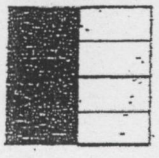
I feel as if I am slowed down:
- Nearly all the time
- Very often
- Sometimes
- Not at all



I get a sort of frightened feeling like 'butterflies' in the stomach:
- Not at all
- Occasionally
- Quite often
- Very often

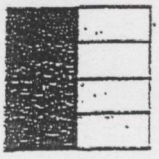


I have lost interest in my appearance:
- Definitely
- I don't take so much care as I should
- I may not take quite as much care
- I take just as much care as ever



I feel restless as if I have to be on the move:
- Very much indeed
- Quite a lot
- Not very much
- Not at all

I look forward with enjoyment to things:
- As much as ever I did
- Rather less than I used to
- Definitely less than I used to
- Hardly at all



I get sudden feelings of panic:
- Very often indeed
- Quite often
- Not very often
- Not at all

I can enjoy a good book or radio or TV programme:
- Often
- Sometimes
- Not often
- Very seldom

Do not write below this line

1. C-2

art VII under on broken line before giving paper to subject for drawing in Part VI.

VI. VISUAL REPRODUCTION A____ B____ C-1____ C-2____ Total____

VII. ASSOCIATE LEARNING

First Presentation

Metal - Iron
Baby - Cries
Crush - Dark
North - South
School - Grocery
Rose - Flower
Up - Down
Obey - Inch
Fruit - Apple
Cabbage - Pen

Second Presentation

Rose - Flower
Obey - Inch
North - South
Cabbage - Pen
Up - Down
Fruit - Apple
School - Grocery
Metal - Iron
Crush - Dark
Baby - Cries

Third Presentation

Baby - Cries
Obey - Inch
North - South
School - Grocery
Rose - Flower
Cabbage - Pen
Up - Down
Fruit - Apple
Crush - Dark
Metal - Iron

First Recall	Easy	Hard
North		
Fruit		
Obey		
Rose		
Baby		
Up		
Cabbage		
Metal		
School		
Crush		
TOTAL		

Second Recall	Easy	Hard
Cabbage		
Baby		
Metal		
School		
Up		
Rose		
Obey		
Fruit		
Crush		
North		
TOTAL		

Third Recall	Easy	Hard
Obey		
Fruit		
Baby		
Metal		
Crush		
School		
Rose		
North		
Cabbage		
Up		
TOTAL		

Easy 1)____
2)____
3)____
(A)Total____
A÷2____
Hard 1)____
2)____
3)____
(B)Total____

SCORE
$\frac{A}{2} + B =$ ____

Ache

Debt

Psalm

Depot

Chord

Bouquet

Deny

Capon

Heir

Aisle

Subtle

Nausea

Equivocal

Naïve

Thyme

Courteous

Gaoled

Procreate

Quadruped

Catacomb

Superfluous

Radix

Assignate

Gist

Hiatus

Simile

Aeon

Cellist

Zealot

Abstemious

Gouge

Placebo

Façade

Aver

Leviathan

Chagrin

Détente

Gauche

Drachm

Idyll

Beatify

Banal

Sidereal

Puerperal

Topiary

Demesne

Labile

Phlegm

Syncope

Prelate