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Exploring Bilingual Cognition in Younger and Older Adults and Second Language Learners

by

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Summary

There is extensive research investigating the benefits of bilingualism on the ways that basic cognitive abilities develop, function and change throughout the lifespan, particularly from cohorts at either end of the developmental lifespan. The central aspect of the bilingual experience that gives rise to generalised effects on cognitive function comes from the well-documented finding that both languages of the bilingual are jointly active, even in situations where only one language is required. Joint activation produces the processing problem of selecting, attending to and maintaining the target language and inhibiting the non-target language. To manage this conflict the domain-general executive control system is recruited, and through its sustained and persistant exercise it is strengthened.

There is much less evidence from young and middle adulthood, perhaps because this age-group is functioning at their cognitive peak and any effects are thereby masked due to insufficiently sensitive tests. However, this life-stage is the time when individuals are most likely to be globally mobile and participating in periods of immersive living and working in environments where a language other than their native one is spoken. This cohort therefore, despite the challenges, presents a unique opportunity to address aspects of the bilingual experience (such as age of acquisition and level of proficiency) and to track the impact of L2 acquisition on cognitive function in language learners at their cognitive peak.

In Chapter 2, the conceptual, methodological and procedural challenges involved in studying the bilingual advanatge are discussed and recent criticisms of the field are addressed. It then details the specifics of the Task- Switching Paradigm and the

behavioural and electrophysiological methods adopted in the studies within this thesis along with the behavioural and electrophysiological components of interest.

Chapter 3 aims to disentangle the impact of age of acquisition on the Bilingual Advantage in young adults who have reached a high level of proficiency and who actively use their L2 on a daily basis. Convergent data from behavioural and electrophysiological measurements of executive control indicates that late acquisition results in the differential reorganising of the networks that support the joint activation of two languages. We observed an overall advantage in late bilinguals on the switch cost which we interpret to be the result of an adaptation in early attentional deployment, as evidenced by an enchanced N1. This, we suggest, has arisen on foot of the additional cognitive effort involved in reaching high proficiency as a late acquisition bilingual.

In Chapter 4 we aspire to track the emergence of the bilingual advantage in young adults learning English as an L2 by examining executive function both behaviourally and electrophysiologically in learners before and after a 6 month period of intensive immersive learning. This study provides insight into the unfolding cognitive skills that accompany gains in L2 proficiency as evidenced by a switch cost advantage observed only in those learners who made greater progress in their language learning. We interpret this to be indicative of separate cognitive effects coming online as differing thresholds of prociency are exceeded.

Chapter 5 explores aspects of the bilingual advantage in older adults, specifically addressing whether sustained active use of both languages is necessary to maintain the associated cognitive advantage. This study employed a wide range of cognitive tests, including a clinical screening tool, the MoCA and found the bilingual advantage to be present in older adults who have maintained active use of both languages. Furthermore, this Chapter revisits the impact of age of acquisition on the bilingual advantage and provides further evidence for an additional enhancement in late bilinguals.

Finally, Chapter 6 presents a discussion of the contributions and implications of these studies, along with suggestions for the future direction of this work.

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Chapter 1 Conceptual Background

1.1 Introduction

"The knowledge of two languages is greater than the sum of their parts" –Ellen Bialystok

The idea that the simple experience of being bilingual extends beyond the confines of the linguistic system, engaging the cognitive control system as a whole, in such a way that quantifiable and incredibly valuable advantages in executive function are observed in bilinguals is tremendously appealing to scientist and layperson alike. The essence and allure of what has now become commonly known as *The Bilingual Advantage* stems from the fact that to some degree, everyone is bilingual. That is to say that in an ever more collaborative globalised world, it is increasingly rare to encounter someone who has had no exposure whatsoever to a language other than their maternal one (Edwards, 2004). Since the publication of the seminal work by Bialystok, Craik, Klein and Viswanathan (2004) the field of bilingual research has attracted unprecedented levels of media attention worldwide. Imaginably, consumers of such media reflect upon the reported findings, their interest and curiosity culminating in one question – is my experience with a second language enough to afford such an advantage to me?

The people who are interested in understanding whether the benefits of bilingualism apply to them range from those who have been raised speaking and switching between two (or more) languages since birth, to those who manage to successfully ask for directions on a holiday abroad. In between lie those who studied a

language for many years at school, but who are incapable of holding more than the most basic of conversations in that language. Or those who report being able to thoroughly comprehend but not produce a second language. Then there are those individuals who have mastered a second language to a reasonably high level of proficiency but who would self-report it as being nowhere near the level of their first language. And those who were once fluent in more than one language, spending years immersed in active use, who later in life report said language as being rusty and out of practice. Whatever the circumstance, the way in which bilingualism develops, the amount of input from either of two languages, the motivation, the implications for one's cultural identity and sense of self, indeed the entire experience of, route to, and outcome of bilingualism will be as unique to each individual bilingual as their own fingerprint.

1.2 Executive Control

One of our most fundamental cognitive abilities is managing to switch at will from one cognitive operation to another. This ability to recognise that Task A has become redundant and to successfully disengage and switch to a now pertinent Task B is a primary function of self-organised behaviour and is considered the responsibility of our executive control system (Wylie, Javitt & Foxe, 2003). Executive functions are general-purpose control mechanisms that modulate the operation of various cognitive sub-processes and thereby regulate the dynamics of human cognition. The executive control system manages cognitive processes such as planning, working memory, attention, problem solving, inhibition, mental flexibility and initiating and monitoring actions. Under the proposed model by Miyake et al. (2000) the aforementioned skills can be grouped in to three core aspects: updating and monitoring of working memory contents (updating); inhibition of proponent responses at the level of latent variables, rather than at the level of manifest variables (inhibition); and shifting between mental sets (shifting).

The context for understanding how the executive control system becomes entangled with the bilingual linguistic system comes with the well documented finding that fluent bilinguals show some measure of joint activation of both languages, and

some interaction between them, at all times – even in contexts that are entirely driven by only one of the languages (Bialystok, Craik & Luk 2012).

1.3 What gives rise to the Bilingual Advantage? Bilingualism and the Joint Activation Model

There are three main sources of evidence that support a joint activation model of the bilingual mind. The first piece of evidence comes from psycholinguistic studies. Tasks involving cross-linguistic priming in which a word presented in one language facilitates retrieval of a semantically related word in a second language, and lexical-decision tasks in which participants decide whether or not long strings of letters are an actual word or non-words in one of their languages (Beauvillian & Grainger, 1987). In tasks such as these, participants are presented, either visually or aurally, with a mixture of real words and pseudowords (nonsense strings that respect the phonotactic rules of a language, like, for example, 'trud' in English). Their task is to indicate, by means of a button press, whether the presented stimulus is a word or not. Bilinguals performing such tasks have displayed interference from their second language (L2) (i.e., tend to respond that a random string of letters is a word even though it doesn't respect the phonotactic rules of the language in which they are being tested, if it does meet the phonotactic rules of their second language). These studies suggest the influence of the currently unused language for both the comprehension and production of speech. It has also been demonstrated that the L2 influences the native language in certain ways. In studying English-Welsh bilinguals, Thierry & Sanoudaki (2012) demonstrated that when reading in English, bilinguals were mentally open to the Welsh order of Noun-Adjective, despite the fact that this is ungrammatical in English.

The second source of evidence is patient studies showing intrusions from the irrelevant language or irrelevant language switches. One case study is that of a patient with a tumour in the white matter of the left frontal lobe who displayed pathological switching between his two languages (Friulian and Italian). The patient compulsively alternated utterances in each of his languages despite being aware that he was required to speak in one or the other language as a function of his interlocutor as evidenced by his frequent tendency to comment on and apologise for doing so (Fabbro, Skrap & Aglioti, 2010). Non brain-damaged bilinguals can separate their languages at will and

use each language in appropriate contexts. They can intentionally combine elements of different languages within an utterance (mixing) or across utterances (switching). However, they hardly ever violate the sociolinguistic rule of taking in to account the demands or needs of their interlocutors.

The third piece of evidence comes from imaging studies revealing that in the case of high-proficiency bilinguals, neuro-anatomical representations of both languages are overlapping (Chee et al, 1999; Perani et al, 1998). A study by Rodriguez-Fornells et al. (2002) assessed behavioural, electrophysiological and brain-imaging measures during word processing in high proficiency Catalan-Spanish bilinguals and monolingual Spanish speakers. Subjects were presented with words on a video monitor and were requested to respond using left or right button presses depending on the first letter of the Spanish word (vowel or consonant). Subjects were instructed to withhold button presses to Catalan and pseudowords. There were no significant group differences in reaction times. Delayed onset latency of the lateralised readiness potential (LRP) suggests that bilinguals were slower in preparing responses to words in the target language. Bilinguals showed slightly more false positive responses to high-frequency Catalan words. Event related potentials (ERPs) showed a typical sensitivity to word frequency in both groups – a modulation of the N400 component (Kutas & Hillyard, 1980) the frequency sensitivity of which is well known to receive contributions from semantic areas of the fusiform gyrus (Nobre & McCarthy, 1995) and has been interpreted as reflecting meaning access (Luck, Vogel & Shapiro, 1996). Neither group showed frequency sensitivity for Catalan words. ERP effects towards Catalan and pseudowords were virtually identical in both groups. The authors posit therefore that the meanings of the words in the non target language are not accessed even in subjects that are highly proficient in that language, and that these words are rejected at a stage before semantic analysis. This study shows that joint activation is managed very efficiently by the brain and suggests that it is probably achieved at the level of an indirect access route to the lexicon.

Marian, Spivey and Hitch (2003) tested Russian-English bilinguals using a task where participants were presented with four pictures simultaneously along with an English aurally presented word. Participants were asked to direct their visual attention to the picture to which that the word corresponded. The study used an eye tracker to

monitor the eye movements of participants. This study showed that bilinguals were distracted by a picture that shared phonology with Russian, even though there was no connection to the meaning of the target picture and no contextual cues indicating that Russian was at all relevant.

A study by Thierry and Wu (2007) examined joint activation in late bilinguals (bilinguals who learned their second language after age 12) and found that their native language was active during processing of their second language. This study collected behavioural and electrophysiological data for Chinese-English late bilinguals (English being their second language) and monolingual controls (30 Chinese, 30 English speakers) performing a 'semantic relatedness task', i.e., they were presented with pairs of words and asked to assess if the words were related in meaning, e.g., ham-train. Unknown to the participants, half of the word pairs were chosen so that they shared a Chinese character in common, for instance the Chinese translation of the word train is Huo Che and ham is Huo Tui. Mandarin Chinese is an 'ideographic language', radically different from languages written in the Roman alphabet (e.g., English or French). Therefore any significant effect of the concealed Chinese character repetition in late bilinguals reading English words would demonstrate spontaneous activation of the native language. The authors found no measurable effect of concealed Chinese character repetition on the behavioural performance of late bilingual participants. However, physiologically, in terms of ERPs, the sematic relatedness of words yielded a significantly smaller amplitude of an ERP known as the N400 in all groups as expected, but the repeated character also led to a smaller N400 for the late bilingual group. Therefore, although irrelevant to the task, it appears that the late bilingual participants were accessing the Chinese forms when making judgements about the semantic relationship between English words.

The consequences of having joint activation of two languages in the mind of bilinguals impact upon both linguistic and non-linguistic processing. In terms of verbal fluency, bilinguals control a smaller vocabulary in each language than monolinguals (Oller & Eilers, 2002) a pattern that is common in both children (Bialystok, Luk, Peets and Yang, 2010) and adults (Bialystok & Luk, 2011). Bilingual adults have also been shown to be slower at lexical retrieval and verbal fluency tasks (Portocarrero, Burright & Donovivk, 2007), and less accurate on picture naming tasks (Gollan, Montoya,

Fennema-Notestine & Morris, 2005), and have shown slower responses in both comprehension (Ransdell & Fischler, 1987) and production (Ivanova & Costa, 2008), even when they are responding in their dominant L1. Finally, bilinguals have also shown a disadvantage on word retrieval tasks in which they are asked to produce as many words as possible that conform to a phonological or semantic cue within 60 seconds, even if responses can be provided in either language (Gollan & Ferreira, 2009) suggesting that retrieval of common words is more effortful for bilinguals. They also encounter more tip-of-the-tongue experiences (Gollan & Acenas, 2004) and demonstrate poorer word identification through noise (Rogers, Lister, Febo, Besing & Abrams, 2006). All of these issues arise out of interference from the non-target language that must be resolved and can be considered the "cost" of joint activation – a small price to pay in light of the many cognitive benefits.

Joint activation results in bilinguals being thus faced with the processing problem of selecting, attending to and monitoring their target language while actively inhibiting the non-target language. This, in addition to the usual rapid online linguistic processing tasks, such as selection of register, collocation and synonym, produces an additional challenge for bilinguals, which is not present for monolinguals. Although there is ample evidence for joint activation during comprehension tasks (Van Heuven, Dijkstra & Grainger, 1998; Spivey & Marian, 1999), the discovery that the non-target language is available during spoken production remains surprising. Unlike the bottom-up processing that characterises word recognition, speaking is initiated by a conceptually driven process that takes a thought and maps it on to available lexical information. In theory, the conceptual nature of spoken production should allow the language to be selected early in speech planning. This may be possible for bilinguals whose L1 is considerably stronger than their L2. However most recent studies of bilingual word production have shown that the intention to speak one language only does not suffice to limit activation to alternatives in that language.

A striking aspect of bilingual speech is that bilinguals rarely make random errors of language. At the same time they are able to code switch and mix with ease when speaking with others who are at similar levels of proficiency (Muysken, 2000). This indicates that the monitoring, selecting and inhibiting of competing languages is carried out with exceptional accuracy. Essentially, bilingual speech production is astonishingly

better than might be expected if we accept the theory of joint-activation and assume that both languages are available in parallel and potentially compete for selection. This observation has led some to propose that bilinguals possess an exquisite mechanism of cognitive control that develops as they gain skill in the L2 (Green, 1998) and that this has consequences more generally for executive control processes and for their neural representation (Abutalebi & Green, 2007). It is assumed that the task of resolving competition between competing languages and directing and maintaining attention is overseen by general cognitive systems, in particular the executive control system.

1.4 How is the Bilingual Advantage Possible? Bilingualism and Neuroplasticity

Of particular significance in contextualising the way in which the bilingual experience has the capacity to extend beyond the linguistic system to impact upon cognition on a larger scale is the acceptance of the enormous potential for plasticity at both cognitive and neuronal levels. A distinctive feature of the human central nervous system is its tremendous capacity for change as a result of human experiences. This change is the signature of learning, a concept defined as the measurable behavioural advantages that emerge as a function of training over time (Hilchey & Klein, 2011). In the field of psychology, questions are often posed regarding the extent to which repeated exposure to an experience or a certain task or set of tasks produces more general cognitive changes. That is to say, when is learning task specific, and when does it transfer to other, qualitatively similar tasks? Furthermore, how much expertise is required before such a transfer may take place? The idea that pervasive experience leaves its trace on development and function has long been accepted in animal studies. Rats placed in stimulating environments that include the opportunity for exercise, social interaction and engagement with stimulating toys develop greater synaptic density and perform better on maze tasks than rats kept in standard wire cages (Klob et al, 2012). These results parallel the well-known effects of socio-economic status (SES) on children's development (Farah et al., 2006).

In humans, dramatic effects on the structure and functioning of the brain have been reported following short intensive experiences such as juggling (Draganski, Gaser,

Busch, Schuierer, Bogdhn & May, 2004) or video game playing (Green & Bavelier, 2008) and long term experiences such as taxi driving (Maguire et al, 2000) and professional musicianship (Elbert, Pantev, Wienbruch, Rockstroh & Taub, 1995). In one sense, acquiring a second language is comparable to the aforementioned experiences. Learning a new language can be an intense undertaking, especially later in life and in the case of individuals who choose to relocate to a country where the target language is spoken and immerse themselves in intensive language courses. Alternatively, learning two languages simultaneously happens easily and naturally alongside the first language in cases of children who are raised speaking and switching between two languages as a function of daily life.

In another sense, language learning is an experience that is incomparable to any other due to its fundamental nature. The acquisition and use of two languages embedded in a mental conceptual structure that is at the centre of human thought processing and behaviour, surely results in a different configuration than that of monolingual minds (Kroll & Bialystok, 2013). The very fact that so much cognitive processing happens through the medium of language presents the potential for the acquisition of additional languages to have knock-on effects on processes such as the laying down of semantically-driven memories, dreams, self-talk, rational thinking and so forth.

1.5 How does Language interact with Cognition?

1.5.1 The impact of language and bilingualism on thought

Indeed research into the ways in which speakers of different languages attend to, remember and reason about the world has uncovered differences in the ways that language shapes even the most fundamental dimensions of human experience: space, time, causality and relationships to others. A ground-breaking example of such has demonstrated that people who speak languages that rely on absolute cardinal directions (north, south, east and west) are remarkably better at orienting themselves, even in unfamiliar landscapes, than those who live in the same environment but speak a different language. The requirements of their language enforce and train cognitive processes such that a non-linguistic skill (in this case spatial orientation) is performed at a level of ability that exceeds what scientists thought humanly possible (Brown, 1994).

Dramatic results such as these highlight the exceptional ways in which the language or languages that we speak can modulate our cognition.

In the case of bilinguals, fundamental social biases have been found to differ as a function of the language in which the question was posed with Arabic-Hebrew bilinguals showing more positive implicit attitudes towards Jews when tested in Hebrew than when tested in Arabic (Danziger & Ward, 2010). The languages that we speak, therefore, may be involved in many aspects of our mental lives and as such, categories and distinctions that exist in particular languages meddle quite broadly with our cognitive processes. A hallmark feature of human intelligence is adaptability, and the globalised world in which we live today has resulted in a broad diversity of languages being shared across the globe. Acquiring a new language can offer a new cognitive toolkit along with new ways of perceiving, categorising and making meaning of the world (Boroditski, 2011).

1.5.2 The impact of bilingualism on the physical brain

At the physical level of the neuron, experience can alter dendritic length, spine density, synapse formation, glial activity and metabolic activity. Crucially, past network activity alters the efficiency with which individual neurons and assemblies of neurons communicate with each other (Hebb, 1949). These processes occur following experience and result in the expansion or reduction of neural networks. At a functional level, cognitive processing can be altered by the experience of training/learning. This is the case, even in the fully formed adult brain. In cases where training in one cognitive ability impacts upon a separate cognitive ability we can assume that similar cognitive processing underlines both activities. One of the basic questions in the field of the neuroscience of bilingualism is whether two languages of bilinguals are processed through the same neural mechanisms. Substantial neuroimaging evidence demonstrates that the brain regions supporting the processing of L1 and L2 in bilinguals are at least partially overlapping (Hernandez, Dapretto, Mazziotta & Bookheimer, 2001; Perani & Abutalebi, 2005). Furthermore evidence from fMRI confirms an overlap in the networks involved in domain general executive control and language switching in bilinguals (Abutalebi & Green, 2008; Luk, Green, Abutalebi & Grady, 2012). This overlap is attributable to the fact that bilingualism naturally increases the cognitive load in

executive processing (Abutalebi & Green, 2007). If we assume that neuroplastic changes are adaptive effects that directly mediate the specific demands of the bilingual experience then we should expect that these changes are absent in the monolingual brain (Green & Abutalebi, 2013). Furthermore we would assume that there would be observable neuroanatomical differences in areas concerned with language learning (Li, Legault & Litcofsky, 2014). Support for these assumptions comes in the form of correlations between increased L2 proficiency and enhanced brain structure for the left prefrontal cortex (Stein et al., 2012), inferior parietal lobule (Mechelli et al., 2004) and temporal poles (Abutalebi et al., 2014), all regions concerned with executive control. Additionally, bilinguals showed increased grey matter density of the anterior cingulate cortex, which is a structure involved in monitoring actions and detecting errors (Abutalebi et al., 2012). These studies support the view that neuroplastic changes occur in the bilingual brain and that these changes occur both in areas related to language and in areas related to executive control.

1.6 Evidence for the Bilingual Advantage

The bilingual advantage has been widely explored in cohorts at either end of the developmental lifespan, with evidence for childhood extra-linguistic advantages dating back to the 1960s (Peal & Lambert, 1962) and a more recent increasing body of evidence for bilingualism as an advantage contributing to cognitive reserve in older adults (Bialystok, Craik & Friedman, 2007). Much less attention has been paid to the bilingual advantage during young and middle adulthood despite the fact that this is the time when individuals are most likely to be globally mobile and participating in periods of immersive living and working in environments where a language other than their native one is spoken. The fact that young adults are functioning at their cognitive peak presents both a challenge and an advantage. Previous research has attributed failures to observe the bilingual advantage in young adults to ceiling effects on tasks employed to measure aspects of executive function (Bialystok, 2006; Costa et al., 2008). And yet, in the case of young adult language learners what better time to explore the effects of L2 acquisition on cognitive function than when the learner is at their cognitive peak? In order to consider the criterion that may impact upon an observable bilingual advantage

in young adults it is useful to first consider the cohorts in which it has been commonly observed.

1.6.1 Childhood

It was once assumed that childhood bilingualism had a negative impact on cognitive development with speculation that exposure to two languages would confuse the child and hinder his/her ability to differentiate between them. Bilingual children's tendency to mix words from two languages in the same sentence (code mixing) was often cited as evidence of this confusion. In fact, code mixing is a normal part of bilingual development (Pearson, 2008) and can be attributed to the fact that, just like young monolinguals, young bilinguals are often limited in their linguistic resourses and if a bilingual child does not know, or cannot quickly retrieve the appropriate word in one language, she may borrow the word from her alternative language (Lanza, 2004). Code switching also frequently happens among adults in bilingual communities triggering children to imitate (Comeau, Genese & Lapaquette, 2003). Therefore, rather than being a sign of confusion, code mixing can be considered a sign of children's ingenuity (Byers-Heinlein & Lew-Williams, 2013). Furthermore, bilingual children do not tend to use their languages haphazardly, Even young children's early code mixing adheres to predictable grammatical rules (Paradis, Nicoladis & Genesee, 2000).

A now classic study by Peal and Lambert (1962) was the first to cast light on the beneficial extra-linguistic consequences of bilingualism for children reporting that English-French bilingual children performed differently to their French speaking monolingual peers. Contrary to the expectations of the authors, the bilingual children were superior on most cognitive tests, especially those requiring symbol manipulation and reorganisation. This difference was later explored and attributed to an advantage in bilingual children's superior metalinguistic awareness, or ability to solve linguistic problems based on their understanding of the difference between form and meaning (e.g. Ben-Zeev, 1977; Bialystok, 1986; Bialystok, 1988; Cromdal, 1999; Galambos & Goldin-Meadow, 1990; Galambos & Hakuna, 1988; Ianco-Worral, 1972) and non-verbal problems that required them to ignore misleading information (Bialystok & Majumder, 1998; Mezzacappa, 2004).

Bilingual pre-schoolers have been shown to have more advanced social skills than their monolingual peers in terms of understanding others' perspectives, thoughts, desires and intentions (Bialystok & Senman, 2004; Goetz, 2003, Kovács, 2009). Young bilinguals have also been found to have enhanced sensitivity to certain features of communication such as tone of voice (Yow & Markman, 2011). These advantages are attributable to the fact that as a function of their environment, bilingual children are presented with the routine exercise of considering the viewpoint of others. Interacting with an interlocutor who speaks only one of the child's languages requires the child to adopt the perspective of the other person and make appropriate language adjustments accordingly.

1.6.2 Older Adults

Following the logic that bilingualism recruits the executive control system, Bialystok and colleagues (2007) examined whether the experience of a lifelong bilingual's management of joint activation of languages would boost cognitive reserve and result in a more effective endurance of the early symptoms of Alzheimer's disease. They found that even in cases where monolinguals had significantly more formal education than bilinguals, there was, on average, a 4.1 year delay in the observable manifestation of Alzheimer's disease as measured by the time at which patients sought clinical help (Bialystok, Craik & Freedman, 2007). This finding was later replicated (bilingual patients being diagnosed 4.3 years later, and the onset of symptoms 5.1 years later) adjusting once again for education but also for occupational status and immigration (Craik, Bialystok & Freedman, 2010). And again (4.5 year delay) adjusting for sex, occupation and urban versus rural dwelling of participants, this time extending the benefit to illiterate bilinguals suggesting that education is not a sufficient explanation for the observed difference (Alladi et al., 2013). In addition bilinguals have also been found to show significantly better cognitive recovery following stroke than monolinguals (Alladi et al., 2016). These studies combine to make the experience of bilingualism highly relevant in terms of its impact on cognitive aging.

In order to explore the ways in which bilingualism might serve as a safeguard against cognitive ageing it is useful to examine cognitive function in the healthy ageing brain. Several cognitive and brain changes accompany natural non-pathological ageing

with some cognitive functions remaining stable, others progressively declining at varying rates. The typical account of this pattern of spared and impaired cognition is that it is reflective of the degree to which tasks require executive control, with decline in performance more evident on tasks requiring updating, switching and inhibiting attention (Braver & West, 2008; Engle, 2002; Hasher at al., 2007). These are precisely the processes for which bilinguals have been shown to hold an advantage and furthermore poor performance on such functions predicts progression to dementia (Clark et al, 2012). The first study to report the bilingual advantage in healthy older bilinguals (Bialystok et al., 2004) was comprised of older lifelong bilinguals who had reported active use of two languages since the age of 6. The study reported less decline in executive control for these older bilinguals than for age-matched monolingual controls.

1.6.3 Young Adulthood

Despite the evidence for robust bilingual advantages in the development of executive control in young children and older adults, findings in young adult populations have been mixed, with some studies showing bilingual advantages and others showing no performance difference between bilinguals and monolinguals. One potential explanation for this is that young adults are at peak performance in terms of their ability to perform the tests that are commonly used to assess bilingual advantages in executive control and therefore ceiling effects are yielded, impeding the detection of group differences (Bialystok, 2006; Costa et al., 2008)

However, some studies have reported advantages in young adults. Bialystok, Craik & Ruocco (2006) studied young and older adults using a dual task paradigm and found a bilingual advantage in performing the classification of visual images during simultaneous classification of auditory information. The task was comprised of two schemes: classify stimuli as numbers or letters, or classify stimuli as animals or musical instruments. The concurrent visual and auditory tasks relied on the same classification scheme in some conditions and in others a different classification scheme was assigned to each modality. A bilingual advantage was found only in the visual classification of numbers and letters (the easier of the two tasks) and the advantage was stable both when the auditory task used the same classification scheme and when it required classification

of animals and musical instruments. The authors concluded that (contrary to their predictions) the bilingual advantage stemmed not from an advantage in switching between tasks, but from an advantage in inhibitory control.

The potential bilingual advantage in task switching was revisited by Prior & McWhinney (2010) who examined college-aged bilinguals' ability to switch between tasks. They used a measure that allows a direct comparison of local switching costs and general mixing costs in an attempt to measure the actual cost of switching between two tasks as opposed to the general task of monitoring two streams of information and subsequently coordinating simultaneous performance. The authors found a pronounced bilingual advantage in switching costs, displaying greater facility at activating a task set in response to a cue and taking less time to overcome residual interference from the previous trial.

The paradigm most widely used to study the bilingual advantage is the Simon task (Simon & Ruddell, 1967). In this task, stimuli are presented under the rule that participants must ignore the position and respond to the colour. In other words, no matter where the target appears on the screen, press the left key for a red target, the right key for a green target. When the stimulus appears on the same side as the response key (congruent trial) both position and response information converge on the correct response. When the stimulus appears at the opposite side to the response key (incongruent trials) an additional processing effort is required to resist the prepotent tendency to respond to the stimuli position cue. The increment in response time between congruent and incongruent trials is known as the Simon effect.

Bialystok and colleagues (2004) found that bilingual adults were better able to resist the misleading information carried by spatial position (i.e., they demonstrated a smaller Simon effect) and therefore concluded that bilinguals have well-developed inhibitory control mechanisms. The Simon effect in adults was replicated by Martin-Rhee & Bialystok (2008), and significant effects supporting the bilingual advantage were found on various other tasks such as the behavioural antisaccade task (Bialystok, Craik & Ryan, 2006; Bialystok & Viswanathen, 2009), and the flanker task in young and middle-aged adults (Costa, Hernandez & Sebastian-Galles, 2008; Emmorey, Luk, Pyers & Bialystok, 2008). In all of these studies, bilinguals were selected for

participation based on their usage of both languages to a high degree of proficiency for most of their lives.

These findings prompt two very important questions in relation to a bilingual advantage: Is early acquisition (i.e., in early childhood) necessary to attain a high level of proficiency in the second language? And secondly, is a high level of proficiency in the L2 necessary before one can reap the cognitive benefits of bilingualism?

1.7 Proficiency and Age of Acquisition

1.7.1 Is Early L2 Acquisition Necessary to Attain High-Proficiency?

The concept of a critical or sensitive period for first language acquisition, the idea that humans are incapable of fully mastering language beyond a certain age, is a controversial topic among researchers with some suggesting it doesn't exist and others proposing that the cut off age ranges anywhere from between five and fifteen years of age (Johnson & Newport 1989; Krashen, 1973; Lenneberg, 1967). There is more consensus around the suggestion that there are similar sensitive period restrictions in relation to the acquisition of a second language with research asserting a single take home point: earlier is better. These studies have proposed that there is an incremental decline in language learning abilities with age (Birdsong & Molis, 2001; Hakuta, Bialystok & Wiley, 2003) and that biological changes during the first two decades of life result in a reduced capacity for learning and retaining the subtleties of language (Johnson & Newport, 1989; Weber-Fox & Neville, 2001). This is often linked to the distinction between implicit and explicit linguistic knowledge. This originates with Lenneberg (1967) who stressed that after puberty, what disappears is the ability to attain automatic acquisition from mere exposure the way children acquire language. After puberty, Lennenberg suggests, language acquisition typically involves a conscious and laboured effort. In addition to this, early environmental factors play a large role in the sense that young children experience a rich language environment where language is bestowed upon them in attention-grabbing, simplified, relevant bundles that have been skillfully adjusted to match their developmental and interest level (Fernald & Simon, 1984). Infants discover language in a bottom up fashon as a feature of the way that caregivers communicate with them allowing them to explore the sounds, syllables, words, phrases and sentences that compose their native language (Byers-Heinlein &

Lew-Williams (2013). Attempts made by the infant to produce language are met with smiles, words of encouragement, repetition and a fanfare of clapping and celebration when intelligible words are uttered. All of this provides a rich, diverse and engaging backdrop, against which language acquisition tends to flourish. Applied to bilingualism, these maturational and environmental factors would suggest that early, even simultaneous acquisition of two languages from birth is most conducive to successful bilingualism.

Certain researchers (Birdsong, 2005; Donaldson, 2011; Montrul, 2009; Muñoz & Singleton, 2001) argue that a more nuanced approach to L2 native-like attainment is warranted, where quality and quantity of linguistic input as well as degree of proficiency play much bigger roles than previously assumed, and where sensitive periods for some, but not all modules of grammar exist. Essentially, the joint activation of two languages, the interaction between them and the influence of one upon the other demonstrates that both languages of a bilingual come to function somewhat differently than that of a monolingual speaker of either language (Kroll, Bogulski & McClain, 2012). Following this logic, many researchers have adopted the position that age-effects on native-like proficiency should only be tested among early and late bilinguals and the monolingual native speaker's performance should not be used as a yardstick against which the bilingual performance is evaluated (Birdsong, 2009, Muñoz & Singleton, 2001).

1.7.2 Is High-Proficiency Necessary for the Bilingual Advantage? The case of Late Acquisition Bilinguals

Though we may consider early, simultaneous acquisition of two or more languages the ideal scenario, we can't ignore the fact that acquisition of a second language in adulthood is becoming increasingly more common and it is therefore crucial to include late, sequential bilingual, and adult second language learner groups in studies in order to determine whether the effects extend to these populations and indeed to explore whether the bilingual advantage expresses itself in divergent ways.

In a study comparing early and late onset bilinguals, only those who started using both languages before the age of 10 showed advantages (Luk et al, 2011). In contrast, Tao et al (2011) found that the impact of bilingualism may unfold differently

in early and late bilinguals with early bilinguals being better at switching and late bilinguals better at inhibiting (Tao et al, 2011). This finding was supported by Bak and colleagues, who found that early childhood bilinguals showed a greater advantage on attention switching, and late childhood bilinguals/early adult bilinguals had an advantage on selective attention and inhibitory control (Bak, Vega-Mendoza & Sorace, 2014). It seems plausible that early simultaneous acquisition of two languages fosters a bilingual experience where switching processes are enhanced, whereas the later, sequential acquisition of a second language gives rise to an experience where more effortful inhibition of the native dominant language is required whilst concurrently selecting the less solidified second language.

1.8 Language Processing in the Brain

1.8.1 The case of Late Bilinguals

A theory asserted by Ullman (2001) claims that the processing of an L2 acquired later in life cannot depend on the same cognitive mechanisms and neural structures as the L1 due to the fact that L1 is acquired somewhat implicitly and mediated by innate learning mechanisms triggered during a critical period. Following this logic, the theory suggests that grammatical knowledge for L2 is declarative rather than implicit. Because implicit and declarative knowledge are mediated by different distinct neural system (left frontal-basal ganglia circuit for implicit and left temporal language area for declarative), L2 acquisition in adulthood could not depend on the same mechanisms used to process the native language.

Brain imaging studies have largely contradicted Ullman's theory (Briellmann et al., 2004; Sakai, Miura, Narafu & Muraishi, 2004; Wartenburger et al., 2003). In particular, in bilinguals carrying out grammatical tasks, the brain structures typically associated with grammatical processing (e.g. Broca's area and the basal ganglia) in L1 were also involved in processing L2.

Wartnenburger and colleagues used fMRI to assess grammatical and semantic judgements in three groups of Italian-German bilinguals: early acquisition high proficiency, late acquisition high proficiency and late acquisition low proficiency. They found that only in the case of early L2 acquisition did the substrates for L1 and L2

grammatical processing overlap, however proficiency level was found to be the main determinant of the cerebral organisation of both grammar and semantics in the late bilinguals (Wartenburger et al., 2003). These studies suggest that grammatical processing of L2 is acquired and carried out through the same computational brain devices underlying L1. Differences arise in terms of the additional resource demands depending on age of acquisition, but these are within the same neural system.

1.8.2 The case of the L2 Learner

According to psycholinguistics, during the early stages of L2 acquisition there may be a dependency on L1 to mediate access to meaning of lexical items (Kroll & Stewart, 1994). As L2 proficiency grows this dependency reduces and as higher levels of proficiency are reached lexical-semantic representations that more closely resemble those in L1 are constructed. According to Green (2003) any qualitative differences between native and L2 speakers disappear once proficiency levels are matched.

L2 learners have the potential to provide powerful insights into the origin and possible mechanism(s) involved in the bilingual advantage in executive control. Furthermore tracking executive control over time while simultaneously tracking progress in L2 acquisition provides the opportunity to explore the stage in emerging bilingualism at which executive control advantages come online.

Osterhout and colleagues (2006) claim that both uncontrolled subject variability and a lack of longitudinal research on changes in processing over time has curbed our understanding of the ways in which the adult brain is influenced by second language acquisition. McLaughlin, Osterhout and Kim (2004) showed that after only 14 hours of L2 training (university level French), students showed a significant change in N400 amplitude during a lexical decision task, despite the fact that behavioural results were at chance level. These results indicate that there is an observable neural response even after minimal L2 training. Furthermore it seems that brain-related functional changes associated with the experience of L2 learning precede behavioural changes.

Recently, Tanner, McLaughlin, Herschensohn and Osterhout (2013) carried out analysis of morphosyntactic processing in native German speakers and native English speakers learning German as an L2 in college-level German courses. EEG was recorded while participants read sentences that were either grammatically correct or violated

German subject-verb agreement. Native German speakers and 3rd year German learners both showed the classic P600 effect, which reliably occurs when processing syntactic anomalies (Osterhout & Nicol, 1999). Among the 1st year learners there was some individual variability with learners displaying the P600 or N400 (which occurs when processing semantic anomalies), but not both. The amplitude of the P600 was positively correlated with behavioural performance for all learners but not for native speakers. These results support the idea that linguistic processing is highly malleable, even in the early stages of second language acquisition and can help to disentangle the confounding suggestion that superior individual cognitive ability may be responsible for effects in late bilinguals. Furthermore these results highlight the usefulness of treating cross-subject variability as a source of evidence rather than a source of noise (Tanner et al., 2013).

More recently Sullivan and colleagues (2014) studied university students who studied either introductory Spanish or introductory psychology over the course of 6 months and found larger P300 amplitude on a Go/No-Go task and smaller P600 amplitude on a sentence judgement task in the Spanish learner group. Similar to the findings of McLaughlin et al (2004) these electrophysiological changes occurred in the absence of behavioural changes (Sullivan, Janus, Moreno, Astheimer & Bialystok, 2014).

Another study that has contributed towards our understanding of the subtleties underlying the bilingual advantage was that of Vega-Mendoza, Sorace & Bak (2015), who examined cognitive functions in late non-balanced bilinguals with different levels of second language proficiency. This study found that the bilingual advantage in selective attention was present both in lower (year 1 language students) and higher (year 4 language students). However, while there was no difference between year 1 students and monolinguals in terms of attention switching and letter fluency, the higher-level year 4 students showed an advantage in attention switching. The authors interpret their findings as evidence that late-acquisition non-balanced bilinguals experience similar cognitive effects to their early-acquisition counterparts but that these advantages emerge at different stages of adult second language learning.

1.9 Overall summary and objectives of thesis

The purpose of this chapter was to provide a review of the relevant literature on bilingualism in terms of the ways in which it is defined, and the various contexts in which it has been studied. A survey of the literature demonstrates that it is widely accepted that both L1 and L2 are constantly active in the bilingual brain and that this joint activation produces the processing problem of inhibiting the non-target language to select the target language. Furthermore, it is understood that general-purpose executive control system is recruited to resolve this problem. Through their additional engagement in managing joint activation, executive functions are fortified and therefore bilinguals display advantages on cognitive tasks that are driven by executive control.

Chapter 2 will outline the paradigm used to explore the bilingual advantage in executive control in this thesis: The Switching Attention Task (SWAT), the methodological issues associated with defining the bilingual and the merits of self-report questionnaires. Additionally Chapter 2 will give an overview of Electroencephalography (EEG) and the Event-Related Potentials (ERPs) of interest in this thesis.

The main objective of Chapter 3 will be to explore whether the bilingual advantage extends to bilinguals who have learned their second language after the age of 12 and to explore whether the mechanisms influenced by early and late acquisition of L2 are dissociable and have lead to differential development or reorganisation of the supporting networks. Executive function will be examined both behaviourally and electrophysiologically within a task-switching paradigm using the Switching Attention Task (SWAT). Behaviourally, the switch cost will be considered the primary measurement of executive control. Rates of false press and omission errors will be interpreted to reflect a measurment of inhibitory control and selective attention respectively and d-prime (d') as an overall measurement of task accuracy. We hypothesise that we will see an overall bilingual advantage for both the early and the late bilinguals relative to their monolingual counterparts but that this advantage may be observable on different aspects of the task reflecting differential development of joint activation management in the early and late bilingual. Further to the behavioural differences we predict that the bilingual advantage will present differently in the

physiology of early and late bilinguals as reflected in ERP component waveform amplitude, in particular early evoked potentials P1 and N1 and in components previously linked to response inhibition within a Go/No-Go paradigm, namely N2/P3.

Chapter 4 will consider whether the emergence of the bilingual advantage can be tracked longitudinally among individuals learning English as an L2. Learners have little or no knowledge of English when they are first tested, providing a monolingual baseline against which they are compared six months later when they are retested having spent 15-30 hours a week engaged in intensive language classes, along with immersing themselves in English outside of school hours by living and working in Ireland. Again, Executive function will be examined at test time 1 and 2, both behaviourally and electrophysiologically within a task-switching paradigm using the SWAT. As in chapter 3, the switch cost will be considered reflective of executive control, false press and omission errors will be interpreted in terms of inhibitory control and selective attention respectively, and d' will be used as a measurement of task accuracy. Once more, early evoked potentials P1 and N1 and Go/No-Go N2/P3 will be the waveforms of particular interest. We predict that there will be no difference between the language learners and the maths learners at baseline (test time 1), but that after 6 month intervention intensive learning period the bilingual advantage will have begun to present itself on certain aspects of the task. As the language learners are, in essence, late-bilinguals-in-training, we therefore predict that the language learners at time 2 should begin to resemble the late bilinguals in terms of both behavioural and physiological patterns.

Chapter 5 aims to examine the bilingual advantage in older Irish adults who have either maintained active use of two languages or who were once bilingual but have not upheld active use of both languages. Additionally, within the group who had maintained active use of both languages we explore whether age of acquisition has had an impact upon current cognitive function. A number of tests are used to assess function across a range of cognitive domains: The Montreal Cognitive Assessment (MoCA) is used to assess global cognition, the Sustained Attention Response Time (SART) is used to measure sustained attention, the Choice Reaction Time (CRT) task is used to measure cognitive response time relative to motor response time and the Color Trail 1 and 2 (CT1, CT2) is used to assess attention and mental flexibility. We predict the bilingual advantage will be most evident in those who have maintained active use of two

languages and less (if at all) evident in those who once were but no longer are bilingual. Furthermore we predict that a differing pattern of behavioural effects may be observable in those who acquired L2 early in life to those who acquired it later.

Finally, Chapter 6 will provide a general discussion of the findings in this thesis in terms of their contributions along with their respective implications and suggestions for future research.

Chapter 2 Paradigm Development & Methodology

2.1 Challenges to the Bilingual Advantage Theory

The theory that being bilingual offers a cognitive advantage is very appealing, especially in light of findings such as Bialystok's (2007) finding that bilinguals show symptoms of dementia on average 4 years later than their monolingual counterparts, and Bak's (2016) finding that bilingualism leads to a better cognitive outcome after a stroke. Although the bilingual advantage is arguably one of the most newsworthy topics in cognitive psychology today (Treccani & Mulatti, 2015), it is important to note that this hypothesis is not uncontested. Paap, Johnson & Sawi (2015), and Klein (2015) failed to replicate the bilingual advantage and in their studies of the literature proclaimed that bilingual advantages in executive function either do not exist at all, or at most, are restricted to specific, as yet undetermined, circumstances.

The field of research into the bilingual advantage is beset with conceptual methodological and procedural challenges. These include defining the degree of linguistic competency required (or lack thereof) to categorise an individual as a bilingual (or monolingual); the identification and isolation of the specific aspects of executive function and their underlying neural substrates involved; the development of testing paradigms which are both valid and reliable while being sufficiently sensitive to tap into the areas of interest. Critics suggest that publication bias, the use of mismatched demographic cohorts and methodological flaws have given rise to a misrepresented view on the bilingual advantage. Bak (2015), in response to the criticisms by Paap and

colleagues, outlines that their claims hinge on two factors: the representativity and quality of their discussion of the literature and the idea that all studies should produce the same results regardless of the population in which they were conducted. The literature reviewed by Paap et al. (2015) may indeed contain biases, but both in favour of and against the bilingual advantage. Furthermore a meta analysis carried out by de Bruin, Trecanni & Della Sala (2015) showed that there is indeed a publication bias towards positive findings but that there is also a significant bilingual advantage effect across studies. The discovery of the former does not serve to negate the latter.

All bilinguals are not created equally: the route to and experience of bilingualism differs in myriad ways from person to person. If no two individual bilinguals are identical then neither are any two groups of bilinguals, and the assumption that all studies should produce the same results, without regard for population differences, is impractical. But far from being a reason to dismiss the merit of the entire field of bilingualism research, potential population and group differences must instead be appropriately acknowledged and accounted for. Group differences can never exclude the possibility of confounds with absolute certainty. Moving beyond the cross-sectional approach towards more longitudinal designs where emerging bilingualism becomes a variable over time and participants' original monolingual baseline acts as a point of comparison can thus be informative. A study by Woumans, Surmont, Struys & Duyck (2015) tested native French speaking children, half of whom would commence an L2 primary school immersion programme. At test time 1 (monolingual baseline) both groups performed equally on all measures. At test time 2, one year later, the group that had become bilingual showed a significant increase in measurements of fluid intelligence (as measured by Ravens Coloured Progressive Matrices) relative to the group who had remained monolingual. This finding, along with Bak's Lothian Cohort study (2014) highlights the merit of longitudinal designs and acts as a compelling counterargument to Paap et al.'s (2015) claim that bilingual advantages are only found in studies in which demographic variables are poorly controlled.

2.1.1 The Direction of Causality

A common issue in cross sectional research is the question of causality, specifically, does bilingualism influence cognitive ability or is it plausible that those endowed with greater cognitive capacity are more likely to acquire a second language? The most compelling evidence for the causal role of bilingualism in improving cognitive function comes from a study of the Lothian Birth Cohort in Scotland (Bak et al., 2014). In 1947, all Scottish children born in 1936 (and therefore aged 11) underwent comprehensive intelligence testing. Around 1000 of them were traced and assessed 60 years later. The results of this study showed that individuals who learned a second language after the age of 11 achieved better cognitive results than predicted from their childhood intelligence scores. This suggests that language learning and active bilingualism can mitigate the effects of cognitive ageing, independently of intelligence. This study provides persuasive evidence for the direction of influence to transfer from bilingualism to cognitive function rather than the reverse (Bialystok et al., 2016).

2.2 Defining the Bilingual

One of the most fundamental decisions to be taken by researchers exploring bilingualism is the degree of linguistic competence required to confer the label "bilingual" or "monolingual" to an individual. Any line drawn when segregating the two must cross multiple linguistic dimensions and threads of ability. Each of the five basic linguistic skills, namely, reading, writing, listening, speaking and pronunciation, can be broken down to a set of sub-skills that may be at quite divergent levels of proficiency for any one individual. Proficiency in one skill does not presuppose proficiency in another. The task at hand is not so much to reach a standard definition of a bilingual, but instead to consider how best to assess varying degrees of bilingualism along with the factors that impact upon it.

2.2.1 Self-Report Questionnaires

Questionnaires are commonly used in bilingual research, asking participants to indicate both self-rated judgements of frequency of usage and levels of proficiency (e.g., Elston-Güttler, Paulmann & Kotz, 2005; Gollan & Acenas, 2004; Gollan & Silverberg, 2001). In this regard, multiple questionnaires have been developed with the purpose of

extracting and exploring the relevant dimensions of the bilingual experience. Li, Sepanski and Zhao (2006) devised an online questionnaire by amalgamating common questions from 41 published questionnaires focusing on self-assessment of first and second language (L1/L2) proficiency, age of L2 acquisition, duration of residence in country where L2 is spoken and home language environment. Marian, Blumenfeld and Kaishanskaya (2007) developed the Language Experience and Proficiency Questionnaire (LEAP-Q), which requires participants to self-report age of acquisition for each language, duration of residence in country where L2 is spoken, extent of language exposure and proficiency in each language. Generally, the main inclusion criterion for a bilingual group seems to be proficiency level in each language (e.g., Bedore, Pena, Joyner & Macken, 2011; Blumenfeld & Marian, 2007; Dixon, Wu & Daraghmeh, 2012; Proverbio, Adorni, & Zani, 2007; Sumiya & Healy, 2008). However, Luk and Bialystok (2013) draw attention to the importance of also considering the daily pattern of language use and the extent of the bilingual experience as per the age at which the bilingual began *actively* using two languages. Age of acquisition and active use throughout the lifespan may not be correlated. The Language Social Background Questionnaire (LSBQ) examines demographic and language background, daily usage of language and self-rated proficiency. Relationships between the different aspects of bilingual experience and onset age of active bilingualism were explored in a large heterogeneous sample of bilingual young adults. Key findings affirmed firstly, that the bilingual experience is multi-factored and therefore not a categorical variable. Secondly, standardised measurements of language proficiency were significantly correlated with self-rated judgements of language proficiency, confirming the validity and merit of self-judgement in the study of bilingual samples (Luk & Bialystok, 2013).

A careful, rigorous self-exploration of language usages and tendencies by the speaker can provide insights into the bilingual experience, and certain threads and themes emerge. Qualitative questions can offer insights into the dominance levels of both languages, considerations of which language emerges spontaneously in times of elevated emotion; prevails in dreams; is used in keeping a personal diary; handles self-talk etc. If a single language does not emerge as a dominant answer then perhaps bilingualism is an apt designation (Edwards, 2004). All of this, of course, rests heavily on the individual's ability to self-report accurately, an assumption of a roughly equivalent sense (across individuals) of what competence means, and a raw willingness

to communicate one's own strengths and weaknesses in terms of proficiency levels of individual skills.

2.2.2 The Language Background and Use Questionnaire

In order to explore the demographic and personal language history, and current language practices of bilinguals and language learners three Language Background and Use questionnaires were developed for use in relation to investigating the bilingual advantage in early and late bilinguals (Chapter 3) and exploring the emergence of the bilingual advantage in adult L2 learners (Chapter 4). All questionnaires were piloted, and subsequently revised. The Bilingual Language Questionnaires are discussed in more detail in the methods sections pertaining to their separate studies. The results from the questionnaires are interpreted as extra-linguistic factors that have the potential to impact upon executive control and as such are correlated with the Switch Cost. In the case of the adult L2 learners questionnaire data was collected at both test time 1 and again following six months of intensive language learning at test time 2. These data are thereby also interpreted in terms of their relationship to the learners' progression in language acquisition.

2.3 Task-Switching Paradigm

Task-switching paradigms have been developed to study the functioning of the executive control system. In a typical task-switching experiment, participants are presented with two or more tasks, each with a set of rules, and are asked to switch between tasks when certain circumstances present themselves. Generally, this entails associating each task with a cue that informs the subject which task is relevant on each trial. Trials are sequenced and arranged such that participants repeatedly perform a task on given trials and are required to switch tasks on other trials (Wylie, Javitt & Foxe, 2004). For instance, subjects might be presented with number letter pairs on every trial and instructed to press or withhold depending on the colour in which the stimuli appear. Task A may be to focus on the green numbers and categorise them according to whether they are odd (withhold) or even (press), Task B may be to focus on the red letters and categorise them according to whether they are vowels (press) or consonants (withhold). Participants are normally given a number of trials, some requiring them to repeat the

task and some to switch from one task to the other. Typically, repeated-task trials result in better performance with shorter reaction times (RTs) and fewer errors (Wylie et al, 2003). This performance decrement on switch trials has been termed the switch cost and is considered to be reflective of the operations of executive functions on switch relative to repeat trials. (Rubinstein, Meyer & Evans, 2001)

2.3.1 The Switch Cost

There are two pertinent competing classes of theory related to switch cost. The first proposes that the switch cost represents the time taken for an executive process or processes to switch the cognitive system from a readiness to perform one task to a readiness to perform the other (Rubinstein et al, 2001). The executive processes are at the top of a processing hierarchy, directing the conformation of the lower level processes that analyse the stimulus and convert its representation into a response. This broad class of theory is referred to as 'reconfiguration theory'. This view is supported by the fact that increasing the length of time between trials (between successive tasks) leads to a decrease in switch cost.

The second class of theory, referred to by Wylie et al (2003) as the 'competition hypothesis' posits that a switch of task is accompanied by changing the weights of a competing cognitive system. This model draws on computational literature (Cohen et al., 1990). Here it is suggested that each task set is comprised of numerous 'nodes', one set of which represents the "goal" for each task. When subjects switch from one goal to another, the weights of these goal nodes are changed in favour of the new task. A commonality between all applications of the competition hypothesis is that cognitive control is arrived at, not through the mediation of some structure that directs or reconfigures the system, but rather through the integrated competition of all the "modules" in the system. There is an interesting point of comparison here between the single and joint activation model of bilingual processing and the reconfiguration and competition model for switching. Namely, reconfiguration is not unlike the idea of accessing independent language systems (single activation) and the competition hypothesis is not unlike joint activation of concepts in the bilingual brain.

2.3.2 The process of task-switching

A study by Yeung and colleagues (2006) supports the theory of a control hierarchy comprising regions responsible for maintaining task-specific information about rules or goals, and regions involved in the coordination of these goals (Yeung, Nystrom, Aronson & Cohen, 2006). The presence of a cue, reminding participants which set of rules are relevant to which task, increases the time subjects have to prepare for the switch and decreases the cost of switching. This has led to speculation that there is a central mechanism that activates brain networks required for completing the new task in response to a cue stimulus. Behaviourally, reaction times are shortened because the brain network mediating the new task is active. This line of reasoning suggests that neurophysiological responses to cue stimuli should reflect the operation of such a mechanism.

One consistent finding is that cues signalling a switch of task are associated with an increased P300 after the cues are presented (Wylie, Murry, Javitt & Foxe, 2008). Models accounting for the results of task switching studies fit in to two broad categories: those that propose that the differences between switch and repeat trials are attributable to a stage-like process (Rubenstein et al, 2001), and those that propose that these differences are due to interference from previously relevant task sets (Wylie et al, 2003). These theories make different predictions in terms of the effects on single-task trials, switch trials and repeat trials. For example, if a stage-like process is required on switch trials, one might expect to find differences in ERP response to switch versus repeat cues. Wylie and colleagues (2008) suggest that the difference between switch and repeat trials is due primarily to differences in the strength of responses within a statistically indistinguishable brain network. That is, that the same mechanisms appear to be employed on switch and repeat trials (no difference in topographical analysis), but to a different extent (stronger global field power on switch than on repeat trials). Their data show that a statistically indistinguishable network is active in preparation for switch and repeat trials, even when subjects demonstrably prepared for the forthcoming task, and when two tasks involved different stimulus-response transformations. This suggests that switching is accomplished through a competitive process in which the possible stimulus response mappings compete with one another. According to this interpretation, a substantial portion of the 'switch cost' is attributable to the time it takes

to resolve this competition and for the system to settle in to a state in which one stimulus response mapping has "won" the competition (becomes more active) (Wylie et al, 2008).

It is unresolved whether a similar mechanism may underlie the preparatory processes associated with the cue. One well replicated finding is that as participants are allowed more time to prepare for a switch of task, their switch cost decreases, although typically not to zero. This has been interpreted as showing that there are indeed some processes that are under our control and can be initiated in preparation for a switch of task, if sufficient time is provided (Wylie et al, 2008).

2.4 Bilingual Language Control

Although there is disagreement regarding the nature of bilingual language control mechanisms, there remains a general consensus that certain aspects of domain-general executive control functions mediate this ability (Abutalebi & Green, 2008). Also unresolved is whether one specific aspect of executive control is responsible for managing the joint activation of two languages. The relationship between bilingual language control and domain-general executive control can be characterised in at least two different ways.

First, bilingual language control could be viewed as being fully subsidiary to the domain-general executive control system. Under this hypothesis, bilinguals would engage the same set of control mechanisms when switching languages as they use when switching between non-linguistic tasks in everyday life. Alternatively, the continuous maintenance that bilinguals exert over their two languages could result in the development of control processes specific to language (Costa & Santesteban, 2004). Under this hypothesis, bilinguals may make use of the domain-general executive control system, but essentially additional processes become specifically employed by language related tasks (Calibra, Hernandez, Branzi & Costa, 2012). Neither theory suggests that bilingual language control is completely independent of domain general executive control. Given that the bilingual advantage is well established it is widely accepted that, should bilingual language control and general executive control not be one and the same mechanism, there is at least considerable crosstalk between the two (Calibra et al.,

2012). In terms of those individuals who learned their second language later in life, it is assumed that overcoming the interference from the more solidified L1 is more difficult therefore late bilinguals may accrue even more gains in executive control training during second language learning.

2.4.1 The mechanisms underlying bilingual language control

The majority of studies reporting the bilingual advantage have employed tasks that involved conflict in the form of task-irrelevant information, such as the Simon task (Bialystok et al., 2004; Bialystok, Martin & Viswanathan, 2005; Martin-Rhee & Bialystok, 2008; Poarch & van Hell, 2012), the flanker task (Costa et al., 2008; Costa et al., 2009; Emmorey et al., 2008; Luk et al., 2011; Marzecova, Asanowicz, Kriva & Wodniecka, 2013; Tao et al., 2011), or the Stroop task (Bialystok, Craik & Luk., 2008, Hernandez, Costa, Fuentes, Vivas & Sebastian-Galles, 2010). The workings of such tasks reflect the conflict in the form of language-irrelevant information faced by the bilingual when selecting the target language and inhibiting the other. The bilingual advantage was therefore assumed to be the result of an enhanced inhibitory control mechanism, fortified through its employment in resolving language interference (Abutalebi & Green, 2007; Bialystok & Martin, 2004; Bialystok et al., 2004, Costa et al., 2008). However, a number of studies have failed to replicate the effects of bilingualism in tasks involving inhibition (Kousaie & Phillips, 2011; Kousaie & Phillips, 2012; Morton & Harper, 2007; Namazi & Thordardottir, 2010; Paap & Greenberg, 2013).

In their 2011 review, Hilchey & Klein examined the available findings on the bilingual advantage and asserted the *bilingual executive processing advantage hypotheses* (BEPA) which suggests that enhanced efficiency of the central executive system, which regulates cognitive processing across a wide variety of task demands, may lead to bilingual advantages across both conflict and non-conflict task trials on any number of tasks that engage executive control. Support for this hypothesis lies in the fact that the majority of studies found the bilingual advantage not just on conflict trials, but on non-conflict trials also. In line with the BEPA hypothesis, several studies have reported the bilingual advantage across a wide range of experimental tasks exploring various cognitive processes. All of these processes involved cognitive flexibility and

ranged from switching between mental sets (Prior & McWhinney, 2010), achieving and maintaining an alert state (Costa et al., 2008; Marzecova et al., 2012) and anticipation (Bonifacci et al., 2011).

2.5 The Switching Attention Task (SWAT)

The task employed to study the functioning of the executive control system appropriate to the following two chapters, specifically to the investigation of the bilingual advantage in early and late bilinguals in Chapter 3, and the exploration of the emergence of the bilingual advantage in adult L2 learners in Chapter 4 is the Switching Attention Task.

2.5.1 Stimuli

The stimuli on the task consisted of letter-number pairs. The letters were drawn from a set containing four vowels (A, E, I, U) and four consonants (B, C, F, K) and the numbers were drawn from a set containing four even (2, 4, 6, 8) and four odd (3, 5, 7, 9) numbers. On each trial one letter and one number were presented pseudo-randomly appearing to the left and right of a fixation cross (e.g. A + 9) with the constraint that no number or letter was repeated on the following trial. One of these characters was presented 1° to the left of central fixation cross, the other was presented 1° to the right of the central fixation cross, this was randomly determined. The stimuli were coloured as follows: for three trials in a row they were red; for the next three they were green; next three were red and so on. These triplets were labelled Switch, Nested and Pre-Switch trial types. Each participant completed 18 blocks of the task. There were 120 trials on each block, which resulted in a total of 2160 trials: 720 of each trial type.

2.5.2 Speed Conditions

Three distinct speed conditions were created in order to manipulate task difficulty. In the Slow speed condition the stimuli remained on the screen for a duration of 180 ms while the inter stimulus interval (ISI) was 1,820, giving an onset asynchrony of 2,000 ms. In the Medium speed condition the stimulus duration remained at 180 ms, while the ISI was reduced to 1,320 ms giving an onset asynchrony of 1,500 ms. In the Fast speed condition the stimulus duration remained at 180ms, while the ISI was further reduced to 820 ms.

2.5.3 Task Procedure

Participants alternated between two tasks, switching from one to the other on every third trial (see Fig. 2.1). When the stimuli were coloured red, participants were instructed to categorise the letter according to whether it was a vowel or a consonant. When the stimuli were coloured green, participants were instructed to categorise the number according to whether it was odd or even. This was a Go/No-Go paradigm in which subjects only responded during the letter trials if the stimuli contained a vowel and only responded during the number trials if the stimuli contained an even number. These instructions were counterbalanced across subjects such that half of the subjects performed the letter task when the stimuli were red and the number task when the stimuli were green, and the rest did the reverse. In all cases participants were asked to respond by making a left mouse button press.

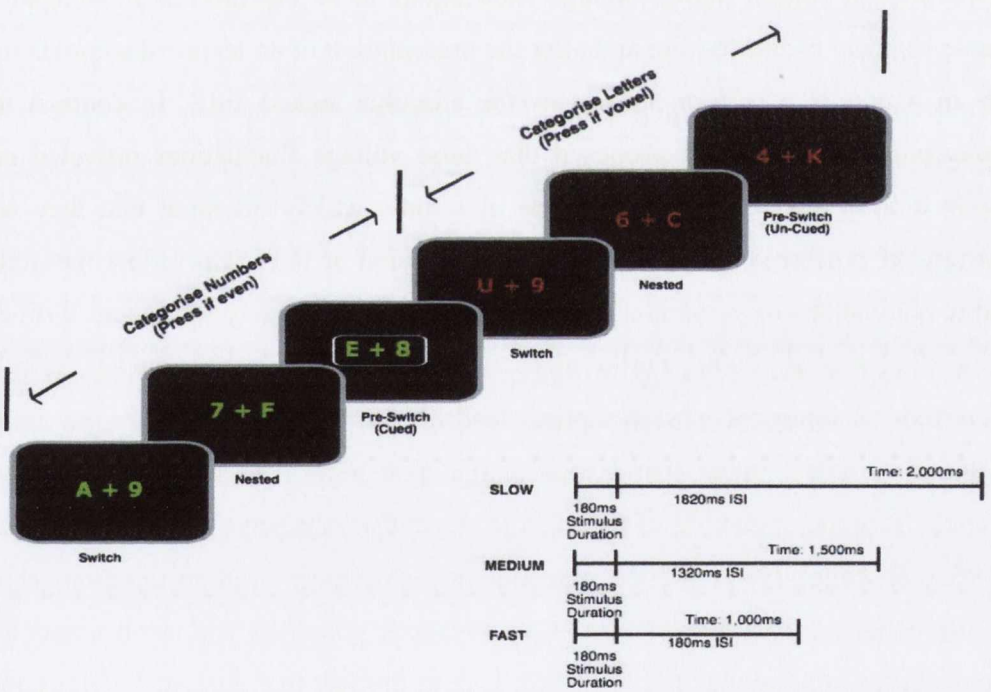


Figure 2.1: Task schematic of Switching Attention Task.

2.6 Electroencephalography (EEG)

Event related potentials (ERP) have become an increasingly popular tool for exploration of the mechanisms underlying the bilingual advantage in executive control. The beginnings of the technique date back to a series of experiments conducted in the 1920s and 1930s by Berger (as cited in Luck, 2005), which showed that the electrical activity of the human brain can be measured by attaching a series of electrodes to the scalp and amplifying the electrical signal. The resulting output represents the electroencephalogram or EEG in the form of rhythmic variations in voltage as a function of time (Coles & Rugg, 1995; Luck, 2005). Fluctuations in voltage are characterised by amplitude measured in microvolts (μV), latency, the time at which events occur and topography, the location on the scalp where a signal is recorded.

The measurement of a participant's EEG response to a repeating series of experimental stimuli allows voltage fluctuations to be captured and averaged for the same segment of time before and after the presentation of an identical stimulus resulting in an averaged waveform known as the stimulus locked ERP. In contrast to early conceptualisations, which proposed that these voltage fluctuations reflected only the brain activity evoked by the stimulus, it is now widely accepted that they reflect a variety of processes. Electrical potentials recorded at the scalp reflect the activity of large populations of pyramidal neurons that are synchronously active and form an open field (Picton et al., 2000). Furthermore, the electrical activity recorded at scalp level is believed to represent post-synaptic, dendritic potentials related to the release of neurotransmitters, rather than axonal action potentials, which represent voltage that travels from the beginning of the axon to the end where neurotransmitters are released (Coles & Rugg, 1995). Action potentials are extremely brief in duration, about one millisecond, whereas the duration of post-synaptic potentials can last between tens and hundreds of milliseconds (Luck, 2005). Due to the fact that electrical activity recorded at the scalp is dependent on the configuration of neurons, ERPs mostly capture the activity of the cerebral cortex rather than that of subcortical structures. This is due to the fact that in the cortical layers, the neurons share a similar orientation and the electrical fields created are less likely to cancel each other out (Coles & Rugg, 1995)

The primary advantage of using EEG is that it provides an online measure of brain activity allowing us to examine the stages of cognitive processing on a millisecond-by-millisecond basis. Despite their excellent temporal resolution, ERPs have very poor spatial resolution, which makes it difficult to establish the exact neural source of the voltage recorded at the level of the scalp. It is also difficult to make precise functional interpretations of the ERP components, given that several cognitive processes typically occur in unison. In comparison to background noise ERPs are very small in magnitude. To account for this, ERPs are typically averaged across trials related to certain experimental stimuli to separate the signal from the noise. The averaged waveform shows clear peaks and troughs in the form of positive or negative deflections, which are referred to as ERP components.

2.6.1 Early Components

The first major visual component is called C1. Unlike other components, C1 is not labelled with either a P (denoting positivity) or an N (denoting negativity) as its polarity can vary depending on whether the stimulus is presented in the upper or lower visual field (Clark, Fan & Hillyard, 1994). For stimuli presented on the horizontal midline, the C1 wave summates with P1 into a single wave. P1 is largest at lateral occipital electrode sites and typically onsets 60-90 ms post-stimulus with a peak between 100-130 ms (Luck, 2005). Traditionally, it was thought that the earlier the components occur in time, the more likely they are to be influenced by external factors such as stimulus characteristics (i.e., exogenous components), and the later they occur in time, the more likely they are to depend on internal factors (i.e., endogenous components). However it has been shown that early components such as P1 and N1 can be linked to increased attentional deployment (Dockree, Kelly, Robertson, Reilly & Foxe, 2005), furthermore successful amplitude modulation of early components has been shown to parallel improved perceptual discriminatory abilities and working memory performance (Berry, 2010; Mishra, 2014). The amplitude of early visual components such as P1 and N1 may be demonstrably impaired by prefrontal lesions, which highlights the relevance of examining these components in the context of executive function.

2.6.2 Components related to response inhibition

Two ERP components have been reliably related to response inhibition as measured in a Go/No-Go paradigm: the N2 waveform and the P3 waveform. The N2 is a negative deflection recorded approximately 200 to 400 ms after the stimulus onset. N2 typically shows maximal amplitude over anterio-central sites (Nieuwenhuis, Yeung, Van den Wildenberg & Ridderinkhof, 2003) and is typically larger on No-Go trials than on Go trials. N2 is proposed to represent response inhibition, conflict monitoring and perceptual mismatching (Botvinick, Braver, Barch, Carter & Cohen, 2001; Duan et al, 2009). The P3 appears as a positive waveform occurring 300-500 ms. after the stimulus onset. P3 has maximal amplitude at fronto-central electrode sites for No-Go trials and at parietal sites for Go trials (Pfefferbaum, Ford, Weller & Kopell, 1985). In terms of processing, P3 is proposed to reflect later stages of inhibition such as response evaluation and monitoring due to its long latency (Duan et al., 2009). Although there is no unanimous consensus in the literature regarding the exact interpretation of the processes underlying N2 and P3, it is generally accepted that they index aspects of executive control (Lamm, Zelazo & Lewis, 2006; Smith, Johnstone & Barry, 2007).

2.6.3 Electrophysiological Measurements

Pertinent to both Chapters 3 and 4 are the specific electrophysiological measurements taken to explore the bilingual advantage in early and late bilinguals (Chapter 3) and to trace the emergence of the bilingual advantage in adult L2 learners (Chapter 4). To this end, Continuous EEG data were acquired using an ActiveTwo System (BioSemi) from 64 scalp electrode in accordance with the standard 10/20 setup, and digitised at 512Hz. Horizontal and vertical eye movements were recorded using two vertical electro-occulogram (EOG) electrodes positioned above and below the left eye and two vertical EOG electrodes at the outer canthus of each eye. EEG data were processed using custom scripts in MATLAB drawing on EEGLAB routines for reading in data files and spherical spline interpolation of noisy channels (Delorme & Makeig, 2004). The EEG data were re-referenced offline to the average reference. EEG data were segmented into epochs centred on target onset using windows of -100 to 500 ms and -100 to 700 ms relative to target onset for the early and late components, respectively. The epochs were then baseline-corrected relative to the 100 ms interval prior to target onset. Response-aligned traces were derived by extracting epochs from -375 to 125 ms relative to the

response on each trial. Trials were rejected if any scalp channel exceeded an absolute value of 100μV at any time during the epoch. A low pass filter of 35Hz was applied to the data.

2.6.4 Event-Related Potential Analyses

A comprehensive event-related potential (ERP) analysis was carried out on five components of interest: two relating to early sensory processing, the P1 and N1 and the three previously discussed components relating to conflict monitoring and response inhibition, the N2, anterior P3 and parietal P3. The P1 and N1 components were measured over posterior parietal sites that showed the greatest deflections at these latencies based on inspection of the grand-average waveforms, namely electrode sites PO7 and PO8 (see Fig. 3.8). The P2 was measured over the central posterior scalp site (Pz) that showed the greatest deflection at this latency based on inspection of the grand-average waveform. Mirroring the existing literature, the N2 and anterior P3 components were measured over three frontocentral electrodes sites (Fz, FCz and Cz; see Fig. 3.9). Based on an inspection of the grand average spatial topographies, the parietal P3 was measured over Pz and POz (see Fig. 3.10). The mean amplitude of each component was calculated for each trial type and group. The mean amplitude of the components was measured across the largest positive or negative peak within an appropriate interval in the stimulus- and response-aligned traces based on inspection of the grand-average waveforms. In the stimulus-aligned grand averages, P1, N1, N2, anterior and parietal P3 mean amplitude was measured across time windows of 75 to 125, 135 to 185, 225 to 325, 300 to 360 and 300 to 360 ms, respectively. In the response-aligned average, the mean amplitude of the parietal P3 was measured across a -100 to 0 ms interval centred on response execution. The build-up rate of the response-aligned parietal P3 component was measured as the slope of a straight line fitted to the unfiltered ERP waveforms across a time window of -100 to 0 ms relative to response execution for each trial type and group.

Chapter 3 An Executive Control Advantage in Late Bilinguals relative to Early Bilinguals and Monolinguals.

3.1 Introduction

The knowledge and regular use of two languages has been shown to have an expansive impact, extending beyond the language system and broadly impacting nonverbal cognitive function. Bilinguals are typically defined as individuals who are equally well-versed in two (or more) languages, which they have been actively using, ideally, from early childhood. However, rising levels of global mobility have dramatically increased the numbers of people who, for various reasons, become bilingual later in life. Individual motivations for acquiring a second language later in life are countless and undoubtedly impact upon the outcome and alter its consequences. But whether we are considering a 20 year old who learns Spanish as an L2 in order to travel around South America, or a 35 year old immigrant in Ireland whose employment prospects and social inclusion heavily depend on their acquisition of English as an L2, both a large literature and observational evidence attest to the fact that the practice of learning a second language later in life is cognitively more difficult than acquiring two languages simultaneously from birth.

Two theories have been proposed to account for why and how the timing of second language acquisition impacts upon successful L2 acquisition. According to the critical period hypothesis (Johnson & Newport, 1989), differential outcomes for early

and late bilinguals can be attributed to the fact that late bilinguals' language progress does not increase at a steady rate and they can not achieve native-like proficiency in L2 (Kalia, Wilbourn & Ghio, 2014). Support for this perspective comes from behavioural studies in which later age of L2 acquisition is associated with lower levels of proficiency. Johnson & Newport (1989) measured intuitive knowledge of English using a grammaticality judgement task among Korean and Chinese long-term residents in the United States. Among early bilinguals (age of acquisition: 3-15) they observed a strong negative correlation between age of acquisition and grammatical knowledge and very little individual variation was observed. However, among late bilinguals (age of acquisition: <15) the correlation disappeared and was instead replaced by considerable individual variation. The findings of a more recent study (Abrahamsson, 2012) were largely in line with Johnson & Newport (1989), finding a robust negative correlation between early bilinguals (age of acquisition: <15) and performance on both a grammaticality judgement task and a voice-onset time task.

In contrast to the critical period hypothesis, the competition and entrenchment model put forward by Hernandez, Li and MacWhinney (2005) asserts that the differences between early and late bilinguals can be attributed to developmental factors that underlie L2 acquisition, such as brain plasticity and L1 entrenchment. This model contends that an infant's early language exposure results in their language being neurologically represented as sounds and therefore early bilinguals, exposed to two languages simultaneously from birth spend considerable time during pre-verbal development processing speech streams from two different languages. According to Hernandez and colleagues, when the time comes for the child to start producing language, this early exposure to two language streams facilitates the bilingual ability to keep both languages separate. In the case of the late bilingual, L1 is solidified before L2 is acquired, which means that a relatively automatic neural circuit of syntactic and semantic networks has already become entrenched by the time L2 is introduced. This results in L2 acting in a parasitic capacity to L1, with words from L2 clustering closely with relevant symbolic and phonological information from L1 and requiring the speaker to call to mind a target word in L1 in order to retrieve the same word in L2. In order to reduce the parasitic dependence of L2 on L1, late bilinguals must recruit a host of cognitive mechanisms and metacognitive strategies like rehearsal, imagery and recoding. Following this logic, it is reasonable to assume that late bilinguals who have

managed to achieve high levels of proficiency are also those individuals who have successfully exercised cognitive mechanisms to resolve the dependence on and interference from L1, and also those who have gainfully developed and harnessed metacognitive strategies.

In the case of highly proficient active bilinguals it is assumed that both languages are constantly jointly activated and that some measure of interaction is in operation at all times, even in contexts entirely driven by one of the two languages (Bialystok, Craik & Luk 2012). Evidence supporting the theory of joint activation comes from psycholinguistic studies (e.g. Beauvillian & Grainger, 1987; Dijkstra & Van Heuven, 2002; Kroll & Stewart, 1994), which suggest the influence of a currently unused language on the production and comprehension of speech. Further evidence comes from patient studies showing intrusions from the non-target language or irrelevant language switches (e.g. Fabbro, Skrap & Aglioti, 2010). Imaging studies also provide evidence in support of joint activation revealing that in the case of high-proficiency bilinguals neuro-anatomical representations of both languages are overlapping (Chee et al., 1999; Marian, Spivey and Hitch, 2003; Perani et al., 1998; Rodriguez-Fornells et al., 2002). Evidence for joint activation also extends to the case of late bilingualism, though potentially manifesting itself in a different way. Thierry and Wu (2007) demonstrated that the native language of late bilinguals (L2 acquired after age 12) was active during processing of their second language on a semantic judgement task.

The context for exploring the ways in which both early and late acquisition of a second language impacts upon both linguistic and general cognitive processing is neuroplasticity, the brain's ongoing capacity for structural and functional malleability (Lövdén et al., 2010). Plastic changes concern the modification of knowledge in the form of skills (such as language ability), and/or processes, in the form of efficiency of functions (such as executive control), manifesting in a change in behavioural performance (Enriquez-Geppert, Huster & Herrmann, 2013).

Neuroimaging studies have shown that bilinguals who acquired L2 before the age of 5 differ significantly from those who acquire L2 after the age of 10 in terms of grey matter density. Specifically, early bilinguals were found to have greater density of

grey matter in the inferior parietal area of the left and right hemispheres relative to late bilinguals (Mechelli et al, 2004). Another study showed that late bilinguals experience additional processing demands using language when compared to early bilinguals as evidenced by increased cortical activity (Hernandez et al., 2007). In addition, late learners typically have trouble with irregular items, showing more diffused neural activity compared to early bilinguals. There is less difference in semantic processing, which appears to be shared between languages and therefore less impacted by age of L2 acquisition (Hernandez & Li, 2007).

Ullman (2001) proposes a model of declarative/procedural language acquisition in which there is a distinction between a memorised lexicon and computational grammar; the former being a matter of declarative memory, the latter, of implicitly learned rules. The distinction between the two is concerned with the division between two memory systems: declarative and procedural. Ullman suggests that those who acquire L2 later in life no longer have access to the procedural system and its customised circuitry, which underpins early language acquisition, and so are required to recruit declarative memory to represent L2, a strategy which is much less efficient. Studies by Abutalebi and colleagues contradict Ullman's theory, showing that once high proficiency is achieved, bilinguals use identical areas for both their languages regardless of age of acquisition (Abutalebi & Green, 2008; Abutalebi & Green, 2007). These studies suggest that it is not so much a question of whether L1 and L2 share cortical representation, but instead that acquiring a new language changes the entire network.

Assuming that high proficiency in both languages is reached, both early and late bilinguals must resolve the conflict created by the joint activation of L1 and L2. It is assumed that bilinguals develop a sensitive mechanism of cognitive control that develops in parallel to L2 (Green, 1998) and operates with meticulous precision to select, engage with and monitor the target language and inhibit the non-target language and that this has consequences more generally for executive processes and for their neural representation (Abutalebi & Green, 2007). It is assumed that the task of resolving competition between competing languages and directing and maintaining attention is overseen by general cognitive systems, in particular the executive control system. Task switching paradigms have been developed to explore the functioning of the executive control system. In a typical task switching experiment, participants are presented with

two or more tasks, each with a set of rules, and are asked to switch between tasks when certain circumstances present themselves. Generally, this entails associating each task with a cue that informs the subject which task is relevant on each trial. Trials are sequenced and arranged such that participants repeatedly perform a task on given trials and are required to switch tasks on other trials (Wylie, Javitt & Foxe, 2004). Participants are normally given a number of trials, some requiring them to repeat the task and some to switch from one task to the other. Typically, repeated-task trials result in better performance with shorter reaction times (RTs) and fewer errors (Wylie et al, 2003). This performance decrement on switch trials has been termed the 'switch cost' and is considered to be reflective of the operations of executive functions on switch relative to repeat trials (Rubenstein, Meyer & Evans, 2001).

The mechanisms influenced by the early or late acquisition of L2 undoubtedly lead to differential development or reorganisation of the supporting networks. Behavioural research on executive function in early and late bilinguals has produced disparate results. Pelham and Abrams (2014) used the Attentional Network Task (ANT) to assess executive function in early and late bilinguals. Participants' ability to suppress interference from distractors was evaluated in terms of accuracy and reaction time (RT). The study found that both early and late bilinguals performed better than monolinguals and that there was no difference in accuracy or RT between the early and late bilinguals. By contrast Luk et al. (2011) used the Flanker task to compare inhibitory control in early and late bilinguals in terms of RT on congruent and incongruent trials and found that early bilinguals had a reduced switch cost relative to the late bilinguals and monolinguals. However the late bilinguals in both studies had significantly lower levels of proficiency than the early bilinguals. Additionally it is important to take note of how participants were classified as early or late bilinguals in these studies. Pelham & Abrams (2014) used the age at which the participant reports becoming fluent in their second language to categorise them as early (pre age 7) or late (post age 13) bilinguals. Luk and colleagues (2011) asked participants to report the age at which they became actively bilingual and used this to categorise them as early (pre 10 years) or late (post 10 years). Additionally the late bilinguals in both studies had significantly lower levels of proficiency than the early bilinguals. Disparate results may therefore be attributed to differing methodology across experiments.

The present study investigated executive function in Early (pre 7) and Late (post 13) high-proficiency active bilinguals within a task-switching paradigm while simultaneously collecting EEG data. Behavioural differences in the switch cost are interpreted to be reflective of the operations of executive processes (Rogers & Monsell, 1995; Meiran, 1996, 2000; Rubinstein et al., 2001; Wylie et al, 2008), while reduced false press and omission errors are taken as a measure of inhibitory control. Electrophysiologically, differences in early sensory components are interpreted to be reflective of early attentional deployment (Dockree et al., 2005). The N2/frontal P3 components are interpreted in the context of response inhibition while parietal P3 is interpreted in terms of attention switching and mapping signal to response.

3.1.1 Hypotheses

H0: There will be no difference, either behaviourally or electrophysiologically, between Early bilinguals, Late bilinguals or Monolinguals

H1: There will be an observable difference, behaviourally and electrophysiologically between Early bilinguals, Late bilinguals and Monolinguals.

3.2 Methods

3.2.1 Participants

20 Early bilinguals (7 male), all of whom acquired their second language before the age of 7 and report active use of L2 daily or almost daily before the age of 12, and 21 Late bilinguals (7 male), who acquired their second language during or after adolescence (age 12) were recruited (see Table 3.1) All bilingual participants report current active use of L2 multiple times on a daily or almost daily basis and were actively bilingual for more than 5 years. The control group was comprised of 26 Monolinguals (18 male) with no functional knowledge of a second language. All participants gave informed consent to procedures approved by the Trinity College Dublin Ethics Committee, which is conducted in accordance with the Declaration of Helsinki.

Table 3.1: Mean and standard deviation for Age of Acquisition, Active Use, and Years of Active Use of L2

Variables	Early Bilinguals	Late Bilinguals
Age of Acquisition	2.75 (2.65)	12.59(.85)
Age of Active Use	5.80(5.6)	19.95(5.50)
Years of Active Bilingualism	22.59 (6.16)	8.81 (4.14)

Assess to and recruitment of Early and Late Bilinguals and Monolinguals

The process of recruiting Early and Late bilinguals was predominantly carried out through two channels: word of mouth and poster advertising. A poster requesting the participation of highly proficient bilinguals who had acquired L2 eiter pre age 7 or post age 12 was displayed in Trinity College Dublin Institute of Neuroscience and School of Psychology, which resulted in the recruitment of 7 Early and 6 Late bilinguals. These individuals spoke English as a second language and were currently attending third level education through English.

The same poster was distributed within the offices of Google and Facebook which resulted in the recruitment of 10 Early and 8 Late bilinguals, all of whom use both languages throughout their daily working lives.

Word of mouth contact was made with former students of Delfin English School, Dublin who had, over the last number of years, graduated and passed the Cambridge Advanced Certificate of English or the Cambridge Proficiency in English exams and had continuted to live and work in Dublin, using English on a daily basis. This resulted in the recruitment of 7 Late bilinguals.

The remaining 3 Early bilinguals were recruited by word of mouth and were individuals who were raised in the Gaeltacht speaking both Irish and English from birth.

The monolinguals were recruited by means of a poster requesting the participation of monolingual individuals who have no functional knowledge of a second language. This poster was displayed in the Maths Department of Trinity College Dublin. Additionally an announcement was made in an undergraduate introductory lecture. This resulted in the recruitment of 26 monolinguals participants, who constituted the control group.

3.2.2 Demographics

Descriptive statistics were used to determine whether the EB, LB and ML (Early bilingual, Late bilingual and Monolingual) groups were appropriately matched in age, years of education (as self-reported on a three-point scale) and IQ as measured by the Test of Non-Verbal Intelligence (TONI-3). (see Table 3.2).

Table 3.2: Mean & standard deviation for group matching variables for language groups

Variables	Early Bilinguals	Late Bilinguals	Monolinguals
Age	27.45 (4.74)	29.04(6.24)	18.73(.77)
***Education Level**	2.95(0.22)	2.95(0.21)	3.00(0.00)
IQ (TONI)	33.80(6.97)	33.09(6.75)	34.07(6.07)

**1=primary, 2=secondary, 3=currently attending/completed third level*

A one-way between-subjects ANOVA revealed that age differed as a function of group ($F_{(2, 64)} = 38.52$, p=0.001). A post-hoc analysis indicated that age did not differ in the Early and Late bilingual groups (p= 0.48). However, the Monolingual group differed significantly in age from the Early bilingual (p= 0.001) and Late bilingual groups (p=0.001). These differences are acknowledged and addressed in the results section. Participants were matched in terms of education level given that all bar two participants were currently attending or had completed third level education. There were no significant differences in IQ as measured by the TONI-3 ($p > 0.05$).

3.2.3 Bilingual Language Questionnaire

Participants completed a language questionnaire (see Appendix A) rating their overall command of each language, along with their level of proficiency in speaking, reading, writing, comprehension and pronunciation on a six-point scale. Participants also

reported their age of acquisition and the age at which they actively began to use two languages daily or almost daily. They described their current and previous language use and practices including factors that contributed to their acquisition of L2 and the rate at which they are exposed to or are using either language in a variety of contexts. Participants were also asked about their perception of their accent when speaking L2 and gave account of which language is favoured for specific mental and emotional activities. Finally, they outlined their motivations for acquiring L2 and reported self-confidence as a language learner.

Test of Non-Verbal Intelligence (TONI-3)

All participants were administered the Test of Non-Verbal Intelligence (Brown, Sherbenou and Johnsen, 1997). The TONI-3 is a language-free measure of nonverbal cognitive ability designed to assess perceptual abstract reasoning and problem-solving abilities. The measure consists of 45 visual designs presented in order of increasing complexity. The instructions are pantomimed by an examiner in order to reduce the influence of language on performance. The participant responds by pointing to the correct response in the stimulus booklet. Each item has between four and six answer choices. The test is discontinued once the participant has made three incorrect responses within five consecutive items. The TONI-3 has a previously reported alpha coefficient of 0.96 (Brown Sherbenou and Johnsen, 1997) indicating strong internal consistency. The TONI-3 shares convergent validity with the WAIS-R, and scores on the TONI-3 have been shown to be strongly positively correlated with the Matrix Reasoning subtest of the WISC-IV. Positive correlations have also been found between the TONI-3 and measures that tap into other aspects of intelligence, such as verbal abilities and processing speed (Atlas, 2001; Brown; DeMauro, 2001; Brown, Sherbenou and Johnsen, 1997).

3.2.4 Procedure

64-channel EEG was recorded while participants completed the Switching Attention Task (See Chapter 2, 2.5 for description of the SWAT and 2.6.3 for description of the specific electrophysiological measurements obtained in this study).

Participants were seated in a dimly lit, sound attenuated, electrically shielded room 80 cm from a computer monitor. Stimuli were presented centrally. Task instructions were given, repeated if necessary, and participants were given a practice trial at the slow condition speed, which was repeated if necessary. A short break was taken after every six blocks in order to minimise fatigue and concentration lapses.

3.2.5 Analysis Strategy

Where ANOVAs were used for statistical analysis and sphericity was violated, Huynh-Feldt corrected significance values are reported. Where ANOVAs yielded significant main effects, Least Significant Difference (LSD) pairwise comparisons were used to identify the levels of the independent variable between which the significant differences lay. The relationship between any two variables of interest was explored using non-parametric Spearman's rho correlations or paramteric Pearson's correlations depending of the underlying normaility of the data.

Data Trimming

Prior to performing analyses, practice trials and trials upon which task instructions had not been followed were excluded from the data. Outliers were removed from specific analyses if their values within that analysis were more than 3 times the interquartile range or more than 2.5 standard deviations above or below the group mean.

3.3 Results

3.3.1 Behavioural Results

Switch Cost as a measurement of Executive Function

A 3 x 3 mixed factorial ANOVA with Group (Early bilingual, Late bilingual, Monolingual) as the between-subjects factor, Speed (1,000ms, 15,00ms, 2,000ms) as the within-subjects factor and the Switch Cost as the dependent variable, was carried out. This analysis revealed a significant main effect of Speed ($F_{(1.90,\ 3.81)}$ =17.38, p=.0001, ηp^2 =. 89) such that as the difficulty of the task increased (i.e., faster conditions) the switch costs for all groups also increased. Additionally, there was a

significant main effect of Group ($F_{(2, 64)}$ = 3.24, p=.045, ηp^2 =.09); and a post-hoc analysis indicated that on measures of Switch Cost RT, Late Bilinguals showed a reliably reduced Switch Cost compared to Early Bilinguals (p=0.025) and to Monolinguals (p=0.036), but Early Bilinguals did not differ from Monolinguals (p=0.773). There was no significant interaction between Speed and Group (p=0.19).



Figure 3.1: Reduced Switch Cost RT in Late Bilinguals

Relationship between Age and the Switch Cost

A number of Pearson's correlations were conducted to assess the relationship between Age and Switch Cost. As there was a significant main effect of Speed in the Switch Cost analysis, switch costs at each speed condition were summed to generate an overall switch cost measurement, which was subsequently correlated with Age. Non-significant relationships were observed between overall Switch Cost and Age for the Early bilinguals (r=0.10, p=0.68), the Late bilinguals (r=0.11, p=0.68) and the Monolinguals (r=0.32, p=0.13).

Overall Reaction Time

To explore overall differences in reaction time between experimental groups across each speed condition a 3x3x3 mixed factorial ANOVA was carried out with Group (EB, LB, ML) as the between-subjects factor, Speed (1,000ms, 15,00ms, 2,000ms) and Trial

Type (switch, nested, pre-switch) as the within-subjects factors and reaction time as the dependent variable, was carried out. This analysis indicated that there was a significant main effect of Speed ($F_{(1.46, 98.38)}$=347.57, p=0.0001); faster reaction times were observed under faster conditions. Furthermore, there was a significant main effect of Trial Type ($F_{(1.46, 98.38)}$=116.60, p=.0001) such that responses were slowest on switch trials relative to nested and repeated trials.

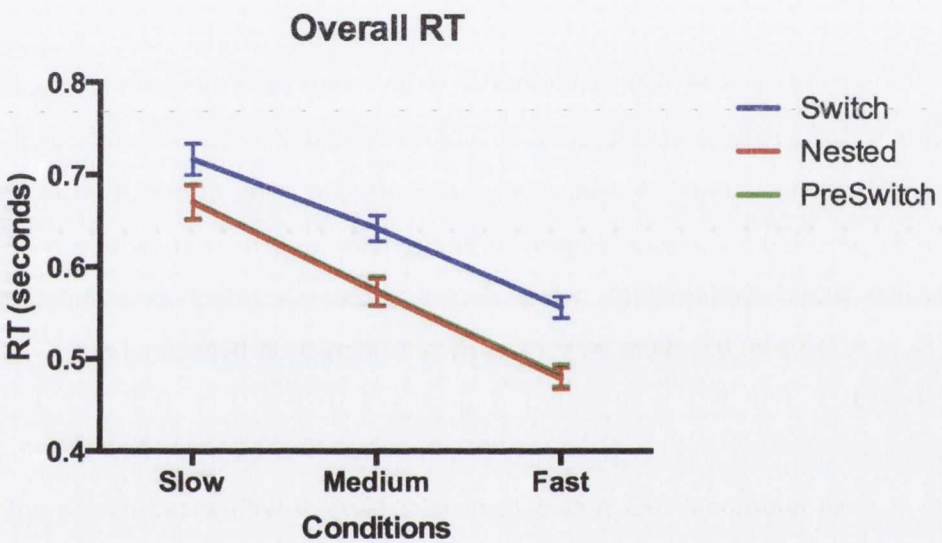


Figure 3.2: Increased RT on Switch Trials

Pre-Switch Cue

On 50% of Pre-Switch trials, a box cue accompanied the presentation of the stimuli signalling a change from number to letter task. Group did not have an impact on Pre-Switch RT on cued vs non cued Pre-Switch Trials ($p > 0.05$).

In order to assess whether there was an effect of cue on the Switch Cost of subsequent trials, a 2x3x3 mixed factorial ANOVA was conducted with Cue (cued vs non-cued trials) and Speed as the within-subjects factors, Group as the between-subjects factor and Switch Cost as the dependent variable. There was no significant main effect of Cue or Group (both p>0.05).

Task Accuracy: D-Prime

In order to assess response accuracy, the proportion of correct responses to go-trials (hits) and the proportion of false presses to no-go trials (false alarms) were calculated. The discriminability index measured by d' was used to separate the means of signal and noise distribution compared with the standard deviation of the noise distribution. The d' scores reflect perceptual sensitivity to the go and no-go conditions with higher values indicating superior sensitivity. Scores range from 0, an indication of inability to discriminate between experimental stimuli, and 4.65, considered to be "effective ceiling" (Macmillian & Creelman, 2005)

A 3x3 mixed factorial ANOVA with Trial Type as the within-subjects factor, Group as the between-subjects factor and measurements of d' accuracy as the dependent variable demonstrated that there was a significant main effect of Trial Type ($F_{(2, 4)}$= 26.94, p=0.001); accuracy improved as the task looped from switch to nested to pre-switch trials. Additionally, while accuracy did not differ as a function of Group ($F_{(2,64)}$=.215 p>0.05) there was a significant interaction between Trial Type and Group (p=.035).

An additional 3x3 mixed factorial ANOVA with speed as the within-subjects factor, Group as the between-subjects factor and measurements of d' accuracy as the dependent variable revealed a significant main effect of Speed ($F_{(2, 4)}$ = 90.52, p=0.001) such that as the task got faster accuracy levels declined. Furthermore, while accuracy did not vary as a function of Group ($F_{(2,64)=}$ .215 p>0.05) there was an interaction between Group and Speed (p=0.01).

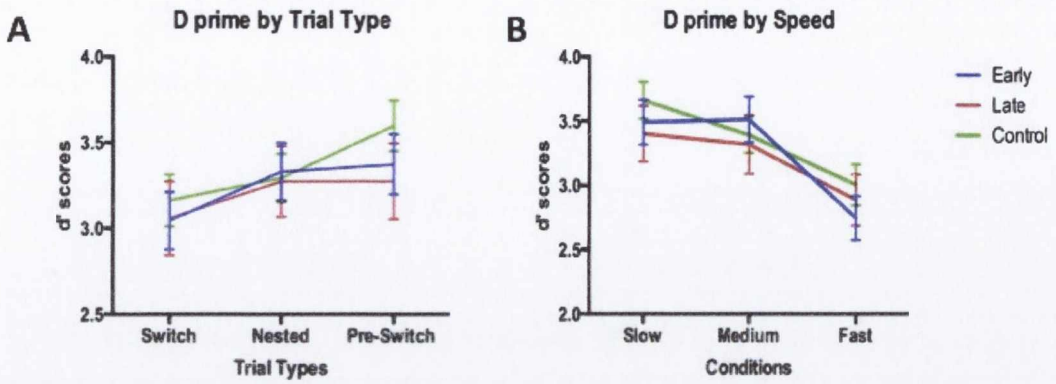


Figure 3.3: Accuracy across Trial Types and Speed Conditions.

A, Accuracy across Trial Type. **B**, Accuracy across Speed Conditions.

False Press Errors

A false press error is registered on No-Go trials where the participant is required to withhold a response and fails to do so. At each speed there is the potential to make 120 false press errors (where the participant has completed six blocks) on each trial type (switch, nested, pre-switch), therefore the proportion of false press errors is calculated as total trial type false press error divided by the number of possible errors.

A 3x3x3 mixed factorial ANOVA with Group (EB, LB, ML) as the between-subjects factor, Speed (1,000ms, 15,00ms, 2,000ms) and Trial Type (switch, nested, pre-switch) as the within-subjects factors and proportion of False Press errors as the dependent variable, was carried out. This analysis indicated that as the difficulty of the task increased such that the speed conditions became faster the proportion of False Press errors increased for all groups ($F_{(1.60,\ 102.65)}$ =70.12, p=.001). There was no meaningful interaction between Group and Speed (p>0.05). A main effect of Trial Type was found ($F_{(1.52,\ 97.35)}$=.886, p=0.001)

There was a significant interaction between Speed and Trial Type such that there were more errors on switch trials under fast conditions (p=0.01). Errors did not vary as a function of Group ($F_{(1,64)}$ = 0.86, p>0.05).

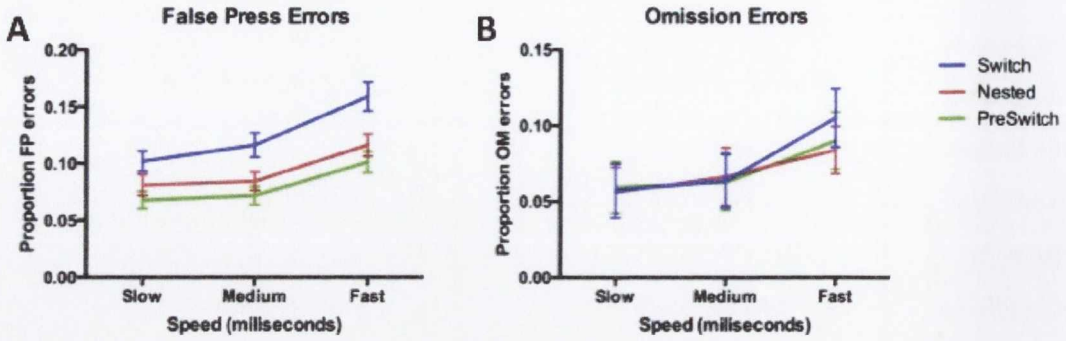


Figure 3.4: Proportion of False Press and Ommission Errors.

A, Proportion of False Press Errors across each Trial Type. **B,** Proportion of Ommission Errors across each Trial Type.

Omission Errors

An omission error is registered on go trials where the participant is required to make a response and fails to do so. At each speed there is the potential to make 120 omission errors (where the participant has completed six blocks) on each trial type (switch, nested, pre-switch), therefore the proportion of omission errors is calculated as total trial type omission error divided by the number of potential errors.

A 3x3x3 mixed factorial ANOVA with Group (EB, LB, ML) as the between subjects factor, Speed (1,000ms, 15,00ms, 2,000ms) and Trial Type (switch, nested, pre-switch) as the within-subjects factors and proportion of omission errors as the dependent variable, was carried out. As the difficulty of the task increased such that the conditions became faster, the number of omission errors increased for all groups ($F_{(1.52, 97.63)}$ =25.42, p=0.001). Additionally, there was no significant main effect for Trial Type ($F_{(1.61, 109.05)}$=0.093, p>0.05) or interaction between Speed and Group or Speed and Trial Type (both p>0.05).

3.3.2 Extra-Linguistic Factors impacting upon Executive Control

Multilingualism

Within the bilingual sample, a number of participants in both the Early and the Late Bilingual groups reported knowledge of additional languages. In cases where participants reported an intermediate or above level of an additional language they were classified as trilingual (three languages), quadrilingual (four languages) or polyglot (more than four languages). A Spearman's rho correlation analysis indicated that there was no significant relationship between Multilingualism and Switch Cost on Fast, Medium or Slow trials (all $p>0.05$)

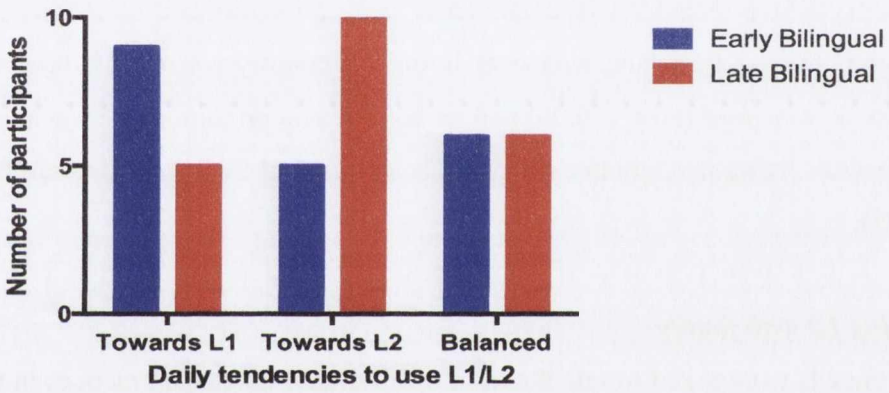


Figure 3.5: Self-Reported Language Balance and Usage Tendencies

Self-Reported Language Balance and Usage Tendencies

Bilinguals were asked to report their daily tendencies to use or switch between one or more of their languages and were subsequently grouped as Tendency towards L1, Tendency towards L2 or Balanced in the case that they reported using and switching between each of their two of their languages equally throughout their daily life. A 3x3 mixed factorial ANOVA with Language Balance Group (Tendency towards L1, Tendency towards L2, Balanced) as the between-subjects factor, Speed (1,000ms, 15,00ms, 2,000ms) as the within-subjects factor and Switch Cost as the dependant variable, was carried out. A main effect of Group ($F_{(1, 38)}$ =69.30, p=0.001 was found such that there were significant differences between all Language Tendency Groups with those who tended towards more frequent use of L2 having the most reduced Switch Cost, followed by those who reported a balanced use of L1 and L2, followed by those who tended towards L1 (all p=0.001).

Formal education in L2

Bilinguals were asked to report the impact of formal education on their acquisition of L2, and additionally to report whether they were currently in formal education carried out through their L2. There were no significant correlations between Language of Education (past or current) and Switch Cost at any speed (all $p > 0.05$).

Living in a country where L2 is spoken

Bilinguals were asked to report the length of time in which they have lived in a country where their second language is spoken, the impact that living in a country where L2 is spoken has had on their acquisition of L2 and whether they are currently living in a country where their L2 is spoken. There were no significant correlations between the length of time participants have been living a in country where L2 is Spoken and Switch Cost at any speed (all $p > 0.05$) and no significant correlations between current or past impact of living in a country where L2 is spoken and Switch Cost at any speed (all $p > 0.05$).

Using L2 with family

Bilinguals were asked to rate the impact of familial language practices in terms of their acquisition of L2. They were also asked to report whether they currently used L2 to communicate with their family. There were no significant correlations between the impact of using L2 with family or current use of L2 with family and Switch Cost at any speed (all $p > 0.05$).

Using L2 with friends

Bilinguals were asked to rate the impact that their use of L2 with friends had on their acquisition of L2. They were also asked to report whether they currently used L2 when communicating with their friends. Additionally, they were asked to indicate what proportion of their friends were speakers of the languages they know well. There were no significant correlations between past or current use of L2 with friends or the proportion of friends who use L2 and Switch Cost at any speed (all $p > 0.05$).

Using L2 with a partner

Bilinguals were asked to report the impact that interacting with a romantic partner had on their acquisition of L2 and were also asked to report whether they currently use L2 at present in a romantic relationship. There was a highly significant negative correlation between use of L2 in a current romantic relationship and Switch Cost at all speeds such that those who reported increased use of L2 in a current relationship displayed a reduced Switch Cost. (Fast r= -.551, p=0.001, Medium r= -706, p= 0.001, Slow r=-.536, p= 0.001).

Using L2 at work

Bilinguals were asked to report the impact that a past or present job had on their acquisition of L2. They were also asked to rate their current exposure to and use of L2 at work. There was no significant correlation between the impact of a past or present job on L2 acquisition and Switch Cost, however there was a highly significant correlation between current use of L2 at work and reduced Switch Cost (Fast r= -.541, p=0.001, Medium r= -675, p= 0.001, Slow r=-.421, p= 0.007).

Other factors of interest

There were no significant correlations between current or past influence of L2 when listening to radio/podcasts/music or watching TV or films or reading or using the Internet (all p >0.05)

Using L2 for mental arithmetic and remembering numbers

No correlations were carried for impact of L1, L2 or balanced use of both on mental arithmetic due to the fact that of 41 bilinguals all, save 2, reported favouring their L1 for mental arithmetic. Similarly, no correlations were carried for impact of L1 L2 or balanced use of both on remembering numbers as all, save 6, bilinguals reported relying on L1 for remembering numbers.

Thinking, dreaming and self-talk in L2

Bilinguals were asked to report their tendencies to use each of their languages for thinking, dreaming and self-talk. There were no significant correlations between balance of languages for dreaming, thinking or self-talk and Switch Cost (all p >0.05).

Self-Perception of a foreign accent in L2

Out of 20 Early Bilinguals, 13 participants self-reported that they perceived themselves to have no accent while speaking their L2, the remaining 7 Early Bilinguals self-reported having a mild accent. Of the 21 Late Bilinguals, 18 self-reported having a mild accent when speaking L2, whereas 2 participants in this group reported perceiving their accent as strong when speaking L2.

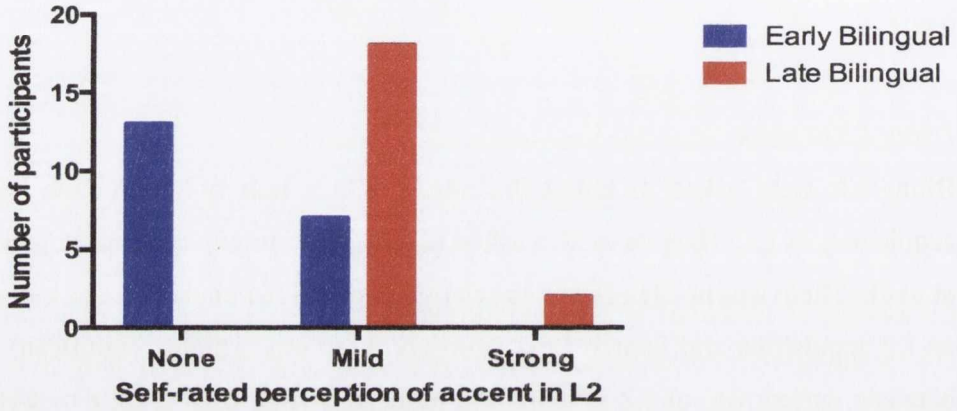


Figure 3.6: Self-Perception of Foreign Accent in L2

Motivation for becoming bilingual

All bilinguals, both Early and Late cited work/job and immigration to a new country as a motivation for learning or maintaining their second language. Of the 20 Early Bilinguals, 10 participants reported that factors outside of their own control were responsible for their becoming bilingual, with 7 of that 10 also and school or university as motivating factors and 7 citing pleasure, recreation and travel as an additional motivation. Of the 21 Late bilinguals, in addition to employment, education seemed to be a strong motivating factor with 16 late bilinguals citing school or university as motivation for learning or maintaining their L2, and 14 citing pleasure, recreation and travel as an additional motivation.

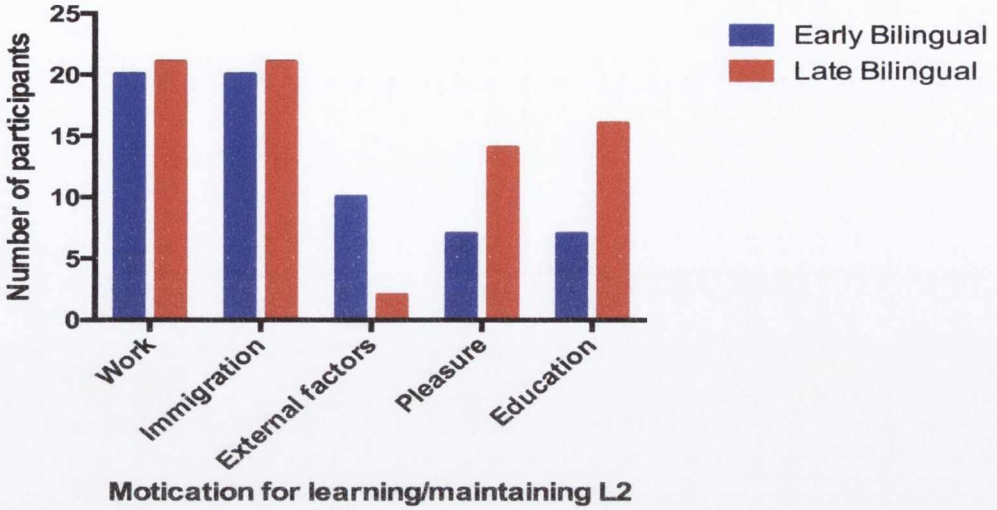


Figure 3.7: Self-Reported Motivation for Learning/Maintaining L2

Confidence in language learning abilities

On a scale of 1-10 All bilinguals self-reported their ability to learn languages in general as being above a 6 with Late Bilinguals self-reporting higher rates of confidence (8/10) in their general aptitude for language learning than Early bilinguals (6/10).

3.4 Electrophysiological Results

3.4.1 Early Components: P1, N1.

The grand average signal time courses aligned to target onset were plotted for each Trial Type and Group (Fig. 3.8). Analysis of the stimulus-aligned waveforms revealed that the mean amplitude of the P1 component was not sensitive to Trial Type and that there was no significant interaction between Trial Type and Group (all $p > 0.05$). P1 amplitude was modulated by Group ($F_{(1,58)} = 4.01$, p=0.023) such that Monolinguals had a significantly more positive mean amplitude than the Early (p=0.009) and Late (p=0.042) Bilinguals. The mean amplitude of the N1 component was also insensitive to the Trial Type manipulation and there was also no significant interaction between Group and Trial Type (all $p > 0.05$). Like P1 amplitude, N1 amplitude was influenced by Group ($F_{(1,58)} = 3.68$, p= 0.03); Monolinguals had a less negative amplitude than the Late (p=0.01), but not the Early (p=0.07) Bilinguals.

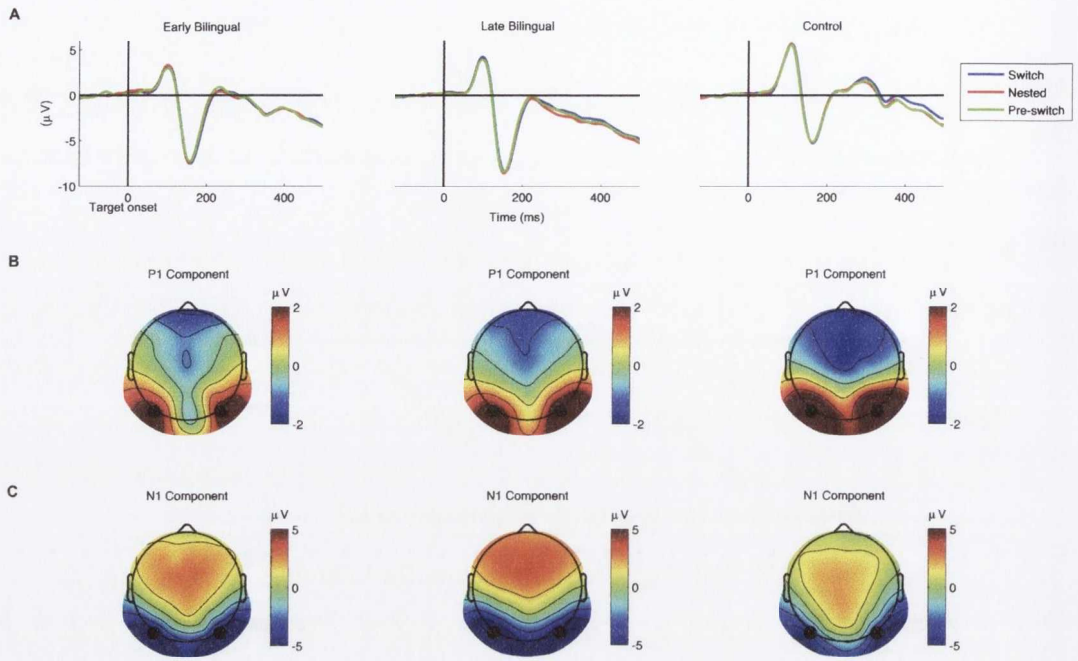


Figure 3.8: Early sensory components were insensitive to Trial Type but were differentially modulated by Group.

A, Grand average waveforms aligned to target onset for the Early Bilingual (left), Late Bilingual (middle) and Control (right) groups. Monolinguals had a significantly more positive P1 component than both Bilingual groups and a less negative N1 component than the Late but not the Early Bilinguals. **B,** Spatial topography of the P1 component across a time window of 75 to 125 ms centred on target onset. **(C)** Spatial topography of the N1 component spanning the interval 135 to 185 ms centred on target onset.

There were no significant correlations between P1 or N1 mean amplitude and the behavioural Switch Cost or behavioural task accuracy as measured by d' in the case of the Early bilinguals and Monolinguals (all $p>0.05$), however in the case of the Late bilinguals, there was a significant negative correlation between the mean amplitude of the Switch N1 and d' on Switch trials, (r=-.672, p=0.01), Nested N1 and d' on Nested trails, (r=-.538, p=0.01), and Pre-Switch N1 and d' on Pre-switch trials, (r=-.462, p=0.03), such that a more negative N1 signalled greater accuracy on all trial types for the Late Bilinguals.

3.4.2 N2 and frontal P3 Components

The grand average signal time courses aligned to target onset were plotted for each Trial Type and Group (Fig. 3.9). Analysis of the stimulus-aligned waveforms revealed that the mean amplitude of the N2 on the Go trials was influenced by Trial Type ($F_{(2, 116)}$ = 7.69, p=0.001) such that the component was significantly more negative on Switch relative to Pre-switch trials (p= 0.001) and Nested trials (p= 0.003). There was no significant difference in the mean amplitude of the Go N2 component recorded on the Nested and Pre-Switch trials (p= 0.64). While the mean amplitude of the Go N2 component was sensitive to Trial Type, it was unaffected by Group and again there was no meaningful interaction between the two factors (all $p > 0.05$).

The mean amplitude of the N2 component on the No-Go trials was also modulated by Trial Type ($F_{(2, 116)}$=3.69, p=.028). Mirroring the pattern of results observed in the Go N2 component, a significantly more negative No-Go N2 amplitude was recorded on Switch relative to Nested trials (p=0.007). While not reaching statistical significance, there was a marginal trend towards a more negative No-Go N2 amplitude on Pre-switch relative to Nested trials (p=0.062). There was no significant difference in the No-Go N2 amplitude measured on the Switch and Pre-switch trials (p=0.48). N2 amplitude on No-Go trials was also not differentially modulated by Group and there was no significant interaction between the two factors (both p>0.05). Analysis of Go relative to No-Go N2 revealed a more negative N2 on No-Go relative to Go trials for Switch (p=0.02) and Nested (p=0.08) trials, but not for Pre-Switch (p=0.15) for all groups.

Analysis of the stimulus-aligned frontal P3 traces on Go trials revealed that there was a significant main effect of Trial Type ($F_{(2, 116)}$ =12.82, p=0.001) such that a significantly more positive frontal P3 amplitude was observed on Nested (p =0.001) and Pre-Switch (p =0.003) relative to Switch trials. There was no significant difference in Go frontal P3 amplitude measured on Nested and Pre-switch trials (p>0.05). As was the case for the N2 component, frontal P3 amplitude on Go trials was unaffected by Group and there was no significant interaction between Trial Type and Group (all p> 0.05).

The frontal P3 measured on NoGo trials was also significantly modulated by Trial Type ($F_{(2, 116)} = 4.2$, $p= 0.017$) such that a significantly more positive frontal P3 amplitude was recorded on Nested (p =0.01) and Pre-Switch (p =0.02) relative to Switch trials. There was no significant difference in No-Go frontal P3 amplitude measured on Nested and Pre-switch trials (p =0.87). As was the case for the Go frontal P3 component, frontal P3 amplitude on No-Go trials was unaffected by Group and there was no significant interaction between Trial Type and Group (all $p > 0.05$). Analysis of Go relative to No-Go frontal P3 revealed a more positive frontal P3 on Go relative to No-Go for Nested trials (p=0.003), but not for Switch (p=0.64), or Pre-Switch trials (p=0.39) for all groups.

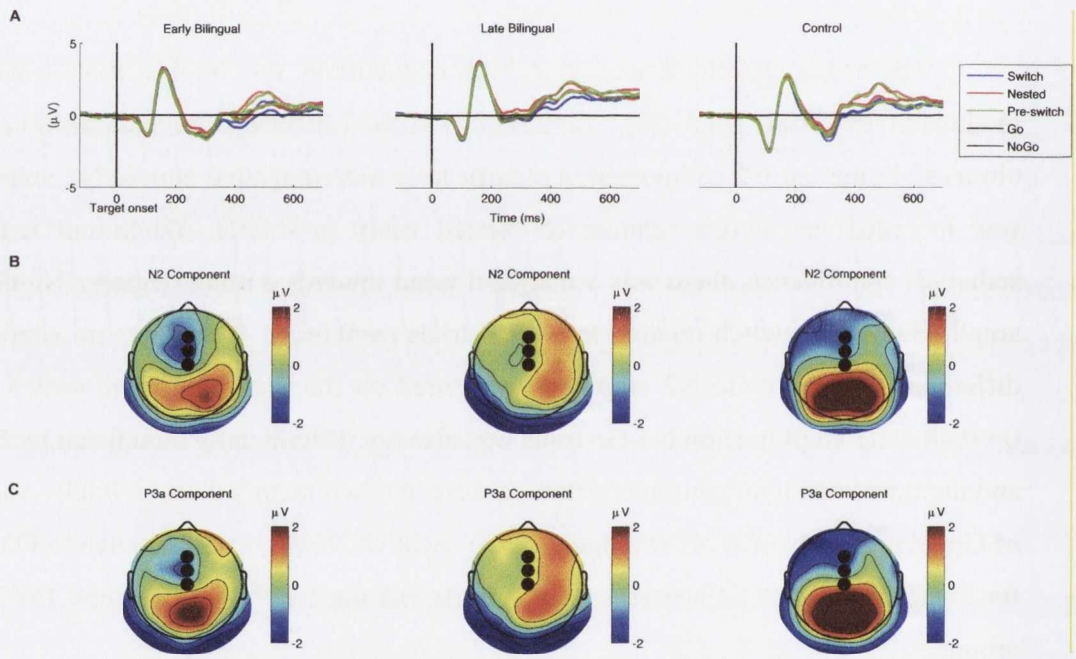


Figure 3.9: Frontal P3 and N2 components differnetially modulated by Trial Type but not by Group.

A, Grand average waveforms aligned to target onset for the Early Bilingual (left), Late Bilingual (middle) and Control (right) groups. **B,** Spatial topography of the N2 component across a time window of 225 to 325 ms centred on target onset for each group. **(C)** Spatial topography of the frontal P3 component spanning the interval 300 to 360 ms centred on target onset for each group.

3.4.3 Stimulus and Response-aligned parietal P3 Component

Analysis of the stimulus-aligned parietal P3 traces on Go trials revealed that there was a significant main effect of Trial Type ($F_{(2, 116)}$= 8.37, p=0.0001) such that a significantly more positive parietal P3 amplitude was observed on Switch relative to Nested (p =0.001) and Pre-Switch trials (p=0.003). Comparable stimulus-aligned parietal P3 amplitude was recorded on the Nested and Pre-Switch trials (p=0.50). Additionally, stimulus-aligned parietal P3 amplitude was modulated by Group ($F_{(1, 58)}$ = 3.92, p= .025); Late Bilinguals differed from Monolinguals (p=.007) but not from Early Bilinguals (p=.302). Finally, there was no significant interaction between the two factors. Analysis of the stimulus-aligned parietal P3 responses on No-Go trials revealed that the mean amplitude of the component was also modulated by Trial Type ($_{F(2, 116)}$ = 5.91, p=0.004). A greater stimulus-aligned No-Go parietal P3 amplitude was observed on Switch relative to Nested (p=0.001) and Pre-Switch Trials (p=0.02). Comparable stimulus-aligned parietal P3 amplitudes were observed on Nested and Pre-switch trials (p=0.39). Again, the stimulus-aligned No-Go parietal P3 amplitude was affected by Group ($F_{(1, 58)}$ = 4.398, p = 0.01). Simple contrasts showed that Late bilinguals differed from Monolinguals (p=.005) but not from Early bilinguals (p=.301)

There was a significant negative correlation between the stimulus-aligned No-Go parietal P3 mean amplitude and Switch Cost for Early bilinguals on Switch (r=-.494, p=0.03), Nested (r=-.487, p=0.03), and Pre-Switch (r=-.471, p=0.04) trials such that an increased parietal P3 indicated a reduced Switch Cost on all trial types for Early Bilinguals but not for the Late bilinguals or Monolinguals (both $p > 0.05$).

Analysis of the parietal P3 traces time-locked to response execution on Go trials revealed that mean amplitude of the component was sensitive to Trial Type ($F_{(2, 116)}$ = 18.73, p= 0.001). A greater response-aligned Go parietal P3 amplitude was observed on Switch relative to Nested (p=0.001) and Pre-Switch Trials (p=0.001). Comparable response-aligned parietal P3 amplitude was observed on Nested and Pre-Switch trials (p=0.33). Again, the response-aligned Go parietal P3 amplitude was affected by Group ($F_{(1, 58)}$ = 3.83, p=0.02). Simple contrasts revealed that Late Bilinguals had reduced mean amplitude compared to Monolinguals (p=0.008) but not Early Bilinguals (p=0.31). The rate of rise of the response-aligned parietal P3 component was unaffected

by both Trial Type and Group and it followed that there was no significant interaction between the two factors (all $p > .05$).

There was a significant correlation for the Late Bilinguals between the rate of rise of the response-aligned parietal P3 and task accuracy as measured by d' on Switch (r=.481, p=0.02), Nested (r=.554, p=0.009), and Pre-Switch, (r=.550, p=0.01) trials. No such correlations were found for the Early bilinguals or Monolinguals (both $p > 0.05$).

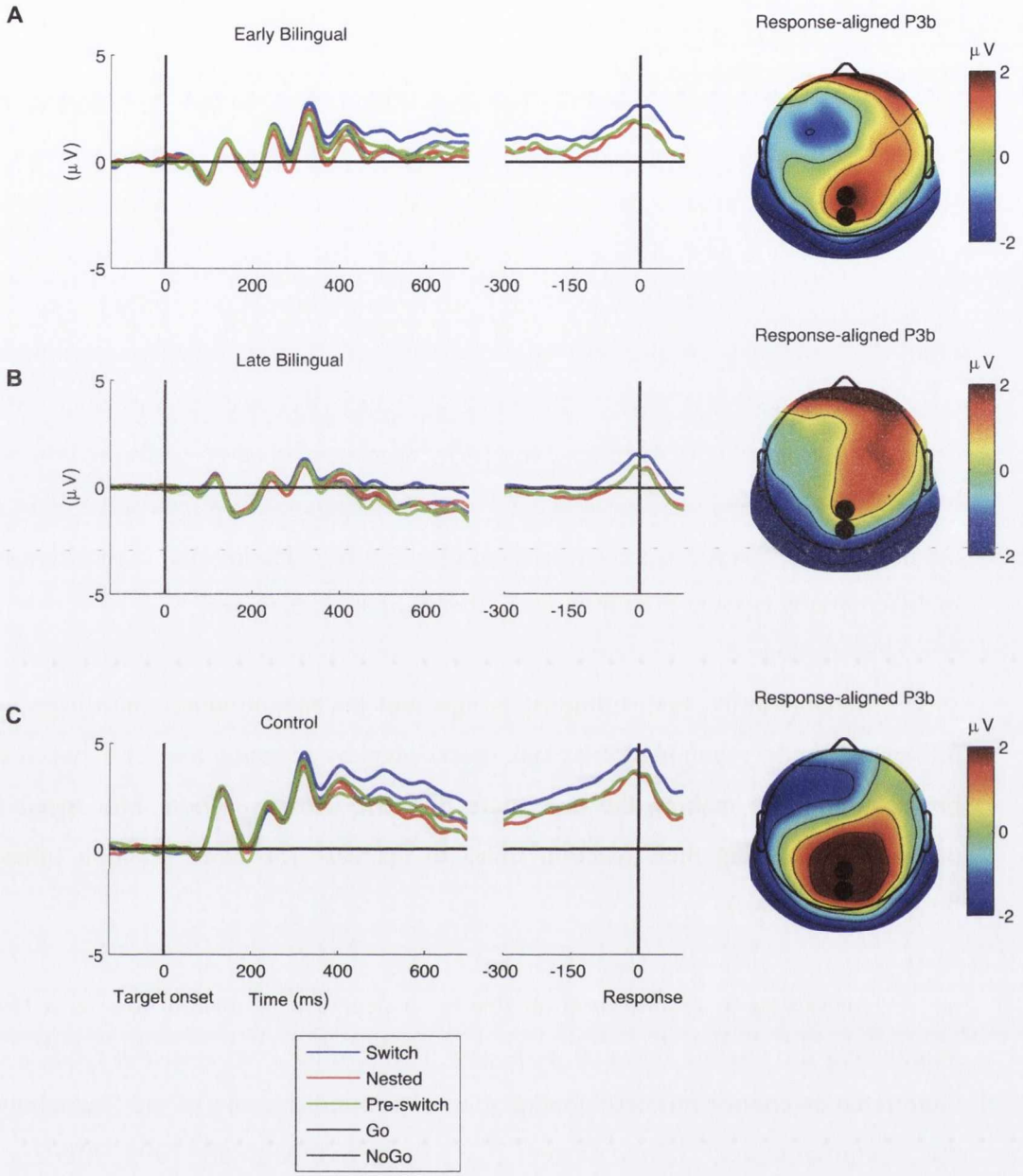


Figure 3.10: Parietal P3 component is differentially modulated by both Trial Type and Group.

Grand average waveforms aligned to target onset (left) and response execution (middle) and the spatial topography of the parietal P3 component spanning the interval of -100 to 0 ms centred on response execution (left) for the Early Bilingual (top), Late Bilingual (middle) and Control (bottom) groups.

3.5 Discussion

The present study investigated the potential bilingual advantage in executive control among young adult bilinguals who had achieved equivalent proficient levels of L2 fluency and who have been actively bilingual for at least five years. The bilingual groups differed in terms of the age at which they had acquired L2 (Early: pre age 7, Late: post age 12). Both behavioural and electrophysiological differences between both the bilingual groups and the monolingual control group were observable. Interestingly, both the Early and the Late bilinguals' task performance and task accuracy correlated with distinguishing ERP components as they performed the SWAT. No such correlations were observed for the Monolinguals. We interpret this to reflect the merit of the SWAT as a measurement of executive function that is sensitive enough to differentially tap into the subtleties of the bilingual experience.

Behaviourally, both bilingual groups and the monolingual control group were influenced by the manipulation of task speed whereby reducing the ISI between stimuli presentation, thus making the task more difficult, drove reaction time speed for all participants, causing their reaction times to decrease (in short, reaction times were fastest on fast trials).

According to reconfiguration theory, a decrease in switch cost as a result of lengthening the interval between trials, and therefore between successive tasks, can be interpreted as control processes being able to accomplish more of the "switching ", or the "reconfiguration," of the system (e.g., Rogers & Monsell, 1995; Merian, 1996, 2000). According to the competition hypothesis, a decreased switch cost is considered to be reflective of more efficient changing of weights in a competing system of "task sets" which represent the "goal" for each task (Wylie et al, 2003). In the case of reconfiguration theory, it is expected that evidence of the operation of the "switching mechanism" would be found in the early stages of a switch trial or during the late stages of a pre-switch trial (or at both times) with minimal activity on the nested trial.

Our reaction time data supports both theories in terms of the switch, but not the pre-switch. All participants were influenced in the same way by Trial Type, showing increased reaction times on Switch trials relative to Nested and Pre-Switch trials,

whereas reaction times on Nested and Pre-Switch trials were equivalent. Accuracy rates were also influenced by the manipulation of task speed with a larger proportion of errors made on fast trials relative to medium and slow. Accuracy levels were also impacted by Trial Type with rates decreasing from pre-switch to nested to switch trials. There were no differences in accuracy rates, or rates of false press or omission errors between the groups. Essentially, the above findings indicate that the task manipulations in terms of both speed and trial type are effective and that all groups of participants performed the task equally well as would be expected based on the existing indication in the literature that ceiling effects may be expected on similar tasks among cognitively healthy young adults (Bialystok, 2006; Costa et al., 2008).

The differences between the groups emerged in terms of the switch cost. Switch cost is considered to reflect the operations of the executive control system and is calculated as the performance decrement between switch and nested trials. As previously mentioned, all groups were influenced by manipulation of task speed demonstrating a greater switch cost on the more difficult (faster) trials. Interestingly, the late bilinguals displayed a significantly reduced switch cost relative to early bilinguals and monolinguals, between whom there was no significant difference. This behavioural finding suggests that late bilinguals display more optimal executive control system functioning relative to early bilinguals and monolinguals. Enhanced bilingual executive function has previously been attributed to the constant need to select the appropriate language and activate all of its interrelated features, a process which is more effortful for late bilinguals who need to select a less solidified L2. Furthermore, selecting the target language simultaneously involves rejecting competition and interference from the non-target language, a task that is also more demanding for late bilinguals who must reject a more entrenched L1. We therefore infer that the additional effort placed on the executive control system of late bilinguals has resulted in the deployment of additional resources to successfully navigate the problem of the joint activation of two languages.

In both the Early and the Late bilinguals there are a number of variables, other than the age at which they became actively bilingual, that potentially contributed to the development and maintenance of the interplay between L2 and executive function. In order to acknowledge and address these contributions the data obtained from the self-report questionnaire was correlated with the switch cost. Previous studies have

generated contradictory results concerning the impact of multiple additional languages on executive function with some studies reporting greater advantages for tri and multilinguals over bilinguals (Bak et al., 2016; Chertkow, Whitehead, Wolfson, Atherton & Bergman, 2010; Kavé, Shorek & Cohen-Mansfield, 2008) and others reporting no additional cognitive benefit to speaking more than 2 languages (Alladi et al., 2013). The present study supports the findings of Alladi and colleagues (2013) finding no correlations between the number of additional languages spoken and a reduction in switch cost, however we acknowledge that our sample size may be insufficient to fully explore this issue and as such further research is merited. Additional variables provided insight into the ways that the bilingual experience entwines with cognitive function. All bilinguals, both early and late, reported that they use their second language frequently either daily or almost daily or indeed that they switch between their first and second language multiple times on a daily basis. However when grouped according to their tendencies to use either language or both languages those that reported a greater tendency to use L2 rather than L1 or a balanced tendency to use both showed a significantly reduced switch cost. This finding draws attention to the distinction between frequency of usage, a factor which may be externally driven as a function of necessity, and tendency to use, a factor which we suggest may be internally driven as a result of an affiliation to one's second language.

Factors such as formal education in L2, living in a country where L2 is spoken, use of L2 with family and friends or for recreational activities such as watching TV or films, listening to podcasts, radio or music and surfing the Internet did not provide any insight either as factors that impacted upon motivations to learn or maintain L2 or as factors whose current exposure fed directly in to executive control advantages. However, there was a strong correlation between current use of L2 at work and a reduced switch cost. This finding may be reflective of a particular feature of this sample due to the fact that a large number of the bilinguals, both early and late, tested in this study work in multilingual companies and reported that a fundamental requirement of their job is their ability to use and switch between their two languages throughout their working day. A further factor that proved to be of interest was the correlation between those who report being currently exposed to L2 in their romantic relationships and a reduced switch cost, highlighting the role of the contexts in which L2 is used in daily life. Noteworthy also are the self-reported motivations for learning or maintaining

active use of L2. Both Early and Late bilinguals report employment and immigration to a new country as highly motivational factors. Unsurprisingly, Early bilinguals attributed more weight to factors outside of their control being responsible for their becoming bilingual while Late bilinguals reported pleasure, recreation and travel as well as education as playing a larger role in their motivation. Furthermore, late bilinguals reported higher levels of confidence in their own general aptitude for language learning than Early bilinguals. These findings highlight the importance of examining the bilingual experience as a whole. The range of variables that are likely to affect measures of executive function is boundless and confounds are inevitable. The range of extra-linguistic factors addressed in this study provided a small insight into the entanglement between the bilingual experience and the bilingual advantage as measured by the switch cost.

Electrophysiologically, the groups differed in terms of visual evoked potentials on both the P1 and N1 components. More specifically both the Early and Late bilinguals showed reduced amplitude on P1 relative to the Monolinguals, while only the Late and not the Early bilinguals showed a more amplified N1 relative to the Monolinguals. This suggests that there may have been differences in arousal level and early attentional deployment in both bilingual groups relative to the Monolinguals. The additional increased N1 for the Late bilinguals correlated with task accuracy across all trial types suggesting that the Late bilinguals deployed augmented early engagement to the discriminative processing of stimuli. Increased attentional deployment has previously been linked to an early negative potential shift during the P1-N1 complex over occipito-parietal scalp (Dockree, et al., 2005). Furthermore, visual N1 amplitude has been shown to be enlarged if an attentional set is established prior to stimulus delivery, which indicates that visual attention can be allocated to task-relevant features through the establishment of an attentional set as a top-down bias prior to stimulus delivery (Foxe & Simpson, 2005). In ageing research accumulating evidence suggests that greater visual evoked neural responses are indicative of an adaptive compensatory strategy in the healthy ageing brain (Daffner et al., 2006; De Sanctis, 2008; Wiegand et al., 2014). Additionally, successful amplitude modulation of early visual-evoked components in older adults has been previously shown using behavioural training paradigms and has paralleled both improved perceptual discriminatory abilities and untrained working memory performance (Berry et al., 2010; Mishra, 2014). Furthermore, lesion studies

have shown that prefrontal lesions impair the amplitude of P1/N1 (Barcelo, Suwazono & Knight, 2000; Voytek et al., 2010). These findings highlight the role of established executive control areas in modulating early visual attentional processes as measured by P1/N1. For the Late bilinguals the correlation between N1 amplitude and accuracy across all trial types on the task suggests that in the case of late acquisition of an L2 which is mastered to a high level of proficiency, a similar adaptive compensatory strategy to that found in older healthy adults may have been developed by the Late bilinguals as a result of the additional "training" of attentional and executive networks in managing joint activation.

Two features of ERP waveforms have been reliably associated with the Go/No-Go manipulation: a larger central anterior negative peak on No-Go relative to Go trials in N2, and an enhanced positive peak at anterior electrode sites in No-Go relative to Go trials in P3. Both bilingual groups and the Monolingual group showed the expected enhanced negative peak on No-Go relative to Go trials for the N2 on Switch and Nested trials, but not on Pre-Switch. N2 enhancement on No-Go trials has been argued to reflect the operation of a cognitive top-down inhibition mechanism needed to suppress the incorrect tendency to respond. Although the processes indexed by N2 appear to be influenced by trial type, such that Switch trials (where conflict is highest) elicited a more negative N2 for both Go and No-Go trials, there were no differences between either of the bilingual groups and the monolinguals. The expected frontal P3 enhanced positive peak on No-Go relative to Go trials was not observed for any group, in fact, contrary to expectations, the frontal P3 was quite diminished for all trials, in particular Switch trials. We interpret these N2/P3 effects to be reflective of equivalent cognitive effort in our bilingual and monolingual groups to manage the conflict created by the switch.

Over parietal electrode sites both Go and No-Go trials impacted on parietal P3 amplitude on various trial types. Here we also observed significant amplitude differences between groups. Wylie and colleagues (2003) found that waveforms associated with the three trial types became increasingly more positive from the Switch to Nested to Pre-Switch trials. We observed entirely the reverse: on both Go and No-Go trials mean amplitude was highest on Switch followed by Pre-Switch and then Nested trials for all groups. Similar to Wylie and colleagues (2003) we draw upon a theory

proposed by Rafal and Posner (1987) originally conceived to account for switches of spatial attention. Although this model was not originally intended to account for switches of non-spatial attention, it nevertheless serves as a starting point to interpret these results. According to this model, the parietal cortex is involved in disengaging spatial attention from the currently relevant visual stimulus, or features of a visual stimulus, and shifting it to allow engagement with new features that have become relevant. The widely accepted finding by Posner et al. (1984) shows that patients with parietal lesions experience particular difficulty with the process of disengaging lends support to this claim. The tasks most commonly used to explore the impact of bilingualism on non linguistic executive functions – including the Simon, anti-saccade, stop-signal and flanker tasks – fall mostly into the category of inhibition rather than controlled shifting of mental sets. However, during language production, bilingualism places particularly high demands on the ability to disengage, shift and reengage attention. Inhibition has typically been assumed to be reflected in amplitude differences in N2/P3 over anterior electrode sites. In fact executive control has largely been associated with fronto-parietal and fronto-striatal networks. Applying Posner's hypothesis of the relevance of the parietal lobes to our results would mean that participants would have to engage with the new task (switch trial) early in the task, they then would maintain this engagement on nested trials and then on pre-switch trials would need to exercise disengagements from the old task in preparation for the following new task. Our data for the parietal P3 fit this theory: maximal amplitude on switch trials reflecting engagement with a new task set, increased (albeit not significant) amplitude also on Pre-Switch trials potentially reflecting disengagement with the no longer relevant task set and minimal amplitude on the Nested trials where there is respite from task demands.

The response locked parietal P3 is comparable to the aforementioned stimulus locked parietal P3 on go trials. The stimulus aligned waveform is associated with decision-related processes with studies suggesting that amplitude is reduced for more difficult decisions (e.g., Donchin et al., 1978; Polich, 1987). The parietal P3 has been linked both to stimulus driven processes concerning decision-making (Donchin & Coles, 1988; Kutas et al., 1977) and also to tactical post decision processes such as response selection and mapping a decision to a response (Verleger et al., 2005). The effects of pre and post decision processes on the parietal P3 can be dissociated by

comparing the stimulus and the response locked waveforms. Sensory and perceptual processes contributing to the decision will only modulate stimulus locked ERPs (Mordkoff & Gianaros, 2000), whereas decision-to-response mapping and response activation will be evident in both stimulus and response locked waveforms. In our data the same trial type effects are evident on both stimulus and response locked parietal P3 with effects of trial type showing maximal amplitude on Switch, followed by Pre-Switch and then Nested trials. However there is also an overall group difference on both the stimulus and response aligned waveforms whereby late bilinguals display a significantly reduced amplitude overall which suggests that at the point of response late bilinguals are required to engage in significantly less effortful processing. Combining behavioural results showing a reduced switch cost and reduced amplitude on parietal P3 waveforms (indicating mediation of disengaging, switching and reengaging) for the late bilinguals suggests that because they have deployed early visual attention (as seen in N1 amplitude) they are engaging their effort at an earlier stage than the early bilinguals and monolinguals. This early discrimination of relevant stimulus information may thereby minimise potential for conflict to occur at higher order levels of stimulus processing and therefore warrants less resolution of competition between tasks at the point of response for the late bilinguals.

Taken together, the aforementioned evidence places the bilingual advantage beyond the explanatory power of any single process or component of executive control. Our results do not show evidence of inhibition playing a dominant role as false press errors and accuracy rates along with N2 amplitude did not differ between monolinguals and bilinguals. Rather, these results suggest that disengaging, switching and reengaging of attention may be key processes worthy of further exploration in the context of the bilingual advantage. Furthermore, these results indicate that there is a discernible difference, both behaviourally and electrophysiologically, in non-linguistic cognitive processing between early and late bilinguals, a difference that is observable even in young adults functioning at their cognitive peak. The principle differences observed in this study suggest that through the additional effort of acquiring L2 in succession to L1 late bilinguals have redoubled their engagement of executive control, potentially configuring it in a different way to early bilinguals. This may allow them to effectively manage joint activation, which in turn has fortified the network through repeated intense exercise. This is evidenced by the reduced switch cost observed for the late bilinguals

relative to both the early bilinguals and monolinguals, and by the reduced parietal P3 mean-amplitude both pre and post response. In summary together these findings imply that the task was cognitively less effortful for the late bilinguals, even though they performed the task as accurately and at the same speed as the early bilinguals and the monolinguals.

Chapter 4 Executive Control differences in Adult Second Language Learners – A Longitudinal Study.

4.1 Introduction

Evidence from those who are bilingual from infancy relative to bilinguals who acquired L2 later in life challenges the belief that the earlier L2 is acquired the greater the cognitive benefits. In fact, overcoming a more solidified L1 may necessitate more effortful exercise of the executive control system and lead to enhanced overall benefits to associated executive functions. Following the logic that those who become bilingual later in life show greater benefits than their early bilingual counterparts it is possible that we may be able to observe the executive control system in training in the case of adults who are intensely acquiring a second language.

Imaging studies show that balanced bilinguals use identical brain areas for achieving identical tasks in their two languages regardless of age of acquisition. For instance, during lexical retrieval tasks L2 related brain activations were found in identical left frontal and temporo-parietal brain areas that are engaged for monolinguals (Chee, Tan, & Thiel, 1999; De Bleser et al., 2003; Hernandez, Dapretto, Mazziotta, & Bookheimer, 2001; Hernandez, Martinez, & Kohnert 2000; Perani et al., 2003; Yetkin, Yetkin, Haughton, & Cox, 1996). However, when it comes to degree of proficiency in or exposure to L2 there are differences in the activations of L1 and L2, interestingly

these activations are found outside areas classically related to language representation but instead in areas related to cognitive control (Abutalebi & Green, 2007)

Kroll & Stewart (1994) argue that as L2 acquisition proceeds, language production in L2 may become progressively less dependent on links to L1 and more independently driven by conceptual input. Conceivably, this would require inhibitory connections to be established between items that regularly compete for selection, which would therefore have implications for the cognitive control system. The course of L2 acquisition has mainly been documented for specific components (such as grammatical rules) using an artificial language, which is typically acquired quite quickly (e.g. Opiz & Friederici, 2004). Although these studies are informative they are not reflective of the natural course of L2 acquisition and as such cannot offer definitive conclusions about the exact mechanisms underlying L2 acquisition.

Osterhout and colleagues used ERPs to study on-line comprehension of L2 in students and found that novel semantic and syntactic properties can elicit native-like profiles relatively quickly (Osterhout, McLaughlin, Pitkänen, Frenck-Mestre, & Molinaro, 2006). McLaughlin, Osterhout, and Kim (2004) found that after only 14 hours of university-level French, students showed a significant amplitude change in N400 during a lexical decision task despite the fact that behavioural performance was at chance. Tanner, McLaughlin, Herschensohn & Osterhout (2013) compared early stage L2 (German) learners (1st year students) with more advanced learners (3rd year students) and native German speakers on grammatical judgments in German and found that both the native speakers and the more advanced learners displayed the classic P600 effect associated with syntactic violations. For the early stage learners the effect was less clear, with some learners displaying the P600 effect and others an N400 effect in response to syntactic violations. Furthermore the P600 effect was positively correlated with behavioural performance for both the early stage and advanced learners, but not for native speakers. These studies indicate that there are observable neural changes in the early stages of L2 acquisition and that these changes are often observable even in the absence of behavioural differences. Moreover, studies such as these suggest that linguistic processing systems are highly malleable but that there is individual variation among learners at the same stage of acquisition and between learners at different levels of progression.

Sullivan and colleagues (2014) investigated the effects of early-stage L2 learning on executive control. Monolingual introductory Psychology students and introductory Spanish students were tested pre and post 6 months of formal instruction on a Go/No-Go task, a sentence judgement task, and a measurement of verbal fluency. After 6 months, the Spanish students showed larger P3 amplitude on the Go/No-Go task and reduced P600 amplitude on the judgement task relative to the psychology students. These differences were found in the absence of behavioural effects. The authors interpreted these results to reflect the cross-domain neuroplastic effect of early L2 training on executive function and suggest that brain functional changes occur on a continuum of the bilingual experience.

Developing skilled performance in a new ability, such as a new language, can be considered in the context of the distinguishing factors between experts and novices. According to De Groot (1965), the difference lies not with the expert's superior memory capacity for relevant information, but in the ability to attend to, recognise and focus on meaningful patterns. De Groot's seminal study found that chess masters showed no advantage over novices in their ability to recall random arrangements of chess pieces on a board, however experts were far superior to novices at reproducing mid-game arrangements in which the pieces bore meaningful relationships to one another. These results demonstrate that the distinguishing factor between an expert and a novice is the superior ability to manage attentional resources and to exercise cognitive control. Language can be viewed as an attention-directing system (Langacker, 1987; Talmy, 1996; 2000; Tomasello, 1998) in the sense that it serves to direct the interlocutor's attention as he/she builds a mental representation of the meaning contained within speech. Talmy (2000) proposes that this involves foregrounding and backgrounding information in particular relationships to each other.

Each language trains its speakers to attend to specific sequences and events in speech. Training from one's native language(s) is firmly entrenched and remarkably resistant to restructuring in adult language acquisition. Consider the hypothetical sentence "The examiner enjoyed reading the thesis". Native English speakers will attend to the past tense of the verb, however if the English speaker was learning Russian she would need to attend to information about completion in the verb, as Russian speakers

would use a different form of the verb if the examiner had finished reading the entire thesis to if there was still a chapter to be read. Slobin (1996) asserts that adults find 'automatising attention' especially difficult in the context of an L2. Segalowitz (2005) expands on this assertion expressing the view that native speakers process language in a way that is automatised, directing attention to details in speech in a fast, efficient and largely unconscious manner eliciting representations corresponding to words and their order.

In the case of an L2, the attention-directing aspect of language will tend to pose a challenge, in particular in highly grammaticised sentences containing, for example, multiple prepositions or defining clauses. Segalowitz (2005) further hypothesised that L2 proficiency is significantly related to the amount of control the bilingual has over attention-directing functions of language. This hypothesis was tested among French-English bilinguals at various levels of L2 proficiency. The task was to shift attention from one language-based attention-directing function to another, namely shifting from time adverbials (words used to direct attention to the temporal location of an event relative to a reference point, e.g. now, afterward, later) to conjunctions (words that link ideas based on the presence or absence of a causal relationship, e.g. although, despite, because) using an alternating runs task-switching design in separate L1 and L2 versions. The sequence involved a predictable alteration between repeating the same task and shifting to the other task. The switch Cost was measured as reaction time coefficient of variation on switch relative to repeated trials and was interpreted to reflect the burden placed on the processing system by efficiently changing attentional focus.

The study found that bilinguals' speed of attentional control in their L2 accounted for a significant proportion of the unique variance in their proficiency. Segalowitz interprets these results to indicate that as a bilingual gains L2 proficiency they also develop the relevant attention control skills, which in turn leads to an overall domain-general attentional-ability improvement. These results highlight the role of attentional control in the development of skilled L2 proficiency and suggest that there is a qualitative jump where fluid access to L2 is no longer a simple increase in speed but rather a transition into more automatic efficient processing. A threshold of proficiency may therefore need to be breached in order to reap the cognitive benefits of bilingualism.

Vega-Mendoza and colleagues (2015) examined cognitive functions in 1st and 4th year Language and Literature students, assessing aspects of attention (sustained, selective and attentional switching), verbal fluency (letter and category) and language proficiency (picture word-association). They found that language students outperformed literature students on a measure of selective attention in both 1st and 4th year. Contrasting results were found on measurements of attentional switching and letter fluency, with no differences between groups in 1st year, while a significant bilingual advantage emerged in 4th year. No differences were found between the groups in terms of verbal fluency. The authors interpreted their findings as evidence that the bilingual advantage can be found in late, non-balanced bilinguals, however different cognitive benefits may appear at various stages of adult L2 acquisition.

Acquiring new sensorimotor skills (Draganski et al., 2004) and conceptual knowledge (Draganski et al., 2006) in adulthood has been shown to alter the grey matter structure of the human brain in task-relevant areas. Imaging studies support the idea that similar structural changes can be observed even after brief training in L2. Mårtensson and colleagues (2012) studied cortical thickness and hippocampal volume in language interpreters before and after three months of intensive language learning and found increases in hippocampal volume and in cortical thickness of the left middle frontal gyrus, inferior frontal gyrus and superior temporal gyrus for interpreters relative to controls. Interestingly, the right hippocampus and left superior temporal gyrus were more malleable in interpreters who achieved higher levels of proficiency in their studied language. Those who struggled to learn the new language displayed larger grey matter increases in the middle frontal gyrus.

The question of the direction of causality cannot be overlooked. That is, rather than the cognitive exercises involved in second language acquisition being beneficial for extra-linguistic executive functioning, it is possible that individuals with better executive function will be better able to master a new language (Klein, 2015). Kempe, Kirk and Brooks (2015) refer to studies that show that nonverbal intelligence and working memory capacity are strong predictors of learners' success. A recent study by Bak and colleagues (2016) addresses the issue of causality. The study set out to determine whether an effect of L2 learning would be observable after just one week of

an intensive language course. In their study they included two control groups – one active, who participated in a non-language course of comparable length (approx. 14 hours) and intensity and one passive, who went about their usual routines. The study found a significant improvement in attentional switching for the language group relative to the passive group who showed no improvement, while the active group assumed a position in the middle. The improvement in attention did not depend on previous knowledge of L2 and was detectable even in the complete beginners. Furthermore, the benefits were sustained on retest 9 months later in those participants who had maintained active use of their L2, defined as using it more than 5 hours per week.

The present study investigates the emergence of the bilingual advantage in students intensively learning English as an L2 through both formal intensive instruction (15-20 hours per week) and the natural immersion provided by having relocated to a country where English is spoken, and a control group of students learning first year university-level mathematics. Within a task-switching paradigm behavioural switch cost and electrophysiological differences are interpreted to be reflective of the operations of the executive control system and are assessed at the beginning and end of six-months of intensive learning.

4.1.1 Hypotheses

H0: There will be no difference, either behaviourally or electrophysiologically, between Language and Maths learners after a six-month period of intensive learning.
H1: There will be an observable behavioural and electrophysiological difference between Language and Maths learners after a six-month period of intensive learning.

4.2 Methods

4.2.1 Participants

This study involved 31 English language learners all of whom had relocated from their home country to Ireland in order to learn English as a second language by attending intensive language courses and immersing themselves in their target language by living, socialising and working in an English speaking country. The study also involved 26 first

year monolingual English speaking university students of Mathematics, who comprised the control group. All participants gave informed consent to procedures approved by the Trinity College Dublin Ethics Committee.

Access to and recruitment of Language and Maths learners

Language learners were recruited by means of a poster displayed in the student area of Delfin English School and also by an announcement made in each class level from beginner to advanced. This resulted in the recruitment of 31 Language learners. Similarly Maths learners were recruited by means of a poster displayed in the Maths Department of Trinity College Dublin and an announcement made in an introductory lecture for undergraduate maths students. This resulted in the recruitment of 26 Maths learners.

Of the 31 English students and 26 maths students who participated in this study at Test Time 1, 16 English (9 male) and 19 maths (14 male) students returned six months later to be re-tested at Test Time 2. Data hereafter pertain to only those participants who were present for both test sessions. (See Table 4.1).

Table 4.1: Nationalities & Native Languages of Language Learners

Nationality	**First Language (L1)**	**Number of Participants**
Brazilian	Portuguese	8
Venezuelan	Spanish	3
Korean	Korean	2
Italian	Italian	1
Japanese	Japanese	1
French	French	1

All language students were enrolled in Delfin English School, an accredited and reputable English language school. Prior to enrolment all learners completed a standardised language level placement test (Appendix D), provided a piece of writing and underwent a speaking test with the school Director of Studies. Learners were then classed according to the Common European Framework of References (CEFR) (Appendix E). Test Time 1 for all learners occurred before the commencement or within the first two weeks of their English language lessons.

Rationale for choosing students of Mathematics as a Control Group

The control group for this study consisted of learners enrolled in 1st year mathematics at Trinity College Dublin. Test Time 1 occurred for all maths learners within the first two weeks of the commencement of their course. Maths students provided a well-matched control group for this study due to the fact that maths, like language, is a symbolic system that was being actively learned and in this case formally instructed. Furthermore the hours of formal tuition for the maths students were appropriately matched with those of the learners.

Test Sessions

Test sessions were 6 months (26 weeks) apart during which time Language Learners underwent either 15 hours or in the case of 3 participants 30 hours of formal English language tuition per week (mean=17.8). Maths students underwent formal tuition of 13 hours in term one and 20 hours in term two per week (mean=16.5)

Efforts to Prevent Attrition

Despite regular contact from the experimenter and informal follow-ups regarding progress in language learning, drop-out rates were high. This was due to the language learners dropping out of school either entirely or reducing the number of hours per week that they spent in class, taking holidays from school thereby reducing the number of weeks of formal instruction they received and, in the case of 5 participants, returning home to their country of origin earlier than expected. The above factors rendered 15 of the Language learners ineligible to return to participate in Test Session 2.

In the case of the Maths learners 7 participants failed to present themselves at Test Session 2 as they were unavailable during the time frame set out by the experimenter due to a high college work load or other personal commitments.

Language Status at Test Times 1 and 2

Of the 16 language learners, 10 reported having no functional knowledge of English or any other additional languages at Time 1, while 6 participants reported beginner's level knowledge of English but no functional knowledge of any additional languages. In terms of having formally studied English in the past, 5 participants reported having been

taught English at primary school, while the remaining 11 reported having never attended formal English classes. Based on their written level placement test (see Appendix D) and a speaking test carried out at their school, the learners were assigned to the following levels (See Table 4.2).

Table 4.2: Langauge Levels of Learners at Time 1 & Time 2

CEFR Level	Class	Learners (n) Time 1	Learners (n) Time 2
A1	Beginner	4	-
A2	Elementary	7	-
B1	Pre-Intermediate	5	3
B2	Intermediate	-	4
C1	Upper-Intermediate	-	7
C2	Advanced	-	2

Language learner progress was tracked according to their advancement to a higher-level (as per CEFR) class. The protocol for student advancement is outlined in Appendix F. At Time 2, the language learners had all made progress in their acquisition of English with 8 of the 16 learners having progressed by two CEFR levels and the remaining 8 having progressed by three levels.

Of the 19 Maths Learners, no participant reported having functional knowledge of, or ability to communicate in a second language, however, all participants reported having been taught a second language at secondary school.

4.2.2 Demographics

Descriptive statistics were first carried out for age, education level (as self-reported on a three-point scale) and IQ (as measured by the Test of Non-Verbal Intelligence, TONI-3; See Table 4.3).

Table 4.3: Mean & standard deviation for group matching variables for learner groups

Variables	Language Learners	Maths Learners
Age	26.25 (4.65)	18.73(0.77)
Education Level	2.75(.44)	3(0.00)
IQ (TONI)	32.00(6.73)	34.31(6.00)

**Education level as rated on a 3-point scale (1=primary, 2=secondary, 3=currently attending/completed third level)*

A one-way between subjects ANOVA revealed a significant effect of Age between the groups ($F_{(1, 32)} = 48.63$, p=.001). These differences are acknowledged and addressed below. Participants were appropriately matched in terms of education level given that all bar two participants (both from the Language Learner group) were currently attending or had completed third level education. No significant differences in IQ were found between Language Learner and Maths Learner groups as measured by the Test of Non-Verbal Intelligence (TONI-3) (F<1).

Language Learner Questionnaire Time 1 and Time 2

Participants completed the Language Learner Questionnaire Time 1 (Appendix B) indicating their nationality, length of residence in an English speaking country, first language, knowledge of additional languages and the level (as per CEFR) at which they have been classed in their English school. The questionnaire also asks participants to self-rate their proficiency in five linguistic skills (reading, writing, speaking, comprehension and pronunciation). They are also asked to rate their levels of exposure to English at various stages throughout their life and the extent to which they are currently using English in a number of contexts. Learners are also asked to report whether they tend to favour their L1 or English for a number of mental activities. Additionally they are asked to report their motivation for learning English and to rate their confidence in their ability to learn languages. Finally the questionnaire requires participants to give an overall estimation of the percentage of time they spend using their first language relative to English.

At Time 2 participants completed the Language Learner Questionnaire Time 2 (Appendix C) which asked them to confirm that they had continued to study English for the duration of time between test sessions and asked them to self-report the level (as per CEFR Appendix E) at which they were currently classed in their English school. Once more learners are asked to self-rate their proficiency across five linguistic skills (reading, writing, speaking, comprehension and pronunciation) and to rate the extent to which they are using English in a number of contexts. Learners are asked to report their tendencies to favour L1 or English for number of mental activities and to give an overall estimation of the percentage of time they now spend using English relative to their first language.

Test of Non-Verbal Intelligence (TONI-3)

All participants were administered the Test of Non-Verbal Intelligence (Brown, Sherbenou and Johnsen, 1997). The TONI-3 is a language-free measure of nonverbal cognitive ability designed to assess perceptual abstract reasoning and problem-solving abilities. The measure consists of 45 visual designs presented in order of increasing complexity. The instructions are pantomimed by an examiner in order to reduce the influence of language on performance. The participant responds by pointing to the correct response in the stimulus booklet. Each item has between four and six answer choices. The test is discontinued once the participant has made three incorrect responses within five consecutive items. The TONI-3 has a previously reported alpha coefficient of .96 (Brown et al., 1997) indicating strong internal consistency. TONI-3 shares convergent validity with the WAIS-R, and scores on TONI-3 have been strongly positively correlated with the Matrix Reasoning subtest of the WISC-IV. Positive correlations have also been found between TONI-3 and measures that tap into other areas of intelligence, such as verbal abilities and processing speed (Atlas, 2001; Brown; DeMauro, 2001; Sherbenou and Johnsen, 1997).

4.2.3 Procedure

64-channel EEG was recorded while participants completed the Switching Attention Task (See Chapter 2, 2.5 for description of the SWAT and 2.6.3 for description of the specific electrophysiological measurements obtained in this study). The SWAT was

administered at both Test Time 1 and again at Test Time 2 in order to facilitate a comparison of switch cost, reaction times, rates of false press and omission errors and accuracy (d') pre and post a six-month period of learning either a new language or maths.

At both Test Time 1 and 2 participants were seated in a dimly lit, sound attenuated, electrically shielded room 80 cm from a computer monitor. Stimuli from the SWAT (as described in Chapter 2, 2.5) were presented centrally. Task instructions were given, repeated if necessary, and participants were given a practice trial at the slow condition speed, which was repeated if necessary. A short break was taken after every six blocks in order to minimise fatigue and concentration lapses.

4.2.4 Analysis Strategy

Where ANOVAs were used for statistical analysis and sphericity was violated, Huynh-Feldt corrected significance values are reported. Where ANOVAs yielded significant main effects, Least Significant Difference (LSD) pairwise comparisons were used to identify the levels of the independent variable between which the significant differences lay. The relationship between any two variables of interest was explored using non-parametric Spearman's rho correlations or paramteric Pearson's correlations depending of the underlying normaility of the data.

Data Trimming

Prior to performing analyses, practice trials and trials upon which task instructions had not been followed were excluded from the data. Outliers were removed from specific analyses if their values within that analysis were more than 3 times the interquartile range or more than 2.5 standard deviations above or below the group mean.

Rationale for splitting the learner group into High and Low Progression Learners

The decision to split the Learner Group into High and Low Progression learners was made post hoc. By virtue of the way that language schools are structured a split in the rate of progress was easily facilitated and, upon examining the data, resulted in a well-balanced split of those participants who had made high and low rates of progress. Had

such an equal balance not presented itself then splitting the groups as such would not have been possible. A similar split was not possible for the Maths learners as the structure of their academic program was not organised in a manner that allowed it.

4.3 Results

4.3.1 Behavioural Results

Switch Cost as a measurement of Executive Function.

A 2x2x3 mixed factorial ANOVA was conducted with Group (Language learner, Maths learner) as the between-subject factor, and Time (Time 1, Time 2), Speed (1,000ms, 15,00ms, and 2,000ms) as within-subject factors and Switch Cost as dependent variable. This analysis revealed a main effect of Speed, ($F_{(2,66)}$=5.31, p= 0.007, ηp^2= .13), demonstrating increasing Switch Cost with shorter ISIs and a significant main effect of Time, ($F_{(1,33)}$ = 4.78, p= 0.03, ηp^2= .12), indicating that the Switch Cost decreased from Time 1 to Time 2. However there was no significant main effect of Group, and no significant interactions between any of the factors (both p>0.05)

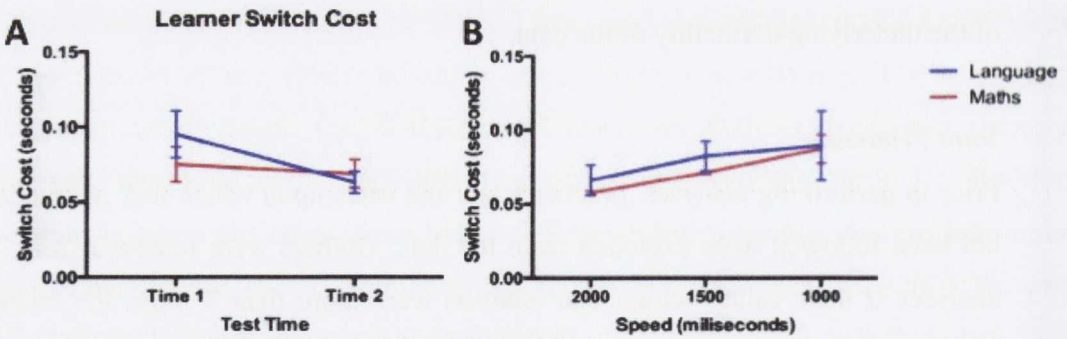


Figure 4.1: Switch Cost differences across Test Time in Learners Switch Cost in **A,** Language learners and in **B,** Maths learners.

Language learners were subsequently divided into two groups based on the number of language proficiency levels by which they progressed over the course of the six months between Test Time 1 and Test Time 2.

Of the sixteen language learners, eight moved up three levels of proficiency (Higher Progression group) and eight moved up two levels of proficiency (Lower Progression group). At baseline (T1) these groups did not differ in term of language proficiency level, Mann-Whitney U=29.5, p= .798. Therefore, at T2, the Higher Progression group had achieved a significantly higher level of proficiency than the Lower Progression group, Mann-Whitney U=11.5, p= .028.

Table 4.4: Mean (standard deviation) language level at T1 & T2 for Learner Group

Group	Test Time 1	Test Time 2
Higher Progression Group	*2.13(0.64)	*5.13(0.64)
Lower Progression Group	*2.00(0.93)	*4.00(0.93)

*1=Beginner, 2=Elementary, 3=Pre-Intermediate, 4=Intermediate, 5=Upper-Intermediate, 6=Advanced.

A further mixed factorial 3x2x3 ANOVA was conducted with Group (Higher progression group, Lower progression group, Maths learner group) as the between-subject factor, and Time and Speed as within-subject factors. Switch Cost was, again, the dependent variable.

Once again there was a significant main effect of Speed ($F_{(2,64)}$ = 4.15, p=0.02, ηp^2= .11) and Time ($F_{(1,32)}$ = 7.51, p= 0.001, ηp^2= .19), and again there was no significant main effect of Group (p>0.05). However, there was a significant interaction between Group and Time ($F_{(2,32)}$ = 5.58, p= 0.008.,ηp^2= .25). Simple contrasts revealed that the Higher Progression group showed a reduction in the Switch Cost from T1 to T2 (p=0.03). By contrast, there was no change in the Switch Cost for the Lower Progression group (p=0.85) or the Maths learners (p=0.46). Between-group comparisons revealed no differences at T1 between the Higher Progression group and either the Lower Progression group (p=.120) or the Maths learners (p=.072). Finally, there were also no reliable between-group differences at T2 (all p>0.05).

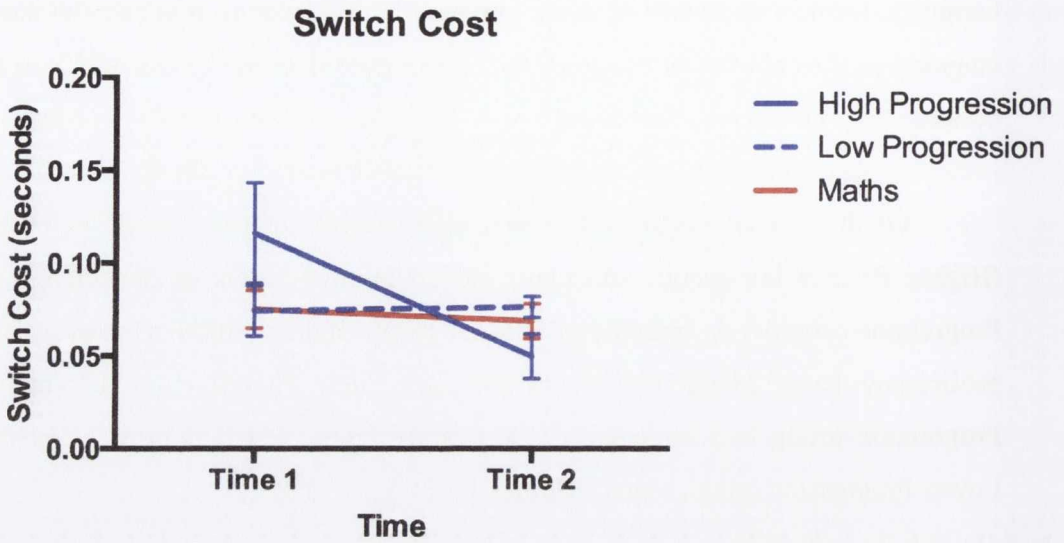


Figure 4.2: Reduced Switch Cost at Test Time 2 for High Progression Learners

Spearman's rho correlation coefficients were conducted to test relationships between the language proficiency level obtained and the Switch Cost at T1 and T2 separately. At both times there were significant negative correlations demonstrating that the higher the level of second language proficiency attained, the lower the Switch Cost (Time 1 rho = -0.532, $p = 0.03$. Time 2 rho = -0.72, $p = 0$ .001).

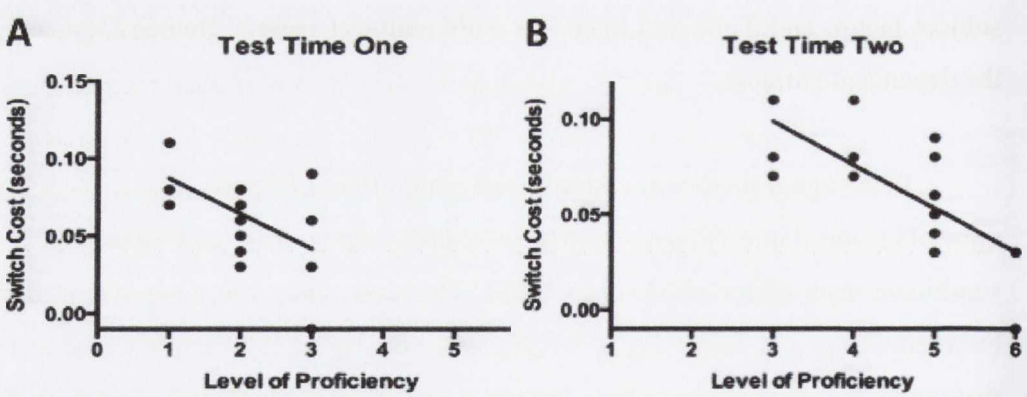


Figure 4.3: Correlations between Level of L2 Proficiency and Switch Cost at Time 1 and Time 2

Age and the Switch Cost

As in the previous study, a series of Pearson's correlations were carried out in order to address the relationship between Age and the Switch Cost. As there was a constant main

effect of Speed in all Switch Cost analysis, Switch Costs at each Speed condition were summed to generate an Overall Switch Cost measurement, for Time 1 and Time 2, which were subsequently correlated with Age. Non-significant relationships emerged between Overall Switch Cost and Age were found for the Learners (r=-.025, p=0.92) and Maths (r=0.368, p=0.12) at Time 1, and for the Learners (r=0.137, p=0.61) and Maths (r=0.398, p=.091). Non-significant relationships emerged between Overall Switch Cost and Age in the High Progression group (r=0.087, p=0.83), the Low Progression Group (r=0.256, p=0.54) at Time 1 and (r=-0.033, p=0.93) and (r=-0.166, p=0.69 at Time 2).

Overall Reaction Time

To explore overall differences in reaction time between experimental groups across each speed and condition a 2x2x3x3 mixed factorial ANOVA with Group (High Progression learner, Low Progression learner, Maths learner) as the between subjects factor, Time (Time 1, Time 2) Speed (1,000ms, 15,00ms, 2,000ms) and Trial Type (Switch, Nested, Pre-Switch) as the within-subjects factors and Reaction Time (RT) as the dependant variable, was carried out. This analysis indicated that there was a significant main effect of Speed ($F_{(2,64)}$=196.81, p=0.0001, ηp^2 = 0.86) demonstrating that RTs decreased as the speed of the task conditions systematically increased. There was also a main effect of Time ($F_{(1,32)}$=15.39, p=.001, ηp^2=0.32) showing a shortening of RTs from Time 1 to Time 2. Additionally there was a further main effect of Trial Type ($F_{(2, 64)}$=114.69, p=0.0001, ηp^2=0.78), such that responses were slowest on Switch trials relative to Nested and Pre Switch trials. However there was no main effect of Group and no significant interactions between any of the factors (all $p > 0.05$).

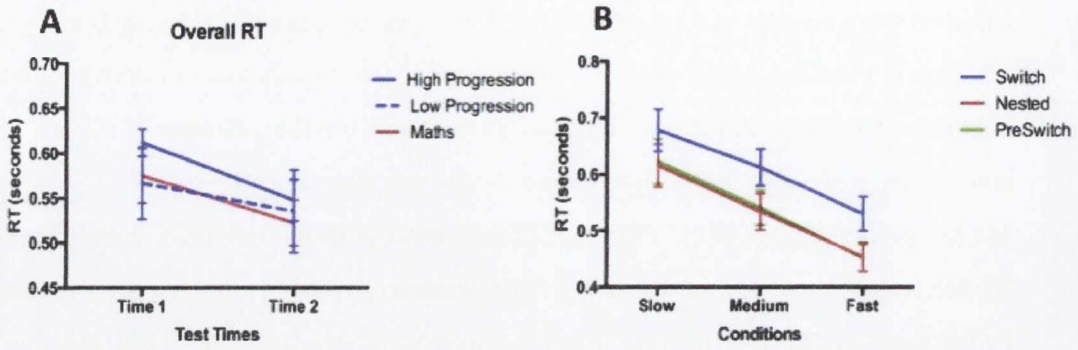


Figure 4.4: Overall RT differences across Test Time and Speed conditions

RT differences in **A,** Test Time and **B,** Speed conditions

Pre-Switch Cue

On 50% of Pre-Switch trials, a box cue accompanied the presentation of the stimuli signalling a change from number to letter task. There was no main effect of group on Pre-Switch RT on cued versus non cued Pre-Switch Trials, (p>0.05) In order to assess whether there was an impact of cue on the Switch Cost of subsequent trials, a 2x3x2x3 mixed factorial ANOVA with Cue (cued versus non-cued trials) Speed and Time (Time 1, Time 2) as the within-subjects factors, Group as the between-subjects factor and Switch Cost as the dependent variable. There was no effect of Cue (p= 0.94), or Time (p= 0.07), nor was there an effect of Group (p= 0.79).

Task Accuracy: D-Prime

As in previous study, response accuracy was assessed by calculating the proportion of correct responses to go-trials (hits) and the proportion of false presses to no-go trials (false alarms). The discriminability index measured by d' was used to separate the means of signal and noise distribution compared with the standard deviation of the noise distribution. The d' scores reflect perceptual sensitivity to the go and no-go conditions with higher values indicating superior sensitivity. Scores range from 0, an indication of inability to discriminate between experimental stimuli, and 4.65, considered to be "effective ceiling" (Macmillian & Creelman, 2005)

In order to assess accuracy at different speeds a 3x2x3 mixed factorial ANOVA was carried out with Group (High Progression, Low Progression and Maths Learners) as

the between subjects factor, Time (Time 1, Time 2) and Speed (1,000ms, 1,500ms, 2,000ms) as the within subject factors and Measurement of d' Accuracy as the dependent variable. There were no significant main effects of Speed, Time or Group and no interactions between any factors (all $p>0.05$).

An additional ANOVA was carried out to assess accuracy on different trial types. The between-subjects factors were as above, within subjects factors were Time (Time 1, Time 2) and Trial Type (Switch, Nested, Pre-Switch) and, again, Measurement of d' Accuracy was the dependent variable. There was a main effect of Trial Type ($F_{(2, 64)} = 22.95$, $p= 0.001$, $\eta p^2= .41$), indicating that accuracy was poorest on Switch relative to Nested ($p=0.005$) and Pre-Switch trials ($p=0.005$). Once again there was no significant main effect of Time or Group and no significant interactions between any of the factors (all $p>0.05$).

False Press Errors

False press errors were analysed separately to examine whether inhibitory control varied as a function of second language proficiency. A false press error is registered on no-go trials where the participant is required to withhold a response and fails to do so. At each speed there is the potential to make 120 false press errors (where the participant has completed six blocks) on each trial type (switch, nested, pre-switch), therefore the proportion of false press errors is calculated as total trial type false press error/number of potential errors.

A 3x3x2x3 mixed factorial ANOVA with Group (High Progression, Low Progression, Maths) as the between-subjects factor, Speed (1,000ms, 1,500ms, 2,000ms), Trial Type (Switch, Nested, Pre-Switch) and Time (Time 1, Time 2) as the within-subjects factors and proportion of false press errors as the dependent variable, was carried out. There was a main effect of Speed, ($F_{(2, 64)} = 21.56$, $p= 0.001$, $\eta p^2 =0.40$) demonstrating that as the difficulty of the task intensified (i.e. faster speed conditions) the proportion of false press errors increased for all groups. A main effect of Trial Type was found ($F_{(2, 64)} =53.46$, $p=0.001$, $\eta p^2 = 0.62$) showing increased false press errors on Switch trials compared to Nested ($p = 0.005$) and Pre Switch ($p= 0.005$). There were no main effects of Time or Group (both $p>0.05$). There was a marginal Time x Trial Type x Group interaction ($F_{(4. 64)} = 2.53$, $p = 0.049$). However, subsequent two-way Time x

Trial Type interactions, conducted for each group separately, did not reach statistical significance ($p > 0.05$)

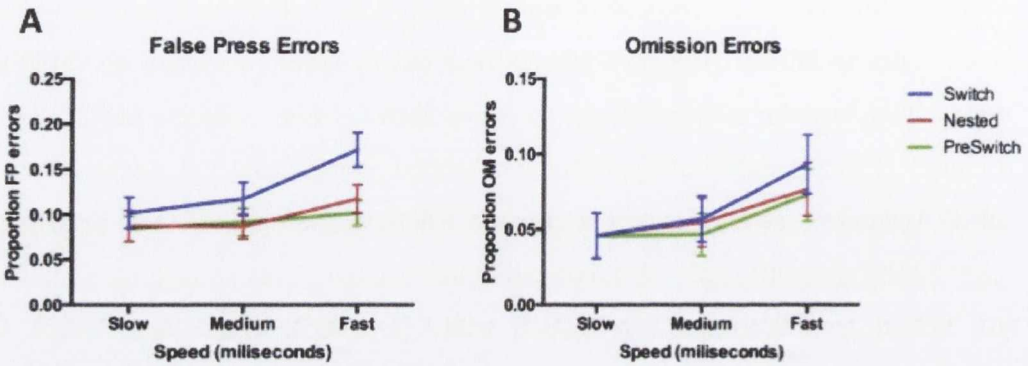


Figure 4.5: Proportion of False Press and Omission Errors for each Trial Type

A, Proportion of False Press errors as a function of Trial Type. **B,** Proportion of Ommission errors as a function of Trial Type.

Omission Errors

Omission errors were analysed in isolation in order to assess whether selective attention varied as a function of second language proficiency. An omission error is registered on go trials where the participant is required to make a response and fails to do so. At each speed there is the potential to make 120 omission errors (where the participant has completed six blocks) on each Trial Type (Switch, Nested, Pre-Switch), therefore the proportion of omission errors is calculated as total trial type omission error/number of potential errors.

A 3x3x2x3 mixed factorial ANOVA with Group (High Progression, Low Progression, Maths) as the between-subjects factor, Speed (1,000ms, 15,00ms, 2,000ms) Trial Type (Switch, Nested, Pre-Switch) and Time (Time 1, Time 2) as the within-subjects factors and proportion of Omission Errors as the dependant variable, was carried out. There was a main effect of speed ($F_{(2, 64)}$ =39.23, p=.0005, ηp^2 =.55) demonstrating that as the difficulty of the task intensified (i.e. faster speed conditions) the proportion of omission errors increased for all groups. There was a main effect of Trial Type ($F_{(2, 64)}$ = 5.83, p=0.009, ηp^2=.15), where increased omission errors were observed on Switch trials compared to Pre-switch trials (p= 0.002) but not on Switch

trials compared to Nested trials (p= 0.09). There were no main effects of Time or Group (both p>0.05). There was a significant Time x Trial Type x Group interaction ($F_{(4, 64)}$ = 2.65, p = 0.041, ηp^2=.14). Subsequent two-way Time x Trial Type analyses for each group revealed a significant interaction only for the Maths group, ($F_{(2,36)}$=3.81, p= 0.032). However, the paired comparisons from Time 1 to Time 2, for each Trial type, did not reach statistical significance (all $p > 0.05$).

4.4 Impact of extra-Linguistic Factors upon L2 acquisition and Executive Control

Length of residence in an English speaking country

No Language Learner reported ever having resided in another English speaking country prior to having arrived in Ireland. The length of time that participants had been living in Ireland prior to Test Time 1 ranged from 2 weeks to 1 year. There was no correlation between Length of Residence in Ireland and Language Level at Time 1 or 2, or Switch Cost at Time 1 or 2 (all $p > 0.05$).

Personal history and route to L2 acquisition

Learners were asked to self-report their exposure to English during various periods of their lives. There were no correlations between Language Level at either Time 1 or Time 2 and exposure to English pre age 7, from 7-14 or 14-21 (all $p > 0.05$). There was a moderate correlation between self-report of exposure to English after the age of 21 and Language Proficiency Level at both Time 1 (r= .549, p = 0.02) and Time 2 (r = .520, p = 0.03)

Self report of proficiency in each of five linguistic skills

Learners' self-reports of proficiency in each of five linguistic skills (Reading, Writing, Listening, Comprehension and Pronunciation) were summed to give an overall self-report measure of proficiency. There was a strong correlation between self-reported overall proficiency and Language Level at Time 1 (r = .666, p = .005) but no significant correlation between self-reported overall proficiency and Switch Cost at Time 1 or 2 (both $p > 0.05$). At Test Time 2 Learners were asked to once more self-report their

levels of proficiency in each of the same five linguistic skills. There was a strong correlation between self-reported overall proficiency and Language Level at Time 2 (r = .878, p = 0.001), and a strong negative correlation with Switch Cost at Time 2 (r = -.731, p = 0.001).

Use of Language and factors that contribute to L2 learning

Learners were asked to consider their use of and exposure to English (relative to their mother tongue) in each of ten contexts. The sole context in which a correlation was found was between Language Proficiency Level at Time 2 and use of English with Friends (r = .600, p= 0.01)

Learners were asked to report the percentage of time that they spoke English relative to their L1 at both Test Time 1 and Test Time 2. At Time 1 the correlation approached significance (r = .496, p = 0.05) while at Time 2 it was highly significant (r= .651, p = 0.006).

Motivation

All of Learners reported work-related motivation for learning English was as a result of their current or future work, and a further 14 cited immigration to a new country as a motivating factor, 14 also reported that they were motivated to learn for pleasure. Additionally, 10 learners reported that their education was a motivating factor and only 2 learners cited factors outside of their control as a reason for learning English.

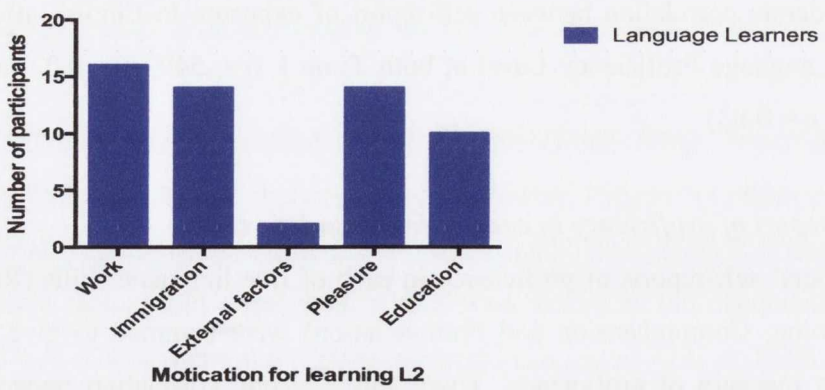


Figure 4.6: Self-Reported Motivation for Learning English

Confidence

At Test Time 1 Learners were asked to rate their confidence in themselves in terms of their ability to learn languages relative to other people they know. There was no correlation between Level of Confidence in ability to learn and Language Level at Time 1 (r = .305, p = 0.25), however at Test Time 2 there was a strong correlation (r =.720, p= 0.002).

Language favoured for cognitive activity

At Test Time 1 all Language Learners reported favouring their L1 for mental arithmetic, remembering numbers, dreaming, thinking, self-talk and expressing emotion. At Test Time 2 all Learners continued to favour their L1 for mental arithmetic and remembering numbers. Four Learners reported having sometimes dreamt in English, 7 Learners reported often using English for thinking and self talk, and 5 participants reported frequently favouring English to express emotion.

4.5 Electrophysiological Results

4.5.1 Early Components: P1, N1

The grand average signal time courses aligned to target onset were plotted for each Trial Type and Group. Analysis of the stimulus-aligned waveforms revealed that the mean amplitude of the P1 component was not sensitive to Trial Type and was not modulated by Group at either Test Time 1 or Test Time 2, nor was there any significant interaction between Trial Type and Learner Progression Group at either test time (all p>0.05). Similarly, the mean amplitude of the N1 component was also insensitive to the Trial Type manipulation at both test times and there was no significant interaction between Learner Progression Group and Trial Type (all $p > 0.05$).

4.5.2 N2 and frontal P3 Components

The grand average signal time courses aligned to target onset were plotted for each Trial Type on Go and No-Go trials and Group at both Time 1 and Time 2. Analysis of the stimulus-aligned waveforms revealed that the mean amplitude of the N2 was influenced

by Trial Type ($F_{(2, 46)} = 3.84$, p=0.02), such that the component was significantly more negative on Switch relative to Nested trials (p= 0.01) but not Pre-Switch trials (p= 0.06). There was no significant difference between Nested and Pre-Switch trials (p=0.48). The mean amplitude of N2 was not influenced by Test Time, or Go/No-Go trials (all p>0.05) and there were no meaningful interactions between factors. The mean amplitude of N2 was influenced by Learner Progression Group ($F_{(1, 23)} = 4.09$, p=0.03); The Low progression learners displayed a significantly more negative N2 than the Maths Learners (p=0.01) but not the High progression Learners (p=0.39). There was no significant difference between the High progression Learners and the Maths Learners (p=0.10).

Analysis of the stimulus-aligned frontal P3 traces on Go and No-Go trials at Time 1 and Time 2 revealed that there was a significant main effect of Trial Type ($F_{(2, 46)} =5.13$, p= 0.01) such that a significantly more positive frontal P3 amplitude was observed on Switch relative to Nested (p =0.02) and Pre-Switch (p =0.01) trials. There was no significant difference in Go frontal P3 amplitude measured on Nested and Pre-switch trials (p =0.07). The mean amplitude of frontal P3 was not influenced by Test Time, or Go/No-Go trials (all p>0.05), and there were no interactions between factors. Furthermore the mean amplitude of frontal P3 was not influenced by Learner Progression Group (p>0.05).

4.5.3 Stimulus and Response-aligned parietal P3 Component

Analysis of the stimulus-aligned parietal P3 traces on Go and No-Go trials at Time 1 and Time 2 revealed that there was a significant main effect of Trial Type ($F_{(2, 46)}$= 7.09, p=0.002) such that a significantly more positive parietal P3 amplitude was observed on Switch relative to Nested (p=0.004) and Pre-Switch (p=0.02) trials. Comparable stimulus-aligned parietal P3 amplitude was recorded on the Nested and Pre-Switch trials (p = 0.84). The mean amplitude of parietal P3 was not influenced by Test Time or Group (both p>0.05), however there was larger parietal P3 amplitude on Go relative to No-Go trials (p=0.02). There were no meaningful interactions between factors (all p>0.05).

Analysis of the parietal P3 traces centred on response execution on Go trials revealed that mean amplitude of the component was sensitive to Trial Type ($F_{(2, 46)}$= 10.39, p= 0.001). A greater response-aligned Go parietal P3 amplitude was observed on Switch relative to Nested (p=0.001) and Pre-Switch Trials (p=0.005). Comparable response-aligned parietal P3 amplitude was observed on Nested and Pre-switch trials (p=0.54) and there was a significant interaction between Trial Type and Test Time (p=0.03) such that at Time 1 parietal P3 mean amplitude on response execution increased from Nested to Pre-Switch and was highest on Switch trials, whereas at Time 2 amplitude was lowest on Pre-Switch trials and rose to Nested and then again was highest on Switch trials. The response-aligned parietal P3 was unaffected by Group (p>0.05). There were no other meaningful interactions between the factors (all p>0.05).

4.6 Discussion

The present study aimed to trace the emergence of the bilingual advantage longitudinally in adults learning English as a second language. Before discussing the results of this study, we would like to first address the caveats with which these results must be interpreted. First and foremost, we acknowledge that the study is underpowered as a result of larger-than-expected dropout rate of participants over the course of the six-month intervention. Based on the meta-analysis carried out by de Bruin & Della Sala (2015), it has been suggested that in order to achieve desirable levels of power at least 139 participants are necessary in each language group (Bakker, 2015). We argue that our repeated measures design in which each learner constitutes his/her own baseline serves to compensate to a slight extent, however we nevertheless interpret the following results and their insights with judicious caution, and appreciate the need for future replication with a larger sample size in order to draw well-grounded inferences from them.

The language learners in this study presented a compelling opportunity to investigate the emergence of the bilingual advantage in executive control and to address the question of the degree of proficiency required in an L2 in order to reap the cognitive benefits accrued by cognitive management of the developing L2 in addition to the solidified L1. At the time at which the learners were first tested they were essentially

monolingual self-reporting little or no functional knowledge of English, and language level placement (written and oral) tests placing them at basic levels. Over the course of six months the learners were immersed both in intensive formal instruction classes and in naturalistic exposure to English by virtue of living in a country where English is the majority language spoken. Previous studies examined language learners attending university level language courses. University level language courses are often directed at the pre-determined collective level of the students in a certain year of study. Often this leaves little room for individual difference in ability and rate of progress. This study was able to capitalise on the way that EFL schools are organised. Students are placed in the level that is initially appropriate for their language ability and thereafter their progression to the next level is entirely self-driven, with some students progressing quickly and others requiring more time.

The initial examination of the results of this study indicated little difference, either behaviourally or physiologically between the learner group as a whole and the control group of monolingual maths students. Both groups were similarly influenced by the manipulation of task speed whereby reducing the ISI between stimuli presentation increased the speed of the response, and for both groups, overall reaction time decreased from test time 1 to test time 2 indicating that any practice effects were comparable across groups. Both groups were equally influenced by trial type with switch trials eliciting a slower reaction time relative to nested and pre-switch trials, indicating that, for all participants, the effort of switching task was more strenuous than repeating the same task or preparing for an upcoming task switch. Equivalent accuracy, as measured by d', was displayed by both groups at both times and comparable error rates of false press and omission errors were exhibited by both groups such that increased instances of false press and omission errors were registered on switch relative to nested and pre switch trials suggesting that neither the language learners or maths learners displayed an advantage in selective attention or inhibition at either test time. Initial analyses also found no difference, at either test time, in switch cost between the learner group as a whole and the maths control group.

However, once the language learner group was split according to rate of language progression, a switch cost difference emerged in the form of a time by group interaction. For those learners who progressed at a faster rate of language acquisition

proficiency increased. Furthermore, there was a moderate correlation between L2 proficiency and switch cost at time one, and a strong correlation between L2 proficiency and switch cost at time 2. We interpret these findings to be reflective of the developing efficiency of the executive control system in response to the emerging need to manage a developing L2. Enhanced executive function in balanced bilinguals, and as demonstrated in the previous study, in late bilinguals in particular, has previously been attributed to the persistent need to select the appropriate language and activate all of its associated features while simultaneously managing competition and interference from the non-target language. The competition and entrenchment model asserted by Hernandez, Li and MacWhinney (2005) suggests that in the case of the adult L2 learner a relatively automatic neural circuit of syntactic and semantic networks pertaining to L1 has already become entrenched by the time L2 is introduced which results in the initial situation of L2 acting in a parasitic capacity to L1. In order to reduce the parasitic dependency of L2 on L1 learners must recruit and exercise cognitive mechanisms and metacognitive strategies in parallel to developing linguistic skills. We cautiously suggest that those who have successfully managed to harness such strategies may be those who have managed to progress more quickly and in turn are those who reap the cognitive benefits of enhanced executive control as reflected in a reduced switch cost. This theory is in accordance with the findings of Vega-Mendoza, West, Sorace & Bak (2015) who observed the bilingual advantage in selective attention in late non-balanced bilinguals in both a lower (year 1) and a higher (year 4) group but found an attention switching advantage only in the higher group suggesting that different cognitive skills emerge along a continuum of developing language proficiency.

The impact of a number of extra-linguistic factors on the interplay between language statuses at times 1 and 2 was also considered. Of particular interest is that self-reported levels of proficiency at both time 1 and 2 correlated with language level, suggesting that the language learners displayed self-awareness in terms of their proficiency and progress. The majority of the language learners reported that their motivation to learn English stemmed from the prospects that it would afford them in terms of their current or future work. This finding is in line with a 2013 survey co-ordinated by the European Commission reporting that Europeans are most likely to identify working in another country as a key advantage of learning a new language. In terms of their use of language outside the classroom, a significant correlation was found

between language level at time two and self-reported tendency to use English with friends. Similarly a strong correlation was found between language level at time 2 and the percentage of time that learners used English relative to their L1 in their daily life. Furthermore at time 1, language learners who reported a high level of confidence in their general aptitude for learning languages were those who had progressed to the higher levels at time 2. All language learners reported that at time 1 they naturally favoured their L1 for a host of cognitive activities such as mental arithmetic, remembering numbers, dreaming, thinking and self-talk. At time 2 all Learners continued to favour their L1 for mental arithmetic and remembering numbers. This reflects findings from the previous study in which fully proficient bilinguals reported that they always rely on L1 to deal with numbers. However after six months of intensive language learning, 4 learners reported having sometimes dreamt in English, 7 Learners reported often using English for thinking and self talk, 3 of whom further elaborated reporting that they use English for thinking and self-talk in "easy" or procedural day to day situations such as cooking or getting dressed and 1 of whom reported using English for thinking or self-talk while day dreaming. Five participants reported frequently favouring English to express emotion, four of whom further elaborated that they enjoyed using "bad language" in English. These results serve to call attention to the fact that over the course of six months, the developing L2 is at the learner's disposal for cognitive processing and that as language development proceeds, L2 production becomes increasingly less dependent on links to L1.

Electrophysiologically, contrary to expectations there were no differences between either the high or low progression learner groups and the maths control group in terms of early components P1 or N1. Based on the findings in Chapter 3 the N1 in particular was of interest due to the fact that greater N1 amplitude was observed in late bilinguals. It was therefore predicted that this component might be modulated for late-bilinguals-in-training. However, contrary to our predictions this effect was not observed. We reiterate the caveat that the study is substantially underpowered but suggest that the N1 remains a component worthy of further exploration in studies of late bilinguals and emerging bilingualism in adult L2 learners. In these cohorts N1 may be an index of a potential adaptive strategy of deploying early attentional engagement to the discriminative processing of stimuli.

Go/No-Go tasks typically elicit reliable N2/P3 waveform features such that a larger central anterior negative peak on No-Go relative to Go trials in N2, and an enhanced positive peak at anterior electrode sites in No-Go relative to Go trials in P3 are typically observed. This trend was not observed in either the high or low progression language learner groups or the maths learner group. Both N2 and anterior P3 were influenced by trial type as evidenced by the fact that on switch trials a more negative N2 mean amplitude and more positive anterior P3 amplitude were observed relative to nested and pre-switch trials. This was also the case for the posterior P3 aligned both to the stimulus and the response. Similar to the behavioural finding that reaction time is slowest on switch trials we interpret this to be reflective of additional effort placed on the cognitive system when it comes to switching task. This N2/P3 pattern was observed at both test times. Furthermore there were no significant differences between either the stimulus or response aligned parietal P3 from test time 1 to test time 2. A previous study (Sullivan et al, 2014) observed physiological difference in the P3 in university level language students after six months of language learning, while finding no behavioural differences. Our results fail to replicate this effect; on the contrary, we observed behavioural differences in the absence of physiological effects. This, we suggest, is attributable to the sample size being too small to yield a sufficiently sensitive physiological measure. Nevertheless, the behavioural finding that the high progression learners displayed a reduced switch cost after six months of language learning is intuitive and suggests that brief L2 training can produce cross-domain, neuroplastic effects on a non-verbal executive function task and that these emerging changes are observable along a continuum of bilingual experience.

Chapter 5 Exploring the Bilingual Advantage in Older Irish Adults

5.1 Introduction

Population ageing has become a global phenomenon. By the year 2075, more than 50% of the European population will be aged over 60, and there will be a three-fold increase in individuals aged over 80, relative to the present day. This dramatic increase in life expectancy reflects the positive strides made in our recent history towards healthier ageing. At the same time, increases in life expectancy go hand in hand with increasing rates of age-related cognitive decline.

Age-related cognitive decline is one of the biggest threats to the well-being of older adults, as well as their ability to live independently. This, along with the risk of experiencing mild cognitive impairment (MCI) or Alzheimer's disease (AD) make understanding the process of cognitive decline, and the search for mediums to ameliorate the effects, a matter of urgent importance. Such progress would contribute significantly to disciplines ranging from economics to public health care (Bialystok et al., 2016).

Research to date has focused heavily on biology and thus the contribution of experiential and environmental factors has often been overlooked. It has been suggested that existing drugs for the symptomatic treatment of dementia are of moderate benefit (Massoud and Gauthier, 2010), and further suggested that said benefit is marginal at best and is also difficult to detect, measure and quantify clinically (Hildreth and Church,

2015). Certain environmental and experiential factors have been shown to impact upon cognitive functioning with ageing and to delay the onset of symptoms of dementia by contributing to cognitive reserve. Such factors include education, social-connectedness and socio-economic status (Stern et al, 1994).

A growing body of work has also heralded bilingualism as a significant contributor to cognitive reserve. The most hard-hitting findings come from studies involving pathological ageing, in which bilingual individuals were found to display symptoms of dementia 4-5 years later than their monolingual counterparts. This effect was replicated in different populations such as Canada (Bialystok et al., 2007), the U.S.A. (Gollan et al, 2011), India (Alladi et al., 2013) and Belgium (Woumans et al., 2015). The studied cohorts included migrants as well as non-migrants, educated as well as illiterate people, both high and low SES and those who acquired L2 early in life as well as those who acquired it later. Furthermore the patterns of language use varied considerably across these studies in terms of frequencies of language use and switching, and yet the effect remained constant. Most exceptionally, the strongest effects were found for those who were less educated. In the Indian cohort, the effects of education disappeared when controlling for bilingualism but the effects of bilingualism remained when controlling for education (Bak and Alladi, 2016; Iyer et al., 2014)

Bilinguals have also been found to show significantly better recovery following a stroke than monolinguals with the percentage of patients with intact cognitive functions post-stroke being more than twice as high in bilinguals than in monolinguals. Furthermore, there were no differences between the groups in terms of vascular risk factors or the age at which the stroke was suffered indicating that the observed differences could not be attributed to an overall healthier lifestyle among bilinguals (Alladi et al., 2016).

With regard to non-pathological ageing, it is widely accepted that cognitive functions that depend on well-learned knowledge and habitual procedures (crystallised intelligence) hold up well in later adult years, whereas abilities that depend on executive control processes (fluid intelligence) decline in efficiency. Bialystok and colleagues (2004), used the Simon Task to show that decline in executive control in older adults was modulated by bilingualism, with less decline for lifelong middle-aged and older

bilinguals than for age-matched monolinguals. Gold and colleagues (2013) examined whether younger and older healthy bilingual adults differed from age-matched monolinguals on a non-linguistic switching task. They found better behavioural performance for the bilinguals in the older age group but no language group effects in the younger adults. Interestingly, the authors also found no significant differences in patterns of brain activation between the younger bilinguals and monolinguals but significant evidence for more efficient brain function for bilinguals in the older adult group. This finding was interpreted such that the older bilinguals seem to use the relevant brain mechanisms more efficiently than monolinguals with the absence of such differences in the younger adult groups being due to the frequently observed ceiling effects on the task.

Perhaps the most stark evidence for the positive impact of bilingualism on cognition comes from Bak and colleagues (2014) who found that individuals who learned a second language after the age of 11 achieved better cognitive results 60 years later than could have been predicted based on their childhood performance on intelligence tests, demonstrating that language learning and use can mitigate the effects of cognitive ageing. Interestingly, as with the aforementioned Indian cohort, the effect was found to be strongest in those whose intelligence scores were initially low, confirming that the effect prevails regardless of childhood intelligence.

In considering the protective effects of bilingualism on non-pathological age-related cognitive decline it is worth exploring the impact of certain language practices such as whether it is necessary to have learned a second language early in life and to have maintained active use of two or more languages throughout the lifespan. A study by Abutalebi and colleagues (2014, 2015) explored this question in Hong Kong where Cantonese is the mother tongue of natives. English is typically acquired at school and is widely used, from then on, as the language of education and subsequently as the language of business and communication. These practices typically generate a relatively balanced use of both Cantonese and English. However, once they retire, many people stop using English and return to predominant use of Cantonese. In this cohort, Abutalebi and colleagues found that only those who maintained a high usage of both languages showed significant effects of neuro-protectiveness against cognitive decline.

Similarly a recent study by de Bruin and colleagues (2015) examined three groups of elderly participants from the Scottish islands of Outer and Inner Hebrides. One group was actively using both Gaelic and English regularly (active bilinguals), the second group, although also Gaelic/English bilinguals, spoke English almost exclusively (passive bilinguals) and the third group were English-speaking monolinguals. The authors found a significant difference between the monolinguals and the active, but not passive, bilinguals.

The Republic of Ireland has two official languages: Irish and English. According to the Irish Constitution, Irish is the first official language, despite the fact that English is the mother tongue of the majority of the country. Irish is one of the minority languages in Europe today, its once prominent position having declined over the past centuries due to social, political and economic factors. Although the aim of the Irish State has been to promote bilingualism in Ireland (O'Laoire, 2005), there are few active Irish speakers outside the educational system apart from in the Gaeltacht (areas where Irish continues to be spoken by a substantial number of inhabitants). Additionally, the number of active speakers in Gaeltacht areas is also diminishing (Ó Giollagáin and Charlton, 2015).

Recent census figures (2011) show that in the Republic of Ireland 41% of respondents reported being able to speak Irish, with only 33% of those people speaking the language weekly or more often than weekly (CSO, 2011). Irish is a core subject at both primary and secondary school, with some schools (Gaelscoillana) operating through the medium of Irish, however a recent study by Darmody and Daly (2015) found that student attitudes towards Irish in the Republic of Ireland tend to be more negative compared to other core subjects. Children attending Irish-medium primary schools tend to have a more positive view of Irish, however post-primary school students reported considering Irish less useful, more difficult and less interesting than English and Maths.

The UNESCO report (2003) notes that a language is in danger 'when its speakers cease to use it, use it in an increasingly reduced number of communicative domains, and cease to pass it on from one generation to the next'. Attitudes regarding the usefulness of the language can play a crucial role in the protection and revitalisation

of minority languages, and support the efforts of speakers in language maintenance. Factors that positively impact upon learning the language include motivation and interest, speaking the language in the home and opportunities to speak it in the community (Darmody & Daly, 2015)

Minority languages are strongly influenced by socio-economic factors within the society. The role of an 'other' language is likely to diminish in situations where a country's economic and political power is represented by one dominant group. O'Rourke and colleagues (2011) argue that the rise and fall of a language cannot be seen as a 'natural' phenomenon that occurs without human or social agency. In other words, public opinion plays a large role in how useful a minority language, like Irish, is considered to be. Das (2004), O'Rourke (2011) and Baker (1992) argue that attitudes, rather than current behaviour, are a better guide for the future 'prosperity' of a language.

In 2010, the Irish Government agreed a 20 Year Strategy for the Irish Language, the aim being to increase the number of people using Irish on a daily basis outside of the education system to 250,000 people over the next 20 years. The strategy has been widely criticised for its weak focus on implementation of suggested policies and practices. The Irish Language Study (2013) reports that 37% of the respondents perceived that the government does too little for the Irish language. Regarding the future of the Irish language, the study found that the most desired outcome (43%) is that the country should remain bilingual, with English as the principal language.

The objective of the present study is to examine the impact of bilingualism on the cognitive function of older Irish adults, specifically to explore whether it is necessary to maintain active use of both languages into older age in order to cognitively gain from the bilingual experience and additionally whether similar advantages are conferred upon older adults who learned L2 later in life. A number of tests are used to assess function across a range cognitive domains, one being a clinical screen tool, the others covering cognitive measures of increasing complexity from processing speed and sustained attention to executive control and mental flexibility.

5.1.1 Hypotheses

Study 1 H0: There will be no observable difference, on any cognitive measurement, between Past Bilinguals, Current Bilinguals and Monolinguals.

Study 1 H1: There will be an observable difference on all cognitive measurements between Past Bilinguals, Current Bilinguals and Monolinguals.

Study 2 H0: There will be no observable difference, on any cognitive measurement, between Early Bilinguals, Late Bilinguals and Monolinguals.

Study 2 H1: There will be an observable difference on all cognitive measurements between Early Bilinguals, Late Bilinguals and Monolinguals.

5.2 Background and Methods

The Irish Longitudinal Study on Ageing (TILDA) is a major inter-institutional initiative led by Trinity College Dublin. TILDA provides high quality data relating to ageing and the lives of older people in Ireland drawing on information from all aspects of their lives, including the economic dimension (pensions, employment, income and assets, etc.) health aspects (physical, mental, service needs and usage, etc.) and social aspects (contact with friends and kin, formal and informal care, social participation, etc.). TILDA's aim is to contribute to developing an environment for successful ageing by characterising the older people living in Ireland and exploring the factors that contribute to healthy ageing. The sample from TILDA is based on the Irish Geodirectory: a comprehensive and up-to-date listing and mapping of all residential addresses in the Republic of Ireland compiled by Ordinance Survey Ireland. Target areas are chosen to represent urban and rural regions throughout Ireland. Wave One data was collected between 2009 and 2011, while Wave Two was collected in 2012. Written informed consent was obtained from 8504 participants. Inclusion criteria for the present study were completion of the relevant measurements and questions pertaining to language use and history. Within these parameters data was available on 5,500 participants.

Access and Recruitment of the TILDA sample.

The method used to select participants for the TILDA study was designed to ensure that the sample is representative of the population of Ireland aged 50 or over. An initial multi-stage sample of addresses was chosen by means of the RANSAM sampling

procedure developed by the Economic and Social Research Institute (ESRI) based on the Irish Geodirectory. Each address in the Republic of Ireland had an equal probability of being selected from the sample list of addresses. The selected addresses (see Fig 5.1) were visited by an interviewer and all persons aged 50 or over (and their spouces/partners of any age) were canvassed to participate in the study. The household response rate to the study was 62%.

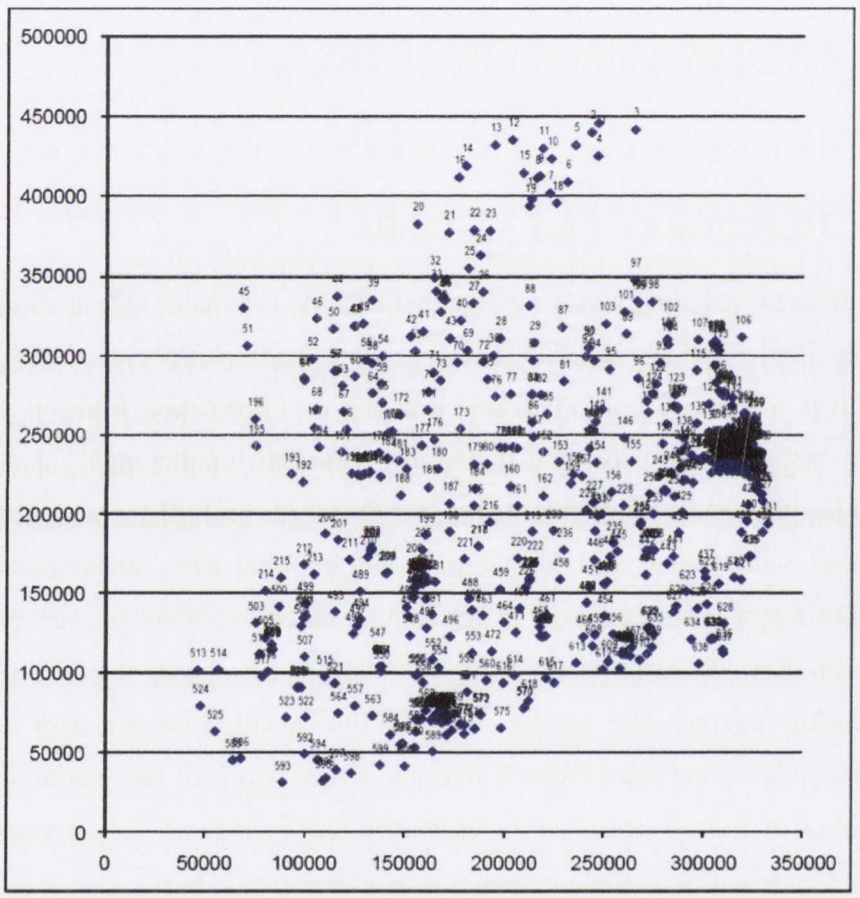


Figure 5.1: A nationally representative sample of adults aged 50 and over, resident in the Republic of Ireland, selected using a population sift.

5.2.1 Cognitive Measurements

A comprehensive cognitive battery of tests assessing memory, planning, attention and responding were carried out. This battery was administered in private and standardised instructions were given to all participants. The following measurements were used in this study:

Montreal Cognitive Assessment (MoCA)

MoCA is a pencil and paper based test that was designed as a rapid screening instrument of global cognition. It assesses different cognitive domains: attention and concentration, executive functions, memory, language, visuo-constructional skills, conceptual thinking, calculations and orientation. The total possible score is 30 points. (See Appendix G).

Sustained Attention Response Time (SART)

The fixed-SART is a computer-based test to measure sustained attention. Numbers between 1 and 9 appear in a fixed sequence and participants are required to make a left button click for every number except for the number 3. The cycle of digits 1-9 was repeated 23 times, giving a total of 207 trials. The task lasted approximately 4 minutes and the following measures were recorded: Mean RT, that is the mean time (ms) taken for each key press in response to digits 1,2 and 4-9 across the entire task and the standard deviation of RT (SD RT) which is a simple measure of overall variability across the task. From here the coefficient of variation was calculated by dividing the SD by the mean. The number of commission errors and omission errors was also recorded.

Choice Reaction Time (CRT) Task

The CRT is a computer-based measure of reaction time that uses a modified keyboard with YES, NO, START and NEXT buttons. Participants held down the START button to begin the task. When the word YES (or NO) appeared on the screen they were required to release the START button and press the YES (or NO) button. They were instructed to return to the START button to trigger the beginning of the next trial. To guard against pre-emptive responding, target offset could not be achieved if the START button was released before the target appeared. There were approximately 100 repetitions presented in random order. The task was self-paced, but participants were instructed to respond as quickly and accurately as possible. Participants were also instructed to use the same finger to hold down the START button and to press either the YES or the NO button. Speed of processing was measured in milliseconds and was split into a 'cognitive response' measure as time from target onset to trigger offset (release of START button) and 'motor response' measured as time from trigger offset to response selection (depression of YES or NO button).

Color Trail 1 and 2 (CT1, CT2)

The Color Trail tests 1 and 2 are paper and pencil based tests upon which the participant's performance is timed. Color Trail 1 mainly reflects visual scanning and processing speed, and Color Trail 2 requires visual scanning, attention, and mental flexibility, making it an executive function task. On Color Trail 1, participants are required to rapidly draw a line connecting circles numbered 1 to 25 in consecutive order as quickly as possible without making errors. On Color Trail 2, participants are once again required to draw a line connecting circles numbered 1 to 25 in consecutive order while, this time, altering between pink and yellow colours for each consecutive circle, as quickly as possible without making any errors.

5.2.2 Preliminary data analysis

Data from Wave One and Wave Two were merged in order to amalgamate demographic variables, cognitive scores and language questions. A 'Language Status' variable was created to distinguish between monolinguals, current bilinguals and past bilinguals and a further 'Language Acquisition' variable was created to categorise Current Bilinguals as either Early (L2 acquired from birth or in Primary School) or Late (L2 acquired in Secondary School or later) (Appendix H).

The number of Monolinguals was disproportionately larger than the other two groups with Current and Past Bilinguals combined making up 16.75% of the number of Monolinguals. To correct for this, a proportionate random sample (17%) of monolinguals were selected for analysis.

An Education variable indicated whether primary, secondary or third level education was obtained and a Socio-Economic Status (SES) variable (coded as per the Central Statistics Office definitions of socio-economic groups, Appendix I) and a Social Connectedness variable (as per Berkman's Social Networks Index) (Appendix J) were also obtained. Table 5.1 shows demographic characteristics of these 1795 participants, grouped by Linguistic Status.

Table 5.1: Demographic characteristics of the sample

Characteristic	Past Bilingual	Current Bilingual	Monolingual
	n = 687	n= 775	n=808
Mean Age (±SD)	64.92 (9.8)	63.36 (9.8)	62.18(9.4)
Sex: Male	248	328	376
Sex:Female	422	434	409
Highest Level of Education			
Primary	98	64	245
Secondary	269	211	350
Third Level	303	486	190
Other Language Acquired			
Irish	537	573	
European	117	245	
Non-European	16	26	
Period of L2 Acquisition			
From Birth	46	133	
Primary School	496	457	
Secondary School	86	128	
Later	34	83	

Analysis Strategy

Prior to performing analysis outliers were removed from specific analyses if their values were more than 3 standard deviations above or below the group mean. Distribution of continuous variables was assessed using histograms and the skewness statistic with standard error. Data that were positively skewed were log transformed. Data that were negatively skewed were transformed using a reflective square root transformation. In both cases transformations reduced skewness and created a more normalised distribution for statistical analysis. Analysis was carried out on transformed variables but the means and standard errors of the untransformed variables are presented. Between-subjects analyses of variance were performed to compare mean differences between groups. To examine the effects of bilingualism independently of other potential

confounding factors, the variables Education, SES and Social Connectedness were adjusted for using Analysis of Covariance (ANCOVA). All reported effects were significant regardless of whether the covariates were included or not.

5.3 Results

5.3.1 Study 1: Current and Past Bilinguals

MoCA

There was a significant main effect of Language Status on MoCA scores $F_{(2, 1792)}$ = 17.72, p= .001, ηp^2 =0.019. The Current Bilinguals performed significantly better than the Past Bilinguals (p=0.0001) and the Monolinguals (p=0.039) and the Past Bilinguals outperformed the monolinguals (p=0.036).

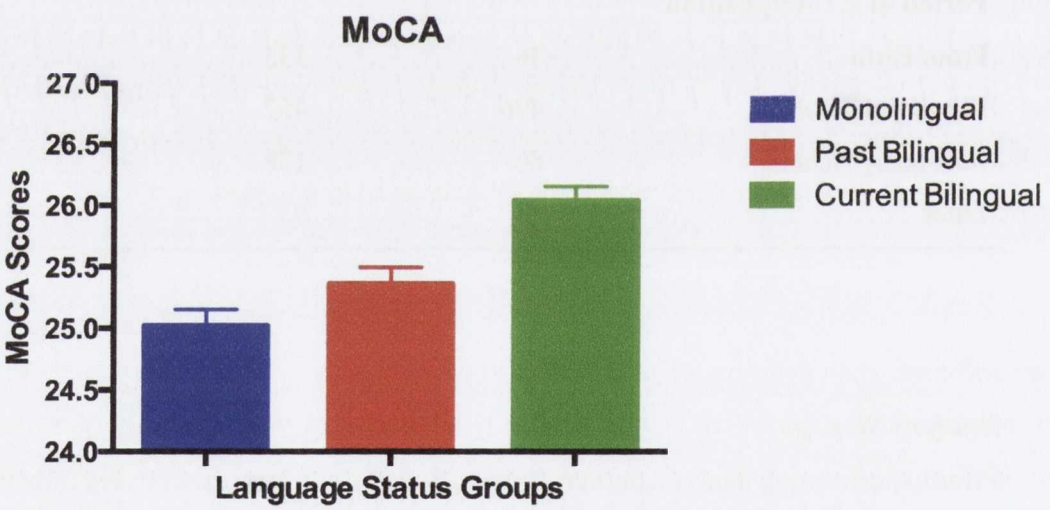


Figure 5.2: Highest MoCA scores in Current Older Bilinguals.

SART

There was a significant main effect of Language Status on reaction time variability in the SART as measured by the coefficient of variation ($F_{(2, 1716)}$ = 4.92, p=0.007, ηp^2 =0.006). Current Bilinguals demonstrated significantly lower reaction time variability relative to Past Bilinguals p=0.003, and Monolinguals (p=0.003) However there was no

significant difference in reaction time variability between Past Bilinguals and Monolinguals (p= 0.966).

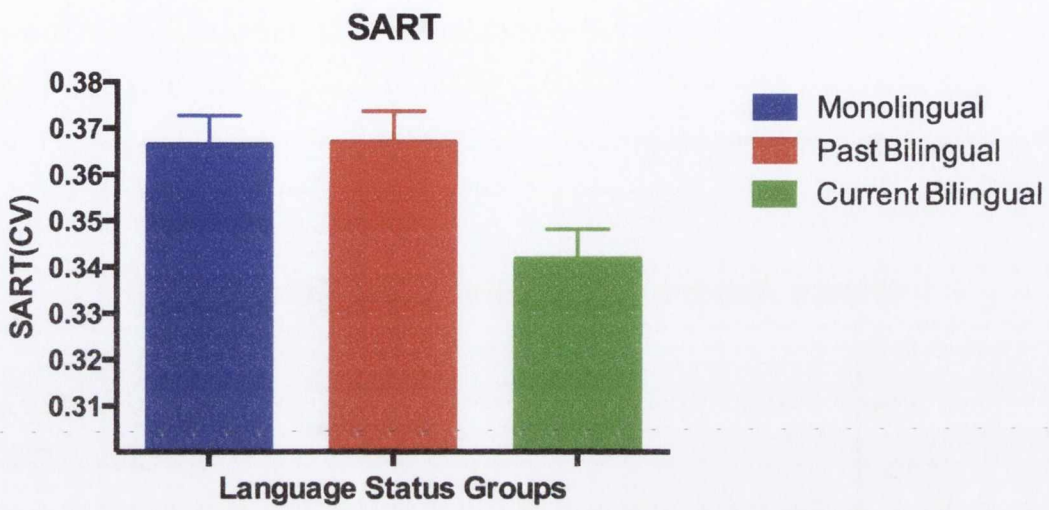


Figure 5.3: Lowest RT variability on SART for Current Bilingual Older Adults

There was also a significant main effect of Language Status on SART errors ($F_{(2, 1711)}$ = 13.92, p= 0.0001, ηp^2=0.01). Current Bilinguals made significantly fewer errors than Past Bilinguals (p=0.001), and Monolinguals (p= 0.001) However there was no significant difference between Past Bilinguals and Monolinguals (p= 0.51)

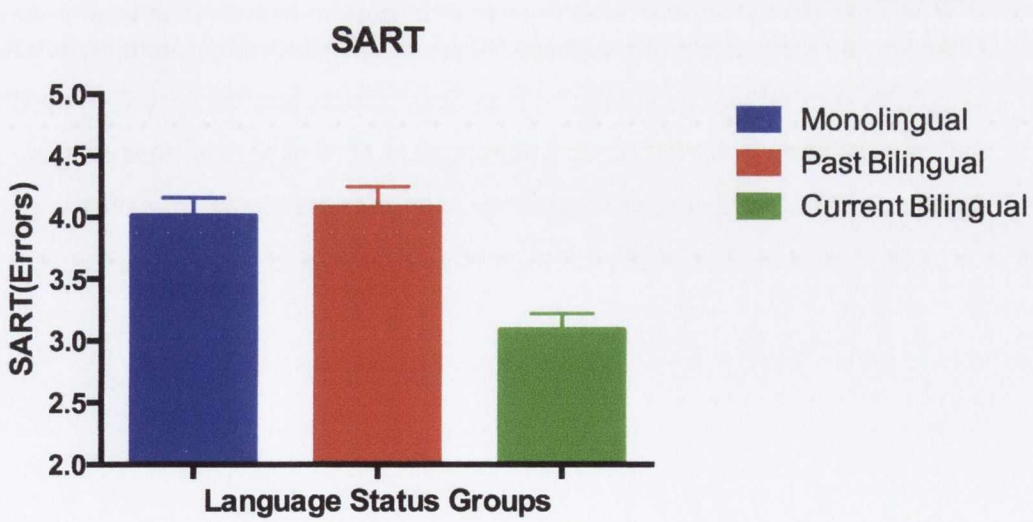


Figure 5.4: Lowest Error Rate on SART for Current Bilingual Older Adults

Choice Reaction Time Test (CRTT)

Cognitive Measure

There was a significant main effect of Language Status on the Cognitive Measurement of CRTT ($F_{(2, 1635)}$ = 8.252, p=0.001. ηp^2= 0.01) with Current Bilinguals performing better than Past Bilinguals (p=0.001), and Monolinguals (p=0.004). However there was no significant difference between Past Bilinguals and Monolinguals (p= 0.32).

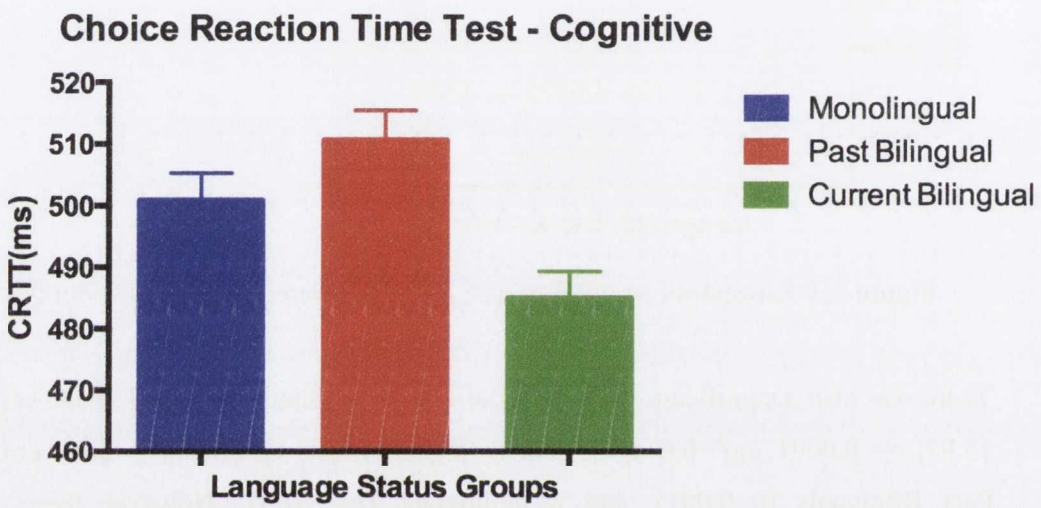


Figure 5.5: Reduced RT on Cognitive CRTT in Current Bilingual Older Adults

Motor Measure

There was no main effect of Language Status on the Motor Measurement of CRTT ($F_{(2, 1635)}$=2.981, p=0.051). There were no significant differences between Current Bilinguals and Past Bilinguals (p=0.07), or Monolinguals (p=0.61). Additionally there was no significant difference between Past Bilinguals and Monolinguals (p=0.20).

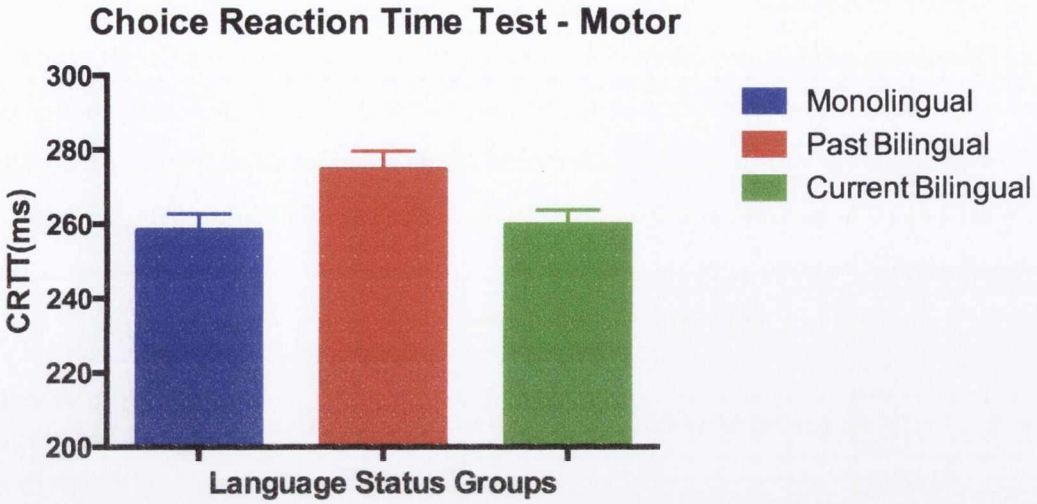


Figure 5.6: No Group differences in RT on Motor CRTT

Colour Trails One and Two

Colour Trails One

There was no significant main effect of Language Status on Colour Trails One ($F_{(2, 1772)}$= 2.279, p = 0.10). Furthermore there were no significant differences between Current Bilinguals and Past Bilinguals (p=0.12), or Monolinguals (p= 0.22) or Past Bilinguals and Monolinguals (p= 0.71).

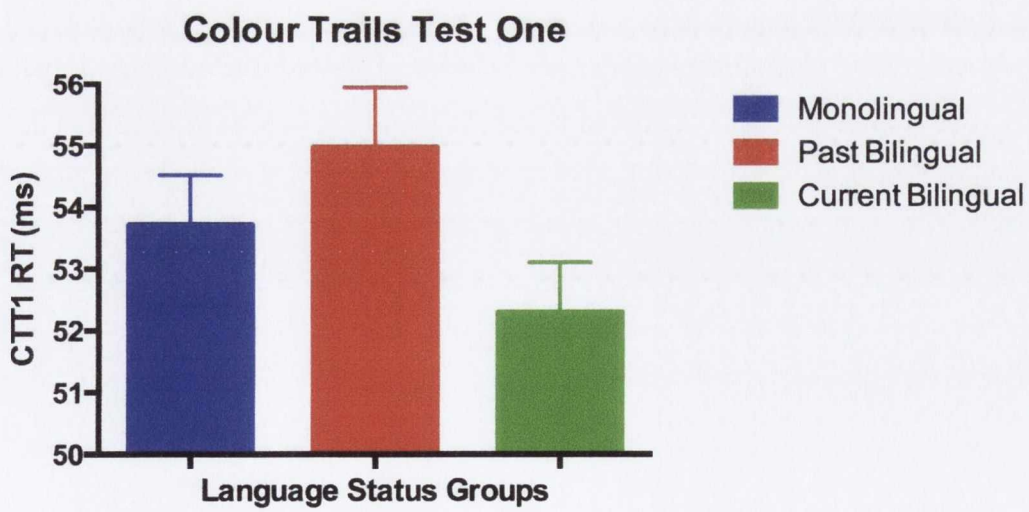


Figure 5.7: No Group differences in performance on Colour Trails 1

Colour Trails Two

There was a significant main effect of Language Status on Colour Trails Two ($F_{(2, 1775)} = 4.662$, p=0.01. ηp^2=.005). Current Bilinguals performed significantly better than Past Bilinguals (p=0.01), and Monolinguals (p=0.003) However there was no significant difference in performance between Past Bilinguals and Monolinguals (p= 0.59).

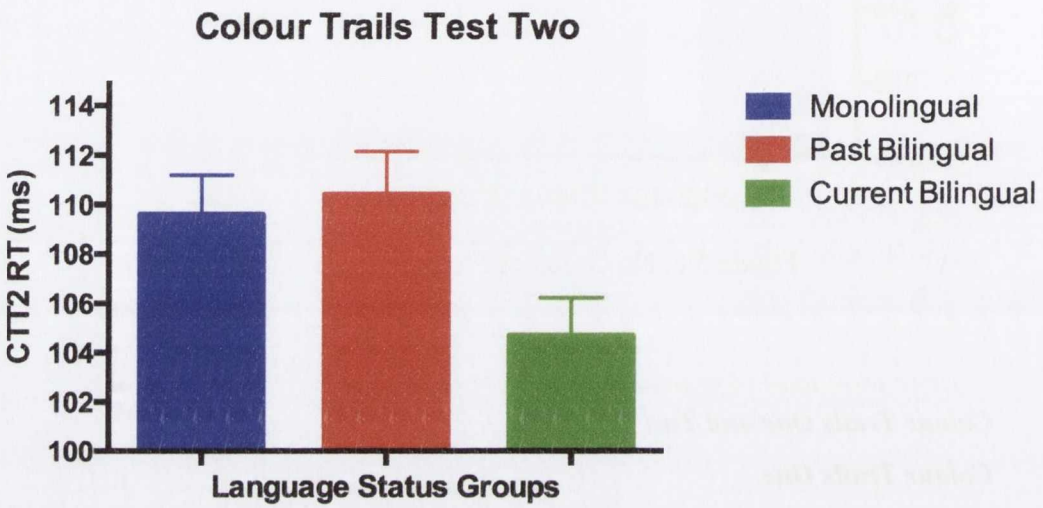


Figure 5.8: Reduced RT on Colour Trails 2 for Current Bilingual Older Adults

5.3.2 Study 2: Early and Late Bilinguals

Table 5.2: Demographic characteristics of the sample

Characteristic	Early Bilingual	Late Bilingual	Monolingual
	n = 585	n= 163	n=808
Mean Age (±SD)	63.81 (9.5)	61.77 (10.5)	62.18(9.4)
Sex: Male	250	63	376
Sex:Female	324	98	409
Highest Level of Education			
Primary	53	5	245
Secondary	161	43	350
Third Level	360	112	190
Other Language Acquired			
Irish	525	43	
European	108	134	
Non-European	20	5	
Period of L2 Acquisition			
From Birth	133		
Primary School	452		
Secondary School		98	
Later		65	

MoCA

There was a significant main effect of Group on MoCA scores ($F_{(2,\ 1222)}$=17.81, p= 0.001, ηp^2 =.028). While there was no significant difference between the Early Bilinguals and the Late Bilinguals (p=0.10) there was a significant difference in MoCA scores between the Monolinguals and the Early (p=0.001) and Late (p=0.001) Bilinguals.

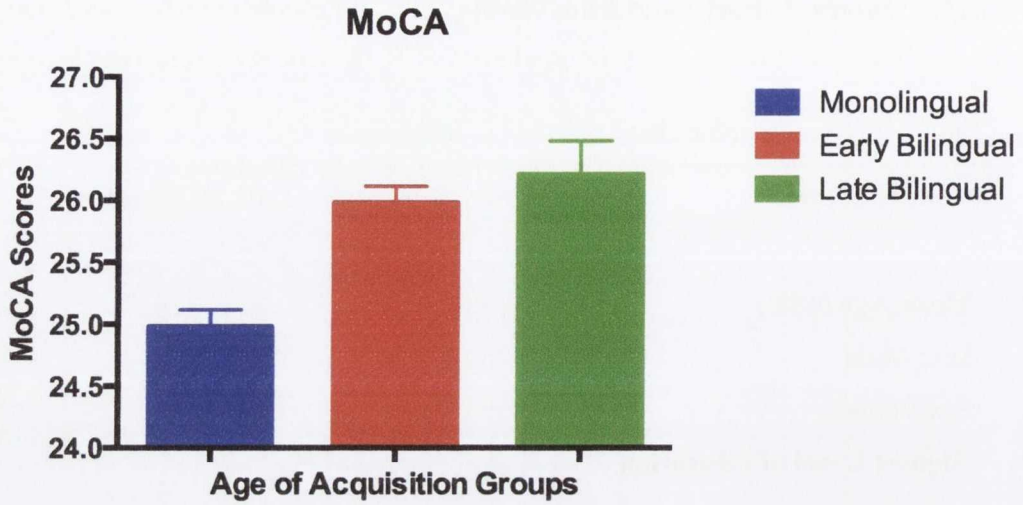


Figure 5.9: Highest MoCA scores for Late Bilingual Older Adults

SART

There was a significant main effect of Age of Acquisition on RT variability on the SART as measured by the coefficient of variation ($F_{(2,1000)}$ = 6.50, p =0.007, ηp^2 =0.012). Late Bilinguals were significantly less variable in their responding than Early Bilinguals (p=0.03), and Monolinguals (p= 0.03) Early Bilinguals also exhibited less RT variability than Monolinguals (p= 0.001).

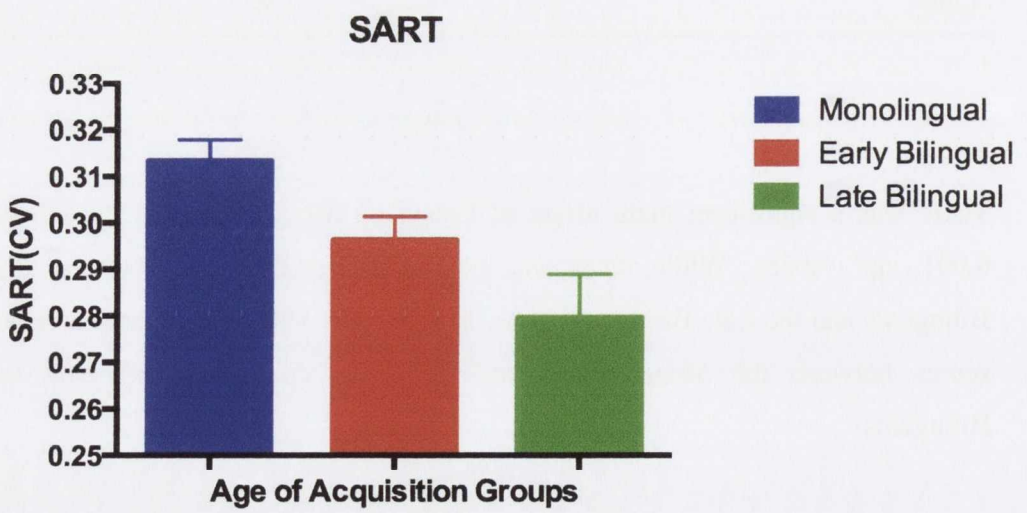


Figure 5.10: Late Bilingual Older Adults demonstrated least RT varibility on the SART

There was also a significant main effect of Age of Acquisition on SART errors $F_{(2, 1119)}$=12.68, p= .0001, ηp^2=.022) such that Late Bilinguals made significantly fewer errors than Early Bilinguals (p=0.03), and Monolinguals (p= 0.001) Early Bilinguals also made significantly fewer errors than Monolinguals (p= 0.001).

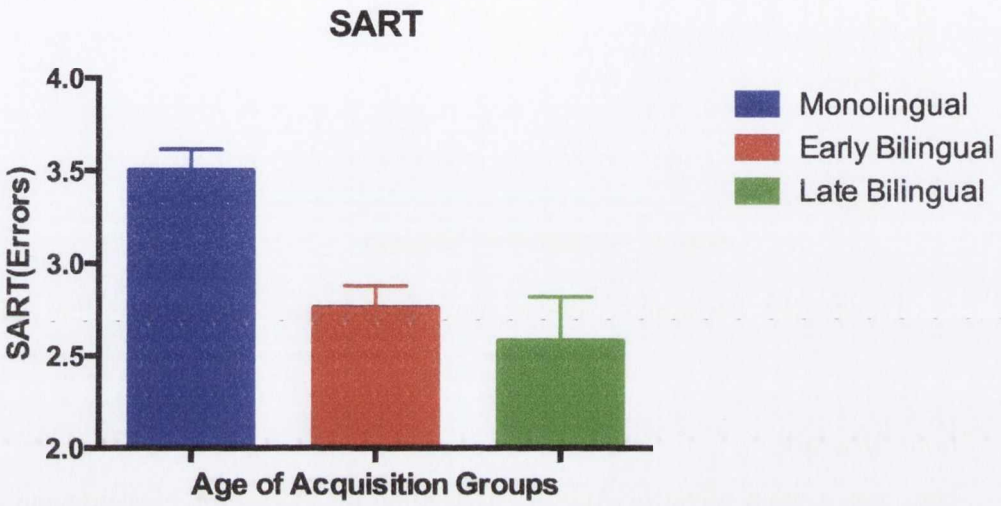


Figure 5.11: Late Bilingual Older Adults registered the fewest errors on the SART

Choice Reaction Time Test (CRTT)

Cognitive Measure

There was a significant main effect of Age of Acquisition on the Cognitive Measurement of CRTT ($F_{(2, 842)}$ = 4.815, p = .008. ηp^2=.011). There was no significant difference between the Early and Late bilinguals (p=0.02) however both the Early and the Late Bilinguals differed from the Monolinguals (p= 0.02, p= 0.004, respectively).

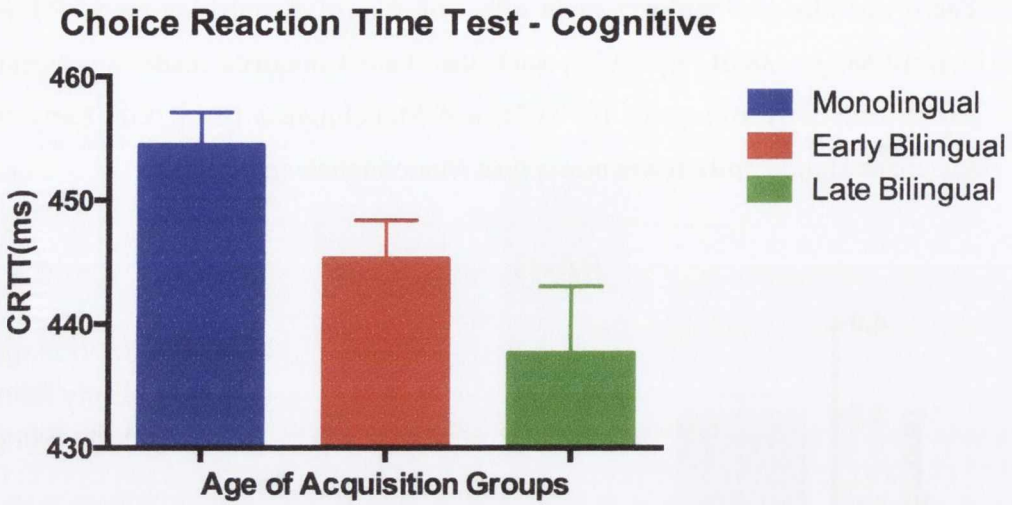


Figure 5.12: Reduced RT on Cognitive CRTT in Late Bilingual Older Adults

Motor Measure

There was a main effect of Age of Acquisition on the Motor Measurement of CRTT ($F_{(2, 1031)}$= 4.588, p=0.01). There was a significant difference between Early Bilinguals and Late Bilinguals (p=.013) but not Monolinguals (p=0.14) And there was no significant difference between Late Bilinguals and Monolinguals (p= 0.10).

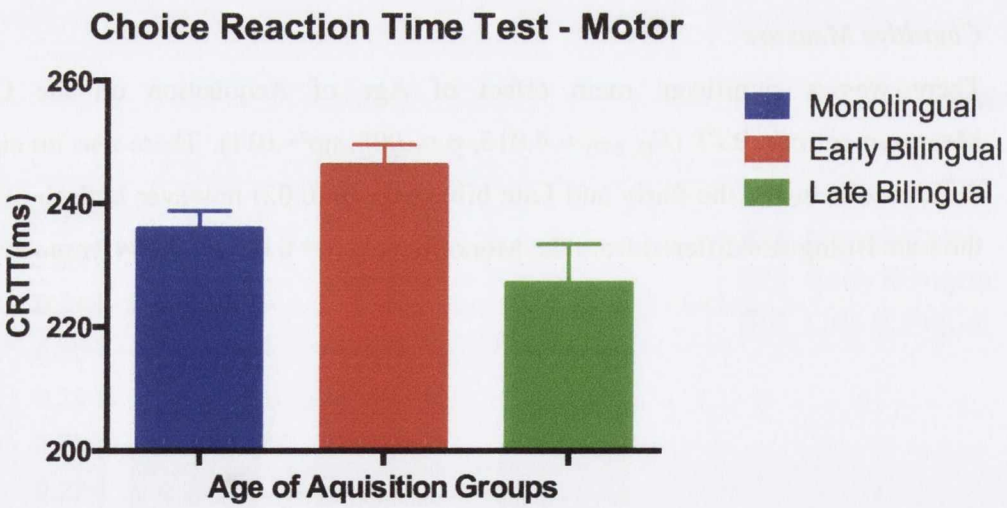


Figure 5.13: Reduced RT on Motor CRTT in Late Bilingual Older Adults

Colour Trails One and Two

Colour Trails One

There was no significant main effect of Age of Acquisition on Colour Trails One ($F_{(2, 877)}$ = .608, p=0.54) such that there were no differences in task performance between Current Bilinguals and Past Bilinguals (p=0.89), or Monolinguals (p= 0.30) or Past Bilinguals and Monolinguals (p= 0.40).

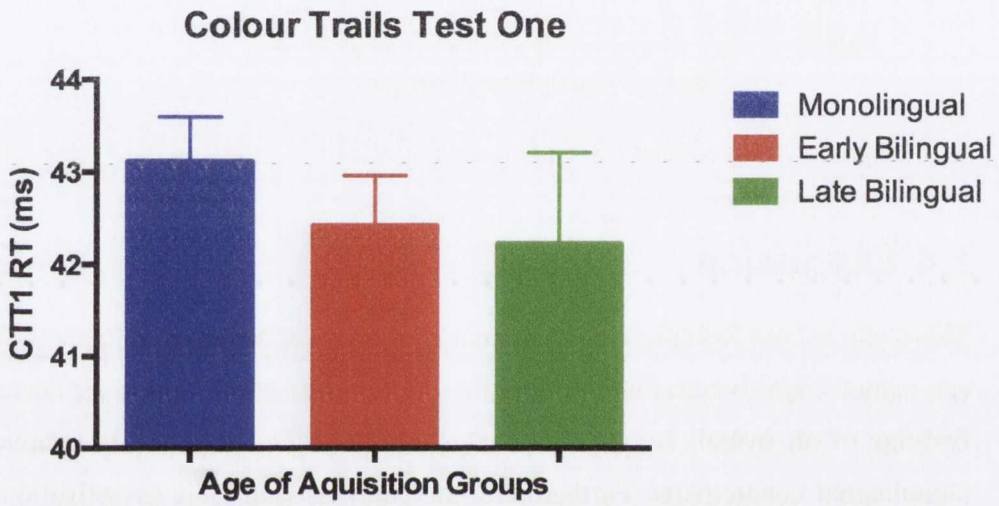


Figure 5.14: No group differences emerged in task performance on the Colour Trails 1

Colour Trails Two

There was a significant main effect of Language Status on Colour Trails Two ($F_{(2, 629)}$ = 3.492, p=0.03. ηp^2=0.010). Late Bilinguals performed significantly better than Early Bilinguals (p=0.02), and Monolinguals (p=0.01) However there was no significant difference in performance between Early Bilinguals and Monolinguals (p= 0.76).

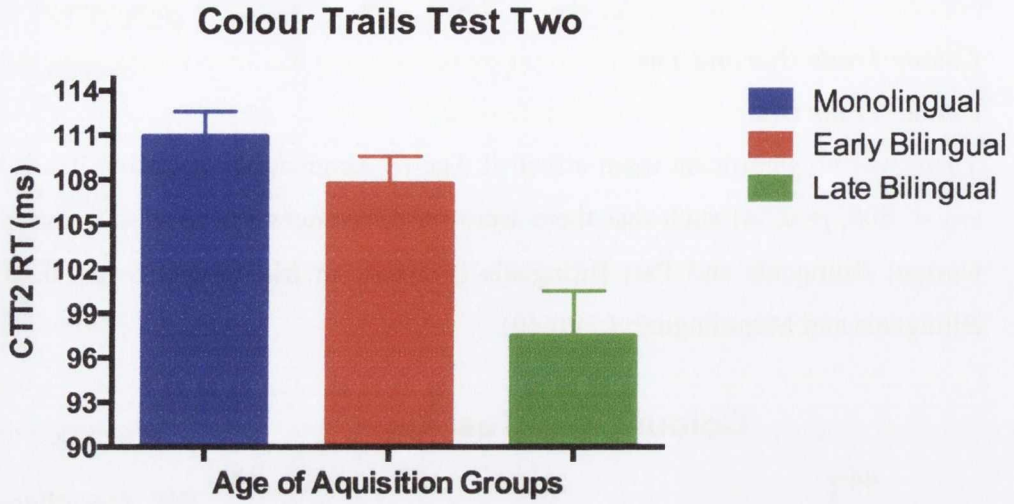


Figure 5.15: Reduced RT on Colour Trails 2 for Late Bilingual Older Adults

5.4 Discussion

This study set out to explore the bilingual advantage proposed to mitigate the effects of age-related cognitive decline in a sample of Irish older adults and to replicate previous findings of an overall cognitive advantage for bilingual individuals relative to their monolingual counterparts. Furthermore, the study extended the investigation to probe the circumstances under which the purported advantage is most evident. Specifically, the aim was to investigate whether a bilingual advantage accrues when active use of both languages is not maintained and also whether the impact of bilingualism on cognitive ageing is similar for both early and late bilinguals. The results of both Study 1 and Study 2 support previous findings (Bialystok et al., 2004; Gold et al., 2013) that bilingual older adults have a cognitive advantage over their monolingual counterparts in terms of global cognition, selective attention, processing speed and executive function.

In study 1 both the Current and the Past bilinguals outperformed the Monolinguals on the MoCA indicating an overall bilingual advantage in global cognition. There was also an additional benefit for Current Bilinguals over Past bilinguals suggesting that optimum benefits are conferred upon those who maintain active use of their second language. Among the Current Bilinguals in Study 2, there were no differences between those who had learned their second language early in life versus those who learned it later; there was, as expected based on the results of Study 1, an advantage for both Early and Late bilinguals over Monolinguals. Higher global

cognition scores lend support to the theory that bilingualism has a neuro-protective effect on cognitive function in a broad sense, delaying the onset of cognitive decline and potentially staving off the effects of dementia.

Sustained attention is the endogenous ability to mindfully and consciously process stimuli whose non-arousing qualities would otherwise lead to habituation and distraction (Robertson, Manly, Andrade, Baddeley & Yiend, 1997). Previous studies (Bialystok, 2008) did not find an advantage for bilinguals relative to monolinguals on the SART, however the current study used the fixed-sequence version of the SART rather than the random-sequence version used in previous research. The random SART has a greater response inhibition loading than the fixed SART due to random stimuli presentation. The fixed SART places a larger endogenous demand upon the sustained attention system due to the predictability of the stimuli presentation. Both false press errors (responding to the number 3) and omission errors (failing to respond to numbers 1,2 and 4-9) on fixed SART reflect lapses of sustained attention, and to a lesser degree, deficits in response inhibition. The current study found the bilingual advantage in the reduced SART coefficient of variation only in the case of current bilinguals with no difference in performance between past bilinguals and monolinguals. The coefficient of variation indexes the variability of performance per millisecond of reaction time: the lower the variability the more stable and more efficient the processing. This was also reflected in the errors made on the SART with Current bilinguals making significantly fewer errors than past bilinguals and monolinguals suggesting an advantage in lapses of attention. Furthermore those who learned their second language later in life showed an additional benefit in sustained attention and made fewer errors. These results suggest that there is a bilingual advantage in sustained attention, however this advantage is only observable when linguistic control of two languages is actively maintained into old age. Furthermore, the more effortful task of acquiring L2 successively to L1 requires the additional exercise of inhibiting L1 to select L2 and appears to confer a further additional advantage on sustained attention.

As expected, the motor measurement of the Choice Reaction Time test showed no differences between the Current, Past or Monolingual groups, however within study 2 there was an advantage for both early and late bilinguals over monolinguals which was unexpected and difficult to explain considering there is no reason to expect

bilingualism to impact upon motor reaction time. On the cognitive measurement, the Current Bilinguals once again outperformed both the Past Bilinguals and Monolinguals. Within the current bilinguals there was no difference between those who learned their second language early and those who learned it later, however both groups continued to show an advantage over monolinguals.

Somewhat inconsistent with the idea that bilingualism impacts specific components of executive control, several studies have reported that overall bilinguals showed faster reaction times than monolinguals. Costa and colleagues hypothesised that the overall speed advantage observed in bilinguals might reveal an impact of bilingualism on the efficiency of conflict monitoring (Costa, Hernandez, Costa-Faidella & Sebastian-Galles, 2009) and Bonifacci and colleagues propose that the overall advantage in processing speed suggests that the bilingual advantage is best defined as domain-general rather than specific. The findings of the current study suggest that active maintenance of two languages, regardless of age of acquisition impacts upon general rather than specific components of executive function.

As Color Trail 1 reflects visual scanning and processing speed without the executive function demands involved in Color Trail 2, no bilingual advantage was expected to be found on CT1, whereas an advantage was expected on CT2. In accordance with expectations there were no differences in performance between Current and Past Bilinguals and Monolinguals on CT1, and no differences between Early, Late and Monolinguals on CT1. However, on CT2 there was an executive control advantage for Current Bilinguals relative to both Past Bilinguals and Monolinguals, between whom there was no difference. Within the Current Bilinguals there was a further executive control advantage for those who had learned their second language later in life while the advantage disappeared for Early Bilinguals relative to Monolinguals. One of the key components contributing to cognitive flexibility is the ability to switch between mental sets (Meiran, 2010). During language production, bilingualism places particularly high demands on shifting abilities, as speakers have to decide when and how to switch back and fourth between their languages. The finding of the current study suggests that advantages in cognitive flexibility in older adults are most pronounced in bilinguals who learned their second language later in life and who maintain active use of both languages.

Importantly, across both studies, and on each of the measurements employed therein, the significant effects of the bilingual experience were not affected by the inclusion of education, socio-economic status or social connectedness as covariates. This finding supports the previous finding by Bak and colleagues (2014) and those of Alladi and colleagues (2013) suggesting that the effect of bilingualism prevails even when controlling for the effects of three factors that have long been considered to be crucial in terms of healthy cognitive ageing. This study further promotes the viewpoint that learning a second language later in life, provided that it is actively maintained, results not only in the same benefits as early acquisition but in fact leads to an even greater advantage in older age. These findings place bilingualism front and centre among the experiential and environmental factors that contribute to healthy cognitive ageing.

A 2014 report based on the findings of the 2011 census found that around 47,000 people were living with dementia in Ireland; this was estimated to double to an estimated 94,000 by 2031 and to reach 152,000 by 2046 (Pierce, Cahill & O'Shea, 2014). A 2012 review estimated that the overall cost of dementia to Ireland was over €1.69 billion (Cahill, O'Shea & Pierce, 2012). Far less tangibly measurable are the social, economic and psychological strains that the illness confers on both the people with the condition and their carers. These figures underline the urgency of the problem and until biological or pharmacological interventions are available to cure or prevent the disease it is useful to turn to environmental factors that can reduce the risk or ameliorate the effects by contributing to cognitive reserve (Bialystok et al., 2016). In Ireland, we have at our disposal a powerful tool to combat age related cognitive decline in our ageing population in the form of the Irish language. However, as outlined by Ó Giollagáin and Charlton (2015), and the 2011 Census, the number of active speakers are declining and as outlined in Darmody & Daly's 2015 report, attitudes towards the usefulness of the Irish language among the younger generation in particular are mostly negative. A positive finding from the Irish Language Study (2013) is that 43% of Irish people believe that the country should remain bilingual and 37% of people would like the government to do more for the future of the Irish language. In accordance with the existing literature, the findings of the present study suggest that the ultimate benefit of promoting Irish-English bilingualism, beyond the merits for cultural national identity,

may significantly contribute to public health and could ultimately result in enhanced, healthier cognitive well-being for the ageing citizens of Ireland.

Chapter 6 General Discussion

The objective of this thesis was to further explore the bilingual advantage in executive control by extending previous research to include predominantly underexplored populations of bilinguals such as high proficiency late bilinguals, adult language learners and inactive past bilinguals. In studying these populations we aimed to contribute to disentangling the specific aspects of the bilingual experience, such as age of acquisition, degree of language proficiency and operative language practices that have the potential to interact with and give rise to the bilingual advantage.

We examined these factors within the context of joint activation: the theory that both languages are simultaneously active and available at all times in the bilingual brain. Joint activation produces a processing problem for bilinguals with regard to selecting and attending to their target language, inhibiting the non-target language, and managing any conflict that may arise between the two. The general-purpose executive control system is recruited to accomplish this endeavour, a reconfiguration not applicable to monolinguals. The additional and pervasive habitual exercise of bilingual language control serves to fortify the executive control system as a whole, thereby giving rise to the bilingual advantage.

Three fundamental questions were addressed in this thesis: i) Does the bilingual advantage extend to individuals who acquired their L2 post adolescence? ii) Can the emergence of the bilingual advantage be traced in adults intensively learning L2? iii) Is it necessary to maintain active use of two (or more) languages in order to sustain the bilingual advantage?

6.1 The bilingual advantage in late bilinguals

6.1.1 Contributions

A common thread throughout the literature on the bilingual advantage is that bilinguals were predominantly categorised as such by virtue of having acquired two languages simultaneously from birth or sequentially in early childhood. Findings from both Chapter 3 and Chapter 5 address the question of whether the bilingual advantage extends to those who acquired their L2 later in life. In Chapter 3 we compared high-proficiency bilinguals who acquired L2 before the age of 7 (early) with those who acquired L2 after the age of 13 (late) and found that early and late bilinguals differed both behaviourally and physiologically. The pivotal finding was that the late bilinguals showed an enhanced executive control advantage relative to the early bilinguals and monolinguals as evidenced by a reduced switch cost. Switch cost was measured as the difference in reaction time between switch and nested trials and is considered to reflect the executive control processes engaged in reconfiguring the cognitive system from a state of readiness to perform task A to a readiness to perform task B.

There are two fitting classes of theory related to the switch cost: the competition hypothesis and reconfiguration theory. The former suggests that switching is accomplished through a competitive process in which the possible stimulus response mappings compete with one another (Wylie et al, 2008). The latter proposes that the switch cost represents the time taken for an executive process or processes to switch the cognitive system from a readiness to perform one task to a readiness to perform the other (Rubenstein et al, 2001). Although it is not possible to distinguish support for either of these two theories based on behavioural results alone, the electrophysiological results, in particular the larger parietal P3 observed on switch trials relative to nested and pre-switch trials, is more consistent with reconfiguration.

The reduced switch cost was found in the absence of an overall reaction time advantage for the late bilinguals, suggesting that the advantage cannot be attributed to superior processing speed in the late bilinguals. Furthermore there were also no differences between the groups in terms of error rates or task accuracy as measured by d', which again suggests that the advantage cannot be attributed to an overall task

performance advantage. We therefore attribute the observed switch cost reduction in the late bilinguals to an overall advantage in processing efficiency in late bilinguals.

Previous studies have attributed the bilingual advantage in executive control to an enhanced inhibitory control mechanism, fortified through its engagement in resolving language interference. Evidence for this was drawn from tasks that involved conflict in the form of task irrelevant information. The workings of such tasks is considered to be reflective of the conflict faced by the bilingual due to the presence of language-irrelevant information during the process of selecting the target language and inhibiting the other. The current study measured inhibitory control by examining the proportion of false press errors committed on the SWAT and predicted that the bilingual advantage in inhibitory control would be observed in the form of a reduction in the proportion of false press errors committed by the bilingual groups relative to the monolingual group. The results from our study indicated no such effect with the proportion of false press errors being equivalent for both the early and the late bilinguals relative to the monolinguals. Our behavioural results therefore do not support the theory that enhanced inhibitory control, at least in the context of the paradigm used to assay inhibition, is responsible for the bilingual advantage.

Furthermore, distinct features of N2/P3 ERP waveforms have previously been referenced as an index of enhanced inhibitory control in bilinguals relative to their monolingual counterparts. N2 enhancement on No-Go relative to Go trials has been argued to reflect the operation of a cognitive top-down inhibition mechanism needed to suppress the incorrect tendency to respond. Such a modulation was not observed in either the early or the late bilinguals in this study. Enhanced N2/P3 was however observed for all participants, bilingual and monolingual alike, on switch relative to nested and pre-switch trials on both Go and No-Go trials. We propose that this is because switch trials are the most cognitively demanding. Our lack of support for the theory that the bilingual advantage stems from an advantage in inhibition is in line with many recent studies (Kousaie & Phillips, 2011; Kousaie & Phillips, 2012; Morton & Harper, 2007; Namazi & Thordardottir, 2010; Paap & Greenberg, 2013).

Instead our data suggest that the late bilingual advantage stems from an enhancement in deploying and sustaining attention to facilitate switching. This is in line

with the findings of Prior & MacWhinney (2010) who found a pronounced bilingual advantage in switch cost in college-aged bilinguals, who also displayed enhanced facility at activating a task set in response to a cue, and took less time to overcome residual interference from the previous trial. The *bilingual executive processing advantage hypotheses* (BEPA) asserted by Hilchey & Klein (2011) suggests that enhanced efficiency of the central executive system may lead to bilingual advantages across both conflict and non-conflict task trials on any number of tasks that engage executive control. Support for this hypothesis comes from multiple studies that have found the bilingual advantage not just on conflict trials, but also on non-conflict trials also, across a wide range of experimental tasks exploring various cognitive processes. All of these processes involved cognitive flexibility and ranged from switching between mental sets (Prior & MacWhinney, 2010), achieving and maintaining an alert state (Costa et al., 2008; Marzecova et al., 2013) to anticipation (Bonifacci et al., 2011).

Physiological results concerning early components were of specific interest, in particular the N1. The N1 has previously been linked to arousal and early attentional deployment. The late bilinguals showed a significantly more enhanced N1 relative to the early bilinguals and the monolinguals. This is the first time that N1 has been linked to the bilingual advantage. However it has previously been interpreted to be reflective of increased attentional deployment in cases where an attentional set is established prior to stimulus delivery suggesting that visual attention can be allocated to task-relevant features by establishing an attentional set as a top-down bias prior to stimulus delivery. Our results showed a correlation between N1 and task accuracy in the case of the late bilinguals which may be indicative of augmented early engagement to the discriminative processing of stimuli. We suggest that the late advantage is potentially attributable to an effective adaptation in early processing that thereby minimises the later processing demands incurred by stimulus-response conflict.

Further evidence for the late bilingual advantage comes from Chapter 5 where older adult bilinguals who are currently actively using two languages showed an advantage over those who reported that they once were, but no longer are actively bilingual. The late advantage was found on the Fixed-SART both in the coefficient of variation, in terms of more stable or less variable response time and also in error rates whereby the late bilinguals made fewer errors. The fixed SART places a large

endogenous demand upon the sustained attention system due to the predictability of the stimuli presentation. Both false press errors and omission errors reflect lapses of sustained attention. This is in line with findings in Chapter 3 suggesting that the late bilinguals show an advantage in attention and also with the findings of Bak and colleagues (2014) who found that late childhood/early adult bilinguals had an advantage on selective attention and inhibitory control.

The late bilingual advantage in older adults was also found on the Color Trails 2 whereas no advantage was found on the cognitively less-demanding Color Trails 1. Color trails 2 is an executive control task that requires subjects to flexibly shift between mental sets. During language production, bilingualism places particularly high demands on shifting abilities, particularly in those who actively switch between languages frequently as a function of daily life. Our findings indicate that advantages in cognitive flexibility in older adults are most pronounced in bilinguals who learned their second language later in life and who maintain active use of both languages.

Taken together these findings demonstrate that not only does the bilingual advantage extend to those individuals who acquire L2 later in life, but in fact they may be afforded an even more pronounced advantage. This we interpret as being a result of the fact that learning an L2 later in life is far more challenging in the context of a joint activation framework. The additional cognitive effort of suppressing a more solidified L1 in order to select a less solidified L2 produces an even greater conflict to be resolved. The executive control system is thereby required to redouble its efforts in order to manage this conflict and is additionally fortified through its sustained exercise.

6.1.2 Limitations and future directions

We should note that no objective measurement of level of proficiency in either L1 or L2 was obtained from the bilinguals due to the fact that there were a wide range of L1s and L2s in the bilingual sample. However all bilinguals reported using and switching between at least two languages on a daily or almost daily basis. Furthermore, as outlined in Chapter 2, self-report ratings of language proficiency are highly correlated with a range of objective and standardised measures of language proficiency and are

widely considered to be an effective, valid and reliable tool for assessing bilingual language status (Marian et al., 2007). It is additionally necessary to note that the monolinguals in this study had some knowledge of Irish owing to the fact that Irish is taught as a compulsory subject at school. All monolinguals reported their Irish to be inactive and below a functional level, however the impact of early exposure to an L2 at school cannot be overlooked.

Given the exclusive reliance on the SWAT as a measure of executive function in Chapters 3 and 4, it is important to acknowledge that this paradigm is not without limitation. The SWAT was selected based on its merit as a task-switching paradigm measuring executive function by means of the switch cost. Inhibition and selective attention were measured based on false press and omission errors. It is possible that these measurements perhaps did not offer enough insight into the mechanisms underlying inhibition and selective attention and therefore future research should consider the inclusion of tasks such as the Stroop and Flanker task as well as the Test of Everyday Attention (TEA) and the SART in order to specifically measure inhibition and selective attention.

Our rationale for manipulating the speed of the task was a result of the ceiling effects previously reported in studying the bilingual advantage in adults who are considered to be functioning at their cognitive peak as a result of their age (Bialystok, 2006; Costa et al., 2008). We expected to potentially see similar effects between bilinguals and monolinguals at the cognitively less demanding slow speed and to then see the emergence of the bilingual advantage once the difficulty of the task was ramped up by increasing the task speed. Instead we saw that all participants were affected in the same way by the manipulation of task speed such that reaction time was driven by the speed increase and more false press and omission errors were committed on fast relative to medium or slow task speeds. The lack of significant interaction between speed and group suggests that the speed manipulation was unproductive and renders this manipulation unnecessary. Future research could employ an adaptive staircase design to control for speed, tailored to each individual. This approach may provide a more sensitive measure of the switch cost, while controlling for differences in speed and accuracy across the task.

6.2 Tracking the emergence of the bilingual advantage in adult L2 learners

6.2.1 Contributions

Because group differences can never exclude, with absolute certainty, the possibility of confounds, moving beyond the cross-sectional approach towards more longitudinal designs where emerging bilingualism becomes a variable over time and participants' original monolingual baseline acts as a point of comparison is insightful. Our attempts to trace the emergence of the bilingual advantage in adults intensively learning an L2 were ultimately underpowered, preventing us from drawing conclusive inferences from the data. However these findings do provide modest insight and a potential starting point for further research. The study initially found no differences in executive function as measured by the switch cost in the language learners when comparing their results at time 2 to those initially collected at time 1. A post hoc investigation of switch cost differences prompted us to split the learners into two groups: high progression and low progression learners. This was made possible due to the organisation of EFL language schools where student progress is driven at an individual level whereby students only progress to a higher level when they have reached a certain level of both objective (as measured by their student progress test) and subjective (feeling confident in their own ability) proficiency. This differs from previous research where university language students are studied. When the groups were separated according to progression levels, the high progress learners showed a switch cost advantage.

Segalowitz & Frenkiel-Fishman (2005) found that bilinguals' speed of attentional control in their L2 accounted for a significant proportion of the unique variance in their proficiency. This result was interpreted to indicate that as a bilingual gains L2 proficiency they also develop the relevant attention control skills, which in turn leads to an overall domain-general attentional improvement. It is therefore possible that the high progression learners in our study have traversed a threshold of proficiency whereby fluid access to L2 has transitioned into more automatic efficient processing. This is in line with the findings of Vega-Mendoza, West, Sorace & Bak (2015) who found that the bilingual advantage in selective attention in late non-balanced bilinguals

was evident in both a lower (year 1) and a higher (year 4) group, however only the higher group showed the advantage in attention switching indicating that separate cognitive effects emerge at different stages of L2 learning.

Green (1998) also theorised that bilinguals develop a sensitive mechanism of cognitive control that develops in parallel to increasing L2 proficiency and operates with meticulous precision to select, engage with and monitor the target language and inhibit the non-target language and that this has consequences more generally for executive processes and for their neural representation (Abutalebi & Green, 2007). Development of this mechanism is potentially bolstered by strategies such as rehearsal, imaging and metacognitive strategies to facilitate successful language learning. Interestingly, in our results there was a strong correlation between self-reported high confidence in aptitude for learning languages (reported at time 1) and progress towards a higher level class (as measured at time 2) suggesting that confidence in ones own abilities with language is conducive to successful progress in learning.

Our study provides persuasive evidence for the direction of influence to transfer from bilingualism to cognitive function rather than the reverse. A common issue in cross sectional research is the direction of causality. Specifically in this context, does bilingualism influence cognitive ability or is it plausible that those endowed with enhanced cognitive abilities are more likely to acquire a second language? This study lends credence to the theory that it is bilingual language control that transfers to an enhancement in executive function and not the reverse due to the fact that at test time 1 (baseline) there were no differences in switch cost between the high and low progression learners, and yet switch cost differences emerged at test 2 only for those who had made a high level of progress in their language acquisition.

Previous research into the early stages of L2 acquisition in adults has found that brain-related functional changes associated with the experience of L2 learning precede behavioural changes. McLaughlin, Osterhout & Kim (2004) found that after only 14 hours of university level L2 training students showed a significant change in N400 amplitude during a lexical decision task despite the fact that behavioural results were at chance level. Similarly Sullivan & colleagues (2014) found changes in P300 amplitude before and after a 6-month introductory Spanish course with no coinciding behavioural

differences. These results suggest that there is an observable neural response even after minimal L2 training. Results from our study found the converse effect: behavioural results after an intensive period of learning in the absence of physiological changes.

6.2.2 Limitations and future directions

The primary limitation faced by this study was reduced statistical power as a direct result of a high dropout rate between test 1 and test 2. Future studies aiming to trace the emergence of the bilingual advantage should consider the merits of providing incentives for the language students' participation, i.e., rewards within their language school or a personalised chart of how their language progress correlates with cognitive changes over time if the student attends multiple repeated test sessions. Furthermore we suggest that future studies should aim to employ cognitive tasks that can be administered within the language school to thereby facilitate more regular repeated test sessions and to include a larger number of participants. Although moving this research outside of the lab would remove the possibility of collecting EEG data, we suggest that a large behavioural study with strong statistical power carried out longitudinally would serve to identify patterns in the emergence of the bilingual advantage that could then be further investigated in the lab.

6.3 The bilingual advantage in active and passive older adult bilinguals

6.3.1 Contributions

Chapter 5 addressed the question of whether or not the bilingual advantage is in evidence even in cases where the L2 is not actively maintained. This study compared active and passive older adult bilinguals across a number of cognitive tests and found that only the active and not the passive bilinguals displayed the bilingual advantage. These results suggest a protective effect of active bilingualism against age-related cognitive decline. Importantly, this effect could not be explained by level of education, socio-economic status or social connectedness. This is in line with previous studies by Bak and colleagues (2014) and those of Alladi and colleagues (2013).

The bilingual advantage has been relatively well explored when it comes to older adults, particularly in studies of pathological ageing where bilingualism has been found to boost cognitive reserve and result in a more effective endurance of the early symptoms of Alzheimer's disease (Bialystok, Craik & Freedman, 2007). This effect has been replicated controlling for education, occupational status and immigration (Craik, Bialystok & Freedman, 2010). And adjusting for sex, occupation and urban versus rural dwelling of participants, this time extending the benefit to illiterate bilinguals confirming that level of education is not a sufficient explanation for the observed difference (Alladi et al., 2013). Bilinguals have also been found to show significantly better recovery following a stroke than monolinguals with the percentage of patients with intact cognitive functions post-stroke being more than twice as high in bilinguals than in monolinguals (Alladi et al., 2016). Although our study did not directly investigate the role of bilingualism in pathological ageing our results strongly indicate that in the case of active older bilingual adults bilingualism serves as a predictor of healthy cognitive ageing.

Previous studies have explored the impact of certain language practices, such as active versus passive use of L2, on the bilingual advantage. Abutalebi and colleagues (2015) found that only those who maintained a high usage of both languages showed significant effects of neuro-protectiveness against cognitive decline. Similarly, de Bruin and colleagues (2015) found a significant bilingual advantage in older adults for active, but not passive, bilinguals relative to their monolinguals counterparts. Our study replicates these findings and highlights the ultimate benefit of reinvigorating active bilingualism in Ireland as the benefits of so doing are strongly linked to the potential to boost cognitive reserve and contribute to healthier cognitive ageing.

6.3.2 Limitations and future directions

Bak and colleagues (2014) found that individuals who learned a second language after the age of 11 achieved better cognitive results 60 years later than could have been predicted based on their childhood performance on intelligence tests, demonstrating that language learning and use can mitigate the effects of cognitive ageing. In line with the findings of Gollan et al., 2011, the effect was found to be strongest in those whose intelligence scores were initially low, confirming that the effect prevails regardless of

childhood intelligence. There was no general intelligence measure available for inclusion in our study, and despite the fact that the findings of Bak et al., 2014 and Gollan et al., 2011 suggest that the bilingual advantage is independent of intelligence levels we cannot overlook the potential that intelligence levels may have had a confounding effect on our results.

The finding that the bilingual advantage is present in current active bilinguals but absent in past bilinguals raises the interesting question of whether it is possible for a past bilingual to regain the bilingual advantage by reengaging active use of their L2. Future studies may potentially address this question by incentivising past bilinguals to participate in refresher language courses as an intervention within a repeated measures experimental design.

6.4 Extra-linguistic factors that impacted upon successful language acquisition in Learners and enhanced executive control in bilinguals

Although the language learners in this study were attending intensive language classes, a substantial amount of their language learning happened outside of the classroom as a result of living and working in an environment in which their L2 is spoken. Kroll & Stewart (1994) suggest that during the early stages of L2 acquisition, there is a dependency on L1 to mediate access to meaning of lexical items. As L2 proficiency improves this dependency reduces. It is therefore useful to explore the range of factors that might best predict successful language acquisition. Questionnaires were administered to the language learners at time 1 and time 2 to investigate these factors and response data was correlated with language learner progress. This data was also correlated with switch cost at times 1 and 2, bearing in mind that the small sample size renders such correlations potentially unreliable but suggestive of further investigation of particular relationships.

The questionnaire data yielded a number of variables of interest, in particular self-reported levels of proficiency strongly correlated with objective proficiency levels (the class level to which the student was assigned in school) highlighting the merit of

self-report ratings of proficiency, even for those at the early stages of L2 learning. Of particular interest, a time 1 self-report of high confidence in general aptitude for learning languages strongly correlated with higher proficiency at time 2. This is particularly surprising in light of the fact that learners had little or no experience of having ever learnt a second language at the test time 1. Unsurprisingly self-reported tendencies to use English outside of the classroom, and with friends strongly correlated with higher proficiency at time 2. Many learners at time 2 reported emerging tendencies to use English for self-talk, particularly for procedural processes such as cooking or getting dressed, and for expressing emotion, in particular for using "bad language". These findings once more suggest that there is a threshold of proficiency whereby fluid access to L2 has transitioned into more automatic efficient processing and that this threshold is breached by engaging strategies such as those described in the questionnaire data.

In terms of the extra-linguistic factors that impacted upon executive control, correlations were found between reduced switch cost and use of L2 at work. This is in line with reports from the learner group and both bilingual groups that they are highly motivated to learn or maintain an L2 due to the benefits it provides in terms of employment. Many bilinguals in the sample reported that a fundamental requirement of their job is the ability to use and switch between their two languages throughout their working day, a factor that, according to our study, bestows them with cognitive advantages.

6.5 Conclusions

Disentangling the complex interplay between bilingualism and cognition and the multitude of factors that potentially contribute to the presence or absence of the bilingual advantage is not a straightforward feat. Overall our results support the presence of the bilingual advantage in certain circumstances and importantly no negative effects of bilingualism were detected in any of our studies.

As the field of bilingual research evolves it is necessary to move away from rigid categorisations of bilinguals as those who learned their L2 early in life or simultaneously acquired two languages from birth and to include more of the spectrum

of underexplored cohorts of bilinguals whose experience of and route to bilingualism has the potential to contribute to addressing fundamental questions. Inclusion of such cohorts however requires recognition that no two bilinguals are identical and therefore differences must be accepted, accounted for and properly acknowledged.

The central finding of this thesis is that the bilingual advantage is enhanced in late bilinguals, which we attribute to the additional cognitive effort of acquiring, becoming highly proficient in and managing a constantly active L2 in adulthood. We suggest that this cognitive feat results in an adaptation in attentional processing that serves to boost domain-general cognitive function. Secondary to this finding, we provide a starting point for tracking the emergence of the bilingual advantage in adult L2 learners. A longer longitudinal study comprised of multiple retest sessions and a large number of participants would contribute substantially to better understanding the trajectory of the developing bilingual advantage.

Finally, our findings concerning older adults contribute to the field of bilingual research both on a global and a local scale. We replicated previous findings of a bilingual advantage in older adults who actively use their L2, and extended the findings to show an additional advantage to older adults who became bilingual late in life but have thereafter maintained active use of two languages. These findings highlight the role of active bilingualism as an environmental factor with the potential to significantly contribute to healthy cognitive ageing.

At a local level, Ireland has at its fingertips a powerful tool to help combat age related cognitive decline in our citizens in the form of our national language. The findings of this study have far reaching implications for national policy and underscore the merit of assigning resources to reinvigorate and promote bilingualism in Ireland.

Ireland holds great potential as a hub for future studies in bilingualism. Our status as a bilingual country provides the opportunity to explore bilingualism across a wide spectrum of experiences and practices that potentially impact upon the presence or absence of the bilingual advantage. Furthermore, being the only native English speaking country in the Eurozone makes Ireland an attractive centre point for students learning English as an L2.

The weight of evidence suggests that the consequences of bilingualism are profound. There is still much to be explored about the effect of bilingualism on cognitive function and the neural correlates that underlie the interplay between the two along with the specific circumstances under which the bilingual advantage is observed. Given the impassioned debates and ever accelerating interest in the field, the very near future will undoubtedly see great strides being made towards a better understanding of the bilingual mind.

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Appendices

Appendix A

Language History Questionnaire for Bilinguals

Please complete this questionnaire and return it to connola5@tcd.ie before you come in to participate.

If you have any difficulty completing this questionnaire or any questions please contact me at the above e-mail address.

Thank you for taking the time to participate in this study.

1. Please provide the following information:

Name: _____ Email: _____ Telephone: _____

Age: _____ Sex: (Male / Female) _____

2. What is the highest level of education that you are currently attending or have completed?

Primary/Elementary school _____ Secondary/High school _____ University _____

4. What is/are your *native language(s)? _____ (*Languages acquired simultaneously from birth)

5. Do you speak more than one language? __ Yes __ No **(If you answered "No", you need not continue this form)**

If you answered, "Yes", please

A. List the languages that you know
B. Indicate the level at which you consider your proficiency to be in each language
(Levels: 1 = Beginner, 2 = Elementary, 3 = Pre-Intermediate, 4 = Intermediate, 5 = Upper-Intermediate, 6 = Advanced).
C. Indicate the frequency at which you use each language
(1 = Never, 2 = Once or twice a year, 3 = Once or twice a month, 4 = Once or twice a week, 5 = Daily or almost daily, 6 = multiple times within the day every day)

A. Language	B. Level	C. Frequency of usage

6. What is your nationality: _____

7. How long have you spent living in a country where your second language is spoken? _____

8. How old were you when you started to learn your second language? _____

9. How old were you when you became *actively* bilingual (i.e. you began to use or switch between two (or more) languages on a daily or almost daily basis)? _____

10. Please select <u>one</u> of the following options that most accurately describes your language use

A. I tend to use my first language more regularly than my second language ☐

B. I tend to use my second language more regularly than my first language ☐

C. I have a balanced tendency to use and switch between each of my two languages ☐

D. None of the above options accurately describe my language tendencies ☐

Explain _____

11. On a scale from zero to 6, please rate your level of proficiency in each of the following linguistic skills relating to your second language

(Levels: 1 = Beginner, 2 = Elementary, 3 = Pre-Intermediate, 4 = Intermediate, 5 = Upper-Intermediate, 6 = Advanced).

Speaking		Reading		Writing		Comprehension		Pronunciation	

12. On a scale from <u>zero to 10</u>, please rate how much the following factors impacted upon your acquisition of your second language (0 = no impact, 10 = a strong impact)

Formal education		Listening to radio/podcasts/music	
Living in a country where your second language is spoken		Past or current job	
Interacting with family		Reading	
Interacting with friends		Using the Internet	
Interacting with a romantic partner		Television/films	

13.On a scale from <u>zero to 10</u>, please rate the extent to which you are <u>currently</u> using your second language in the following contexts (0 = not using it at all, 10 = very regularly using it)

Formal education		Listening to radio/podcasts/music	
Living in a country where your second language is spoken		Current job	
Interacting with family		Reading	
Interacting with friends		Using the Internet	
Interacting with a romantic partner		Television/films	

14. In your perception, how much of a foreign accent do you have in your second language?
Strong / Mild / None

15. How often do you use each of your languages for the following activities? Please write the language in the box on the left and circle the appropriate number in the table according to the scale below.

(1= Never, 2= Rarely, 3= Occasionally, 4= Sometimes, 5= Frequently, 6= Very Frequently, 7= Always)

Language	Arithmetic (e.g. counting, multiplication, subtraction	Remembering numbers (e.g. telephone numbers)	Dreaming	Thinking	Talking to yourself	Expressing emotions (e.g. anger, affection etc)
	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7
	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7
	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7

16. Please select one or more answer(s) that most closely describes your motivation for learning/maintaining your second language

Work/job ☐ School/university ☐ Pleasure/ recreation/travel ☐ Immigration to a new country ☐

Factors outside of my control e.g. place of birth/family circumstances ☐

Other reasons ☐ please specify _____

17. On a scale from 1 to 10 rate your language learning abilities. In other words, how good do you feel you are at learning new languages in general (e.g. relative to friends or people you know)? _____

18. What proportion of your current friends are speakers of the languages that you know well? Indicate below the language they speak and the percentage of time that you spend speaking each language to them. (Total percent should add to 100%).

Language	Percent (%)

19. If there is anything else that you feel is interesting or important about your language background or language use, please comment below.

Appendix B

Language History Questionnaire for ESL Learners **TIME 1**

Please complete this questionnaire and return it to connola5@tcd.ie before you come in to participate.

If you have any difficulty completing this questionnaire or any questions please contact me at the above e-mail address.

Thank you for taking the time to participate in this study.

1. Please provide the following information:

Name: _____ Email: _____ Telephone: _____

Age: _____ Sex: (Male / Female) _____

2. What is the highest level of education that you are currently attending or have completed?

Primary/Elementary school _____ Secondary/High school _____ University _____

3. What is/are your *native language(s)? _____ (*Languages acquired simultaneously from birth)

4. Are you learning English at the moment? Yes ☐ No ☐

5. What level class have you been placed in?

Beginner ☐ Elementary ☐ Pre-Intermediate ☐ Intermediate ☐ Upper-Intermediate ☐ Advanced ☐

6. Is English your second language? Yes ☐ No ☐

7. Do you know any other languages? Yes ☐ No ☐

8. Is this your first time studying English? Yes ☐ No ☐

If you answered 'No" please give some information about your past experience of learning English (i.e. how old were you? What type of class did you attend and for how long?)

_____

_____

_____

_____

9. On a scale from zero to 6, please rate your level of proficiency in each of the following linguistic skills relating to your second language

(Levels: 1 = Beginner, 2 = Elementary, 3 = Pre-Intermediate, 4 = Intermediate, 5 = Upper-Intermediate, 6 = Advanced).

Speaking		Reading		Writing		Comprehension		Pronunciation	

10. What is your nationality: _____

11. How long have you spent living in a country where English is spoken? _____

12. How old were you when you started to learn English? _____

13. At various stages throughout your life, how much exposure have you had to English?

(1= Never, 2= Rarely, 3= Occasionally, 4= Sometimes, 5= Frequently, 6= Very Frequently, 7= Always)

Please also give details

From birth to age 7 [ ] _____

From age 7 to age 14 [ ] _____

From age 14 to age 21 [ ] _____

From age 21 to now [ ] _____

14.On a scale from zero to 10, please rate the extent to which you are currently using English in the following contexts:

At school		Listening to radio/music	
Interacting with flatmates		Job	
Interacting with family		Reading	
Interacting with friends		The internet	
Interacting with a partner		Television/movies	

15. How often do you use each of your languages for the following activities? Please write the language in the box on the left and circle the appropriate number in the table according to the scale below.

(1= Never, 2= Rarely, 3= Occasionally, 4= Sometimes, 5= Frequently, 6= Very Frequently, 7= Always)

Language	**Arithmetic (e.g. counting, multiplication, subtraction**	**Remembering numbers (e.g. telephone numbers)**	**Dream**	**Think**	**Talk to yourself**	**Express emotions (e.g. anger, affection etc)**
(First language)	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7
English	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7

16. What is your main reason for learning English? Please select one or more answer(s).

Work/job ☐ School/university ☐ Pleasure/ recreation/travel ☐ Immigration to a new country ☐

Factors outside of my control e.g. place of birth/family circumstances ☐

Other reasons ☐ please specify _____

17. On a scale from 1 to 10 rate your language learning abilities. In other words, how good in general do you feel you are at learning new languages (e.g. relative to friends or people you know)? _____

18. What percentage of the time do you spend speaking your first language and English?

Language	**Percent (%)**
My first language	
English	

19. If there is anything else that you feel is interesting or important about your language background or language use, please comment below.

Appendix C

Language History Questionnaire for ESL Learners **TIME 2**

Thank you for continuing to participate in this study.

1. Please provide the following information: Name: _____

2. Are you learning English at the moment? Yes ☐ No ☐

3. What level class are you now in?

Beginner ☐ Elementary ☐ Pre-Intermediate ☐ Intermediate ☐ Upper-Intermediate ☐ Advanced ☐

4 On a scale from zero to 6, please rate your level of proficiency in each of the following linguistic skills relating to your second language

(Levels: 1 = Beginner, 2 = Elementary, 3 = Pre-Intermediate, 4 = Intermediate, 5 = Upper-Intermediate, 6 = Advanced).

Speaking		Reading		Writing		Comprehension		Pronunciation	

5.On a scale from zero to 10, please rate the extent to which you are currently using English in the following contexts:

At school		Listening to radio/music	
Interacting with flatmates		Job	
Interacting with family		Reading	
Interacting with friends		The internet	
Interacting with a partner		Television/movies	

6. How often do you use each of your languages for the following activities? Please write the language in the box on the left and circle the appropriate number in the table according to the scale below.

(1= Never, 2= Rarely, 3= Occasionally, 4= Sometimes, 5= Frequently, 6= Very Frequently, 7= Always)

Language	**Arithmetic** (e.g. counting, multiplication, subtraction	**Remembering numbers** (e.g. telephone numbers)	**Dreaming**	**Thinking**	**Talking to yourself**	**Expressing emotions** (e.g. anger, affection etc)
(First language)	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7
English	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7

7. What percentage of the time do you spend speaking your first language and English?

Language	Percent (%)
My first language	
English	

Appendix D



Student language level is determined using the scales which correspond to Common European Framework of References.

Our levels are described as follows:

A1 Elementary

A2 Pre Intermediate

B1 Intermediate

B2 Upper Intermediate

C1 Advanced

Level Placement Test

Delfin English School

Do not write on this question paper. Write on the answer page only. Choose one answer only.

Example : He ____likes____ tea

A) like	B) like you	C) likes	D) liking

The answer is C=likes

SECTION 1

1) He's _____ actor, that's his job.

A) a	B) the	C) an	D) his

2) Is this pen _____?

A) yours B) the yours C) you D) my

3) Where are you _____?

A) for B) from C) at D) too

4) How _____ students are in the class?

A much B) many C) manys D) too manys

5) I didn't hear you, could you _____ that, please?

A) retell B) say C)repeat D) recount

6) Jim _____ T.V. when the telephone rang in the next room.

A) was seeing B) was watching C) watched D) watching

7) What are _____ names?

A) their B) theirs C) there D) theres

8) He _____at 7 o'clock every day.

A) gets up B) is getting up C) get up D) was getting up

9) She _____ a black suit today.

A) is having B) wears C) has D) is wearing

10) That shop is _____ than this one.

A) more cheap B) cheaper C) cheaply D) more cheaper

11) I like _____football with friends at the weekends.

A) playing B) play C) do D) making

12) She's very famous – everybody _____ her.

A) knows B) is knowing C) know D) are know

13) What _____ next weekend?

A) do you do B) are you doing C) are you do D) will you doing

14) My sister finishes her homework _____ than me.

A) more quickly B) quicker C) more quick D) quicklier

15) This is _____ cake I've ever tasted.

A) delicious B) the more delicious C) the most delicious D) most delicious

16) She's an old friend – I've known her _____years.

A) in B) for C) since D) during

17) Great news everyone – we _____ go to school tomorrow.

A) ought to B) must to C) don't have to D) mustn't to

18) If you touch the oven, you _____ burn yourself.

A) will B) should C) would D) can to

19) The friend _____ house I stayed in is coming for dinner tonight.

A) whom B) who C) which D) whose

20) If some aliens landed on earth, I _____ make friends with them.

A) can B) may C) would D) will

SECTION 2

21) He _____ the dentist next week at 4:30.

A) is seeing B) going to see C) will seeing D) saw

22) I _____ been to France.

A) haven't never B) have never C) didn't ever D) not ever

23) I _____ play tennis every Thursday but now I don't.

A) used to B) use to C) getting used to D) used

24) Guests _____ use any electrical appliances in their rooms.

A) can't to B) should C) must not D) don't have to

25) I am completely soaked. I _____ taken an umbrella.

A) could had B) should C) might have D) should have

26) He _____ what I was doing but I refused to tell him anything.

A) asked **B) told** **C) said** **D) informed**

27) By the year 2020 the ozone layer _____ disappeared.

A) is going to **B) will** **C) is** **D) will have**

28) If Tim _____ the car more carefully, he wouldn't have had the accident.

A) would drive **B) had driven** **C) drove** **D) drives**

29) When Joe arrived at the party Sarah wasn't there. She _____ home.

A) have been **B) went** **C) would go** **D) had gone**

30) I don't know yet if I'm going out at the weekend – it depends _____ the weather.

A) by **B) to** **C) for** **D) on**

SECTION 3

31) He is said _____ a multimillionaire.

A) being **B) to be** **C) to make** **D) to have**

32) I don't really mind where we _____as long as I get something to eat soon.

A) are stopping **B) stopped** **C) will stop** **D) stop**

33) It won't work _____ you insert the battery.

A) before **B) after** **C) until** **D) as soon as**

34) He was busy _____ his homework.

A) at making **B) make** **C) doing** **D) to do**

35) It's only the second time I _____ Harry, but I feel as if we're already friends.

A) met **B) have meet** **C) meet** **D) have met**

36) I wish I _____ so much – I feel terrible.

A) didn't eat **B) hadn't eaten** **C) hadn't ate** **D) haven't eaten.**

37) Although he was badly injured, he _____ crawl his way to safety.

A) can **B) could** **C) managed to** **D) was able**

38) When I was young, you _____ be twenty-one before you could get into nightclubs.

A) must **B) would** **C) had to** **D) should**

39) You _____ milk – I've got plenty in the fridge.

A) mustn't buy **B) needn't to buy** **C) needn't have bought** **D) needn't bought**

40) Did you remember _____ your mum? She said it was important.

A) phoning **B) to phone** **C) phoned** **D) phone**

Appendix E

Proficient User	C2	Can understand with ease virtually everything heard or read. Can summarise information from different spoken and written sources, reconstructing arguments and accounts in a coherent presentation. Can express him/herself spontaneously, very fluently and precisely, differentiating finer shades of meaning even in more complex situations.
	C1	Can understand a wide range of demanding, longer texts, and recognise implicit meaning. Can express him/herself fluently and spontaneously without much obvious searching for expressions. Can use language flexibly and effectively for social, academic and professional purposes. Can produce clear, well-structured, detailed text on complex subjects, showing controlled use of organisational patterns, connectors and cohesive devices.
Independent User	B2	Can understand the main ideas of complex text on both concrete and abstract topics, including technical discussions in his/her field of specialisation. Can interact with a degree of fluency and spontaneity that makes regular interaction with native speakers quite possible without strain for either party. Can produce clear, detailed text on a wide range of subjects and explain a viewpoint on a topical issue giving the advantages and disadvantages of various options.
	B1	Can understand the main points of clear standard input on familiar matters regularly encountered in work, school, leisure, etc. Can deal with most situations likely to arise whilst travelling in an area where the language is spoken. Can produce simple connected text on topics which are familiar or of personal interest. Can describe experiences and events, dreams, hopes and ambitions and briefly give reasons and explanations for opinions and plans.
Basic User	A2	Can understand sentences and frequently used expressions related to areas of most immediate relevance (e.g. very basic personal and family information, shopping, local geography, employment). Can communicate in simple and routine tasks requiring a simple and direct exchange of information on familiar and routine matters. Can describe in simple terms aspects of his/her background, immediate environment and matters in areas of immediate need.
	A1	Can understand and use familiar everyday expressions and very basic phrases aimed at the satisfaction of needs of a concrete type. Can introduce him/herself and others and can ask and answer questions about personal details such as where he/she lives, people he/she knows and things he/she has. Can interact in a simple way provided the other person talks slowly and clearly and is prepared to help.

Appendix F



LEVEL TRANSFERS

Teachers inform the Director of Studies when a student is ready to take a level change test after considering various different factors including weekly test results (pass result=60%), attendance (at least 80% of classes), participation in class and homework. The level change tests involve a grammar test, a piece of writing and a speaking test which are all directly related to the syllabus. They are consistent with what learning outcomes are required for the level they are moving from. These level learning outcomes correspond with Common European Framework of References and are displayed on the classroom wall at all times.

Once a student has completed a level change test and if their test results show that they have achieved the level learning outcomes, they progress. All students MUST complete the level change test before it is agreed that they are ready to change level. The results are recorded in student progress.

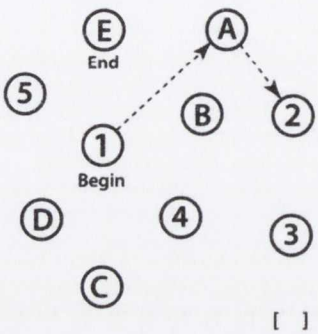
The only other reason for a student to take a level change test is if they wish to test their current level.

Appendix G

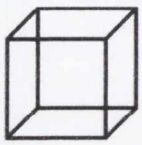
MONTREAL COGNITIVE ASSESSMENT (MOCA)
Version 7.1 Original Version

NAME : **Date of birth :**
Education : **DATE :**
Sex :

VISUOSPATIAL / EXECUTIVE — POINTS



Copy cube



[ ] [ ]

Draw CLOCK (Ten past eleven) (3 points)

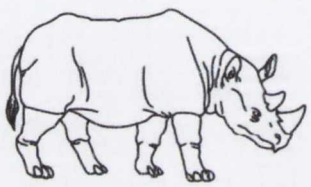
[ ] Contour [ ] Numbers [ ] Hands

__/5

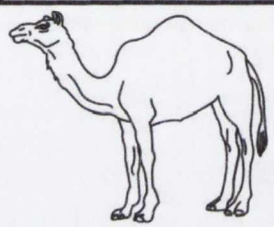
NAMING



[ ]



[ ]



[ ]

__/3

MEMORY Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED
1st trial					
2nd trial					

No points

ATTENTION Read list of digits (1 digit/ sec.).
Subject has to repeat them in the forward order [ ] 2 1 8 5 4
Subject has to repeat them in the backward order [ ] 7 4 2 — __/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors
[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B — __/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65
4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt** — __/3

LANGUAGE Repeat : I only know that John is the one to help today. [ ]
The cat always hid under the couch when dogs were in the room. [ ] — __/2

Fluency / Name maximum number of words in one minute that begin with the letter F [ ] ____ (N ≥ 11 words) — __/1

ABSTRACTION Similarity between e.g. banana - orange = fruit [ ] train – bicycle [ ] watch - ruler — __/2

DELAYED RECALL

	FACE	VELVET	CHURCH	DAISY	RED	Points for UNCUED recall only
Has to recall words **WITH NO CUE**	[ ]	[ ]	[ ]	[ ]	[ ]	
Optional Category cue						
Optional Multiple choice cue						

__/5

ORIENTATION [ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City — __/6

© Z.Nasreddine MD **www.mocatest.org** Normal ≥ 26 / 30

TOTAL __/30
Add 1 point if ≤ 12 yr edu

Administered by: _____

Appendix H

THE FOLLOWING QUESTIONS ASK YOU ABOUT YOUR ABILITY TO USE MORE THAN ONE LANGUAGE FLUENTLY.

1. ARE YOU CURRENTLY FLUENT IN MORE THAN ONE LANGUAGE?

PLEASE TICK ONE BOX

YES ☐ IF 'YES' GO TO QUESTION 4

NO ☐

2. WERE YOU EVER FLUENT IN MORE THAN ONE LANGUAGE?

PLEASE TICK ONE BOX

YES ☐

NO ☐ IF 'NO' GO TO QUESTION 6

3. WHAT AGE DID YOU STOP USING THE SECOND LANGUAGE IN WHICH YOU WERE FLUENT?

ENTER THE AGE IN YEARS

☐

4. APART FROM ENGLISH, WHICH OTHER LANGUAGES ARE/WERE YOU FLUENT IN?

PLEASE TICK ANY BOXES APPROPRIATE TO YOU

Irish ☐

Other European ☐

Other non-European ☐

5. FROM WHAT AGE WERE YOU EXPOSED TO THE SECOND LANGUAGE(S) IN WHICH YOU ARE/WERE FLUENT?

PLEASE TICK ONE BOX

From birth ☐

From primary school ☐

From secondary school ☐

From later than secondary ☐

3

Appendix I

Socio-economic Group

The entire population was classified to one of ten specific socio-economic groups (introduced in 1996). In addition a residual group entitled. "All others gainfully occupied and unknown" was used where sufficient details were not provided. The classification aims to bring together persons with similar social and economic statuses on the basis of the level of skill or educational attainment required. In defining socio-economic group no attempt is made to rank groups in order of socio-economic importance.

The socio-economic group of persons aged 15 years or over who are at work is determined by their occupation and employment status. Unemployed or retired persons aged 15 years or over are classified according to their former occupation and employment status. The detailed classification used for determining the socio-economic group of all persons at work, unemployed or retired is given in Appendix 7.

Persons on home duties or at school/college, who are members of a family unit, were classified to the socio-economic group of the person in the family on whom they were deemed to be dependent. Thus, if the head of a family was at work, unemployed or retired, dependent persons were assigned to his/her socio-economic group. If the head was neither at work, unemployed nor retired (e.g. never worked, permanently disabled, etc.) or if his/her occupation was not known, they were assigned to the socio-economic group of the principal earner in the family - if there was no such earner, they were assigned to the **unknown** socio-economic group. Other persons engaged in home duties or at school/college who were not members of a family unit, such as persons living alone or relatives of a head of household who were not members of the family unit (e.g. widowed grandparents, etc.), were assigned to the **unknown** group.

The socio-economic groups used in the census are as follows:

A Employers and managers
B Higher professional
C Lower professional
D Non-manual
E Manual skilled
F Semi-skilled
G Unskilled
H Own account workers
I Farmers
J Agricultural workers
Z All others gainfully occupied and unknown

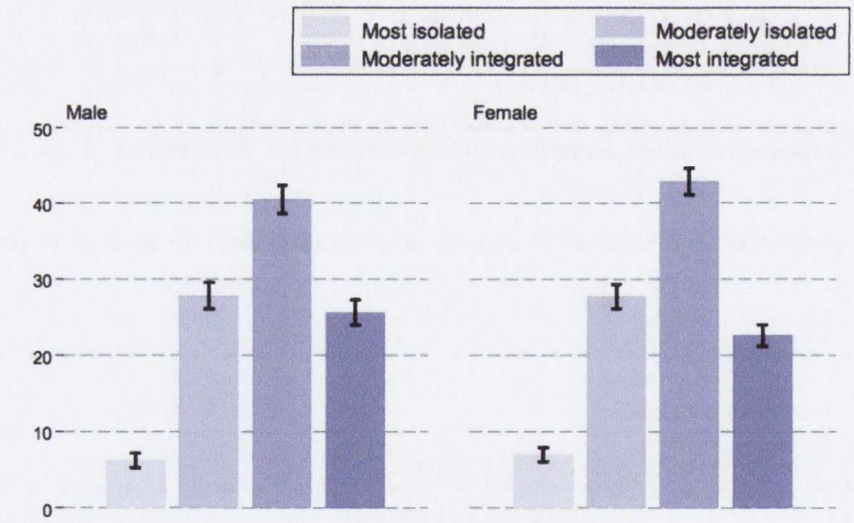
Appendix J

4.4 Social engagement

In TILDA, the extent of each respondent's social engagement is measured using the Berkman-Syme Social Network Index (SNI) (1). This index is a composite measure of four types of social connections: marital status (married vs. not married); sociability (frequency of contacts (0=few to 1=many) with close children, relatives and friends, church group membership (yes (1) or no (0)), and membership in other voluntary organisations (yes (1) or no (0)). Scores from each social connection type are combined to create four levels (0-4) of social connection or engagement: most isolated (0-1), moderately isolated (2), moderately integrated (3) and most integrated (4) (1).

Using the Social Network Index, the patterns of social connection in the older adult population of Ireland are similar for both men and women, and across all age groups. Figure 4.4 shows that 6% of women and 7% of men are classified as being most isolated, while 26% of men and 23% of women fall into the most integrated level of social engagement. Most respondents are classified as moderately integrated, regardless of age or sex. Interestingly, in the oldest age group (75+), men are more socially integrated than women.

Figure 4.4. Proportion (%) of older people within each Berkman-Syme Social Network Index level of social connection, by sex



Note. N = 6262; Missing obs = 1916; Error bars correspond to 95% confidence intervals

Appendix K

Coláiste na Tríonóide, Baile Átha Cliath
Trinity College Dublin
Ollscoil Átha Cliath | The University of Dublin

21st January 2013

F.A.O. Anne-Marie Connolly

School of Psychology Research Ethics Committee

Dear Anne-Marie,

I am pleased to inform you that your application entitled "Cognitive changes in emerging bilinguals" has been approved by the School of Psychology Research Ethics Committee.

It is not routine policy of the Committee to issue duplicate or replacement letters confirming ethical approval. It is therefore the responsibility of the applicant to keep the approval letter safe.

Yours sincerely,

Prof. Richard Carson
Chair
School of Psychology Research Ethics Committee

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