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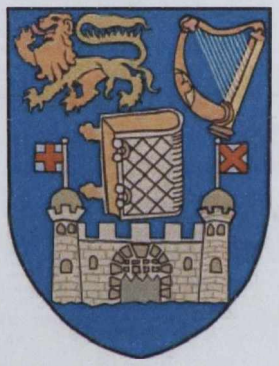
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NATURALNESS PERCEPTION OF MATERIALS:

A SENSORY, AFFECTIVE OR COGNITIVE EVALUATION?

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BA MSc



A thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy to the University of Dublin, Trinity College

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October 2009

Declaration

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We are made one with what we touch and see

Oscar Wilde (1854-1900)

Summary

The studies reported in this thesis contribute to a new and emerging field of investigation, which focuses on the neural processes underlying pleasure, aesthetics and moral evaluations in the brain by merging this field with that of texture perception and the evaluation of materials in terms of naturalness. Research spanning many disciplines of literature demonstrates that humans possess a strong positive bond with nature, and that this relationship influences our preferences in food and landscapes, and can impact on our health and well-being (see Chapter 1). While a preference for naturalness has been implicated across many domains, the perception of naturalness in texture materials has been limited. This is surprising given that considerable effort is expended in the manufacturing industry in the production of imitation materials that are cheap and robust whilst still appealing to the consumer. The research presented in this thesis addresses this gap in the literature by examining the perception of naturalness in wood and fabric textures, focussing on the contribution of touch and vision in the categorisation of naturalness, and exploring the cortical processes that are involved in the evaluation of naturalness.

Given that the studies reported here contribute to an existing body of texture perception literature, a review of the behavioural and neuroimaging studies that have utilised textures as stimuli was conducted, and examined whether the senses of touch and vision behave in an independent or integrated manner for the perception of texture (see Chapter 2). In the empirical studies, the perception of naturalness was investigated using a set of natural and artificial wood and fabric textures. Here, behavioural studies were conducted to examine whether participants were adept at categorising these ecological stimuli as 'natural' or 'unnatural' (see Chapter 3). In these studies, it was demonstrated that people are skilled at categorising wood and fabric stimuli in terms of naturalness in the

absence of any external information such as labelling. In light of the suggestion that people have a preference for naturalness in food and landscapes, an exploration of the relationship between perceived naturalness and other sensory and perceptual dimensions such as harshness, hedonics (like), value and familiarity for a set of fabric textures was carried out (see Chapter 4). It was observed that for fabric stimuli, the perception of naturalness is positively related to judgements of harshness, value, and hedonics. In particular, the primary role of the physical property of harshness was apparent in the perception of naturalness in fabrics. Following this, the brain processes associated with naturalness were examined (both in terms of physical naturalness and perceived naturalness) using a set of wood and fabric stimuli (see Chapters 5 and 6). The neuroimaging results indicated that the evaluation of naturalness in materials invokes a network of brain regions that have been previously implicated in texture-related perceptual tasks, decision-making, and moral and affective evaluations.

Together these results highlight the complex mechanisms that underlie the evaluation of naturalness in materials. Further investigations examining the perception of naturalness across a wider stimulus set, using a number of methodological modifications, should focus on attempting to unravel the relationship between naturalness and other sensory and higher-order dimensions. This future work will help elucidate the importance of naturalness for the consumer, and will have critical implications within the manufacturing and advertising industries.

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Abbreviations

ACC	Anterior cingulate cortex	**OFC**	Orbitofrontal cortex
Amg	Amygdala	**PCC**	Posterior cingulate cortex
ANOVA	Analysis of variance	**PoG**	Postcentral gyrus
BA	Brodmann area	**PET**	Positron emission tomography
BOLD	Blood-oxygen-level dependent	**PO**	Parietal operculum
CoS	Collateral sulcus	**POC**	Parieto-occipital cortex
EEG	Electroencephalography	**PPA**	Parahippocampal place area
EP	Exploratory procedure	**PPC**	Posterior parietal cortex
FCT	Free classification task	**SAT**	Spatial arrangement task
fMRI	Functional magnetic resonance imaging	**SE**	Standard error
GM	Genetic-modification	**SI**	Primary somatosensory cortex
IOG	Inferior occipital gyrus	**SII**	Secondary somatosensory cortex
IPS	Intraparietal sulcus	**STS**	Superior temporal sulcus
LOC	Lateral occipital complex	**TMS**	Transcranial magnetic stimulation
MCC	Mid-cingulate cortex	**TR**	Repetition time
MDS	Multi-dimensional scaling	**TV**	Tactile to visual
MEG	Magnetoencephalography	**V1**	Primary visual cortex
MOG	Medial occipital gyrus	**V2**	Secondary visual cortex
MP-RAGE	Magnetisation prepared rapid acquisition gradient echo	**VT**	Visual to tactile
MR	Magnetic resonance	**%AUC**	Percentage area under the curve
NAcc	Nucleus accumbens	**%CS**	Percentage change score

Chapter 1

General Introduction

1.1 Introduction

As our planet becomes progressively more urbanised and populated, we are living increasingly less in the leafy and wild environments of our ancestors. Yet, for most of us, interacting with nature evokes positive feelings, and in the case of a natural environment, can bring solace and relieve stress. As human beings, our relationship with nature is a complex one. Mother nature provides us with many useful materials for shelter and food, yet these resources are limited, and are gradually diminishing due to our over-consumption and exploitation. Advances in the manufacturing industry have brought about many products that are convincing mimics of the natural item, for example in the domains of food, textiles or household surfaces. Yet the extent to which these imitations appeal to the consumer, and whether there is a perceivable difference between the natural item and the unnatural mimic is largely unknown.

From a perceptual sciences viewpoint "naturalness" is an attractive topic of investigation for a number of reasons. Firstly, given our tendency to prefer certain natural items to synthetic imitations (see Section 1.2), it is important to know whether we can perceive differences in the naturalness of materials when external information such as labels and advertising are not available. For example, when we touch or see a piece of fabric, do we rely on the tag to tell us what fibres comprise the sample, or are we adept at perceiving these subtle material properties at a sensory level? Secondly, if we can perceive naturalness independently of whether external information is available, it is of interest to understand what senses contribute to this ability, and how. That is, can we perceive the naturalness of a stimulus based on exploration using touch alone, vision alone, or do we use these modalities together to inform our decision?

Within the context of the studies reported here, the term "naturalness" was defined as "derived from nature". Section 1.2 discusses the body of literature that has explored the

relationship that humans have with nature. Here, research in the domains of food and landscapes is presented. Furthermore, the influence of naturalness on well-being, the use of "natural" technology and the motivations behind a natural preference are discussed. Following from this, Section 1.3 considers the research that has been conducted on the aesthetic, desirability and moral evaluation of stimuli. Finally, Section 1.4 outlines the research that was conducted in the present thesis.

1.2 A preference for naturalness

Despite an increasingly modernised culture, the influence of nature on human preference, health and consumer behaviour remains steadfast. In the domain of food, naturalness is associated with positive attitudes, which seem to hold cross-culturally (Rozin, Fischler, & Shields-Argelés, in prep). However, a preference for naturalness seems to be category dependent, for example, people report a preference for food in the natural form, but not for medicines (Rozin, Spranca, Krieger, Neuhaus, Surillo, Swerdlin, et al., 2004); suggesting that in some cases the effectiveness of a natural stimulus is uncertain. The advent of innovative food technologies such as genetic-modification (GM), pressure processing and nanotechnology may be welcomed in the food sector, but often cause consumers to be apprehensive about purchasing these items (Frewer, Howard, & Shepherd, 1995; Siegrist, 2008). Furthermore, the acceptance of GM foods is largely dependent on perceived naturalness, such that the more natural a food is perceived initially, the less genetic-modification is seen as acceptable (Tenbült, de Vries, Dreezens, & Martijn, 2005; Tenbült, de Vries, van Breukelen, Dreezens, & Martijn, 2008).

Within the context of our environmental surroundings, a large number of studies have investigated the influence of different physical attributes on the affective experience of a landscape (from forests to urban settings). While a number of factors seem to influence the preference for one environment over another, the naturalness of the scene has

been consistently identified to be important (e.g. Hagerhall, Purcell, & Taylor, 2004; Hur, Nasar, & Chun, 2010; Kaplan & Herbert, 1987; Kaplan & Kaplan, 1989; Kaplan, Kaplan, & Wendt, 1972; Lamb & Purcell, 1990; Ode, Fry, Tveit, Messager, & Miller, 2009; Purcell & Lamb, 1984; Purcell & Lamb, 1998; Purcell, Lamb, Peron, & Falchero, 1994; Strumse, 1994). For example, people show a preference for visual scenes depicting environments with vegetation, water and trees rather than environments that have been interfered with by man, i.e. either built-up or natural environments that have been altered (Purcell, et al., 1994; Strumse, 1994).

Contact with nature is also thought to promote happiness, healthiness and even healing (see Frumkin, 2001, 2003; Groenewegen, van den Berg, de Vries, & Verheij, 2006; Malenbaum, Keefe, Williams, Ulrich, & Somers, 2008). For example, the benefits to health of owning a pet are widely known and include a reduction in stress (e.g. Allen, 1997; Serpell, 1991; Siegel, 1990), and improved cardiovascular symptoms (Anderson, Reid, & Jennings, 1992) controlling for exercise and nutrition. The presence of plants is also thought to contribute to improved physical and mental health. Horticultural therapy, which promotes the therapeutic benefits of gardening, is widely used in prisons, special needs schools and nursing homes as a tool for improving mental-health (see the American Horticultural Therapy Association). Viewing nature alone can influence healing, as demonstrated by Ulrich (1984) who showed that post-operative patients who stayed in a room with a window facing a natural scene had shorter recovery time, less pain medication and fewer complaints than those whose window faced an outside wall. Further studies have shown that exposure to images of nature in a recovery setting can improve anxiety, pain threshold and tolerance (Tse, Ng, Chung, & Wong, 2002; Ulrich, Lunden, & Etinge, 1993). Notably, images of abstract art can actually exacerbate anxiety levels (Ulrich, et al., 1993). This suggests that there is something that is particular to natural scenes, and not simply

experiencing the art, that is mediating recovery in these studies. In this context, our preference for naturalness appears to go beyond an aesthetic motivation and may be driven by something more basic in our human makeup.

With technology becoming increasingly sophisticated and natural environments within urban settings becoming smaller, virtual environments are being introduced into our lives. For example, considerable time is spent in virtual worlds such as Second Life® (Linden Research Inc., 2009), Animal Crossing© (Nintendo, 2008) and The Sims™ (Electronic Arts Inc., 2007). While these environments allow the user to socialise, strategise and even tend flowers (see Figure 1.1), it is difficult to imagine that they can provide the same benefits to the user that interacting directly with nature can. Despite this, there seem to be some well-being benefits of this virtual nature for the user. For example, the presence of real-time views of nature displayed on a high-definition television as a virtual "window" have been shown to positively influence the well-being, cognitive functioning and mood of employees in windowless office settings in a university setting (Friedman, Freier, Kahn, Lin, & Sodeman, 2008). However, while experiencing technological nature (i.e. static or dynamic images of nature) seems to be better than not interacting with nature at all, it is no match for the real thing (Kahn, et al., 2008; Kahn, Severson, & Ruckert, 2009).

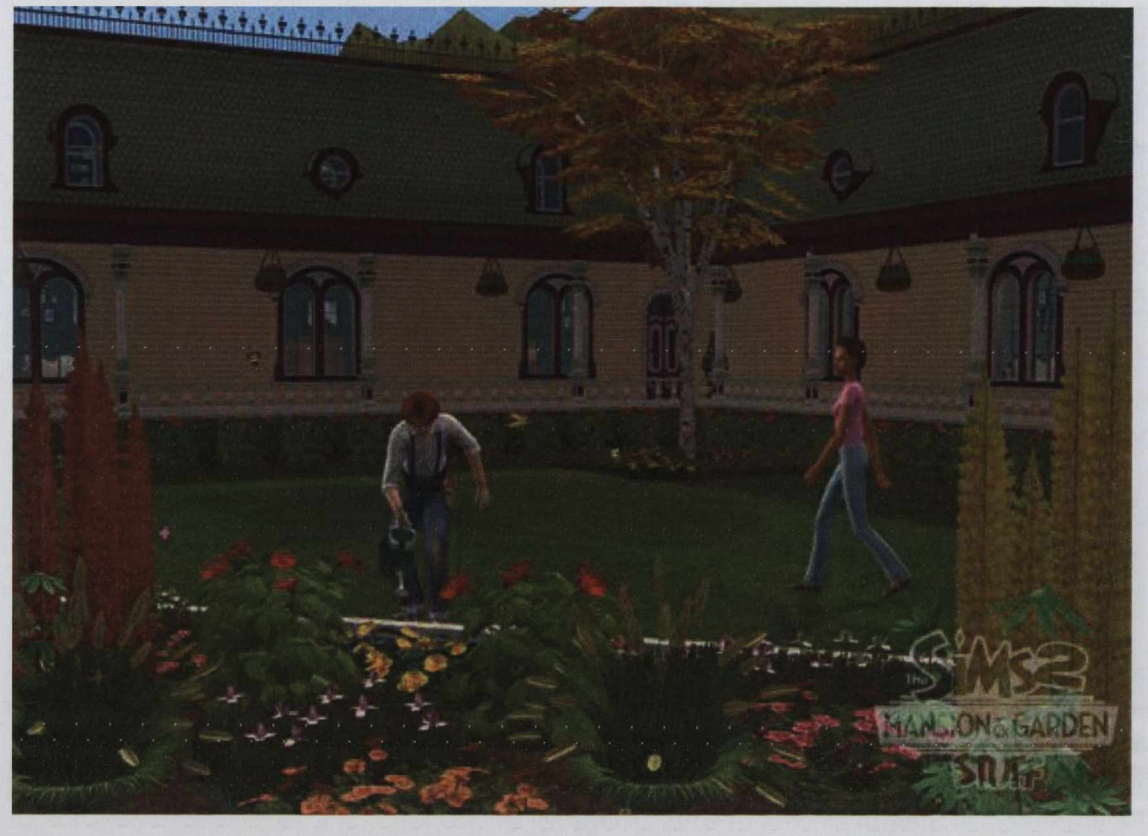


Figure 1.1. Snapshot taken from The Sims™ (Electronic Arts Inc., 2007). Virtual worlds are becoming an increasingly popular place to socialise, strategise and can provide a platform for interacting with virtual nature.

Several researchers have offered a theoretical explanation for our preference for naturalness. The *biophilia* hypothesis (Kellert & Wilson, 1993; Wilson, 1984) contends that since human beings are a product and part of nature, we have an instinctive bond with other living things and we wish to be close to and experience nature. This evolutionary perspective suggests that humans have an innate desire to experience the environment in which our ancestors lived. This hypothesis is supported by the finding that experiencing nature in our environment can promote health and well-being benefits, but it does not account for the damage that can be caused to nature in the pursuit of experiencing natural products, i.e. by using natural surfaces such as marble in our household, we are damaging natural resources.

Rozin and colleagues (Rozin, et al., 2004; Spranca, 1992) proposed two main categories of beliefs that may underlie the preference for natural entities: instrumental and ideational. Instrumental beliefs are those pertaining to the superior functional or material properties of natural entities and have four potential causes. Firstly, natural entities may be considered better due to the damaging effect that human intervention with nature typically has, which is often irreversible and widespread. Secondly, natural entities may be considered to be superior in terms of healthiness (e.g. foods or cleaning products) and/or effectiveness (e.g. wooden flooring); or conversely, unnatural entities may be ascribed with negative beliefs, which are subject to acts of commission (i.e. human intervention and transformation), leading natural entities to be superior due to an omission bias. Thirdly, natural entities may be considered to more pleasing to the senses (e.g. "natural foods taste better"). Finally, natural things may be considered to be purer and therefore safer to humans (e.g. less toxic). On the other hand, ideational beliefs are those concerning the potential superior moral or aesthetic properties of natural entities and have two underlying causes. Firstly, given a preference for normative order, natural entities are better than unnatural entities because they exist prior to unnatural entities (which are created through human intervention). Secondly, natural is inherently better regardless of whether it exists prior to unnatural. These beliefs may not act independently, and given the context of the situation the motivation for natural or unnatural may change. In order to clarify the validity of these beliefs, it is necessary to look at a number of scenarios in which the perception of naturalness is under scrutiny.

The perceived naturalness of an entity may be influenced by the degree of manipulation or human intervention. One mechanism of transformation that has been discussed in the literature is the principle of contagion. Here, when two entities come into contact with each other, properties of each object pass to the other and remain

permanently. An everyday example of this is if an insect landed in a drink and was removed, the drink continues to be perceived as contaminated. Typically, the idea of contagion is strongly biased towards the negative side (Rozin & Royzman, 2001) whereby there is a tendency to focus on the entity with negative contaminating properties rather than the positive purifying properties of the other. Drawing from this hypothesis, if a natural entity is considered to be inherently good, and human intervention considered inherently bad, the contamination caused by human contact on natural entities would be more salient than the purifying power of natural entities on humans. Extending this proposal, when machines or chemicals (which are human-made and thus suggest the influence of human presence) contact a natural entity (e.g. food), the negative human contagion may transfer to the natural item (Rozin, et al., 2004). Indeed, the degree of process has been shown to influence the perception of naturalness in terms of food and water acceptability (Rozin, 2006). For example, tomato paste that is twice transformed, i.e. to which a chemical is added and subsequently removed, is considered less natural than the original entity, such that process dominates content (Rozin, 2005, 2006). Thus the level of perceived naturalness appears to be subject to manipulation through human intervention, transformation, and contagion. While this is somewhat intuitive for edible items (i.e. food, water), it remains to be seen how the level of process impacts on the perception of naturalness in other entities such as textiles.

In consideration of the instrumental perspective, while it may be plausible that natural entities are superior to unnatural counterparts, there has been little investigation into the actual superior advantage of natural products over unnatural entities. To assume that this is the case across all scenarios would be a simplification. For instance, in a sensory-superiority investigation of organic versus commercially grown foods, there may be no apparent taste superiority for organic products (e.g. Schutz & Lorenz, 1976), and in

some cases they are less appealing (e.g. Lester, Manthey, & Buslig, 2007). Further investigation that examines the functional effectiveness of natural entities across medicinal and industrial applications is necessary to unravel this claim.

Rozin and colleagues (Rozin, et al., 2004; Spranca, 1992) argue in favour of an ideational system for people's motivation towards natural entities. In line with this, in a series of cross-cultural studies examining the environmental reasoning and values in children, Kahn and colleagues (Kahn, 1999, 2002; Kahn & Friedman, 1995; Kahn & Lourenço, 2002) demonstrated that anthropocentric reasoning (i.e. how affecting the environment affects humans) was central to children's conceptions of the physical and social world. Similar to Wilson and colleagues (Kellert & Wilson, 1993; Wilson, 1984), Kahn is in support of an evolutionary affiliation between humans and nature, and believes that as humans increasingly adapt to a loss of nature, there will be a cost to our physical and psychological well-being.

Overall, there is much multi-disciplinary evidence that suggests a positive relationship between humans and nature, and in certain domains that naturalness is preferred (e.g. food and landscapes). However, little remains known about how we perceive naturalness in materials, and what role the senses of touch and vision play in this process; this is the primary focus of this thesis. An important dimension of understanding the perception of naturalness, is to explore the underlying brain mechanisms that are involved in perceiving a stimulus as 'natural' or 'unnatural'. Given the general preference and positive association that we have with nature and natural items, it seems plausible that underlying mechanisms involved in the perception of naturalness would include those that are associated with rewarding or pleasurable stimuli.

1.3 Aesthetics, desirability and moral evaluations in the brain

Within the neuropsychological literature on reward processing in the brain, the investigations examining the neural correlates of aesthetic preference in art and scenes are of particular interest to the current thesis. A recent study using fMRI has shown that judging a painting as beautiful rather than neutral elicited activation in the anterior cingulate cortex (ACC) and left parietal cortex (Kawabata & Zeki, 2004). In a similar study, Vartanian and Goel (2004a, 2004b) observed that using a set of abstract and representational paintings, activation in the right caudate nucleus decreased as preference ratings decreased, while that in the left cingulate sulcus, and bilateral occipital and fusiform gyri were related to the positive preference ratings. Using magnetoencephalography (MEG), Cela-Conde and colleagues (2004) observed activation in the left prefrontal dorsolateral cortex for images (paintings and photographs) that were perceived as beautiful, implicating this area as an aesthetic evaluation area in their study. Furthermore, Jacobsen and colleagues (2006) observed that, relative to symmetry judgements, the aesthetic evaluation of novel geometric shapes activated frontomedian regions (BA 9/10), bilateral prefrontal (BA 45/47), posterior cingulate cortex (PCC), left temporal pole, and the temperoparietal junction. Biederman and colleagues (e.g. Biederman & Vessel, 2006; Yue, Vesse, & Biederman, 2007) demonstrated that activity in the parahippocampal cortex, occipito-temporal cortex (within the collateral sulcus; CoS), was associated with preferred real-world scenes, which they suggest is attributable to the presence of μ-opiod receptors within these regions. While these studies may differ in their specific findings, conceivably due to stimulus and methodological differences (see however Nadal, Munar, Capó, Rosselló, & Cela-Conde, 2008), they act as a starting point of a potentially fruitful area of examination, i.e. the investigation of the neural correlates of aesthetic experience.

The desirability of an item may include both liking and wanting components of reward. Desire can manifest across many categories including interpersonal, financial, and materials. Recently, Kawabata and Seki (2008) demonstrated that classifying a stimulus (event, person or object) as desirable rather than undesirable or indifferent was associated with activity in the superior OFC (BA 11), along with the ACC (BA 32) and mid-cingulate cortex (MCC; BA 24). Here the MCC was involved in the desirability evaluation irrespective of the valence of the desirability. Studies of facial attractiveness have indicated the role of the the ACC, OFC, posterior insula and superior temporal sulcus (STS) in explicit attractiveness judgement tasks (e.g. O'Doherty, Winston, Critchley, Perrett, Burt, & Dolan, 2003; Winston, O'Doherty, Kilner, Perrett, & Dolan, 2007). From these studies these regions appear to be involved in interpersonal reward linked to desirability and attractiveness.

The moral evaluation of a stimulus has recently received interest in the neuropsychological literature. Distinctions in cortical activity have been demonstrated for evaluative judgements (e.g. 'bad' versus 'good') relative to non-evaluative judgements (e.g. 'past' versus 'present') in the medial and ventrolateral prefrontal cortex, while negative evaluative judgements have been shown to activate the Amg (Cunningham, Johnson, Gatenby, Gore, & Banaji, 2003). Furthermore, moral evaluations with direct impact on a personal level elicit greater activation in the medial frontal gyrus (BA 9/10), PCC/precuneus (BA 31/7), and bilateral STS (BA 39) relative to impersonal moral and non-moral judgements, whilst areas commonly implicated in working memory and cognitive processes such as the dorso-lateral prefrontal cortex (BA 46) and inferior parietal lobule (BA 40) presented relatively greater activation for impersonal moral judgement over the other conditions (Greene, Nystrom, Engell, Darley, & Cohen, 2004; Greene, Sommerville, Nystrom, Darley, & Cohen, 2001). Similar activations have been observed in

frontomedian regions, ventral prefrontal cortex and PCC, in a number of moral and social evaluation studies (e.g. Johnson, et al., 2002; Moll, Eslinger, & Oliveira-Souza, 2001; Moll, Oliveira-Souza, Bramati, & Grafman, 2002; Zysset, Huber, Ferstl, & von Cramon, 2002). These studies highlight the complex nature of the evaluative process in moral judgements, which involves a network of affective, decision-making, and cognitive regions.

Despite a growing interest into human preference and pleasure and its underlying circuitry in the brain, few studies have examined the perception of hedonics in material stimuli. This is surprising given the effort that is expended in industry to design and manufacture materials and surfaces that appeal to the consumer. Indeed, a better understanding of the affective relationship that humans have with materials, in particular with the manipulation of naturalness in materials, would be an invaluable resource to the manufacturing industry, and would facilitate a greater insight of affective processes in the brain.

1.4 Outline of the present thesis

In the literature, the influence of naturalness is well documented in terms of food preference (e.g. Rozin, 2005, 2006; Rozin, et al., 2004), landscape preference (e.g. Ode, et al., 2009; Purcell & Lamb, 1998), and benefits to health (see Frumkin, 2001). Despite an abundance of investigations into the perception of naturalness in particular objects, material properties have received surprisingly little attention in this area. A recent exception is the work by Overvliet and Soto-Faraco (in prep) who used multiple scaling measures observed that participants are adept at categorising the naturalness of wood, fabric and stone, and that these results were relatively unchanged when different scaling methods were utilised. Moreover, little is known about how the visual and tactile senses contribute to how natural a material is perceived. Although past research gives us a

fascinating insight into the perception of naturalness, the majority of it has been conducted by using written descriptions of stimuli rather than through direct sensory exploration of the stimuli. Therefore, further investigations are needed to clarify whether the perception of naturalness relies simply on the sensory properties of these stimuli, or whether other higher-order evaluations are involved. When advertising and labelling information are not present, how do we perceive the naturalness of materials?

The experiments presented in this thesis add to an existing body of literature on texture perception, and as such an exploration of the current standing of knowledge in this area provides a foundation for these investigations. Considering this, a review was conducted of the behavioural and neuroimaging studies that have utilised textures as stimuli, and examined whether the senses of touch and vision behave in an independent or integrated manner for the perception of texture (see Chapter 2). In the empirical studies, the perception of naturalness was investigated using a set of natural and artificial wood and fabric textures. Behavioural studies were conducted which examined whether participants were adept at categorising these ecological stimuli as 'natural' or 'unnatural' (see Chapter 3). Next, the relationship between perceived naturalness and other perceptual dimensions such as hedonics, value and familiarity was examined (Chapter 4). Following this, an examination of the brain processes associated with naturalness (both in terms of physical naturalness and perceived naturalness) using a set of wood and fabric stimuli was carried out (see Chapters 5 and 6).

CHAPTER 2

VISION AND TOUCH: INDEPENDENT OR INTEGRATED SYSTEMS FOR THE PERCEPTION OF TEXTURE?

Authorship

This review chapter was written by T. A. Whitaker in collaboration with Dr. C. Simões-Franklin and Prof. F. N. Newell, and resulted in the following publication:

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2.1 Introduction

When we see or touch the surface of an object we encode information that allows us to make perceptual decisions about that object for the purpose of recognition or action, or for more aesthetic judgements such as the quality or attractiveness of the item. Object information can be based on both geometric (e.g. shape, size, orientation and curvature), and material properties, (e.g. temperature, compliance, texture, and weight) and both the visual and tactile modalities contribute to the representation of objects based on these characteristics. Texture information in particular is an inherent material characteristic of the surface of any object and provides an important cue for its perception. For instance, the scaly skin of a snake or the hairy skin of a kiwifruit can help us distinguish these objects through touch or vision, even when shape information is not fully available. Yet, despite a growing interest in recent years on the behavioural and neural correlates of object recognition across modalities, relatively less attention has been given to the multisensory perception of material properties such as texture and roughness.

Although a number of review articles have considered texture perception in general (e.g. Landy, 1996; Lederman & Klatzky, 2004), or tactile texture perception (Hollins & Bensmaïa, 2007; Lederman, 1982; Taylor, Lederman, & Gibson, 1973), and visual texture perception (Bergen, 1991; Landy & Graham, 2004) in particular, none have looked specifically at the effects of multisensory inputs on texture perception from both a behavioural and neuroimaging perspective. The following review aimed to investigate to what extent vision and touch contribute independent information to the representation of an object surface or whether this information is integrated into a single representation.

Texture (*n.*) is defined as the feel, appearance, or consistency of a surface, substance, or fabric (Oxford English Dictionary, 2008). Consequently, texture information is distinct from more global shape information but can nevertheless contribute to the

perception of an object. Evidence that texture perception is distinct from shape perception comes from a variety of sources, including behavioural, neuroimaging and neuropsychological literatures (e.g. Amedi, von Kriegstein, van Atteveldt, Beauchamp, & Naumer, 2005; Zhang, Weisser, Stilla, Prather, & Sathian, 2004). For example, Milner and colleagues (James, Culham, Humphrey, Milner, & Goodale, 2003; Milner, et al., 1991) have studied the sensory and perceptual abilities of patient D.F., who has visual form agnosia as a result of carbon monoxide poisoning. D.F. presents severe visual deficits including visual form perception, brightness, motion and depth. However, D.F. maintains the ability to use pattern information to aid suitable preshaping and hand rotation when reaching for an object (Milner, et al., 1991). Along with her ability to discriminate colour, D.F. is able to use surface properties to identify objects despite remaining perceptually unaware of their form (Humphrey, Goodale, Jakobson, & Servos, 1994), suggesting that texture processing is distinct from global shape processing.

Historically, each of the senses has been studied in isolation; although there has been an increased interest towards exploring multisensory interactions on perception (see Marks, 1978). With regards to texture perception in particular, a number of studies have provided some evidence of multisensory influences. Information about the texture of a surface or object can be mediated through different sensory modalities such as touch, vision and audition. Although touch and vision are the more obvious senses for perceiving texture, audition can also play a role in texture perception. For example, the sound of someone rubbing their fingers on a surface provides valuable information about the roughness of that surface (Lederman, 1979; for a review see Lederman & Klatzky, 2004). Similarly, von Schiller (1932) noted that noise bursts or tones repeated at regular intervals influence the perception of roughness by touch. More recent demonstrations of audiotactile integration in texture perception include the so-called *parchment-skin illusion* (Guest,

Catmur, Lloyd, & Spence, 2002; Jousmaki & Forss, 1998), where distorted auditory feedback affects the perceived roughness or smoothness of the hands rubbing together. Interestingly, investigations of food preference have indicated the role of audition in perception of food and drink (for a review see Zampini & Spence, 2010), for example the perception of how crispy or stale a potato crisp can be influenced by varying the loudness of a presented sound during biting (Zampini & Spence, 2004).

Although audition can influence tactile perception of texture, the extent to which vision and touch influence each other for texture perception is not well understood. For example, some studies have revealed sufficient differences in behavioural performance (e.g. Bergmann Tiest & Kappers, 2007), and neural activations (e.g. Randolph & Semmes, 1974; Servos, Lederman, Wilson, & Gati, 2001) across these modalities, while others have demonstrated no difference in performance across modalities (e.g. Guest & Spence, 2003a; Lederman & Abbott, 1981). Moreover, other studies have suggested that different texture information is encoded across vision and touch (Heller, 1989; Klatzky, Lederman, & Reed, 1987; Sailer, Eggert, Ditterich, Hassenzahl, & Straube, 2003). As such, it is possible that the representation of an object's material properties benefits from qualitatively unique information, rather than the integration of redundant information encoded across these modalities (Millar, 1994). However, evidence for complete independence across the visual and tactile systems for the perception of texture is not consistent, as some studies have reported that texture information can be shared across modalities. This evidence raises the question of whether it is the nature of the information or the particular perceptual process that determines whether texture information can be integrated across the senses. In the following sections the evidence from the literature on the perception of texture across vision and touch with the aim of elucidating the nature of the relationship between these modalities for texture perception is reviewed. Here, the focus on texture perception for the

purpose of recognition and discrimination is made, and the authors have considered the literature on the affective aspects of texture perception to be outside the scope of this review (for reviews see Essick, McGlone, Dancer, Fabricant, Ragin, Phillips, et al., 2010; McGlone, Vallbo, Olausson, Loken, & Wessberg, 2007). In the following sections, the visual and tactile senses are compared according to the manner in which information is encoded, the nature of the information processed, and the neural systems underlying texture perception within and across these modalities. Finally, directions for future research are suggested, which will help to better determine the relative contributions of these sensory modalities to our perception of texture.

2.1.1 Tactile and visual sensory exploration of texture

The haptic system makes use of particular stereotyped motor patterns or *exploratory procedures (EP)* when examining an object or surface (Klatzky & Lederman, 1987; Lederman & Klatzky, 1987) and each EP optimally extracts information about a particular property for the benefit of subsequent perceptual performance (Klatzky, Lederman, & Reed, 1989). The EP typically performed for encoding texture is lateral motion, that is, the fingertips move back and forth over a textured surface (Lederman & Klatzky, 1987). Accordingly, the fingertips have a high density of specialised mechanoreceptors ideal for this task (Johansson & Vallbo, 1979; Vallbo & Johansson, 1984), as well as a large area within the somatosensory cortex dedicated to processing stimulation from the fingers relative to other body parts (Sutherling, Levesque, & Baumgartner, 1992).

For texture, it is apparent that motion plays a key role in tactile perception. For example, early research on the role of motion in texture perception, using varying sandpaper surfaces, demonstrated that observers rated their sensations as different depending on whether static touch or dynamic passive touch (i.e. movement of the surface

over a stationary fingertip) was used (Menees & Zigler, 1923). Accordingly, Hollins and Risner (2000) demonstrated that the discrimination of sandpaper samples was more difficult using static touch rather than dynamic passive touch for fine textures; a finding that led to the duplex theory of texture perception (which is discussed later). However, of interest is whether active touch (i.e. movement of the hand over a surface) is necessary for efficient encoding, or whether dynamic passive touch is sufficient for tactile texture perception. When investigating the haptic perception of roughness in sighted and blind observers, Heller (1989) observed no difference in performance between these groups, and notably, no difference in performance between active touch and dynamic passive touch. Furthermore, roughness perception (Lederman, 1981, 1983; Verrillo, Bolanowski, & McGlone, 1999) and roughness discrimination (Lamb, 1983) do not vary as a function of whether active or passive dynamic touch is used. In sum, these findings indicate that relative motion, rather than hand movement, is important for encoding texture information.

Although texture perception is successfully conveyed through touch, in everyday experience textures are rarely encountered by touch alone. The visual perception of texture gives the observer important information about the surface of an object or even the depth of a plane (Gibson, 1933; Gibson & Radner, 1937). Moreover, the surface properties of an object are often primarily perceived through vision (Schifferstein, 2006; Schifferstein & Cleiren, 2005) which then may guide the tactile system to explore the surface. Thus, when we see an object, we may then reach out our hand to further investigate the properties of its surface.

Like touch, the visual system explores external information in an active, dynamic way through a series of eye movements and fixations over the stimulus of interest (for a review see Findlay & Gilchrist, 2003). However, a recent study comparing exploration strategies across vision and touch for texture perception, suggests that these strategies may

be modality-specific. Sailer and colleagues (2003) reported that whilst different textures affected the nature of haptic exploration procedures these had no effect on visual exploration. Moreover, their study indicates that as a consequence of these modality-specific exploratory procedures, different information about texture may be encoded by vision and touch.

2.1.2 Stimulus properties encoded by touch and vision

Our daily experience of textures may involve many vast types of surfaces such as fabric, stone and sandpaper to name a few. The variation in the perceived roughness of these textures is reflected in the sensory mechanisms that encode this information. In 1925, Katz proposed that both spatial and temporal cues mediate tactile texture perception. Katz argued that spatial cues such as size, shape and distribution of surface elements, are responsible for our perception of coarse textures such as Braille characters, whereas vibrational cues elicited by the movement of the finger as it moves on a surface are used for fine texture perception (Katz, 1925). Although his views were relatively ignored over many decades, his idea was later to become the basis of much research activity that led to the so-called duplex theory of tactile texture perception pioneered by Hollins and colleagues (Hollins, Bensmaïa, & Risner, 1998; Hollins & Risner, 2000). According to this theory, coarse and fine textures are mediated by a distinct receptor system (Bensmaïa & Hollins, 2003; for a review see Hollins & Bensmaïa, 2007; Hollins, et al., 1998; Hollins, Bensmaïa & Roy, 2002; Hollins, Bensmaïa & Washburn, 2001; Hollins, Fox & Bishop, 2000; Hollins & Risner, 2000). The systems and their underlying neurophysiological mechanisms have been well-characterised by psychophysical experiments conducted by Gescheider, Verrillo and colleagues (e.g. Bolanowski, Gescheider, Verrillo, & Checkowsky, 1988; Gescheider, Bolanowski, & Hardick, 2001; Gescheider, Bolanowski,

Pope, & Verrillo, 2002; Verrillo & Gescheider, 1975, 1977; Verrillo, Gescheider, Calman, & Van Doren, 1983).

Coarse surfaces, with spatial period above the interval 0.1-0.2mm (Hollins & Bensmaïa, 2007; Hollins & Risner, 2000), are perceived based on their spatial variation by the afferent firing rates of slowly adapting type I mechanoreceptors, such as Merkel receptors (Blake, Hsiao, & Johnson, 1997; Connor, Hsiao, Phillips, & Johnson, 1990; Connor & Johnson, 1992; Yoshioka, Gibb, Dorsch, Hsiao, & Johnson, 2001). A common stimulus used when studying coarse texture perception is grooved metal plates, as they can be easily modified depending on the investigation at hand. In a series of studies using these stimuli with monkeys, Goodwin and Morley (Goodwin & Morley, 1987a, 1987b; Morley & Goodwin, 1987) characterised the responses of the cutaneous mechanoreceptive afferents in terms of the spatial period of the gratings and the movement characteristics. A number of studies have demonstrated that the degree of spacing between grooves is an important spatial feature for tactile roughness perception such that as spacing increases so does the perceived roughness (Goodwin, John, Sathian, & Darian-Smith, 1989; Lederman & Taylor, 1972; Sathian, Goodwin, John, & Darian-Smith, 1989). Temporal cues have also been reported to play a role in the perception of coarse textures (Cascio & Sathian, 2001; Gamzu & Ahissar, 2001), although this effect is modest. Despite both spatial and temporal information being available during the exploration of coarse surfaces through touch, spatial information appears to be sufficient for the perception of coarse surfaces (Hollins, Lorenz, & Harper, 2006).

Relative to coarse surfaces, fine textures seem to be encoded differently in the tactile system. Fine surfaces, with spatial period below 0.1mm-0.2mm (Hollins & Bensmaïa, 2007; Hollins & Risner, 2000) seem to be perceived on the basis of vibrations elicited on the skin during exploration. This signal is mediated by rapidly adapting

mechanoreceptors, such as Pacinian or Meissner corpuscles in the skin (see Bensmaïa & Hollins, 2003). The observation that discrimination of fine surfaces is better when the surface moves across the finger tip, therefore inducing vibration, compared to when it is in stationary contact with the fingertip supports the role of cutaneous vibration in the tactile perception of fine textures (Hollins & Risner, 2000). Additionally, a surface that is vibrating, in the Pacinian-sensitive range of 150-400 Hz, is perceived as rougher than an identical surface that is not vibrating (Hollins, Fox, et al., 2000). Furthermore, by reducing the sensitivity of the vibrotactile channels through vibratory adaptation, discrimination of fine surfaces is impaired relative to a no-adaptation condition (Hollins, et al., 1998; Hollins, et al., 2002).

Together, these results indicate that vibrotaction plays an important role in the perception of fine textures. However texture-elicited vibrations can be perceived in terms of either their temporal or intensive properties. For example, roughness can be determined temporally, as a function of the *frequency* of the texture-induced vibrations elicited on the skin, or roughness can be determined by the *intensity* of these vibrations. Empirical findings tend to support the reliance on an intensity code. For example, although the frequency hypothesis predicts that as the frequency of vibrations elicited on the skin increases then the stimulus surface would be perceived as increasingly smoother, Bensmaïa and Hollins (2003) reported that this is not necessarily the case. Furthermore, the tendency to judge a vibrating surface as rougher increases as the amplitude of the vibrations increase, independent of the frequency of those vibrations (Hollins, Fox, et al., 2000). Moreover, Miyaoka and colleagues (1999) demonstrated in a discrimination task that when typical scanning velocities were used the temporal frequencies that would be elicited by their surfaces were outside the range that could be determined by the vibrotactile system (i.e. <1 kHz). In support of the intensity hypothesis, difference thresholds of the perceived

roughness of fine abrasive surfaces were found to be in the same range as those obtained in a height-discrimination involving varying ridge heights (Miyaoka, et al., 1999), suggesting that roughness perception relied on amplitude rather than frequency information. In sum, the findings are in favour of the intensity theory of roughness for fine texture perception.

Although roughness, a highly prominent perceptual dimension of texture, has been the main focus of tactile texture perception (see Hollins & Bensmaïa, 2007; Jones & Lederman, 2006), this is clearly not the only dimension of texture. Other studies have found that properties other than frequency information or vibrotactile intensity can also contribute to the perception of surface texture. For example, a power relation between subjective roughness judgements and stimulus friction has been observed using abrasive papers (Ekman, Hosman, & Lindstrom, 1965). Also, Smith and colleagues (2002) found that perceived roughness correlated with the average rate of change of the tangential touching force. Furthermore, compressibility has been found to be an important cue for texture perception in touch, albeit to a lesser extent than roughness (Bergmann Tiest & Kappers, 2006).

Many studies investigating the role of touch in texture perception have used artificially produced surfaces such as gratings, sandpaper, raised dot patterns and etched surfaces (e.g. Connor, et al., 1990; Gescheider, Bolanowski, Greenfield, & Brunette, 2005; Klatzky, et al., 1989; Lederman & Abbott, 1981), however few have investigated tactile texture perception using more high-level or 'natural' stimuli. This may largely be due to the difficulty in quantifying the physical properties of natural materials. Some exceptions include studies by Hollins and colleagues (Hollins, Bensmaïa, Karlof, & Young, 2000; Hollins, Faldowski, Rao, & Young, 1993) which have investigated the perceived dimensions of tactile surface textures using various familiar materials (including wood and straw). Hollins and colleagues used multidimensional scaling (MDS) methods along with

dynamic passive touch and found evidence for two main orthogonal dimensions which were elicited in their texture perception task namely, rough-smooth and soft-hard, and a number of relatively weaker dimensions, sticky-slippery (Hollins, Bensmaïa, et al., 2000; Hollins, et al., 1993), flat-bumpy, and warm-cool (Hollins, et al., 1993). Earlier, Yoshida (1968a, 1968b) used MDS with 25 different familiar materials (including glass and different fabrics), and found that the main contrast for their samples was between metallicness and fibrelikeness. More recently, Ballesteros and colleagues (2005) used a number of convergent methods to study the dimensions of haptic space for various ecological textures (including plastics, cork and fur). Their results, based on both a spatial arrangement task (SAT) and a free classification task (FCT), indicated a two-dimensional space solution with bipolar dimensions. While the SAT revealed the combined dimensions of rough-smooth and slippery-adherent, the FCT revealed the dimensions of smooth-adherent, and rough-slippery. The authors suggested that, depending on the task, the extremes of the dimensions are combined differently. In a similar study, Picard and colleagues (2003) investigated the influence of semantics on haptic texture space of 24 seat cover materials using a similarity classification task. They observed 3 to 4 continuous dimensions, including orthogonal dimensions soft-harsh, and thin-thick, and to a lesser extent, the separate dimensions of relief and hardness.

The dimensions revealed by these different studies may be based on the particular properties of the stimuli used in the tasks. Since the materials used by Picard and colleagues (2003) were all fabrics, it is difficult to compare their results with previous findings. Furthermore, many previous investigations have used too few materials to make realistic judgements on the number of dimensions that exist in the representation of haptic texture. To address this, Bergmann Tiest and Kappers (2006) tested participants on a free-sorting task of 124 varying common materials using active touch. Using such a broad set of

stimuli elicited a four-dimensional haptic material space, which as the authors interpreted involves dimensions such as roughness and compressibility. However, although our understanding of the tactile perceptual space for ecological surfaces is growing, the role of vision has received relatively less attention. As such, our knowledge of how vision may affect the tactile perception of ecological textures is relatively poor.

Whilst the information encoded from a surface leads to the perception of its roughness or texture, attention can also play a role in both tactile and visual texture perception. The role of spatially-selective attention in tactile texture perception was investigated by Sathian and Burton (1991). They demonstrated using grooved metal plates that although spatial attention may be useful in detecting the absence of a texture change, discerning its direction, and discriminating between different textures, it plays a minimal role in the detection of an abrupt change in texture. However, this ability to detect a change in texture is a key characteristic of visual perception along with a number of other dimensions, including contrast changes, reflectance, luminance, and cluster. In particular, the ability to detect borders between different textures is an important aspect of visual object segregation. This enables the observer to determine whether a scene contains two or more textured regions. A real-world example of this is an animal determining the location of its prey in a visually complex environment; by using camouflage many animals can disguise themselves from their predator. A texture boundary arises if two adjacent image regions are distinguished as having distinct surface textures. These boundaries may then be used to identify and segment the figure from the background which can subsequently aid in shape perception.

The visual texture segregation literature mainly focuses on the ability of the observer to effortlessly discriminate pairs of texture regions. Early investigations focussed on defining what aspects of image structure and features give rise to pre-attentive texture

segregation. As such, the distribution of properties, such as brightness, colour, size, contour, slope, and contour termination were found to affect textural segmentation (Beck, 1972, 1973; Marr, 1976; Olson & Attneave, 1970). Later, Julesz and colleagues (Julesz, 1981; Julesz, Gilbert, & Victor, 1978) proposed the idea of 'textons', which represent such features as size, orientation, line terminations and line crossings, and which they argued, formed the basis of texture segregation. Alternatively, it was suggested that the orientation and spatial frequency-tuned channels mentioned in the spatial vision literature (De Valois & De Valois, 1988; Graham, 1989, 1992) may be sufficient for modelling texture segregation. Since then, a number of similar models, based on selective filtering for orientation and spatial frequency in a visual scene, have been suggested to account for the ability of the visual system to segment texture information in a visual scene into meaningful wholes (for a review see Landy & Graham, 2004).

The perceptual representation of the spatial information present in irregular textures, such as those found in the real world, have often been examined using scatter-dot displays. These enable the investigation of the perception of spatial texture attributes in isolation from other properties of surfaces such as luminance, colour and spatial frequency. Scatter-dot displays may be manipulated such that they differ in terms of apparent number of dots (i.e. numerosity), and spacing (i.e. cluster), which each may contribute to the perception of texture density (for a review see Durgin, 1995). Texture density, that is the number of elements per unit of area, is a simple way of describing a textured area and is thus an important cue for surface segregation (Barlow, 1978; Marr, 1982). Cluster can be thought of as a measure of the variance of densities present in a texture (Ginsburg & Goldstein, 1987). Durgin (1995) suggests that the visual system represents texture density independent of number, and that the representation of perceived cluster depends, in part, on the processes underlying the perception of texture density. In any case, both cluster and

numerosity seem to be important featural dimensions that are independently encoded by the visual system for the perception of texture, particularly surface or two-dimensional texture.

The visual system can also perceive three-dimensional texture patterns. For example, Ho and colleagues (2007) found that the visual perception of three-dimensional texture is affected by the interaction of the illuminant and local height variations in the texture. They also observed that roughness constancy was not always consistent across varying viewpoints of the observer. In particular, they found that a surface was consistently judged to be rougher as it was illuminated from a more oblique angle, even when more cues to the illuminant position were provided. In other words, the perception of three-dimensional texture in vision is not invariant to changes in view or illumination. Clearly illumination changes would not affect the perception of texture through touch, however it remains to be seen whether observer viewpoint affects tactile texture perception in the same way as it does for visual texture perception.

2.1.3 Behavioural evidence for cross-modal interactions in texture perception

From the evidence discussed above, it seems that although the properties of the surface of an object are readily discriminable by touch and vision, these modalities encode and process texture information in distinct ways. For example, although the spatial properties of objects, such as shape, volume or size, are most efficiently recognised by vision, surface roughness is particularly salient to the tactile sense (Klatzky, Lederman, & Reed, 1987) and may be better assessed using touch than vision (Heller, 1989), suggesting performance differences across these modalities in the perception of texture.

Early comparative investigations between visual and tactile texture perception, however, indicate no clear difference in discrimination performance across these modalities (e.g. Binns, 1936). Similarly, a number of more recent studies have indicated

that differences in performance between the modalities in discriminating textures, such as sandpaper, are small to non-existent (Bjorkman, 1967; Heller, 1982; Jones & O'Neil, 1985; Lederman & Abbott, 1981; Rexroad & White, 1987). For example, Brown (1960) observed no difference between tactile, visual and visuo-tactile performance in a roughness paired-comparison task using wood samples of varying roughness. Moreover, Guest and Spence (2003a) reported finding no difference between tactile and visual performance on roughness discrimination of fabrics. However, Bergmann Tiest and Kappers (2007) used a wide variety of familiar textures in a free-sorting task, and reported a performance benefit for tactile over visual texture perception. According to their findings, the medium frequency roughness band (i.e., 0.1 mm) was important for judgements of roughness in the tactile rather than the visual system, for which a larger spatial scale (i.e., 1.0 mm) was preferred. This is in line with the known detection thresholds across the modalities for touch, measured as 0.98 mm on a static grating orientation discrimination task (Van Boven & Johnson, 1994) whereas for vision, features at length scale of 0.2 mm are at or below threshold.

Differences between the senses in texture discrimination and recognition performance suggest that information encoded across vision and touch may not transfer efficiently across modalities. Although the recognition of both familiar and unfamiliar object shapes is possible when explored through one modality, e.g. touch, and identified in another, e.g. vision (see Easton, Srinivas, & Greene, 1997; Ernst, Lange, & Newell, 2007; Newell, Ernst, Tjan, & Bülthoff, 2001), the extent to which information about texture can be efficiently shared across modalities is not as well understood.

The efficient transfer of texture information between touch to vision has been shown in both newborn infants (Molina & Jouen, 2001; Sann & Streri, 2007), and 1-month old infants (Meltzoff & Borton, 1979). Molina and Jouen (2001) examined the Hand

Pressure Frequency of neonates as they felt objects that varied in texture information, while they were simultaneously presented with either a congruent or incongruent visual object. Overall, their results revealed that manual activity was modulated by vision. Meltzhoff and Borton (1979) demonstrated that 1-month olds can visually recognise objects they have previously explored orally by the texture of the object, i.e. that efficient tactile to visual (TV) transfer is apparent. More recently, Sann and Streri (2007) investigated bi-directional cross-modal transfer of both shape and texture between vision and touch in newborns. Using 3D objects, they observed that newborns visually recognized an object learnt through touch, but failed to tactilely recognize a visually learnt object. In contrast, they observed a bi-directional cross-modal recognition of texture. These studies suggest that newborn's have the ability to compare and texture information between vision and touch.

In a series of experiments, Picard (2007) investigated intra-modal and cross-modal performance in the perception of texture in older children (5 and 8 year olds) using a match-to-sample task with fabric samples. For both age groups, performance, i.e. number of correct matches, was equivalent across vision and touch when the task was relatively easy (i.e. the sample and distracter textures shared different degrees of softness and thickness). However, when the test stimuli shared similar tactile properties, visual recognition was better than tactile recognition performance. Interestingly, stimulus context did not affect cross-modal (visuo-tactile) performance, suggesting that cross-modal recognition was resolved using mainly bottom-up perceptual processing of the test stimuli.

Picard (2007) also found that visual to tactile (VT) performance improved between the ages of 5 and 8 years using difficult to discriminate textures although there was no corresponding improvement in unimodal or TV performance. Picard (2007) argued that this relative improvement in VT performance was indicative of a shift to more efficient

top-down processing in the older children. However, Picard (2006) also reported differences between VT and TV performance in adults in texture recognition tasks. As such, a difference in the encoding of information across these modalities is likely to account for the poor transfer of information from touch to vision relative to from vision to touch. Further studies investigating the role of learning and development in cross-modal transfer are needed to unravel these differences.

In addition to how information is transferred across modalities, another pertinent issue is understanding how the senses act together for the perception of texture. Several studies have investigated multisensory interactions for texture perception, although the evidence is generally inconsistent regarding whether the senses optimally combine information to enhance perception. For example, Ballesteros and colleagues (2005) explored whether bimodal exploration of the same texture stimuli affected the perceptual dimensions produced by participants relative to unimodal exploration. They found that across both a SAT and a FCT the goodness of fit was better in the bimodal condition than the unimodal, haptic condition.

On the other hand, studies which have used a sensory conflict paradigm have suggested little interaction between the senses in texture perception. The idea behind this paradigm is that if a common multisensory representation of texture exists, then this representation will be based on an optimal combination of information from across the two senses (e.g. Ernst & Banks, 2002) or, if information in one sense is more reliable than the other then that one sense may dominate the other for perception (Lederman & Abbott, 1981). An example of sensory dominance has been demonstrated by Rock and Victor (1964) for shape perception: when a conflict between visual and tactile information arises, visual information can 'capture' the tactile input such that the visual experience dominates the tactile interpretation of the size of an object.

Using a conflict paradigm similar to that of Rock and Victor, Lederman and Abbott (1981) examined how a discrepancy between visual and tactile inputs affects texture perception. They found that when discrepant visual and tactile texture information was available, the texture percept was based on an equal weighting across these modalities. However, Lederman and Abbott found no difference in a range of tasks involving judgements of roughness across unimodal visual and tactile and bimodal visuo-tactile conditions. In other words, they did not find evidence of multisensory enhancement in behavioural performance involving texture perception. Similarly, Jones and O'Neil (1985) compared roughness judgements across unimodal, visual and tactile, and bimodal conditions and found no difference between these conditions on accuracy performance. Jones and O'Neil reported that decision speed was quicker in vision than in touch but that decision speed in the bimodal condition was the average of these two conditions. In contrast, Heller (1982) observed that using vision and touch together improved accuracy on a three-alternative smoothness rating task, relative to the unimodal conditions; although on closer examination this benefit for the bimodal condition was the result of the observer viewing their hand movements during the task rather than any benefit on the perception of texture *per se*. Finally, Guest and Spence (2003b) reported evidence for tactile dominance in texture perception. Using a sensory conflict paradigm, they observed that visual discrimination performance was affected by incongruent tactile distracters but that tactile performance was not affected by congruent or incongruent visual information. Collectively, these studies suggest that using both the visual and tactile modalities together does not seem to benefit texture perception relative to unimodal inputs. These findings further suggest that information may not be optimally integrated, as this information may be qualitatively different across modalities. Indeed, this review of the nature of the stimulus properties encoded across these modalities suggests that this is the case and that each modality encodes texture information in a specific manner that is most appropriate to

the physiology of that system. As such, it may not be entirely unexpected that texture information is not combined into a multisensory representation.

According to the *modality precision* or *modality appropriateness* hypothesis (Welch & Warren, 1980) input from different modalities is weighted as a function of the relative unimodal capabilities with respect to the task demands. For example, vision is thought of as the spatial sense and consequently, visual perception has been shown to be more accurate and precise on spatial tasks, such as form-matching, than tactile perception (e.g. Bryant & Raz, 1975; Cashdan, 1968; Milner & Bryant, 1970). Visuo-spatial superiority may be due to the fact that spatial information can be encoded in a parallel manner by vision whereas the tactile system has to rely on sequential encoding of spatial information, a task that is clearly demanding on memory resources because of the need to integrate spatial information over time. However, unimodal tactile and visual performance have been found to be similar on texture perception tasks (e.g. Lederman & Abbott, 1981), although that is not to say that participants did not encode different properties of texture in a modality-specific manner, i.e. in a way most appropriate to the sensitivities of each modality.

As such, the lack of evidence of better performance in bimodal relative to unimodal conditions may be due to different information encoded in each modality. Furthermore, this difference in encoded information may be mediated by attention, such that some features are more salient and are more easily attended to in one modality rather than another. This so-called *directed attention* hypothesis (Welch, Widawski, Harrington, & Warren, 1979) has received some support in the literature (Cannon, 1970; Kelso, Cook, Olson, & Epstein, 1975; Warren, 1979), although it is not known to what extent attention affects multisensory texture perception. However, Lederman (1979) proposed a variant of this theory, namely the *ecological validity* hypothesis, where cues from one modality (e.g.

touch) may be more ecologically valid to, or reliably encoded by one modality than cues from another modality (e.g. vision) for the purpose of the task, and may therefore dominate perception.

Interestingly, several studies have suggested that when vision and touch are combined for the purpose of texture perception, task demands can affect the relative dominance of each modality to the percept. For example, Lederman and colleagues (1986) demonstrated that when a judgement dimension was altered, e.g. from judgements of spatial density to roughness, the relative weighting of visual and haptic inputs on the decision changed. Later, in a similarity grouping task, Klatzky and colleagues (1987) showed that when participants were given instructions that biased them towards visual inputs, they sorted the stimuli initially by shape. On the other hand, when participants were biased toward tactile similarity, objects were sorted primarily in terms of material properties, such as texture. Furthermore, when discriminating between objects that varied in terms of material properties (i.e. roughness, hardness, thermal properties, and weight), observers used tactile information to guide their visual decisions (Klatzky, et al., 1987).

2.1.4 Neural correlates of unimodal tactile and visual texture perception

As well as behavioural differences between vision and touch in the perception of texture, these systems are supported by different neural substrates in the brain. For example, the major cortical regions underlying tactile texture perception are the primary and secondary somatosensory areas, the posterior parietal cortex as well as other more anterior brain regions such as the pre-frontal cortex (for an illustration of the human brain see Figure 2.1). The visual processing of texture, on the other hand, involves cortical areas of the brain that are generally distinct from those involved in tactile perception such as primary visual cortex, the collateral sulcus and other higher visual areas such as the fusiform gyrus (for an illustration see Figure 2.2). The following paragraphs give an

overview of the main brain regions that have been reported to be activated during texture perception across vision and touch and assess to what extent these neural systems work together or independently. These studies will include both electrophysiological and neuroimaging data in both monkeys and humans.

In touch, the primary somatosensory cortex (SI) receives primary afferent connections from the thalamus and is located in the post-central gyrus (PoG) of the human brain. Based on its cytoarchitectonic characteristics, SI can be further divided into areas 3a, 3b, 1 and 2. Early lesion work in monkeys suggested that several of these cytoarchitectonic areas might be responsible for texture perception. For example, work by Randolph and Semmes (1974) on SI indicated that an ablation of area 3b impaired shape and texture discrimination in the monkey, whereas ablation in area 1 only impaired texture perception.

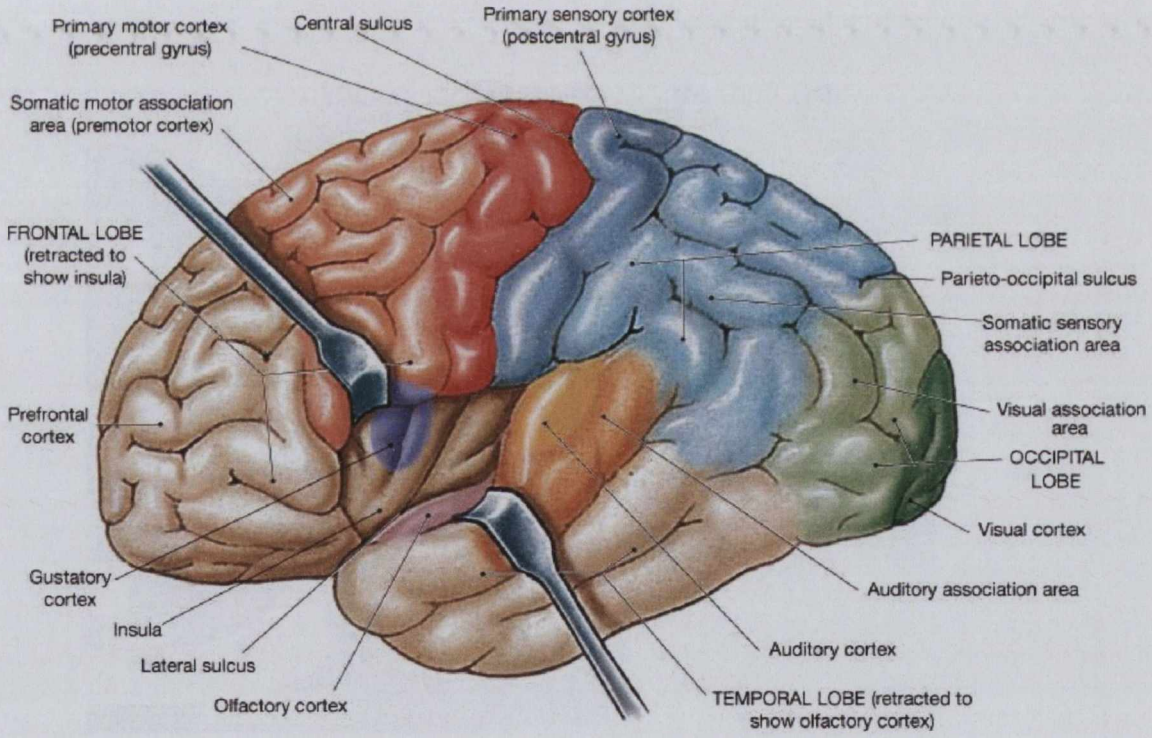


Figure 2.1. The human brain. Lateral view of the cortex illustrating the major functional areas involved in sensation and perception. Reprinted from Silverthorn and Ober (2007).

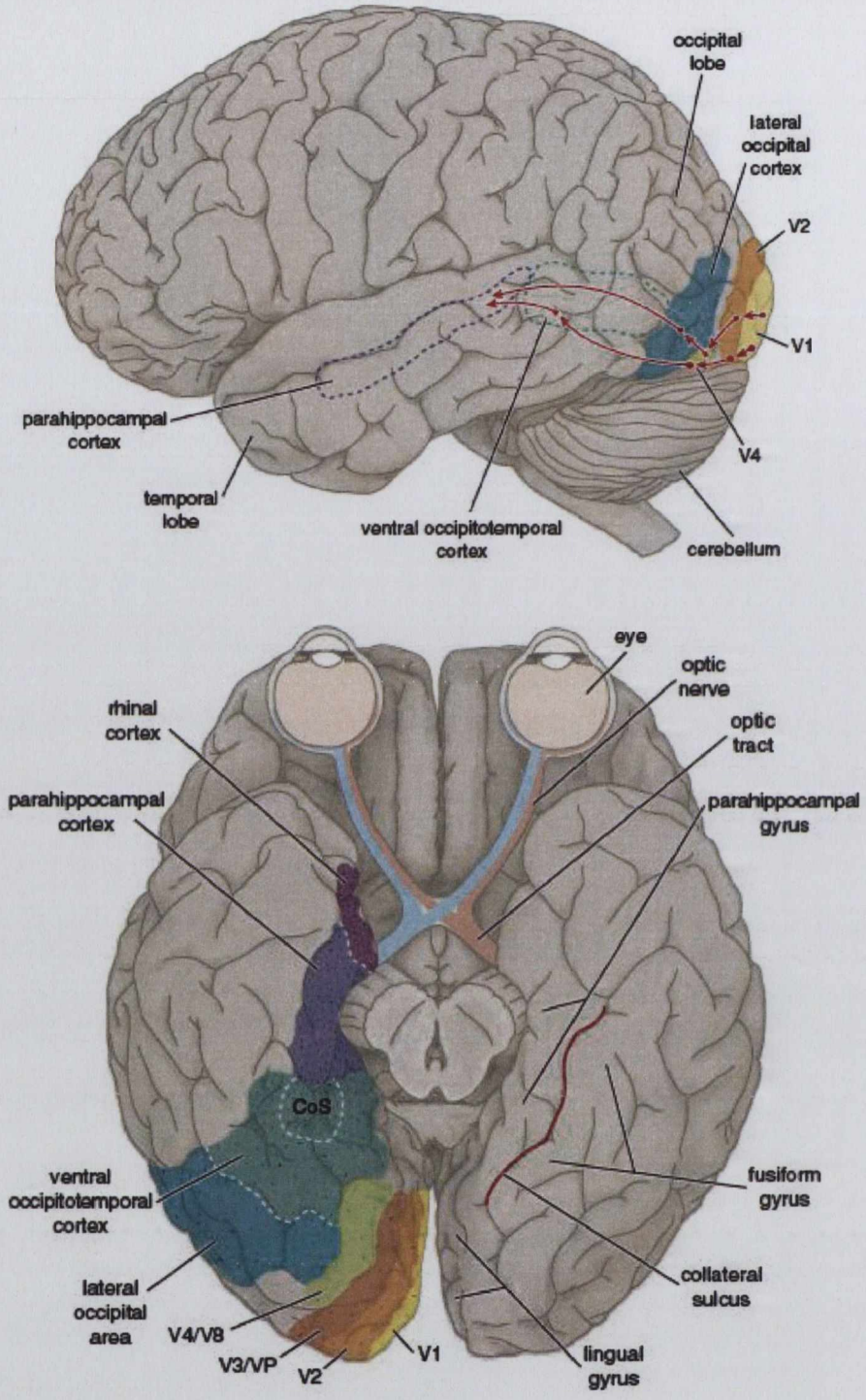


Figure 2.2. The human brain. Regions of the visual cortex are highlighted along with the visual ventral stream (*top; red arrows*) and CoS which have been implicated in texture perception tasks. Reprinted from Biederman and Vessel (2006).

In agreement with these lesion works, studies based on single unit-recordings have also confirmed the involvement of these areas in texture perception. For example, neuronal activity in areas 3b, 1 and 2 signal differences in textures explored through active touch. Darian-Smith and colleagues (1982) reported that single neurons in areas 3b and 1 discharge when the monkey rubs the contra-lateral finger pad across a textured surface. In a further set of electrophysiological studies, where monkeys were trained to detect differences between smooth and rough textures, such as raised Braille characters, texture-related activity was observed in areas 3b, 1 and 2 (Ageranioti-Belanger & Chapman, 1992; Chapman & Ageranioti-Belanger, 1991). Texture-sensitive neurons can be further classified as graded, if their discharge rate is proportional to the changes in spatial period, or non-graded, if the discharge rate varies with a change in spatial period but does not provide information about the magnitude of this change. In SI, texture related neurons exhibit graded responses, i.e. their firing rate increases with increasing spatial period of gratings (Sinclair & Burton, 1988) and of raised-dot surfaces (Jiang, Tremblay, & Chapman, 1997), suggesting that SI encodes texture based on mean firing rates.

With the advance of non-invasive neuroimaging techniques, it is possible to gain insight on which areas of the cortex are being recruited during texture discrimination in the human brain. Notably, SI is systematically activated in texture perception studies, independently of the specific stimuli or task, and temporary disruption of SI by transcranial magnetic stimulation (TMS) over the SI cortex impaired the discrimination of grating textures (Zangaladze, Epstein, Grafton, & Sathian, 1999). Using fMRI, Servos and colleagues (2001) investigated the neural subtracts of haptic texture, shape and hardness perception. They observed activity in the Somatosensory cortex contra-laterally to the exploring hand for all three classification tasks. They also reported a common posterior region for shape and texture discrimination, whereas hardness discrimination activated a

more anterior location of SI. In the previous studies, the stimuli used would be classified as coarse textures, since their spatial period is above the range 0.1-0.2 mm. Although, as previously discussed, vibrations elicited when the fingers move across a textured surface, which then activate the Pacinian system, may underlie roughness perception of fine surfaces. A way of targeting this system is by passively applying vibratory stimuli to the fingertips. By using fMRI and vibrotactile stimuli Nelson and colleagues (2004) observed that activations in SI reflect the changes in the vibrotactile amplitude which further confirms both the important role of SI in texture perception, and lends support to the idea of intensity coding for fine texture perception.

Another brain region consistently activated by tactile texture perception is the secondary somatosensory cortex (SII), which is located in the parietal operculum (PO). In contrast to SI, SII shows bilateral activation after unilateral stimulation and its neurons show larger and widely overlapping receptive fields (Burton, 1986), in line with its integrative role in somatosensory processing. Electrophysiological and histological studies in primates and humans have greatly contributed to our understanding of the structure and function of SII over the last two decades. Cytoarchitectonic studies in primates have revealed three distinct subdivisions in the SII cortex, each one of which with a complete somatotopic map (for a review see Kaas & Collins, 2003). More recently, Eickhoff and colleagues (Eickhoff, Amunts, Mohlberg, & Zilles, 2006; Eickhoff, Grefkes, Zilles, & Fink, 2007) studied the cytoarchitectonic organization of 10 human post-mortem brains and identified four distinct cytoarchitectonic areas in the parietal operculum (OP1-4). They further compared the SII locations reported in 57 fMRI and positron emission tomography (PET) studies with the four PO subdivisions and observed a wide overlap between the two (Eickhoff, Schleicher, Zilles, & Amunts, 2006) concluding that the histological defined

maps OP1-4 of the human PO can be interpreted as an anatomical correlate of the functionally defined SII region.

Unilateral and bilateral ablation of SII has been shown to impair texture discrimination in monkeys (Garcha & Ettlinger, 1980; Ridley & Ettlinger, 1976, 1978). Interestingly, Ridley & Ettlinger (1976) found that roughness discrimination did not appear to be affected by a bilateral removal of SII. In contrast, Murray and Mishkin (1984) reported that monkeys with bilateral SII removal were severely impaired in learning a texture discrimination task and had increased roughness discrimination thresholds. The distinction in these results may be due to the different extent of the lesions across studies.

The involvement of SII in texture perception has been further confirmed by single-unit recordings in SII neurons in monkeys (Jiang, et al., 1997; Pruett, Sinclair, & Burton, 2000, 2001; Sinclair & Burton, 1993). Sinclair and Burton (1993) recorded activity of SII neurons while the monkeys actively explored pairs of gratings differing in spatial period (0.75 – 3.15 mm) and indicated which grating was smoother. They observed that texture-sensitive SII neurons exhibited both positive and negative graded changes in firing rate with changes in the spatial period of the gratings. In another study, two monkeys were trained to discriminate a standard surface of spatial period 2.0 mm, from three other modified surfaces of spatial period 3.0, 4.0, and 5.0 mm (Jiang, et al., 1997). Their results revealed that activity in the majority of the texture-sensitive SI neurons was graded, while the larger majority of activation from the texture sensitive neurons in SII was non-graded. According to the authors, one possible explanation for the discrepancy in the results is that the non-graded response from SII cells in their study may be due to SII neurons being tuned for finer textures.

More recently a series of neuroimaging studies have also revealed the involvement of PO and posterior insula in tactile texture processing in healthy humans. In a recent fMRI

study by Stilla and Sathian (2008), activity in the posterior insula and PO was observed when subjects haptically explored different textures. Using a different approach, Kitada and colleagues (2005) looked at the brain activity during a tactile roughness-estimation task using fMRI. Participants were asked to estimate the roughness of three different gratings, each with a spatial period of 0.5, 1.2, or 1.5 mm, with a tactile control condition using the same textures but without performing the estimation task. Activity during the estimation task was observed in the PO and posterior insula bilaterally and in the right lateral pre-frontal cortex. The PO and posterior insula also showed significant activation in the control condition, indicating that these areas are involved in the sensory processing of the gratings rather than in the cognitive task or rating the roughness. Furthermore, graded activity was observed in the PO according to the spatial properties of the encoded stimulus.

Three different PET studies have compared roughness discrimination with length discrimination (Ledberg, O'Sullivan, Kinomura, & Roland, 1995; O'Sullivan, Roland, & Kawashima, 1994; Roland, O'Sullivan, & Kawashima, 1998). In these studies, roughness discrimination activated PO more than length discrimination, whereas length discrimination activated the intraparietal sulcus (IPS; O'Sullivan, et al., 1994; Roland, et al., 1998). This series of studies stresses that the involvement of the PO is discrimination of microgeometric properties of objects (texture) rather than their macrogeometric properties (shape and length).

The posterior parietal cortex (PPC) has also been implicated in tactile processing of texture. In monkeys it contains Brodmann's areas 5 and 7, whereas in humans these two areas only correspond to the superior part of PPC, above the intraparietal sulcus, while the inferior part of PPC includes the human specific Brodmann's areas 39 and 40 (Zilles & Palomero-Gallagher, 2001). The PPC is known as the "parietal association area" and is considered as a multisensory area that integrates tactile information with other sensory

modalities (for a review see Culham & Valyear, 2006). Although activation in the IPS has been observed during grating orientation discrimination tasks (Harada, et al., 2004; Van Boven, Ingeholm, Beauchamp, Bikle, & Ungerleider, 2005; Zhang, et al., 2005), this region seems to be specific for haptic shape rather than texture perception (Bodegard, Geyer, Grefkes, Zilles, & Roland, 2001; O'Sullivan, et al., 1994; Roland, et al., 1998), as well as cross-modal shape perception (Zhang, Weisser, Stilla, Prather, & Sathian, 2004). For example, Roland and colleagues (1998) observed IPS activation during shape and length discrimination but not during roughness discrimination.

Other brain regions have also been implicated in roughness estimation tasks, such as the right pre-frontal cortex (Kitada, et al., 2005; Van Boven, et al., 2005; Zhang, et al., 2005). Activation in the pre-frontal cortex has been observed during the discrimination of the speed of a brush on the palm of the hand (Bodegard, Geyer, Naito, Zilles, & Roland, 2000), discrimination of the length of parallelepipeds (Stoeckel, et al., 2003), and discrimination of two-dot Braille characters (Harada, et al., 2004). Although these areas are activated during tactile discrimination, activation seems more related to the cognitive component of the task rather than the sensory processing necessary for texture estimation.

Over the past 10 years, a large number of neuroimaging studies have focused on identifying the neural substrates of object recognition by vision, and very few studies have directly investigated visual texture perception. In any case, texture perception by vision is thought to occur in the early stages of visual processing, although the underlying mechanism or regions involved in this type of perception are not well understood. Bergen and Adelson (1988) suggest that early vision can be thought of as a process that extracts information about the material properties of an object. More recently, Landy and Graham (2004) proposed different processing mechanisms for patterns that differ in their luminance intensity (i.e. first-order patterns) and patterns that differ in contrast or texture (i.e. second-

order patterns). Based on this theory, several fMRI studies have tried to identify the brain regions involved in the processing of first- and second- order patterns (e.g. Kastner, De Weerd, & Ungerleider, 2000; Larsson, Landy, & Heeger, 2006; Schira, Fahle, Donner, Kraft, & Brandt, 2004; Thielscher, Kölle, Neumann, Spitzer, & Grön, 2008). They all observed that the output of the first-stage filters in the primary visual cortex (V1) was subject to further analysis (second-stage filter) in the extrastriate cortex. Furthermore, Thielscher and colleagues (2008) observed parametric modulation of orientation contrast in area V4.

A recent fMRI study by Peuskens and colleagues (2004) investigated the processing of surface texture by asking participants to attend to either the shape or the surface texture of randomly deformed spheres presented visually. The texture specific areas, i.e. the areas that were exclusively activated by texture, were located in the collateral sulcus (CoS) and the lingual gyrus of the cortex, while shape specific areas included the lateral occipital complex (LOC) and IPS. Notably, attention to the surface properties preferentially activated regions in the ventral stream only, whereas attention to object shape activated regions in both the ventral and dorsal streams. The involvement of the CoS in visual texture perception is in line with results demonstrating that this region responds to texture patterns compared to faces and letter strings (Puce, Allison, Asgari, Gore, & McCarthy, 1996). Similar results were obtained by Cant and Goodale (2007) during an fMRI investigation of the neural correlates of visual texture perception. They observed that the processing of the surface properties of an object selectively activated the inferior occipital gyrus (IOG) and CoS, relative to shape tasks, which selectively activated the LOC. In accordance with this, in a behavioural equivalent paper, Cant and colleagues (2008) observed that form and surface properties were processed independently. Here, changes in colour were successfully ignored while attending to changes in texture and vice

versa. This set of neuroimaging results indicate that the CoS is a crucial brain area for texture processing by vision. Furthermore, its close anatomical proximity to the parahippocampal place area (PPA), an area normally associated with scene processing (Epstein, Harris, Stanley, & Kanwisher, 1999; Epstein & Kanwisher, 1998) as well as behavioural evidence that surface properties aid to scene recognition, hint at the possibility of the PPA also be a part of this network of areas involved in the analysis of surface properties.

These results also confirm the existence of two different pathways in object recognition: the dorsal pathway for processing surface properties and the ventral pathway for processing geometric properties. This dissociation is further confirmed by lesion studies affecting one pathway and leaving the other intact. For example, patient D.F. who has impaired shape but not texture discrimination presents large bilateral lesions that include LOC, although her fusiform gyrus and parahippocampal cortex remain largely intact (Humphrey, et al., 1994; James, et al., 2003; Milner, et al., 1991). Further evidence for the role of the fusiform gyrus in visual texture perception has been observed (Beason-Held, et al., 1998), along with the lingual gyrus (Beason-Held, et al., 1998; Peuskens, et al., 2004) and other regions in the parieto-occipital cortex (POC), although these areas are not thought to be specific for texture processing *per se*.

The studies mentioned suggest that cortical areas of the brain that are specific for the perception of texture within each modality. However, none of the studies mentioned investigated the role of both vision and touch on neural activity during texture perception. In the following section we address what cortical areas are involved in the common processing of texture across modalities.

2.1.5 Neural correlates multisensory texture perception

Some studies have suggested that, in humans, activity in the visual cortex is present during tactile perception (for a review see Sathian, 2005). Indeed a number of studies examining the function of the visual cortex in blind participants have observed recruitment of this region during Braille reading (e.g. Amedi, Raz, Pianka, Malach, & Zohary, 2003; Büchel, Price, Frackowiak, & Friston, 1998; Cohen, Celnik, Pascual-Leone, Corwell, Faiz, et al., 1999; Melzer, Morgan, Pickens, Price, Wall, & Ebner, 2001, Sadato, Okada, Honda, & Yonekura, 2002; Sadato, Pascual-Leone, Grafman, Deiber, Ibanez, & Hallett, 1998; Sadato, Pascual-Leone, Grafman, Ibanez, Deiber, Dold, & Hallett, 1996). This cross-modal plasticity appears to be dependent on a critical period of visual development, as TMS administered to medial occipital regions disrupts Braille reading in early blind but not late blind participants (Cohen, Weeks, Sadato, Celnik, Ishii, & Hallett, 1999). As many of these studies used specific shapes/Braille as stimuli, it is difficult to determine whether visual activation is due to imagery or multisensory processing. However, Sathian and colleagues (1997) suggest that although visual imagery has been implicated in the tactile perception of some macro-geometric properties of objects, such as shape and size, its involvement in the perception of texture is thought to be minimal. For example, they used PET during tactile discrimination of grating orientation and assessed the role of visual imagery in this task. The task was contrasted against a control spacing task where participants judged whether the ridges were too large or too small. The results revealed that the tactile grating orientation task, and not the tactile grating spacing task, significantly increased regional cerebral blood flow in the contralateral POC, a cortical region considered to be part of the visual cortex (see also Sergent, Ohta, & MacDonald, 1992).

In a later study, Zangaladze and colleagues (1999) used TMS to temporarily inactivate the POC and the SI area during tactile orientation and spacing tasks. They found

that disrupting the function in the POC area interfered with the discrimination of grating orientation but not the spacing task, suggesting that activation in visual areas is specific to some tactile tasks but perhaps not those involving texture. On the other hand, Merabet and colleagues (2004) used repetitive-TMS over the occipital cortex while subjects performed a tactile roughness discrimination task and an inter-dot spacing task. They observed that functional disruption of the occipital areas (V1/V2) impaired the spacing task but not the roughness task. This study suggests that visual areas are activated during specific tactile tasks involving texture perception, although the role of visual imagery can probably not be ruled out. For example, in another recent study by Merabet and colleagues (2007) tactile exploration of raised dots patterns resulted in activation of V1 and deactivation of the extrastriate cortical regions. The results of this set of studies may indicate the involvement of visual imagery when participants are conducting a task based on more geometric (i.e. orientation) rather than material (i.e. texture) properties of a stimulus. This suggests that these two properties, orientation and roughness are distinct and are further underpinned by distinct regions of activation in the human brain.

Newman and colleagues (2005) investigated the role of visual imagery of material and geometric properties on cortical activation when information about familiar objects was retrieved from memory. In this experiment, participants were instructed to mentally evaluate a pair of objects along either a material dimension (roughness, hardness and temperature; e.g. "what is rougher: pear or egg?") or a geometric dimension (size and shape; e.g. "what is bigger: marble or grape?"). The fMRI results showed that, although the same network of brain areas was activated for both material and geometric properties, the IPS was more activated when participants were asked about geometric properties, whereas the extrastriate cortex was more activated for material properties. Interestingly, imagery of material properties also resulted in a small activation in the right somatosensory and pre-

motor areas, although no haptic input was present. On the other hand, area LOC was equally activated for both material and geometric properties, although a trend was observed for slightly larger activation for geometric properties. Several studies have argued that LOC is a multisensory processing region involved in shape processing (see Amedi, von Kriegstein, van Atteveldt, Beauchamp, & Naumer, 2005). However, in this study LOC was also activated for roughness imagery, but not for hardness and temperature. This might be due to the fact that roughness, although a material property, relies heavily on shape processing (i.e. the visualization of an object may provide cues to the roughness of its surface). Therefore, it is not clear whether the LOC was activated during roughness processing because of associations with object shape.

Most neuroimaging research in this area has not specifically addressed multisensory perception of texture. In a recent exception, Stilla and Sathian (2008) used fMRI to investigate visuo-tactile processing of shape and texture. Here, the authors used two sets of stimuli including objects with the same shape but with different textures, to study texture perception independently of shape. For texture, the right medial occipital gyrus (MOG) in a region close to V2 was the area commonly activated by touch and vision. Although this region was more responsive to visual than to haptic textures, it had a significant activation above baseline for textures explored through touch. Despite an overlap in MOG for vision and touch in texture perception, the absence of a correlated activity between these modalities led the authors to suggest that this region is not multisensory, but may reflect the co-existence of unimodal neuronal populations.

Despite an abundant behavioural literature investigating texture perception, neuroimaging studies with this focus are still relatively sparse. Apart from utilising similar stimuli as their behavioural counterparts (e.g. gratings, raised-dot patterns), the behavioural and neuroimaging texture perception studies are reasonably distinct, and little connection is

made. As the neuroimaging literature mainly investigates texture perception using vision and touch in isolation, it is difficult to conclude whether these senses are independent or integrated for texture perception. However, recent work by Stilla and Sathian (2008), which specifically looks at texture using both modalities, may hint at the senses being independent, in parallel with what can be drawn from behavioural studies. Further research is needed to better understand the relationship between both unimodal and multisensory texture perception, and activation in the brain. Other areas for future study are suggested in the following section.

2.2 Discussion

Over the past century, research investigating objects and their material properties has been growing. Texture perception in particular has received a great amount of attention; in particular, the ability of different senses to discriminate textures which may aid the recognition of objects has been investigated. From these explorations, it appears that few differences exist in terms of behavioural performance in texture perception across vision and touch for texture discrimination. However, the results of several studies investigating cross-modal and multisensory perception suggest that these modalities perceive texture in qualitatively different ways. As a consequence, cross-modal performance is often not as good as unimodal texture perception (e.g. Picard, 2007). Furthermore, texture discrimination does not seem to benefit from an integration of information across modalities (Jones & O'Neil, 1985; Lederman & Abbott, 1981). Evidence from neuroimaging studies suggests few cortical regions in common for touch and vision during unimodal texture perception. On the other hand, bimodal or multisensory processing of texture information seem to activate areas commonly thought of as visual areas, such as the lateral and medial occipital cortices (e.g. Stilla & Sathian, 2008).

A number of potential directions for future research were apparent to the authors whilst reviewing the literature. Many studies to date on the perception of texture have used artificial stimuli, such as gratings and raised-dot patterns, where the physical parameters such as spatial frequency and amplitude can be highly controlled. However, given our remarkable ability at perceiving natural textures, especially considering the irregularities in texture information across these types of stimuli, investigations of more everyday texture perception are now very timely. A shift towards exploring the perception of more natural materials may provide beneficial information for the development of virtual environments and have important implications for industry in the design and manufacture of products with appealing textures. Utilising real materials is challenging, as the ability to control the physical characteristics of the stimulus is more difficult than for artificial stimuli. Most of the literature on texture perception focuses on the concept of roughness, while ignoring other important dimensions of texture. Ideally, it would be desirable to select a set of stimuli which, although similar, would differ across a number of dimensions such as roughness, compressibility, temperature, and luminance and examine the influence that altering one dimension at a time has on behavioural and neurophysiological results.

Additionally, although the lateral motion EP is optimal for texture perception (Lederman & Klatzky, 1987), of interest is whether this will hold when real textures are used. For example, a wood surface may have particular features (such as a knot) which would focus the attention of the explorer. While previous studies in tactile texture perception often control the subjects' exploration of the stimuli, this is no longer valid for visual exploration. To this end, it would be interesting to examine if unconstrained tactile and visual exploration of real textures focus on the same features (e.g. asymmetries).

Future directions in texture perception research must also involve convergent methodologies, such as behavioural studies, neuroimaging and electrophysiology. Open

questions, such as the role of temporal cues in texture perception could be explored by combining techniques such as fMRI and EEG, which provide complementary information about accurate location and timings of activation. Behavioural results have shown that, although temporal cues are available, they do not seem to be necessary for coarse texture perception. Moreover, the neural underpinnings involved in temporal processing of texture information are, as yet, unknown.

Finally, in order to complement the wealth of behavioural studies, more studies investigating the neural correlates of multisensory texture perception across a range of stimuli and tasks are required. However, this is not without its challenges as one major difficulty with neuroimaging bimodal protocols is that the visual stimulus must either be displayed as an image (and therefore incurs artificiality), or the hand of the observer will be in view. This poses a problem for the design of the experiment, and introduces the limitation of manipulating the visual stimulus on dimensions such as luminance and viewpoint. Addressing these issues and moving in these directions would, in the authors' opinion, be advantageous for the area of texture perception.

CHAPTER 3

BEHAVIOURAL MEASURES OF NATURALNESS PERCEPTION

Authorship

In the following chapter, Experiment 1 was printed as a short paper in proceedings arising from the EuroHaptics conference (Madrid, 2008):

Whitaker, T. A., Simões-Franklin, C., & Newell, F. N. (2008). The natural truth: The contribution of vision and touch in the categorisation of "naturalness". Haptics: Perception, Devices, and Scenarios, 319-324

3.1 Introduction

As consumers we frequently have to choose between natural things and synthetic mimics. Clothing, household surfaces and flooring, medicines and cosmetics, food and cleaning products come in so many varieties, and can contain natural or imitation natural components. Advertising attracts the consumer by highlighting the "natural" and "organic" properties of a product, despite a cocktail of natural and synthetic components often being present. In the literature, the influence of naturalness is well documented in terms of food preference (e.g. Rozin, 2005, 2006; Rozin, et al., 2004), and landscape preference (e.g. Ode, et al., 2009; Purcell & Lamb, 1998). However, the perception of naturalness among general material stimuli (i.e. wood, fabric, stone etc.) has yet to be explored experimentally. When advertising and labelling information is not present, how do we perceive the naturalness of materials?

3.1.1 Perceiving "naturalness"

Different material properties including texture, colour, compressibility and temperature all add to how natural a surface or object may appear. Colour, particularly diagnostic colour, and other surface properties have been shown to aid recognition of natural objects, such as fruit and vegetables (e.g. Humphrey, et al., 1994; Therriault, Yaxley, & Zwaan, 2009), suggesting that these features may be linked to the perceived naturalness of these items. In the texture perception literature, ecological textures are becoming more frequently used when examining roughness and other dimensions of perceptual texture space (Ballesteros, et al., 2005; Bergmann Tiest & Kappers, 2006, 2007; Brown, 1960; Guest & Spence, 2003a, 2003b; Hollins, Bensmaïa, et al., 2000; Hollins, et al., 1993; Picard, 2007; Picard, et al., 2003), although none have investigated the perception of these materials in terms of naturalness.

Independently, the senses of vision and touch are excellent at texture categorisation, discrimination and identification (see Chapter 2). Interestingly, investigations of multisensory integration in texture perception have thus far failed to find evidence of summative integration of information between vision and touch, rather a weighted averaging of the perceptual input has been suggested (Guest & Spence, 2003a; Jones & O'Neil, 1985; Lederman & Abbott, 1981; Lederman, Thorne, & Jones, 1986). This is in contrast to multisensory enhancement observed in other ecological stimulus classes such as speech (e.g. Calvert, Campbell, & Brammer, 2000), and food (e.g. Dalton, Doolittle, Nagata, & Breslin, 2000). Thus, multisensory integration and enhancement seems to be stimulus-specific in nature, and research based on highly controlled non-ecological stimuli may yield different findings than that based on naturally occurring stimuli. Using ecological textures as stimuli, this series of experiments aimed to investigate how input from vision and touch contributes to the perception of naturalness of wood and fabric surfaces.

3.1.2 Outline of experiments

Despite the increasing use of ecological materials and objects, there has been no implicit examination of the perception of the naturalness of these stimuli. In light of this, Experiment 1 investigated at a behavioural level, how vision and touch contribute, either independently or bimodally, to the perception of naturalness of wood and fabric stimuli. This study sought to examine whether the perception of naturalness differed as a function of exploration modality, and if using vision and touch simultaneously significantly altered the perception of naturalness relative to exploring using these modalities independently. Furthermore, using separate stimulus sets of wood and fabric, an investigation of whether the contribution of touch and vision to the perception of naturalness varied as a function of material type was conducted. In preparation for later neuroimaging studies (see Chapters 5

and 6), Experiment 2 investigated whether the perception of naturalness of wood and fabric stimuli in the visual condition varies as a function of stimulus presentation type, i.e. whether using images during the visual presentation significantly altered naturalness perception.

3.2 Experiment 1

This experiment investigated how a set of wood and fabric stimuli are perceived in terms of their naturalness. Exploration of the stimuli was carried out using touch only, vision only, and using both vision and touch simultaneously (hereinafter referred to as bimodal). In this way, an examination of whether perceived naturalness varied as a function of exploration modality (touch, vision), and whether using these modalities together influenced the perception of the naturalness of different material surfaces was conducted.

3.2.1 Method

Participants

All studies reported in this thesis were approved by the Psychology Research Ethics Committee at Trinity College Dublin prior to testing (see Appendix A for ethics approval letter).

Thirty right-handed undergraduate and postgraduate students (22 female, mean age 23 years, age range 17-52) of Trinity College Dublin participated in this study for nominal pay or research credits. All participants reported normal or corrected-to-normal vision, no tactile impairments, no history of neurological or psychological disorders, and no particular experience with either wood or fabric materials (either professional or otherwise). Following a briefing on the experimental protocol, participants provided written consent to take part in the study (see Appendix B for behavioural forms). For all

studies reported in this thesis, handedness was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971; see Appendix C).

Stimuli and apparatus

Stimuli

Thirty unique samples were randomly selected to cover a wide range of wood surfaces commonly encountered in everyday life. The sample set represented different degrees of natural and unnatural wood (see Table 3.1). The natural stimuli consisted of tiger oak and cognac oak samples, which had different finishes including raw, weathered, sanded, waxed, and oiled. The unnatural stimuli consisted of laminate, veneer, vinyl, and high-quality photocopy. Each stimulus was mounted behind a plastic frame using an epoxy adhesive. The frame had an 80 x 80 mm window through which the sample could be viewed or touched. Some of the thinner samples required a firm backing, which was achieved by fixing Plexiglas behind these samples. During presentation, the orientation of the stimuli was constrained such that the grain of wood consistently lay along the y-axis, i.e. perpendicular to the participant.

Twenty fabric samples created for the purpose of these studies were used as stimuli. These fabrics consisted of different combinations of wool, cotton, acrylic and polypropylene woven together to achieve a variety of natural and unnatural samples (see Table 3.2). Natural samples consisted of 100% natural fibres (i.e. wool and cotton) or 75% wool plus 25% cotton, 50% of each and 25% wool plus 75% cotton. Unnatural samples consisted of 100% unnatural fibres (i.e. polypropylene and acrylic) or 75% polypropylene plus 25% acrylic, 50% of each and 25% polypropylene plus 75% acrylic. Fabrics had either a coarse or fine finish. Each stimulus was mounted onto a wooden block, 80 x 80 mm. Edges of the fabric were fixed behind the block so that these could not be viewed or felt during exploration. During presentation, the orientation of the stimuli was constrained

such that the warp of the fabric weave consistently lay along the x-axis relative to the participant.

Table 3.1. *Description of the wood stimuli used. Perceived naturalness (%) for each stimulus across exploration modality condition is displayed.*

				Exploration Modality		
Stimulus	Wood Type	Finish	Stimulus Category	Touch Only	Vision Only	Bimodal
1	Tiger Oak	Raw	Natural	95.00	90.00	100.00
2	Cognac Oak	Raw	Natural	100.00	85.00	100.00
3	Tiger Oak	Weathered	Natural	90.00	65.00	100.00
4	Cognac Oak	Weathered	Natural	95.00	85.00	100.00
5	Tiger Oak	Sanded	Natural	90.00	50.00	90.00
6	Cognac Oak	Sanded	Natural	80.00	55.00	80.00
7	Tiger Oak	Waxed	Natural	75.00	55.00	85.00
8	Cognac Oak	Waxed	Natural	80.00	65.00	80.00
9	Tiger Oak	Oiled	Natural	75.00	75.00	70.00
10	Cognac Oak	Oiled	Natural	55.00	80.00	75.00
11	Tiger Oak	Varnished	Natural	30.00	85.00	55.00
12	Cognac Oak	Varnished	Natural	45.00	40.00	35.00
13	Tiger Oak	Manufactured	Natural	20.00	70.00	55.00
14	Cognac Oak	Manufactured	Natural	35.00	90.00	70.00
15	Imitation Oak	Laminate	Unnatural	30.00	60.00	35.00
16	Imitation Oak	Laminate	Unnatural	45.00	55.00	30.00
17	Imitation Oak	Laminate	Unnatural	35.00	45.00	20.00
18	Imitation Oak	Veneer	Unnatural	20.00	80.00	15.00
19	Imitation Oak	Soft Vinyl	Unnatural	35.00	40.00	5.00
20	Imitation Oak	Soft Vinyl	Unnatural	25.00	40.00	55.00
21	Imitation Oak	Soft Vinyl	Unnatural	70.00	55.00	35.00
22	Imitation Oak	Hard Vinyl	Unnatural	35.00	10.00	10.00
23	Imitation Oak	Hard Vinyl	Unnatural	15.00	25.00	0.00
24	Imitation Oak	Hard Vinyl	Unnatural	0.00	50.00	20.00
25	Imitation Oak	Vinyl	Unnatural	5.00	45.00	5.00
26	Imitation Oak	Vinyl	Unnatural	15.00	0.00	0.00
27	Imitation Oak	Vinyl	Unnatural	10.00	0.00	10.00
28	Imitation Oak	Photocopy	Unnatural	0.00	25.00	0.00
29	Imitation Oak	Photocopy	Unnatural	5.00	30.00	0.00
30	Imitation Oak	Photocopy	Unnatural	5.00	45.00	0.00

Table 3.2. *Description of the fabric stimuli used. Perceived naturalness (%) for each stimulus across exploration modality condition is displayed.*

				Exploration Modality		
Stimulus	Fabric Type	Finish	Stimulus Category	Touch Only	Vision Only	Bimodal
1	100% Wool	Fine	Natural	80.00	90.00	65.00
2	100% Cotton	Fine	Natural	40.00	90.00	75.00
3	75% Wool 25% Cotton	Fine	Natural	60.00	85.00	85.00
4	75% Cotton 25% Wool	Fine	Natural	60.00	80.00	80.00
5	50% Wool 50% Cotton	Fine	Natural	50.00	80.00	80.00
6	100% Wool	Coarse	Natural	70.00	100.00	95.00
7	100% Cotton	Coarse	Natural	55.00	100.00	95.00
8	75% Wool 25% Cotton	Coarse	Natural	75.00	95.00	90.00
9	75% Cotton 25% Wool	Coarse	Natural	85.00	95.00	100.00
10	50% Wool 50% Cotton	Coarse	Natural	80.00	95.00	75.00
11	100% Acrylic	Fine	Unnatural	75.00	60.00	85.00
12	100% Poly	Fine	Unnatural	10.00	0.00	15.00
13	75% Acrylic 25% Poly	Fine	Unnatural	50.00	15.00	20.00
14	75% Poly 25% Acrylic	Fine	Unnatural	0.00	0.00	5.00
15	50% Poly 50% Acrylic	Fine	Unnatural	5.00	0.00	0.00
16	100% Acrylic	Coarse	Unnatural	65.00	55.00	70.00
17	100% Poly	Coarse	Unnatural	5.00	0.00	15.00
18	75% Acrylic 25% Poly	Coarse	Unnatural	40.00	10.00	0.00
19	75% Poly 25% Acrylic	Coarse	Unnatural	35.00	5.00	5.00
20	50% Acrylic 50% Poly	Coarse	Unnatural	50.00	0.00	10.00

Apparatus

The apparatus consisted of a table at which the participant sat and a curtain which prevented the participant from viewing the stimuli during tactile exploration. The participant and experimenter sat on either side of the curtain and the experimenter presented each stimulus one at a time to the participant. In the touch only condition, stimuli were presented behind the curtain and participants reached underneath to explore the surfaces. In the vision only condition, the curtain was raised for a specific interval. In the bimodal condition, the curtain was again raised, and the participants were able to both see and feel each stimulus. Stimuli were presented under controlled timing, which was monitored by the experimenter using a stopwatch. To avoid any auditory influences during exploration, participants wore sound-excluding headphones throughout the study.

Experimental design

The experiment was based on a three-way mixed design with material type (wood, fabric) and stimulus category (natural, unnatural) as within-subjects factors and exploration modality (touch only, vision only and bimodal) as a between-subjects factor. Perceived naturalness of each stimulus was the dependent variable measured (response type: 'natural', 'unnatural').

The experimental protocol was based on a binary decision task where participants categorised each explored stimulus as either 'natural' or 'unnatural'. The experiment consisted of two blocks, each based on the material of the stimuli: wood and fabric. Participants were pseudo-randomly assigned to an exploration modality for each block, such that for a given participant, wood and fabric were never explored using the same modality type. Within each block, the stimuli were presented in random order, twice per participant. The order of blocks was counter-balanced across participants to avoid order effects. Each stimulus was presented twice per exploration modality, per material type, thus there was a total of 100 trials per participant.

Procedure

Within the context of this experiment, the term 'natural' was defined to each participant as a texture surface that was "derived from nature". Exploration of the stimuli in the touch only condition was practised prior to testing, and was constrained as follows: participants completed three clockwise rotations on the surface using their right index finger under limited timing such that each rotation took approximately one second, resulting in three seconds of exploration per stimulus. This type of exploration reflects the 'lateral motion' exploratory procedure described by Lederman and Klatzky (1987), yet is circular to take into account that the materials may have different information available to touch along the horizontal and vertical axes. In the vision only condition, the experimenter

raised the curtain, and the surface of a stimulus was viewed for three seconds. In the bimodal condition, the curtain was raised and the participant carried out three clockwise rotations while simultaneously viewing the surface of the stimulus.

Each trial began with a single stimulus being placed on the table, and consisted of three seconds exploration of each stimulus. Following exploration, the participant indicated verbally whether each stimulus was 'natural' or 'unnatural'. The same experimental procedure was used for both the wood and fabric material types.

3.2.2 Results

For each stimulus, the percentage of 'natural' responses across participants was calculated, and is displayed in Table 3.1 for wood stimuli and in Table 3.2 for fabric stimuli. While the main focus of this research is the perception of naturalness, and not accurate categorisation of a stimulus in terms of naturalness *per se*, it is noteworthy that categorisation of the stimuli was above chance (50%) for all exploration modality conditions. For wood, stimuli were on average correctly categorised 73.83% in the touch only condition, 66.17% in the vision only condition, and 81.83% in the bimodal condition. For fabric, stimuli were correctly categorised 66.0% in the touch only condition, 88.25% in the vision only condition, and 80.75% in the bimodal condition. As the study was interested in examining perception rather than accuracy, the analyses reported were conducted on the perception of naturalness across participants. Throughout this thesis only significant results or those approaching significance will be discussed.

Perceiving naturalness across materials and exploration type

For each participant, the percentage of 'natural' responses for each condition was calculated and was used for analysis. In order to examine whether perceived naturalness varied as a function of material type and exploration modality, a 2 x 2 x 3 mixed-design

ANOVA with Material Type (wood *vs.* fabric) and Stimulus Category (natural *vs.* unnatural) as the within-subjects factors and Exploration Modality (touch only *vs.* vision only *vs.* bimodal) as the between-subjects factor, was performed on participant's mean percentage of 'natural' responses for each condition. Posthoc analyses reported in this chapter were conducted using the Bonferroni criterion. A main effect of Stimulus Category was observed, $F_{(1, 27)} = 368.90$, $p < 0.001$, such that the natural stimuli were significantly more likely to be categorised as 'natural' than the unnatural stimuli. Neither Material Type nor Exploration Modality yielded significant main effects.

A significant two-way interaction was observed between Material Type and Stimulus Category, $F_{(1, 27)} = 5.58$, $p < 0.05$ (see Figure 3.1, Panel A). This interaction was likely to be driven by differences between the materials for each of the stimulus categories. For instance, in the natural stimulus category, fabric stimuli ($M = 80.17$) were more likely to be categorised as 'natural' than wood stimuli ($M = 72.62$), this difference approached significance ($p = 0.054$); there was no significant difference in perceived naturalness across material types in the unnatural stimulus category. A significant two-way interaction was observed between Stimulus Category and Exploration Modality, $F_{(2, 27)} = 6.09$, $p < 0.01$ (see Figure 3.1, Panel B). This interaction was likely to be driven by differences across exploration modality for each of the stimulus categories. For example, in the natural stimulus category, stimuli were less likely to be categorised as 'natural' when explored using touch only ($M = 67.21$) than using either vision only ($M = 80.86$) or bimodal exploration ($M = 81.11$), these differences approached significance ($p = 0.060$ and $p = 0.051$ respectively); there was no significant difference in perceived naturalness across exploration modality in the unnatural stimulus category; nor an interaction between Material Type and Exploration Modality.

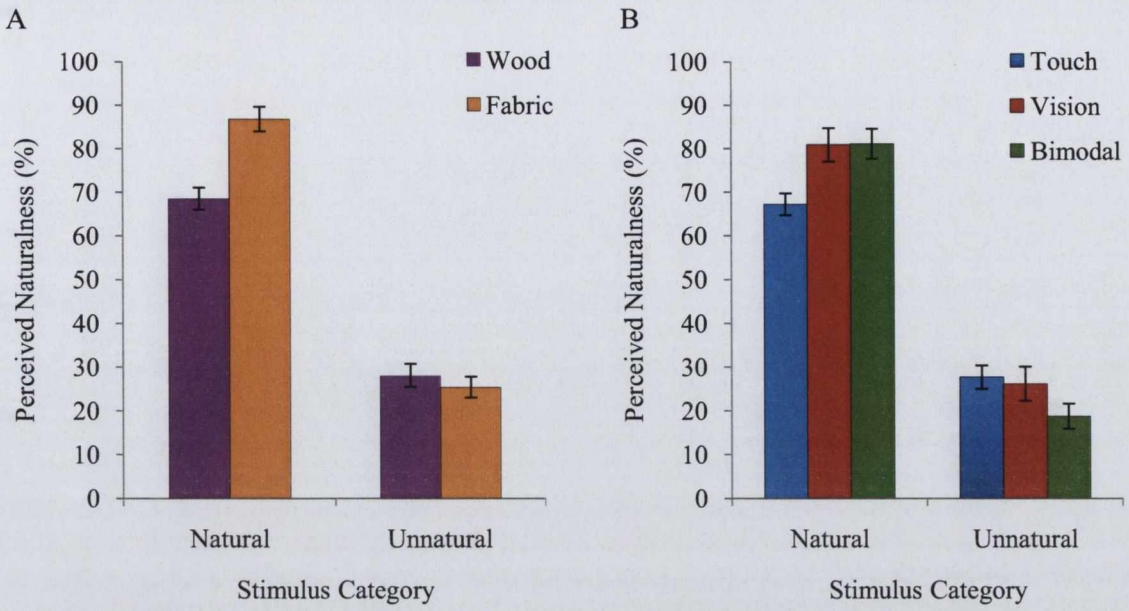


Figure 3.1. Illustration of the 2-way interactions observed in Experiment 1. Panel A represents the interaction between material type and stimulus category, and Panel B represents the interaction between stimulus category and exploration modality. Error bars represent ±1 SE from the mean.

A significant three-way interaction was observed between Material Type, Stimulus Category and Exploration Modality, $F_{(2, 27)} = 21.96$, $p < 0.001$ (see Figure 3.2). For wood stimuli, in the unnatural stimulus category, stimuli were more likely to be categorised as 'natural' when explored using vision only ($M = 37.81$) than when using either touch only ($M = 21.88$) or bimodal exploration ($M = 15.00$), although this difference was only significant in the case of bimodal exploration ($p < 0.01$). All other contrasts were not significantly different. Thus, for the wood stimuli, bimodal exploration did not lead to a significant enhancement in the perception of naturalness than found in the best unimodal condition (i.e. touch).

For fabric stimuli, in the natural stimulus category, stimuli were less likely to be categorised as 'natural' when explored using touch only ($M = 65.50$) than when using either vision only ($M = 91.00$) or bimodal exploration ($M = 84.00$), although this difference was only significant in the case of vision only exploration ($p < 0.01$). All other contrasts were not significantly different. Thus, for the fabric stimuli, bimodal exploration did not

lead to a significant enhancement in the perception of naturalness than found in the best unimodal condition (i.e. vision).

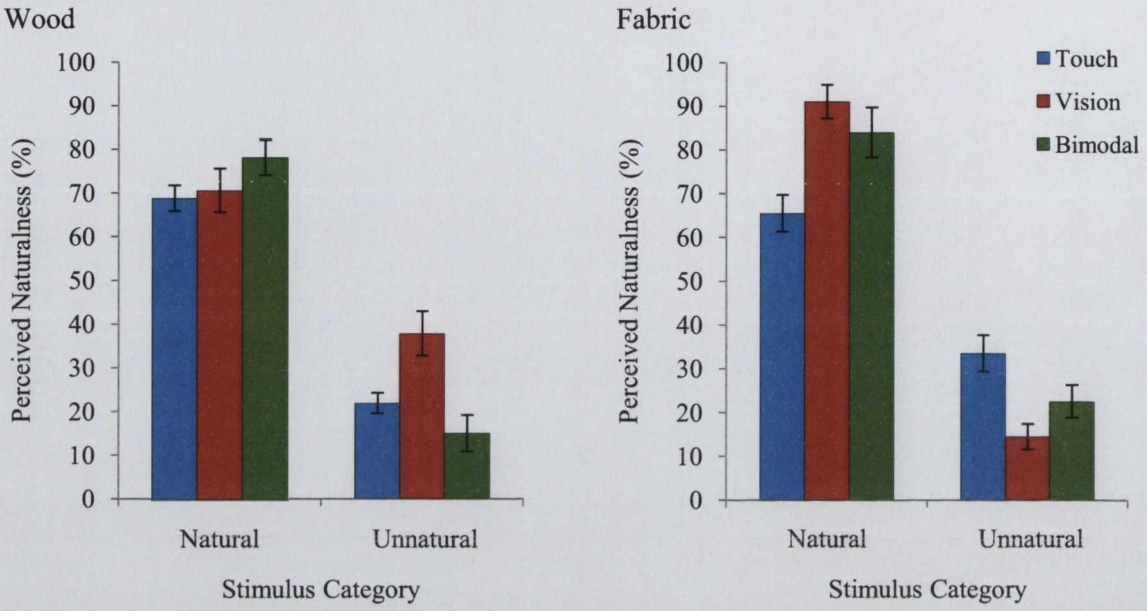


Figure 3.2. Illustration of the 3-way interaction between material type, stimulus category and exploration modality observed in Experiment 1, separated by material type. Error bars represent ±1 SE from the mean.

Examination of a response bias in naturalness categorisation

In order to examine whether there was a bias in participants' naturalness categorisation responses, a 2 x 2 x 3 mixed-design ANOVA with Material Type (wood *vs.* fabric) and Response Type ('natural' *vs.* 'unnatural') as the within-subjects factors and Exploration Modality (touch only *vs.* vision only *vs.* bimodal) as the between-subjects factor, was performed on the percentage of total 'natural' or 'unnatural' responses for each condition (see Figure 3.3). There were no significant main effects nor interactions observed, suggesting that there was no bias in responding either 'natural' or 'unnatural' across material type or exploration modality.

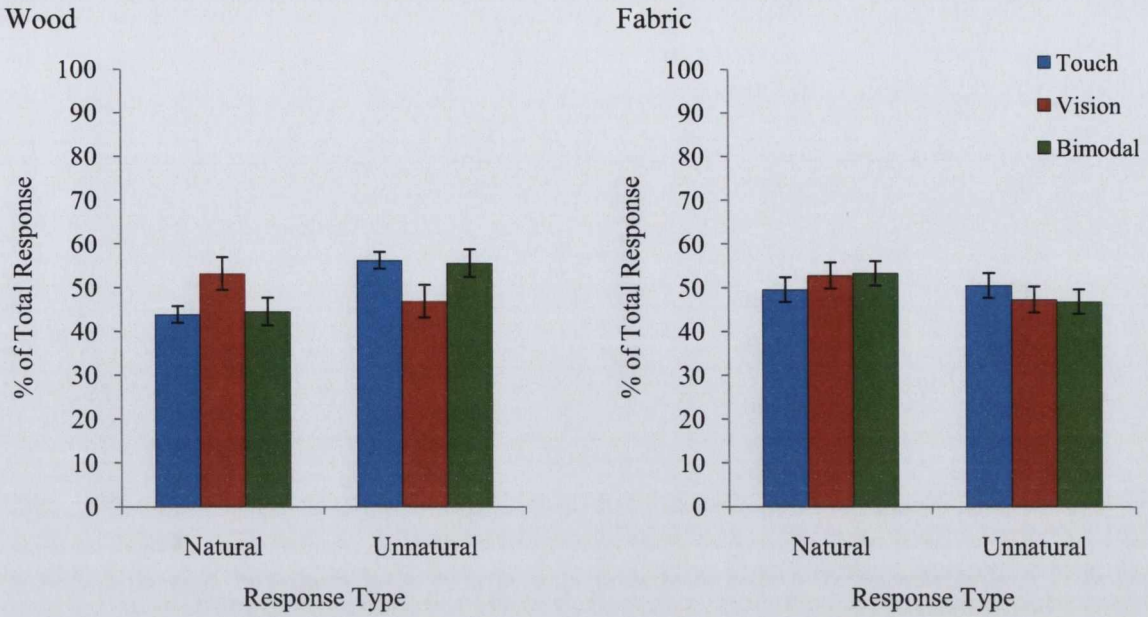


Figure 3.3. Illustration of the percentage of 'natural' and 'unnatural' responses given in Experiment 1 across exploration modality, separated by material type. Error bars represent ±1 SE from the mean.

Contribution of touch and vision to the perception of naturalness

To further quantify the unique contributions of touch and vision to the perception of naturalness the perceived naturalness data, i.e. the percentage of 'natural' responses across participants, following exploration using touch only and vision only was fitted to the bimodal data using a simultaneous linear regression method. For wood stimuli, unimodal touch and vision accounted for 83.9% of the variance in the perception of naturalness following bimodal exploration, which was highly significant, $F_{(2, 29)} = 76.61$, $p < 0.001$. Both touch only ($\beta = 0.697$, $p < 0.001$), and vision only ($\beta = 0.332$, $p < 0.001$) were significant predictors of the perception of naturalness in the bimodal condition. Notably, for wood stimuli, touch only was a better predictor of the perception of naturalness in the bimodal condition than vision only. For fabric stimuli, unimodal touch and vision accounted for 91.2% of the variance in the perception of naturalness following bimodal exploration, which was highly significant, $F_{(2, 19)} = 99.87$, $p < 0.001$; here vision only ($\beta =$

0.906, $p < 0.001$) was a significant predictor of the perception of naturalness in the bimodal condition.

3.2.3 Discussion

These results suggest that for wood and fabric textures, vision and touch contribute to the perception of naturalness, albeit in qualitatively different ways. The perceptual categorisation results suggest that the senses combine the encoded information for the perception of naturalness in a stimulus-specific manner. For wood stimuli, naturalness perception was led by touch, and perception did not change when touch was supplemented by vision in the bimodal condition. However the reverse was observed for fabric stimuli, where vision led naturalness perception and did not significantly benefit from the addition of touch in the bimodal condition. Notably, for fabric stimuli bimodal performance was similar to the average of the unimodal inputs, which is consistent with previous research (Guest & Spence, 2003a; Jones & O'Neil, 1985; Lederman & Abbott, 1981; Lederman, et al., 1986); however, this effect was not found for the wood stimuli. These performance differences observed across exploration modalities may be a function of their relative sensitivities for the various material properties of the surfaces.

3.3 Experiment 2

In preparation for later neuroimaging studies (see Chapters 5 and 6), Experiment 2 was conducted to examine whether the perception of naturalness of wood and fabric stimuli in the visual condition varied as a function of stimulus presentation, i.e. whether using images of the stimuli during the visual presentation significantly altered naturalness categorisation relative to viewing the actual stimuli. As it was not feasible to present the stimuli directly in the visual condition within the MR scanner, due to physical constraint of the size of the bore being too small, this study investigated whether using images of the

samples would alter the perception of naturalness. Here, exploration of the stimuli was carried out using vision only (hereinafter referred to as vision image), and using both vision and touch simultaneously (hereinafter referred to as bimodal image). By comparing performance with Experiment 1, an investigation was carried out to evaluate whether the perception of naturalness varied as a function of presentation type (real, image), and whether using touch and vision together altered any bias that may arise.

3.3.1 Method

Participants

Twenty right-handed undergraduate and postgraduate students (14 female, mean age 24.1 years, age range 18-33) of Trinity College Dublin participated in this study for nominal pay or research credits. All participants reported normal or corrected-to-normal vision, no tactile impairments, no history of neurological or psychological disorders, and no particular experience with wood or fabric (either professional or otherwise). Following a briefing on the experimental protocol, participants provided written consent to take part in the study.

Stimuli and apparatus

Stimuli

A set of wood and fabric samples, as outlined in Experiment 1, were used as stimuli. For each stimulus, a high-resolution image was captured using a 10-megapixel Nikon camera, within a DigiEye System (VeriVide Ltd.) under a diffuse uniform light setting that imitated daylight. Each image was cropped to 850 x 850 pixels using Photoshop® (Adobe Systems, version 10.0.1, San Jose, CA), and was centrally displayed on a blank background (black, RGB: 0, 0, 0).

Apparatus

The apparatus used was the same as Experiment 1, with the addition of a 21" CRT monitor (60 Hz refreshment rate, 1280 x 1024 pixel resolution) placed on the experimental table. In the vision image condition, a stimulus was centrally displayed on screen. In the bimodal image condition, a tactile stimulus was presented behind the curtain, while a simultaneous congruent image of the stimulus was displayed on screen. In both conditions, stimuli were presented for three seconds. To avoid any auditory influences during exploration, participants wore sound-excluding headphones throughout the study.

Experimental design

The experiment was based on a three-way mixed design with material type (wood, fabric) and stimulus category (natural, unnatural) as within-subjects factors and exploration modality (vision image, bimodal image) as a between-subjects factor. Perceived naturalness of each stimulus was the dependent variable measured (response type: 'natural', 'unnatural'). Condition blocking, randomisation, and total trial number were the same as in Experiment 1.

Procedure

Within the context of this experiment, the term 'natural' was defined to each participant as a texture surface that was "derived from nature". In the vision image condition, a stimulus was displayed on screen for three seconds. In the bimodal image condition, the participant carried out three clockwise rotations on the surface of a stimulus while simultaneously viewing a congruent image of the stimulus on screen for three seconds.

Each trial comprised of a single stimulus being presented, and consisted of three seconds exploration of each stimulus. Following exploration, the participant indicated

verbally whether each stimulus was 'natural' or 'unnatural'. The same experimental procedure was used for both the wood and fabric material types.

3.3.2 Results

As in Experiment 1, categorisation of the natural and unnatural stimuli was above chance (50%) for all exploration modality conditions. For wood, stimuli were correctly categorised 61.7% in the vision image condition, and 68.5% in the bimodal image condition. For fabric, stimuli were correctly categorised 78.5% in the vision image condition, and 75.0% in the bimodal image condition. As the study was interested in examining perception rather than accuracy, the analyses reported were conducted on the perception of naturalness across participants.

Examining the influence of visual presentation on perceived naturalness

For each participant, the percentage of 'natural' responses for each condition was calculated and was used for analysis. In order to examine the influence of presentation type on the perception of naturalness, we pooled the data with that of Experiment 1. A 2 x 2 x 2 x 2 mixed-design ANOVA with Material Type (wood *vs.* fabric) and Stimulus Category (natural *vs.* unnatural) as the within-subjects factors and Exploration Modality (vision only *vs.* bimodal) and Presentation Type (real *vs.* image) as the between-subjects factors, was performed on participant's mean percentage of 'natural' responses for each condition. A main effect of Stimulus Category was observed, $F_{(1, 36)} = 341.82$, $p < 0.001$, such that the natural stimuli were significantly more likely to be categorised as 'natural' than the unnatural stimuli. A main effect of Material Type was observed, $F_{(1, 36)} = 13.77$, $p < 0.001$, such that the fabric stimuli were significantly more likely to be categorised as 'natural' than the wood stimuli. Neither Exploration Modality nor Presentation Type yielded significant main effects.

A significant two-way interaction was observed between Material Type and Stimulus Category, $F_{(1, 36)} = 18.77$, $p < 0.001$ (see Figure 3.4, Panel A). This interaction was likely to be driven by differences between the materials for each of the stimulus categories. For example, in the natural stimulus category, fabric stimuli ($M = 86.75$) were significantly more likely to be categorised as 'natural' than wood stimuli ($M = 68.48$, $p < 0.001$); there was no significant difference in naturalness perception across material types in the unnatural stimulus category. A significant two-way interaction was observed between Presentation Type and Stimulus Category, $F_{(1, 36)} = 7.67$, $p < 0.01$ (see Figure 3.4, Panel B); however closer examination revealed that there was no significant difference between the presentation types for each of the stimulus categories. A significant two-way interaction was observed between Material Type and Presentation Type, $F_{(1, 36)} = 6.20$, $p < 0.05$ (see Figure 3.4, Panel C); however closer examination revealed that there was no significant difference between the presentation types for each of the material types. All other two-way contrasts were not significantly different.

A significant three-way interaction was observed between Material Type, Stimulus Category and Exploration Modality, $F_{(1, 36)} = 12.20$, $p < 0.01$ (see Figure 3.5). There was a significant difference between the vision only exploration modality conditions in the natural stimulus category across material types ($p < 0.001$), such that natural stimuli were less likely to be categorised as 'natural' for wood stimuli ($M = 62.14$) than for fabric stimuli ($M = 90.25$). A significant three-way interaction was observed between Material Type, Presentation Type and Exploration Modality, $F_{(1, 36)} = 6.79$, $p < 0.05$ (see Figure 3.6). There was a significant difference in naturalness perception between the vision image conditions across material type ($p < 0.001$), such that wood stimuli ($M = 40.85$) were less likely to be categorised as 'natural' than fabric stimuli ($M = 60.75$). All other contrasts were not significantly different.

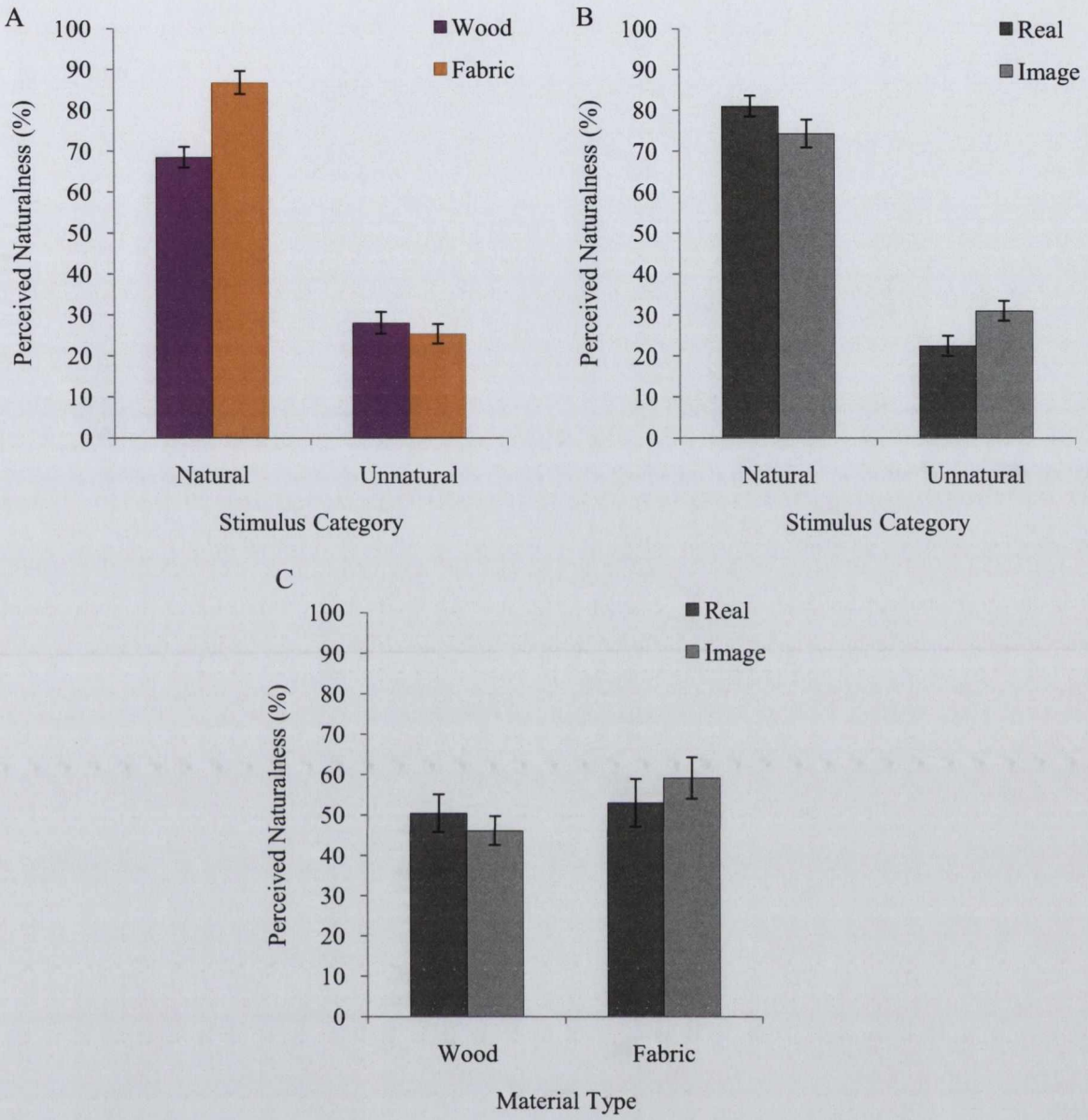


Figure 3.4. Illustration of the 2-way interactions observed in Experiment 2. Panel A represents the interaction between material type and stimulus category, Panel B represents the interaction between presentation type and stimulus category, and Panel C represents the interaction between material type and presentation type. Error bars represent ±1 SE from the mean.

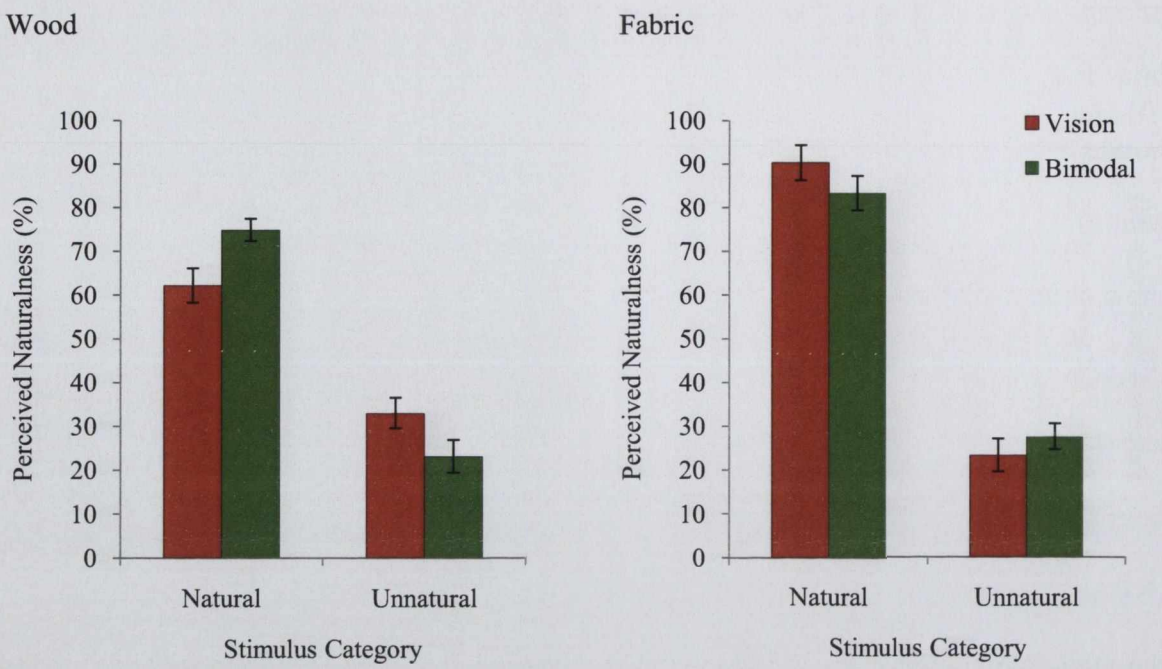


Figure 3.5. Illustration of the 3-way interaction between material type, stimulus category and exploration modality observed in Experiment 2, separated by material type. Error bars represent ±1 SE from the mean.

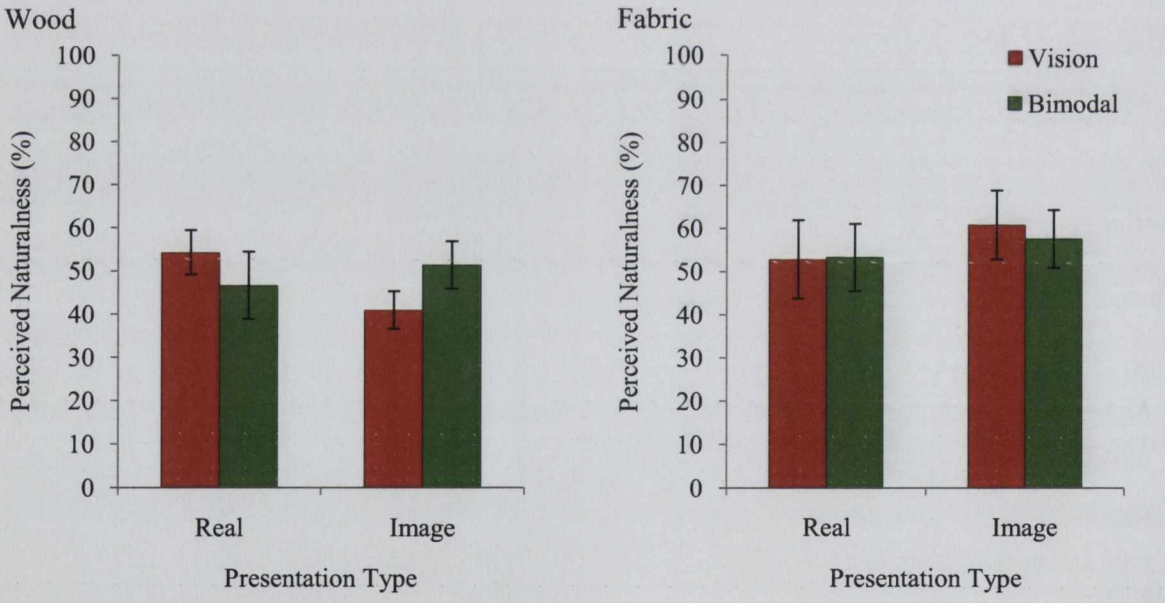


Figure 3.6. Illustration of the 3-way interaction between material type, presentation type and exploration modality observed in Experiment 2, separated by material type. Error bars represent ±1 SE from the mean.

Examination of a response bias in naturalness categorisation

In order to examine whether there was a bias in participants' naturalness categorisation responses, a 2 x 2 x 2 mixed-design ANOVA with Material Type (wood *vs.* fabric) and Response Type ('natural' *vs.* 'unnatural') as the within-subjects factors and Exploration Modality (vision image *vs.* bimodal image) as the between-subjects factor, was performed on the percentage of total 'natural' or 'unnatural' categorisation responses for each condition (see Figure 3.7). There were no significant main effects observed. A significant two-way interaction was observed between Material Type and Response Type, $F_{(1, 18)} = 14.96$, $p < 0.01$. For fabric stimuli, there was a significantly lower percentage of 'unnatural' responses ($M = 40.75$) than 'natural' responses ($M = 59.13$); there was no difference in percentage of 'natural' and 'unnatural' responses for wood stimuli.

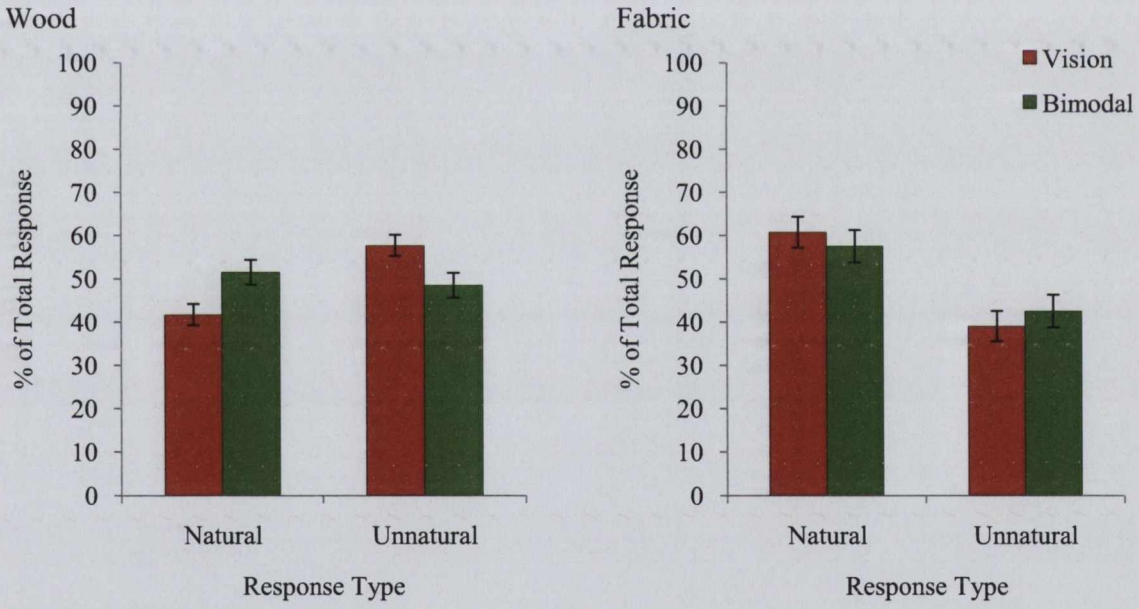


Figure 3.7. Illustration of the percentage of 'natural' and 'unnatural' responses given in Experiment 2 across exploration modality, separated by material type. Error bars represent ±1 SE from the mean.

Determining the relationship between real and image presentation types

Comparing the results of Experiments 1 and 2, Pearson's correlations were conducted between the visual and bimodal conditions for wood and fabric stimuli. For

wood stimuli (see Figure 3.8), there was a strong positive correlation between perceived naturalness in the vision real and vision image conditions, $r_{(28)} = 0.66, p < 0.001$. Similarly, there was a strong positive correlation between perceived naturalness in the bimodal real and bimodal image conditions, $r_{(28)} = 0.84, p < 0.001$. Likewise, for fabric stimuli (see Figure 3.9), there was a strong positive correlation between perceived naturalness in the vision real and vision image conditions, $r_{(18)} = 0.83, p < 0.001$. Similarly, there was a strong positive correlation between perceived naturalness in the bimodal real and bimodal image conditions, $r_{(18)} = 0.70, p < 0.01$.

3.3.3 Discussion

These results indicate that while there may be some loss in naturalness perception for both wood and fabric stimuli when using images in the visual presentation, that it is not substantial enough for concern in later experiments. Overall, there was no significant main effect of presentation type. Furthermore, for both wood and fabric stimuli, there was no significant difference in the real or image presentation types across exploration modality. Moreover, for both wood and fabric stimuli, there was no significant benefit to naturalness perception when supplementing the vision image condition with tactile exploration (bimodal image condition). The correlations between the visual and bimodal conditions of Experiments 1 and 2 indicated a strong relationship between the real and image stimulus presentation types for both wood and fabric. Overall, using images in the visual presentation does not appear to have a significant influence on the naturalness perception of materials.

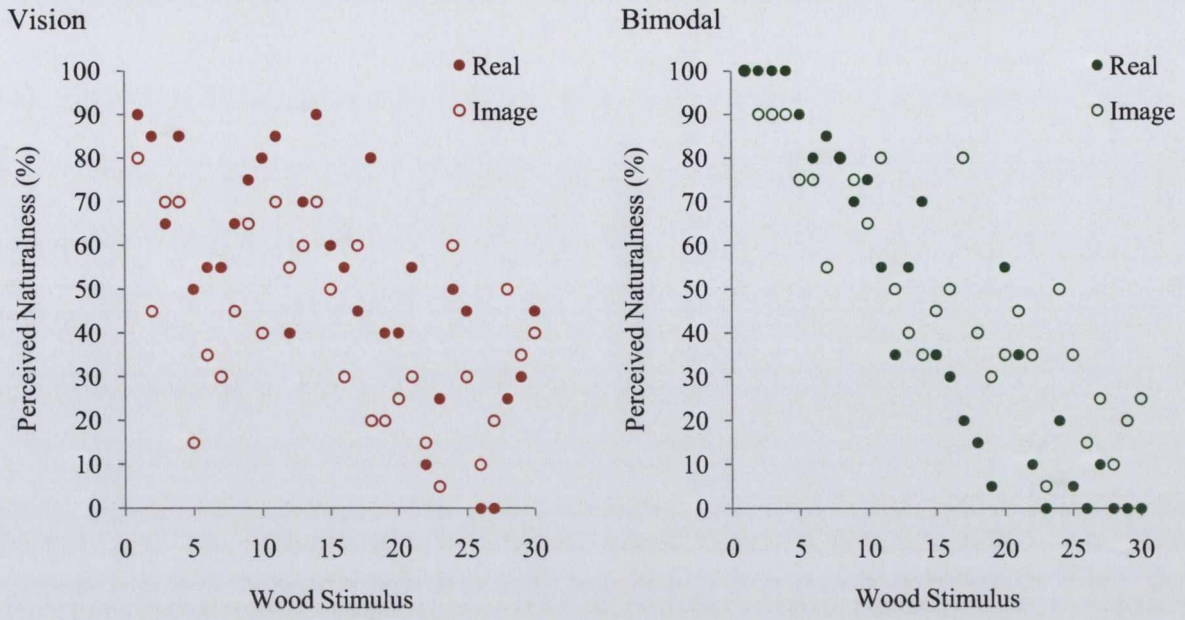


Figure 3.8. Scatterplots illustrating the relationship between real and image presentation types (Experiments 1 and 2) for the perceived naturalness of each wood stimulus, separated by exploration modality.

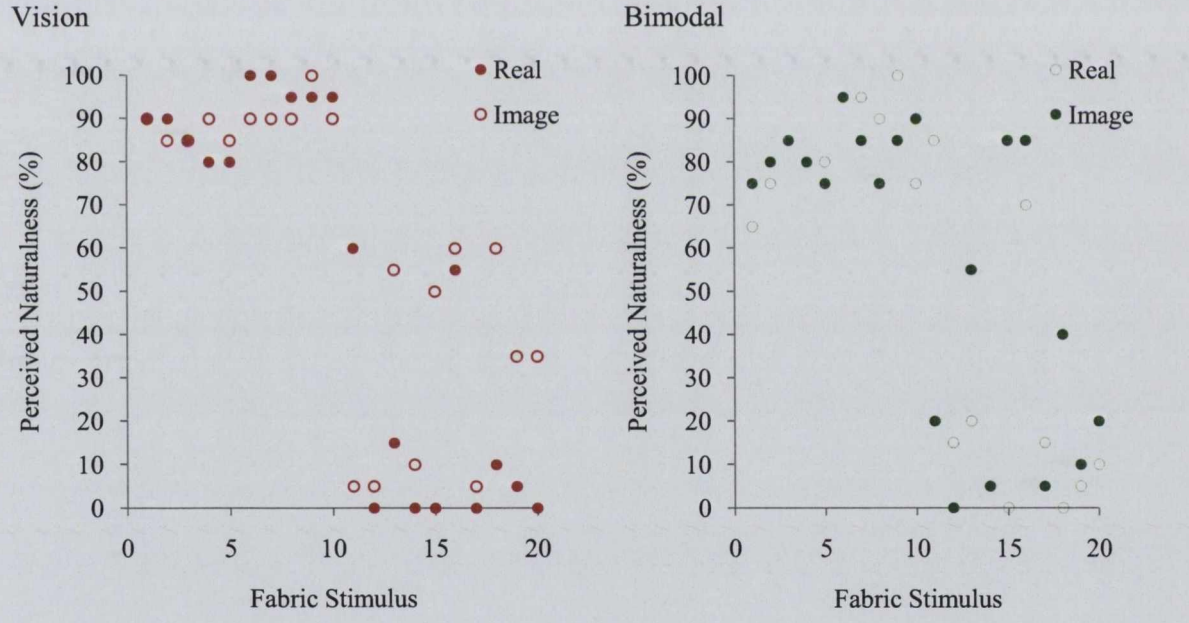


Figure 3.9. Scatterplots illustrating the relationship between real and image presentation types (Experiments 1 and 2) for the perceived naturalness of each fabric stimulus, separated by exploration modality.

3.4 General Discussion

The experiements conducted in this chapter demonstrated behaviourally that participants are adept at perceiving the naturalness of wood and fabric stimuli when explored through touch and vision. Here, participants could only rely on information presented to these senses when categorising these stimuli, and had no prior information about the samples that were presented to them. The results of Experiment 1 demonstrated that for wood, the touch only exploration condition was a better predictor of naturalness perception in the bimodal condition than the vision only exploration condition, while for fabrics, the vision only exploration condition was a better predictor of naturalness perception in the bimodal condition. This finding is important as it indicates the stimulus-specific nature of the perception of naturalness in material surfaces. Furthermore, there was no benefit to naturalness perception when exploring through touch and vision simultaneously, for either wood or fabric. These findings suggest that for naturalness perception of ecological textures, touch and vision are qualitatively different. In the following chapters we examine the relationship of perceived naturalness with other perceptual dimensions such as hedonics, value and familiarity (Chapter 4), and explore the brain processes associated with the perception of naturalness of wood and fabric stimuli (Chapters 5 and 6).

CHAPTER 4

NATURALNESS PERCEPTION: A MULTIDIMENSIONAL EVALUATION

Authorship

The following chapter is being prepared as part of a larger collaborative paper with colleagues at the Universitat de Barcelona:

Overvliet, K. O., Whitaker, T. A., Simões-Franklin, C., Soto-Faraco, S., & Newell, F. N. (in prep). A natural preference: The relationship between perceived naturalness and hedonics in a set of ecological stimuli. *Manuscript in Preparation, title TBC*

4.1 Introduction

Many studies have demonstrated that vision and touch are skilled at evaluating, discriminating and categorising textures and objects (for a review see Lederman & Klatzky, 2004; Whitaker, Simões-Franklin, & Newell, 2008). Further, Chapter 3 showed that these senses are adept at perceiving the naturalness of different wood and fabric stimuli. Whether this perception relies simply on the sensory properties of these stimuli, or whether other higher-order evaluations are being made is unknown. Following from the suggestion that naturalness preference in foods and medicines is ideational (Rozin, et al., 2004), it could be hypothesised that the perception of naturalness in wood and fabric is more than just a sensory discrimination, and involves higher-order evaluations of the materials.

4.1.1 Outline of experiment

Given that a preference for naturalness has been reported in the domains of food and landscapes (see Chapter 1), this study sought to examine whether such a preference exists for other material stimuli (i.e. fabric). Further, the relationship between the perceived naturalness of fabric stimuli and sensory characteristics (roughness, harshness), affective characteristics (hedonics, pleasantness) and cognitive characteristics (value, familiarity) was investigated.

This experiment examined at a behaioural level, the relationship between perceived naturalness and a range of other perceptual dimensions (value, hedonics, roughness, harshness, pleasantness, and familiarity) for a set of fabric stimuli. Exploration of the stimuli was carried out using touch only, vision only, and using both vision and touch simultaneously (herein referred to as bimodal). In this way, whether the relationship between perceived naturalness and a particular characteristic varied as a function of

exploration type (touch, vision), and whether using these modalities together influenced this relationship was examined.

4.2 Method

4.2.1 Participants

Participants (n = 147) were recruited from an opportune voluntary sample of attendees at a public exhibition at the Science Gallery, Trinity College Dublin (100 female, mean age 32.7 years, age range 16-81). All participants reported normal or correct-to-normal vision, no tactile impairments, no history of neurological or psychological disorders and no particular experience with fabric (either professional or otherwise). Of these participants, 123 were right-handed, and 130 were native English speakers (the other 17 were fluent English speakers). Following a briefing on the experimental protocol, participants provided written consent to take part in the study.

4.2.2 Stimuli and apparatus

Stimuli

The stimuli consisted of 42 fabric samples, which comprised of different combinations of wool, cotton, acrylic and polypropylene woven together to achieve a naturalness continuum. Within this continuum, stimuli consisted of 100% natural fibres (i.e. wool and cotton), 75% natural mixed with 25% unnatural (i.e. acrylic and polypropylene), 50% natural mixed with 50% unnatural, 25% natural mixed with 75% unnatural, and 100% unnatural fibres (for more details, see Appendix D). Fabrics had either a coarse or fine finish. Each stimulus was mounted onto a wooden block, 80 x 80 mm. Stimuli were presented in groups of six, and were mounted onto a card, which had six 82 x 82 mm openings, through which the stimuli could be seen or felt (see Figure 4.1).

These six samples were pseudo-randomly grouped such that each stimulus card had at least one 100% natural sample present.

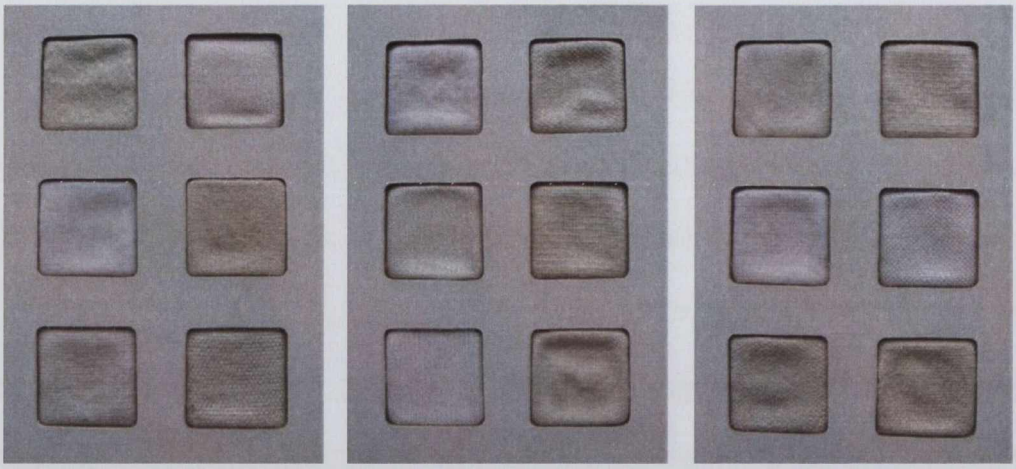


Figure 4.1. Examples of the stimulus cards used. Stimuli were presented in groups of six, with at least one 100% natural sample per grouping.

Apparatus

The apparatus consisted of a table at which the participant stood, on top of which three exploration boxes were placed (see Figure 4.2). In the touch only condition, participants reached their hand through an opening at the front of the exploration box to feel each of the six stimuli, but their view of the stimuli was prevented by means of an opaque glass window. In the vision only condition, participants viewed the stimuli from above through a glass window. In the bimodal condition, participants reached their hand through an opening at the front of the exploration box to feel the stimuli, while at the same time viewing the stimuli from above through the glass window. The exploration boxes and stimulus cards were constructed such that the order of the boxes, and stimulus cards could be rearranged.

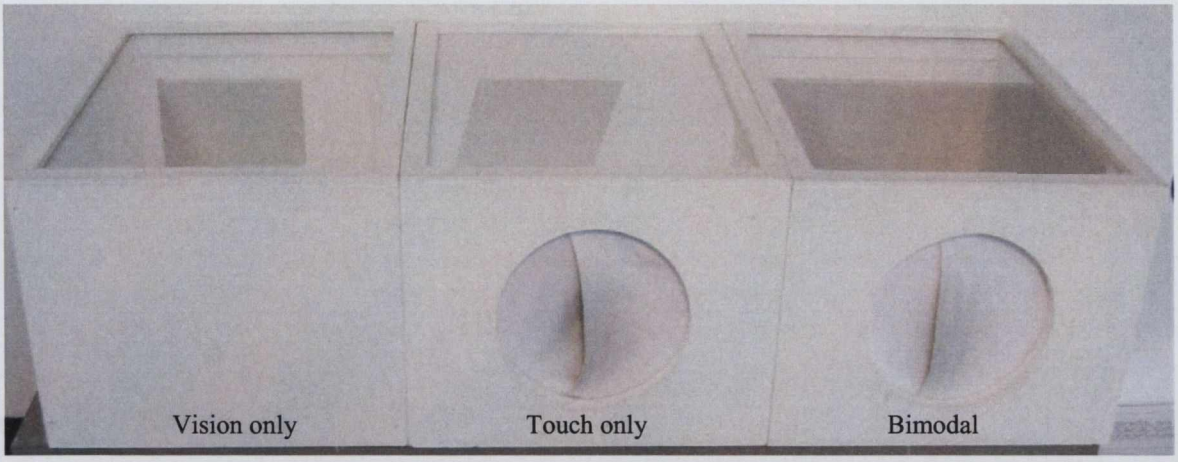


Figure 4.2. Image of the experimental setup, consisting of three exploration boxes. In the vision only condition, participants viewed the stimuli above through a glass window. In the touch only condition, participants reached through an opening to touch the stimuli, while viewing was prevented using an opaque glass window. In the bimodal condition, participants could view and touch the stimuli simultaneously.

4.2.3 Experimental design

The experiment was based on a two-way mixed design with exploration modality (touch only, vision only and bimodal) as a within-subjects factor and rating dimension (naturalness, value, hedonics, roughness, harshness, pleasantness, familiarity) as a between-subjects factor. Participants' rating of each stimulus for a particular dimension was the dependent variable measured.

The experimental protocol was based on a labelled-scaling task where participants rated each explored stimulus on a 7-point scale (for more details, see Appendix E). The experiment consisted of three blocks, each based on the exploration modality used: touch only, vision only, and bimodal. Within each block, six pseudo-randomly ordered stimuli were presented on a stimulus card. Thus, for each participant there were total of 18 samples. Participants were randomly assigned to a particular rating scale such that a given

participant conducted one of the rating scales only. The order of blocks, stimulus cards, and rating scale were randomised across participants to avoid order effects.

4.2.4 Procedure

Each trial consisted of exploring a single stimulus within the exploration box, and rating this stimulus from 0 to 6. Six trials were conducted per exploration modality. Stimulus exploration was unconstrained in terms of time and procedure; however, participants were required to complete each experimental block before continuing to the next. Participants provided their ratings for each stimulus on a response sheet, which was collected by the experimenter on completion of the study.

4.3 Results

The mean rating of each sample for each dimension was calculated for the touch only, vision only, and bimodal exploration conditions separately. To examine the relationship between perceived naturalness and the other dimensions, Pearson's correlations were conducted between the different rating scales for each exploration modality condition (see Table 4.1).

For touch only, perceived naturalness was strongly correlated with harshness and value, and moderately correlated with hedonics. For vision only, perceived naturalness was strongly correlated with harshness, and moderately correlated with value, hedonics, and familiarity. For the bimodal condition, perceived naturalness was strongly correlated with harshness, value, hedonics, and moderately correlated with familiarity and pleasantness.

Table 4.1. *Pearson's correlations between each dimension across exploration modality for fabric stimuli.*

Modality	Characteristic	Value	Hedonics	Roughness	Harshness	Pleasantness	Familiarity
Touch only	Naturalness	0.631**	0.350*	-0.171	0.748**	0.245	0.210
	Value		0.424**	-0.150	0.533**	0.166	0.175
	Hedonics			-0.533**	0.384*	0.386*	0.273
	Roughness				-0.442**	-0.425**	-0.393**
	Harshness					0.496**	0.433**
	Pleasantness						0.185
Vision only	Naturalness	0.455**	0.351*	0.265	0.633**	0.209	0.331*
	Value		0.128	0.097	0.426**	0.398**	0.399**
	Hedonics			0.063	0.315*	0.120	0.357*
	Roughness				0.063	-0.058	0.077
	Harshness					0.201	0.220
	Pleasantness						0.364*
Bimodal	Naturalness	0.505**	0.561**	-0.002	0.786**	0.317*	0.410**
	Value		0.432**	-0.101	0.480**	0.351*	0.498**
	Hedonics			0.138	0.490**	0.362*	0.428**
	Roughness				0.154	-0.256	-0.387*
	Harshness					0.286	0.507**
	Pleasantness						0.519**

Note. *$p<0.05$, **$p<0.001$

Across all exploration modality conditions, perceived naturalness was positively correlated with harshness, value and hedonics such that the more natural a fabric was perceived, the more harsh, expensive and liked it was. Scatterplots illustrating the relationship between perceived naturalness and perceived harshness, value and hedonics are displayed in Figure 4.3. In order to examine these relationships in more detail, regression analyses were conducted, as outlined in the following section.

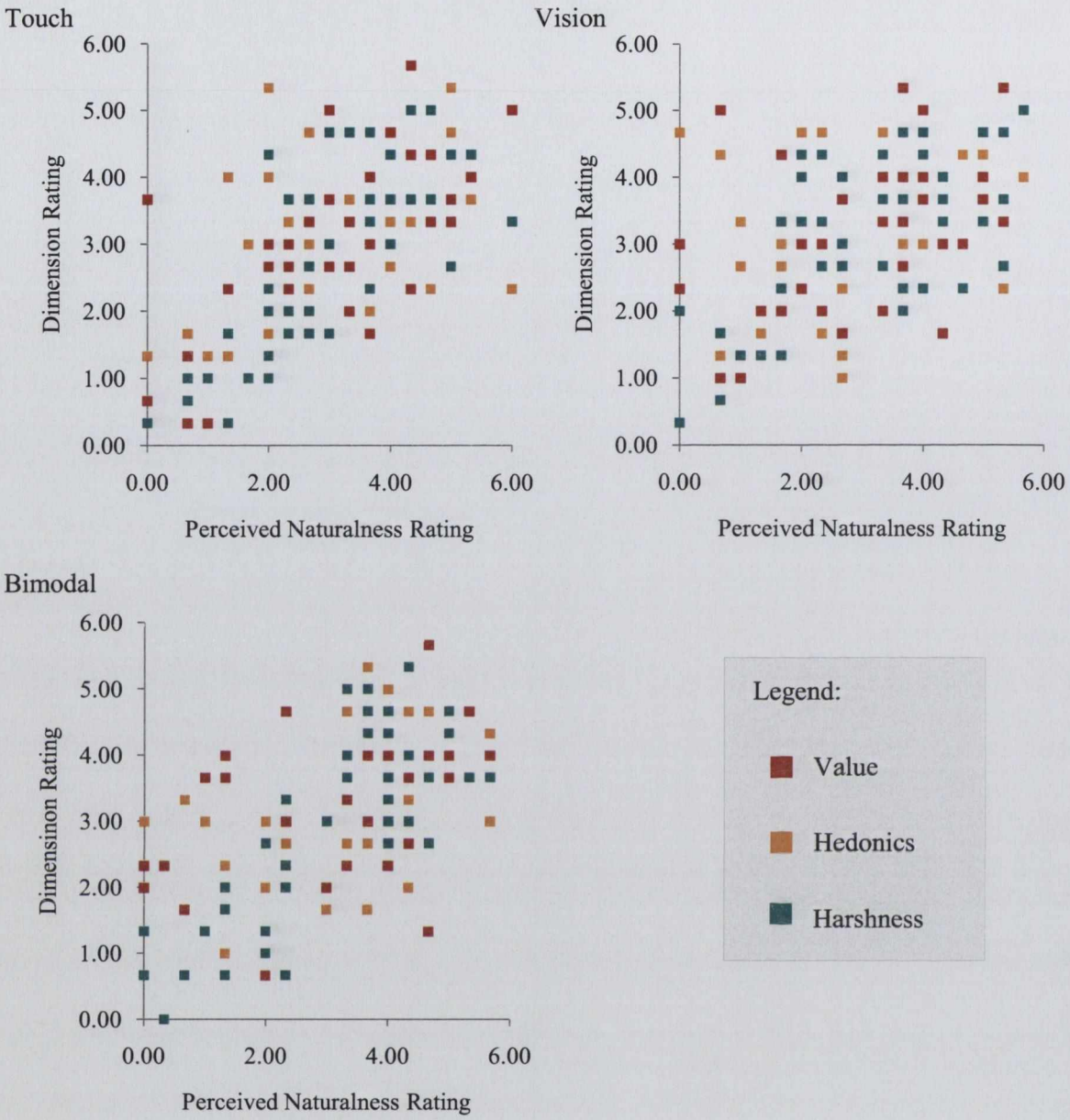


Figure 4.3. Scatterplots illustrating the relationship between perceived naturalness and perceived value, hedonics and harshness, separated by exploration modality.

4.3.1 Predicting perceived naturalness from other dimensions

To examine the extent to which perceived naturalness was predicted by the other dimensions, the individual contributions of each dimension to perceived naturalness across exploration modality was calculated using a linear regression method (see Table 4.2). For

touch only, significant predictors of perceived naturalness were perceived harshness, value and hedonics. For vision only, significant predictors of perceived naturalness were perceived harshness, value, hedonics and familiarity. For the bimodal condition, significant predictors of perceived naturalness were perceived harshness, value, hedonics, familiarity and pleasantness.

Table 4.2. *Contribution of each dimension to perceived naturalness across exploration modality for fabric stimuli as calculated by a linear regression method.*

Exploration Modality	Dimension	r	R^2	$F_{(1,40)}$	p
Touch only	Value	0.631	0.398	26.45	***
	Hedonics	0.350	0.123	5.59	*
	Familiarity	0.210	0.044	1.85	*n.s.*
	Roughness	0.171	0.029	1.21	*n.s.*
	Harshness	0.748	0.560	50.94	***
	Pleasantness	0.245	0.060	2.56	*n.s.*
Vision only	Value	0.455	0.207	10.42	**
	Hedonics	0.351	0.123	5.61	*
	Familiarity	0.331	0.109	4.91	*
	Roughness	0.265	0.070	3.01	*n.s.*
	Harshness	0.603	0.364	22.90	***
	Pleasantness	0.209	0.044	1.83	*n.s.*
Bimodal	Value	0.505	0.255	13.72	**
	Hedonics	0.561	0.314	18.33	***
	Familiarity	0.410	0.168	8.08	**
	Roughness	0.002	0.000	0.000	*n.s.*
	Harshness	0.786	0.617	64.46	***
	Pleasantness	0.317	0.100	4.47	*

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

To further quantify the contributions of each dimensions to the perception of naturalness a hierarchical stepwise linear regression method was conducted across exploration modality. For touch only, in the first model where harshness was the only predictor, 56.0% of the variance in naturalness perception was accounted for, which was significant, $F_{(1, 41)} = 50.90$, $p < 0.001$. In the second model that also included value, 63.5% of the variance in naturalness perception was accounted for, which was significant, $F_{(2, 41)}$

= 33.95, $p < 0.001$. For vision only, one model resulted where harshness was the only predictor and 40.1% of the variance in naturalness perception was accounted for, which was significant, $F_{(1, 41)} = 26.74$, $p < 0.001$. For the bimodal condition, in the first model where harshness was the only predictor, 61.7% of the variance in naturalness perception was accounted for, which was significant, $F_{(1, 41)} = 64.46$, $p < 0.001$. In the second model that also included hedonics, 65.8% of the variance in naturalness perception was accounted for, which was significant, $F_{(2, 41)} = 37.49, p < 0.001$.

4.4 Discussion

These results suggest that a number of dimensions contribute to the perception of naturalness in fabric stimuli. The correlations reported here indicated that there was a positive relationship between perceived naturalness and perceived harshness, value and hedonics. This finding is of particular interest given the between-subjects design of the study, i.e. participants were not explicitly aware that the study was examining the relationship between perceived naturalness and these dimensions. Despite this, the more natural a fabric was perceived, the more harsh, expensive and liked it was perceived.

The regression results highlighted the primary role of sensory information in the perception of naturalness, as indicated by the consistent presence of the harshness dimension across exploration modality. Notably, the roughness characteristic did not seem to contribute to the perception of naturalness in this study. Given that the stimuli used were fabric samples, it is plausible that harshness, i.e. from soft to harsh, is a more appropriate verbal label for evaluating fabrics than roughness, i.e. from smooth to rough. The finding that the more natural stimuli were perceived, the harsher they were perceived was not, in this case, so surprising considering that untreated natural fibres such as wool and cotton are typically quite harsh. Further investigation which examines the perceptual dimensions of

other materials (e.g. wood) could help unravel whether semantics play a role in the differences between the dimensions of roughness and harshness that were observed here.

These results also suggested the role of higher order evaluations in the perception of naturalness. Perceived value contributed to the prediction of perceived naturalness during tactile exploration, while perceived hedonics contributed to the prediction of perceived naturalness during bimodal exploration. Overall, the findings suggest that the perception of naturalness in fabrics is multidimensional and involves both sensory and higher-order processes. While the primary role of physical information was apparent (i.e. harshness), the role of affective (i.e. hedonics) and cognitive (i.e. value) processes in the perception of naturalness was also indicated. Given the observation that a preference for naturalness exists across many diverse dimensions such as food and landscape preference, it is not surprising that the perception of naturalness in materials is not entirely based on physical properties, but also includes an affective or reward-like evaluation. The following neuroimaging studies sought to explore how naturalness (physical and perceived) is represented in the brain (see Chapters 5 and 6).

CHAPTER 5

ELUCIDATING THE CORTICAL CORRELATES OF NATURALNESS PERCEPTION

PART I – WOOD TEXTURES

Authorship

This chapter is currently being prepared for journal submission:

Whitaker, T. A., Simões-Franklin, C., & Newell, F. N. (in prep). An fMRI investigation of the cortical areas underlying the visual and tactile perception of "naturalness" in wood textures. Manuscript in Preparation.

5.1 Introduction

The behavioural studies presented in Chapter 3 demonstrated that participants were adept at categorising "naturalness" in wood and fabric stimuli. Furthermore, the senses appeared to behave in stimulus-specific manner, such that naturalness categorisation was more efficient using touch for wood, and using vision for fabric. Following this, Chapter 4 demonstrated that for fabric textures, stimuli that are perceived as more natural tend to be rated as more harsh, expensive and are liked more. In keeping with this, a recent extension of this study showed that for fabric, wood and stone textures, stimuli perceived as more natural are rated as more liked (Overvliet, Whitaker, Simões-Franklin, Soto-Faraco & Newell, in prep). These findings are in line with previous reports of a preference for naturalness in foods, landscapes (e.g. Ode et al., 2009; Purcell & Lamb, 1998; Rozin, 2005, 2006; Rozin et al., 2004). Since little is known about how we discriminate natural things from synthetic counterparts, and moreover what cortical areas are recruited in this process, an investigation into the perception of these stimuli is timely.

In order to perceive the material properties of an object, the information encoded through the sensory modalities of touch and vision is of primary importance. Many studies have demonstrated that touch and vision are skilled at evaluating, discriminating and categorising textures (see Lederman & Klatzky, 2004). Furthermore, these senses appear to act independently rather than in an integrated fashion for the perception of texture (see Whitaker, et al., 2008). For example, activation specific to tactile texture perception has been well documented in SI (e.g. Servos, et al., 2001; Zangaladze, et al., 1999), and more recently the secondary somatosensory area and posterior insula (e.g. Kitada, et al., 2005; Stilla & Sathian, 2008). In the visual system on the other hand, whilst activation in V1 has been observed when processing of first- and second-order patterns (e.g. Kastner, et al., 2000; Larsson, et al., 2006), texture-related activation has been shown in extra striate

regions such as the CoS, MOG, IOG, fusiform, parahippocampal and the lingual gyri (Beason-Held, et al., 1998; Cant & Goodale, 2007; Peuskens, et al., 2004). Furthermore, the CoS and lingual gyrus elicit texture-specific activation independent of form (Cant, Arnott, & Goodale, 2009; Cant & Goodale, 2007; Cavina-Pratesi, Kentridge, Heywood, & Milner, 2010; Peuskens, et al., 2004; Puce, et al., 1996), and colour (Simões-Franklin, Stapleton, Whitaker, McGlone, & Newell, in prep). Moreover, an extensive study of the visual form agnosia patient, D.F., who is unable to recognise shape yet maintains the ability to perceive surface properties, along with a number of fMRI investigations in healthy subjects have led Cant, Goodale and colleagues to propose a distinct neural pathway in the visual system which is involved in the processing of surface properties independent of form (Cant & Goodale, 2007; Humphrey, et al., 1994; James, et al., 2003; Milner, et al., 1991). They propose that this pathway projects ventro-medially from area V1 into the fusiform gyrus and parahippocampal cortex. However, the findings from other studies suggest that this pathway may not necessarily be involved exclusively in visual texture perception. For example, Stilla and Sathian (2008) observed a common area of activation in the MOG following visual and tactile exploration during a texture perception task. These findings suggest that there is task-dependent activation in a dedicated neural pathway of the cortex, and that this pathway is involved in both tactile and visual texture perception. The extent to which this pathway is involved in higher-level perceptual tasks, such as judging whether a texture is natural or not, is unknown.

The processes underlying the semantic categorisation of objects have been widely reported in the literature (for reviews see Bookheimer, 2002; Martin, 2001; Martin, 2007; Martin & Chao, 2001; Thompson-Schill, 2003). Of particular interest to this study are the investigations pertaining to the dissociation in cortical activations between living and non-living things. Category-specific neural responses have been observed along the ventral

stream and lateral occipital-temporal cortex, regions known to play a role in object perception (e.g. Amedi, Malach, Hendler, Peled, & Zohary, 2001; Grill-Spector, Kourtzi, & Kanwisher, 2001; Grill-Spector, et al., 1998; James, et al., 2003; Malach, et al., 1995). Furthermore, differential activation has been demonstrated for living things, i.e. animals and faces, in lateral regions (e.g. the lateral fusiform and inferior temporal gyri) and non-living things i.e. tools, in medial regions (e.g. the medial fusiform, lingual and parahippocampal gyri) of the ventral stream (e.g. Chao, Haxby, & Martin, 1999; Mahon, et al., 2007; Noppeney, Price, Penny, & Friston, 2006; Wierenga, et al., 2009). Notably, this dissociation has been observed not only using visual images as stimuli, but also using corresponding auditory labels (Mahon, Anzellotti, Schwarzbach, Zampini, & Caramazza, 2009). Thus, these regions play a role in the semantic knowledge and interpretation of objects. However, to the authors knowledge, no investigation has been conducted on the semantic categorisation of surface properties independent of form, such as how natural they are perceived as being.

The concept of reward, in particular the underlying mechanisms in the brain involved in processing rewarding stimuli, is becoming an increasingly popular topic of investigation in the neuropsychological literature. A wide range of investigations spanning varying rewarding scenarios including monetary, interpersonal, tactile and visual aesthetics, and moral evaluation have indicated a network of cortical regions that play a role in the evaluation of aesthetics, desirability and morality (see Chapter 1) including the cingulate cortex and ventral visual stream among others. Limited investigations have been conducted which utilised textures in their examination of reward mechanisms, with a few exceptions. For example, stimulus-specific activations in the orbitofrontal and cingulate cortices have been shown when the hand is touched with a velvet (pleasant) over a stylus (unpleasant) stimulus (Rolls et al., 2003). Given the observation that perceived naturalness

is positively related to judgements of hedonics for a range of ecological textures (see Overvliet, Whitaker, Simões-Franklin, Soto-Faraco & Newell, in prep), it could be hypothesised that the perception of naturalness would elicit reward-related structures in the brain. This study sought to examine the perception of naturalness using a set of wood stimuli, and to explore the brain processes involved during a naturalness categorisation task.

5.1.1 Outline of experiment

The investigation of an abstract and multi-dimensional concept such as naturalness is challenging. This study was conducted primarily as an exploration into naturalness perception and, as far as the authors are aware, is the first to investigate the brain processes that are involved in this task.

Primarily, this investigation sought to uncover the presence of any brain activations that were specific to natural stimuli (compared to unnatural stimuli), i.e. whether the physical naturalness of the stimuli influenced changes in the BOLD response. Secondly, this study sought to examine whether the perception of a stimulus as 'natural' activated brain regions distinct from when a stimulus was perceived as 'unnatural', i.e. whether the perceived naturalness of the stimuli influenced changes in the BOLD response. Furthermore, this study investigated how these brain processes differed as a function of exploring a stimulus using touch or vision independently or in combination (i.e. bimodal). It was predicted that the exploration of natural and unnatural stimuli would elicit activation in sensory cortices, and could invoke not only decision-making, but also affective mechanisms.

5.2 Method

5.2.1 Participants

Sixteen right-handed undergraduate and postgraduate students (9 female, mean age 23.8 years, age range 18-32) of Trinity College Dublin participated in this study for nominal pay or research credits. All participants reported normal or corrected-to-normal vision, no tactile impairments, no history of neurological or psychological disorders, and no particular experience with wood materials (either professional or otherwise). Following a briefing on the experimental protocol and fMRI method, participants provided written consent to take part in the study (see Appendix F for MRI forms).

5.2.2 Stimuli and apparatus

Stimuli

The stimuli consisted of eight unique wood samples, four natural and four unnatural. These particular stimuli were taken from a larger pool of wood surfaces, which were used in a previous behavioural pilot study on naturalness perception (see Chapter 3), and were highly rated as 'natural' or 'unnatural' (as appropriate) in the pilot study. The natural stimuli consisted of tiger oak and cognac oak samples, which had different finishes: raw, weathered, and oiled. The unnatural stimuli consisted of vinyl and a high-quality photocopy.

During presentation, the stimuli were constrained such that the grain of wood consistently lay along the y-axis relative to the participant. Each stimulus was mounted behind a plastic frame using an epoxy adhesive. The frame had an 80 x 80 mm window through which the sample could be viewed or touched. Some of the thinner samples required a firm backing, which was achieved by fixing Plexiglas behind these samples. For

visual presentation of each stimulus, a high-resolution image was captured using a 10-megapixel Nikon camera, within a DigiEye System (VeriVide Ltd.) under a diffuse uniform light setting that imitated daylight. Each image was cropped to 850 x 850 pixels using Photoshop® (Adobe Systems, version 10.0.1, San Jose, CA), and was centrally displayed on a blank background (black, RGB: 0, 0, 0).

Apparatus

The experiment took place in a Philips Intera Achieva 3.0 Tesla MR system (Best, The Netherlands). Each mounted stimulus was fixed to a custom-built MR-compatible tactile apparatus (Lyons, Darling, Whitaker, Simões-Franklin, & Newell, in prep). The apparatus consisted of a conveyor belt mechanism, which was rotated using an attached handle so that each stimulus was presented underneath the participant's hand and thus avoided any unnecessary movement of the participant's arm. Visual images and cueing instructions were presented via a mirror system that reflected a 1280 x 1024 pixel display, projected on a panel placed behind the participant's head outside the magnet. The mirror was mounted on the head coil in the participant's line of vision. Responses were recorded using a two-button fibre-optic response pad (Cambridge research systems), which was placed directly underneath the participant's left hand during the experiment. The participant used their index and middle fingers to respond to each trial during the study. Stimulus presentation was controlled using Presentation® software (www.neurobs.com), which was synchronised with trigger pulses from the MR scanner.

5.2.3 Experimental design

The experiment was based on a two-way factorial design with stimulus category (natural, unnatural) and exploration modality (touch only, vision only, bimodal) as within-

subjects factors. Perceived naturalness was the dependent variable measured (response type: 'natural', 'unnatural').

The experimental protocol was based on a binary decision task where participants were required to categorise each explored stimulus as either 'natural' or 'unnatural'. The experiment consisted of three runs of trials, with stimuli explored using one exploration modality type per run. The order of these runs was counterbalanced across participants. Within each run, trials were presented in a pseudo-randomised order such that stimuli were grouped by stimulus category (natural, unnatural), with each stimulus presented once per grouping in random order. In this way, the experimental protocol was based on a block-design, with stimulus type acting as mini-blocks of trials. Each of the eight stimuli was presented six times per exploration modality, a total of 144 trials.

5.2.4 Procedure

Within the context of this experiment, the term 'natural' was defined to each participant as a texture surface that was "derived from nature". Exploration of the stimuli in the touch only condition was practised prior to testing, and was constrained as follows: participants completed three clockwise rotations on the surface using their right index finger under limited timing such that each rotation took approximately one second, resulting in three seconds of exploration per stimulus. This type of exploration reflects the 'lateral motion' exploratory procedure described by Lederman and Klatzky (1987), yet is circular to take into account that the materials may have different information available to touch along the horizontal and vertical axes. During each trial in the vision only condition, a stimulus image was presented for three seconds. During each trial in the bimodal condition, a stimulus image was presented on the display while the participant simultaneously touched (as in the touch only condition) a congruent sample.

An illustration of the temporal sequence of events during a typical trial in each of the exploration modality conditions is displayed in Figure 5.1. In all conditions, participants were cued to begin exploration by the disappearance of a fixation cross on the visual display. In the tactile only condition, the visual display remained blank (black; RGB: 0, 0, 0) for the duration of exploration. In the visual only condition, the exploration hand (right) remained still. Once exploration was complete, a question mark symbol appeared on the visual display for one second, which acted as a cue to respond. The participant was then required to categorise the stimulus as 'natural' or 'unnatural' by pressing the relevant button on a two-button response pad using their left hand. Following the response cue, a fixation-cross appeared on screen for three seconds, i.e. until the beginning of the next trial.

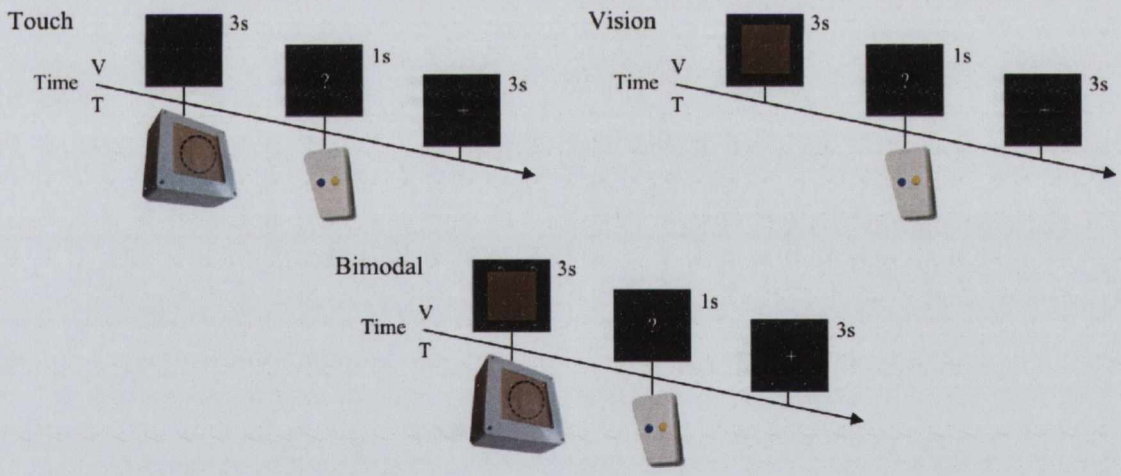


Figure 5.1. Illustration of the sequence of events in a trial. In the touch only condition, a tactile stimulus was presented while the screen was blank. In the vision only condition, an image appeared on screen while no tactile stimulus was presented. In the bimodal condition, a simultaneous congruent tactile and visual stimulus were presented.

5.2.5 Data acquisition

Scanning started with 31.5 seconds of standard scout images to adjust head positioning, followed by a reference scan to resolve sensitivity variations. Imaging used a parallel SENSitity Encoding (SENSE) approach (Pruessmann, Weiger, Scheidegger, & Boesiger, 1999) with a reduction factor of 2. A high-resolution T1-weighted MP-RAGE (magnetization-prepared rapid gradient echo) anatomical sequence was acquired for each participant (180 oblique-axial slices, field of view 230 mm, slice thickness 0.9 mm, voxel size 0.9 x 0.9 x 0.9, total duration 5.43 minutes) to allow subsequent activation localization and spatial normalization.

Functional data of the entire brain were collected using a T2* weighted echo-planar imaging sequence: 32 non-contiguous (10% gap) 3.5-mm axial slices, echo time 35 ms, repetition time (TR) 2000 ms, field of view 224 mm, matrix 64 x 64 mm in Fourier space. Each one of the three functional scans had a duration of 5.88 minutes. The spontaneous changes in frequency were automatically corrected by the Intera Achieva by means of a dynamic stabilization (real time frequency adjustment) after each TR.

5.2.6 Data analysis

All analyses were conducted using Analysis of Functional NeuroImages software (AFNI, http://afni.nimh.nih.gov; Cox, 1996). After image reconstruction, the functional and structural data were aligned (Saad, et al., 2009). The time-series data were then linearly de-trended and motion-corrected using 3D volume registrations (least-squares alignment of three translational and three rotational parameters), and warped onto the standard stereotaxic Talairach space (Talairach & Tournoux, 1988). Activation outside the brain was removed using an edge-detection algorithm.

Stimulus-based analysis

The initial analysis of the functional data was based on stimulus category (natural, unnatural), and included data acquired during all trials, i.e. including also those trials where participants categorised the naturalness of the stimulus incorrectly (see 'response-based analysis' for an analysis of the perceptual-related data). For each participant, a haemodynamic response model was generated for natural stimulus blocks (using unnatural stimulus blocks as baseline) for each exploration modality (touch only, vision only, bimodal) based on the convolution of the corresponding time series with a gamma function (Cox, 1996). A regression analysis followed for each exploration modality condition, comprising of a block regressor (for natural against unnatural stimuli) and the motion-corrected time-series files were accommodated for nuisance variance. The boxcar regression parameter values for each of the time series were converted into percentage change-scores (%CS), which served as the block activation measures. Individual activation maps were spatially blurred using a Gaussian kernel with 3 mm r.m.s. isotropic deviation.

Prior to a group analysis the individual activation maps for the natural-unnatural contrast for each modality condition were determined with single-sample *t*-tests against the null hypothesis of zero activation change (i.e. no change relative to tonic task-related activity). Significant voxels passed a voxel-wise statistical threshold ($t = 2.95$, $p < 0.01$) and were required to be part of a larger 442 μl cluster of contiguous significant voxels. Thresholding parameters were determined through a Monte Carlo simulation and resulted in a 5% probability of a cluster surviving due to chance.

In order to compare the natural-unnatural contrast across exploration modality, the activation maps were combined for all conditions. These maps, normally referred to as an 'OR-map' (like the Boolean 'OR' operator), include the clusters that were significantly activated by any of the conditions.

Response-based analysis

Following consideration of the behavioural responses, a second functional analysis was conducted based on the response of each participant to each stimulus as 'natural' or 'unnatural'. A haemodynamic response model was generated for each participant for their response type for each exploration modality condition (touch only, vision only, bimodal) based on the convolution of the corresponding time series with a gamma function (Cox, 1996). The time series data was created such that an event of interest corresponded with the exploration of a stimulus. A regression analysis followed for each exploration modality condition, comprising of two event-related regressors (for 'natural' and 'unnatural' response types), and the motion-corrected time-series files were accommodated for nuisance variance. The boxcar regression parameter values for each of the time series were converted into percentage area-under-the-curve scores (%AUC; Murphy & Garavan, 2005), which served as the event-related activation measures. Individual activation maps were spatially blurred using a Gaussian kernel with 3 mm r.m.s. isotropic deviation.

Prior to a group analysis the individual activation maps for the 'natural' and 'unnatural' responses for each exploration modality were determined with single-sample *t*-tests against the null hypothesis of zero activation change (i.e. no change relative to tonic task-related activity). Significant voxels passed a voxel-wise statistical threshold ($t = 3.29$, $p < 0.005$) and were required to be part of a larger 284 μl cluster of contiguous significant voxels. Thresholding parameters were determined through a Monte Carlo simulation and resulted in a 5% probability of a cluster surviving due to chance. In order to conduct statistical comparisons between the 'natural' and 'unnatural' responses across the three exploration modality conditions, the activation maps were combined in an OR-map of all conditions.

To further investigate the relationship between perceived naturalness and exploration modality, a voxelwise analysis using a three-factor ANOVA was performed with response type ('natural', 'unnatural') and exploration modality (touch only, vision only, bimodal) as fixed factors and participant (16 levels) as a random factor. Unlike the OR-map approach, this voxelwise ANOVA only reveals the brain areas that show a main effect of response type or exploration modality, or the interaction between these main factors. Furthermore, it levels out any brain area that is equally activated by the different conditions, i.e. any cluster that is mutually activated across the levels of a fixed factor would not be apparent. For this analysis, significant voxels passed a voxel-wise statistical threshold ($p < 0.01$) and were required to be part of a larger 433 µl cluster of contiguous significant voxels. Thresholding parameters were determined through a Monte Carlo simulation and resulted in a 5% probability of a cluster surviving due to chance.

5.3 Results

5.3.1 Behavioural results

While the main focus of this research is the perception of naturalness, and not accurate categorisation of a stimulus in terms of naturalness *per se*, it is noteworthy that categorisation of the stimuli was above chance (50%) for all exploration modality conditions. Stimuli were correctly categorised 87.76% in the touch only condition, 74.61% in the vision only condition, and 85.42% in the bimodal condition. As the study was interested in examining perception rather than accuracy, the analyses reported were conducted on the perception of naturalness across participants.

Perceiving naturalness across materials and exploration type

For each participant, the percentage of 'natural' responses for each condition was calculated and was used for analysis. In order to examine whether perceived naturalness

varied as a function of material type and exploration modality, a 2 x 3 factorial ANOVA with Stimulus Category (natural *vs.* unnatural) and Exploration Modality (touch only *vs.* vision only *vs.* bimodal) as within-subjects factors was performed on participant's mean percentage of 'natural' responses for each condition. A main effect of Stimulus Category was observed, $F_{(1, 15)} = 424.25$, $p < 0.001$, such that the natural wood stimuli were significantly more likely to be categorised as 'natural' than the unnatural wood stimuli. There was no main effect of Exploration Modality.

A significant interaction was observed between the two main factors, $F_{(2, 30)} = 7.24$, $p < 0.01$ (see Figure 5.2), however using the Bonferroni posthoc criterion, these contrasts did not reach significance.

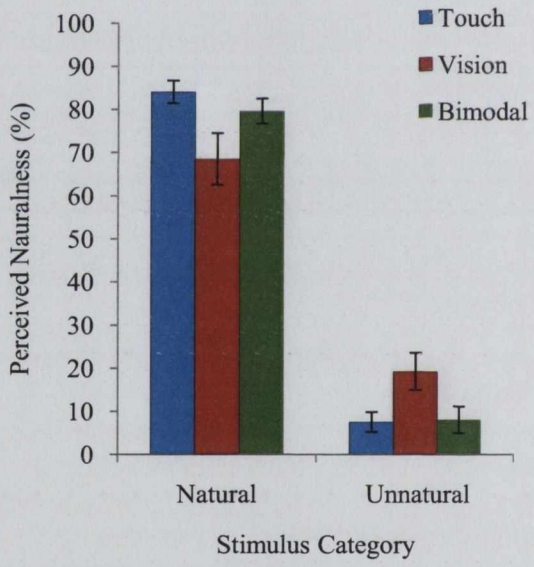


Figure 5.2. Illustration of the 2-way interaction between stimulus category and exploration modality. Error bars represent ±1 SE from the mean.

Examination of a response bias in naturalness categorisation

In order to examine whether there was a bias in participants' categorisation responses, a 2 x 3 factorial ANOVA with Response Type ('natural' *vs.* 'unnatural') and Exploration Modality (touch only *vs.* vision only *vs.* bimodal) as within-subjects factors

was performed on the percentage of total 'natural' or 'unnatural' responses for each condition (see Figure 5.3). A main effect of Response Type was observed, $F_{(1, 15)} = 9.15$, $p < 0.01$, such that participants made significantly more 'unnatural' responses than 'natural' responses. There was no main effect of Exploration Modality, nor an interaction between the two main factors.

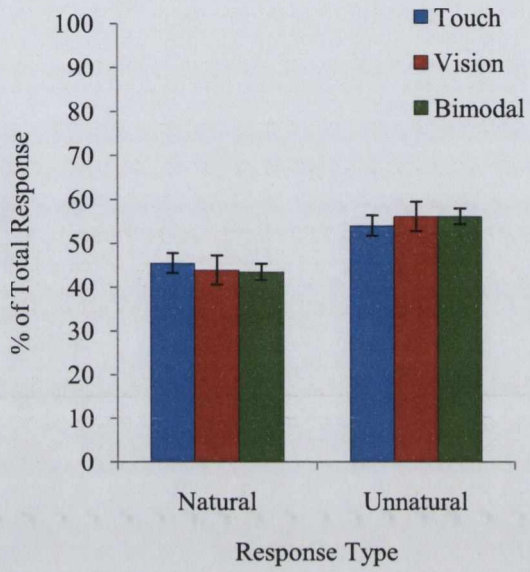


Figure 5.3. Illustration of the percentage of 'natural' and 'unnatural' responses given across exploration modality. Error bars represent ±1 SE from the mean.

5.3.2 Functional results

Stimulus-based analysis

An initial whole-brain analysis investigated the brain areas activated by the natural-unnatural contrast across exploration modality, i.e. areas that showed a significantly greater change in BOLD activity during natural stimulus blocks compared to a baseline of unnatural stimulus blocks. The results revealed a wide network of brain regions activated by the natural-unnatural stimulus contrast (see Figure 5.4 and Table 5.1). Subsequent *t*-tests comparing activation in these regions to a baseline of zero activation change were conducted to clarify the significance of the activation level for each condition. Specifically, the cerebellum was activated specifically for the natural-unnatural contrast during the

touch only exploration condition. Furthermore, a number of areas along the cingulate gyrus (anterior and posterior), along with the anterior insula and MOG were activated specifically for the natural-unnatural contrast during the bimodal exploration condition. Notably, there were no clusters detected that met the adopted statistical threshold corresponding a natural-unnatural contrast for the vision only exploration condition. Moreover, there were no areas observed common to touch only, vision only or bimodal exploration modality conditions for the natural-unnatural contrast.

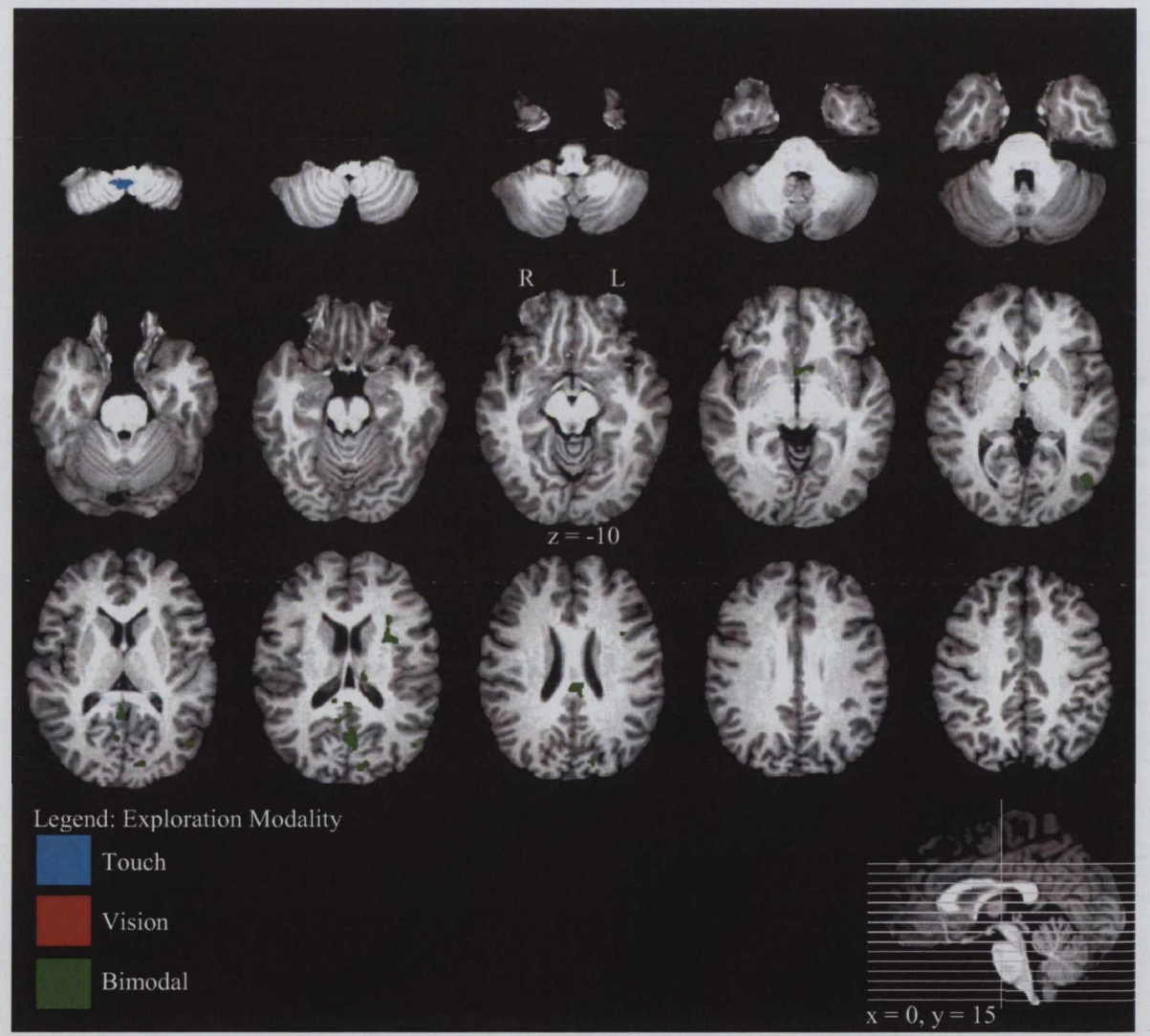


Figure 5.4. Axial views of the brain of an individual participant with superimposed significant activation for the natural-unnatural stimulus contrast across exploration modality (whole-brain analysis, $p<0.05$ corrected).

Table 5.1. *Brain regions eliciting significant activation for the natural-unnatural stimulus contrast across exploration modality (whole-brain analysis, $p<0.05$ corrected).*

			Centre of Mass			Vol.	
Anatomical Structure	Side	BA	x	y	z	µl	> 0
Cingulate/Insula							
Caudate/Anterior cingulate	L	25	-3	11	-2	871	B
Precuneus/Posterior cingulate	L	31/18	-1	-67	18	900	B
Posterior cingulate	L	23	-5	-29	24	570	B
Posterior cingulate	R	30/29	3	-47	16	946	B
Anterior insula/Claustrum	L	13	-31	9	18	877	B
Occipital							
Middle occipital/temporal gyrus	L	19/39	-47	-70	8	795	B
Cuneus/Middle occipital gyrus	L	18	-13	-85	17	578	B
Cerebellum							
Cerebellum	R	-	4	-46	-60	498	T

Note. Hemispheric location (side) and corresponding Brodmann area (where appropriate) are reported. The coordinates are given within the framework of the standardized stereotaxic brain atlas of Talairach and Tournoux (1988). Positive values for *x*, *y*, and *z* denote, respectively, locations to the right, anterior and superior of the anterior commissure. Exploration Modality: T=touch only, B=bimodal.

Response-based analysis

A subsequent whole-brain analysis (OR-map) investigated the activation associated with 'natural' and 'unnatural' response types across each exploration modality. The results revealed a wide network of brain regions associated with perceiving a stimulus as 'natural' and 'unnatural' (see Figure 5.5 and Table 5.2). Subsequent *t*-tests comparing activation in these regions to a baseline of zero activation change were conducted to clarify the significance of the activation level for each condition.

A number of activated clusters were observed across response type including the right inferior frontal gyrus, bilateral middle temporal gyrus, and bilateral cingulate gyrus. Furthermore, there were a number of regions that showed response-specific activation for either 'natural' or 'unnatural' responses to wood stimuli. For example, the left fusiform gyrus, bilateral parahippocampal gyrus and left precuneus were activated during the exploration of perceived 'unnatural' stimuli only. When activation levels were compared across response types, greater activation was observed when stimuli were perceived as

'unnatural' than 'natural' in the left superior parietal lobule, left lingual gyrus, and the right PCC.

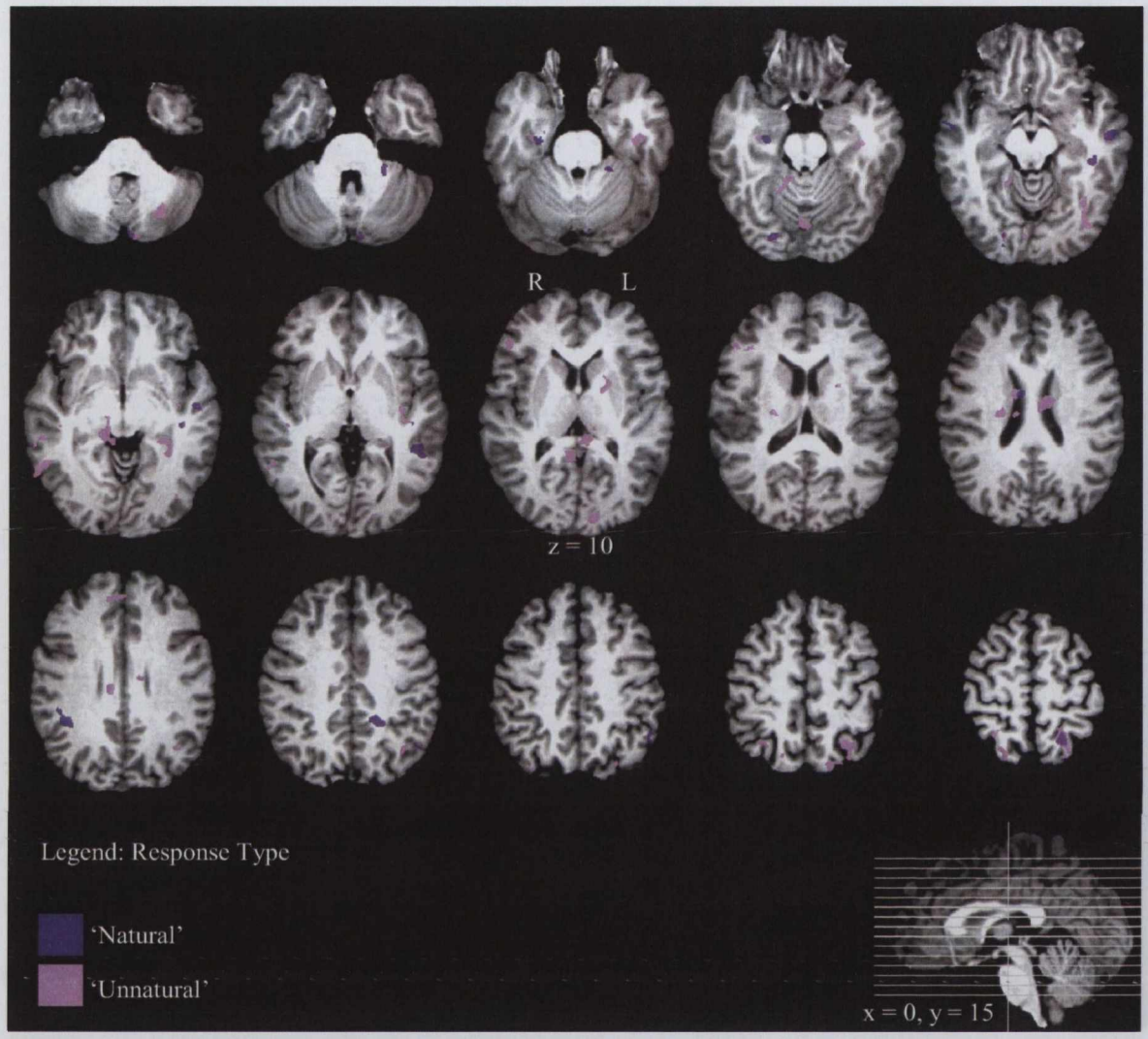


Figure 5.5. Axial views of the brain of an individual participant with superimposed significant activation associated with 'natural' and 'unnatural' response types across exploration modality (whole-brain analysis, $p<0.05$ corrected).

Table 5.2. *Brain regions eliciting significant activation for 'natural' and 'unnatural' response types across exploration modality (whole-brain analysis, $p<0.05$ corrected).*

			Centre of Mass			Vol.		
Anatomical Structure	Side	BA	x	y	z	µl	> 0	Contrast
Frontal								
Inferior/Middle frontal gyrus	R	46	46	32	13	520	N, U	*n.s.*
Medial/Superior frontal gyrus	R	9/6	5	43	32	405	-	
Temporal								
Middle/Superior temporal gyrus	R	21	51	-29	-2	499	N, U	*n.s.*
Middle/Superior temporal gyrus	L	21/22	-48	-42	4	468	-	
Middle/Superior temporal gyrus	L	21/22	-55	-11	-9	546	N, U	*n.s.*
Posterior insula/Superior temporal gyrus	L	22/13	-41	-22	-4	738	N, U	*n.s.*
Middle/Inferior temporal gyrus	R	37/21	56	-53	-1	783	U	
Middle/Inferior temporal gyrus	R	21	60	-5	-13	326	N, U	*n.s.*
Fusiform gyrus	L	20	-41	-15	-22	447	U	
Parahippocampal gyrus/Hippocampus	R	36/35/20	30	-13	-23	719	-	
Parahippocampal gyrus/Thalamus	R	27/30	10	-31	-4	716	U	
Parahippocampal gyrus/Hippocampus	L	19	-28	-40	-2	669	U	
Parietal								
Superior parietal lobule/Precuneus	L	7	-25	-61	56	1962	N, U	U>N*
Superior parietal lobule/Precuneus	R	7	23	-63	56	667	U	
Inferior parietal lobule	L	40/39	-51	-57	42	370	N	
Precuneus/Angular gyrus	L	39	-38	-63	34	284	U	
Supramarginal gyrus	R	40	41	-42	32	320	N, U	*n.s.*
Cingulate/Sub-Cortical								
Cingulate gyrus/Caudate body	L	-	-11	-9	26	677	N, U	*n.s.*
Cingulate gyrus/Caudate	R	-	9	-2	24	491	N, U	*n.s.*
Cingulate gyrus	R	23	9	-19	30	420	N, U	*n.s.*
Cingulate gyrus/Precuneus	L	31	-20	-43	38	293	N, U	*n.s.*
Posterior cingulate	R	29/30	4	-46	10	418	N, U	U>N*
Caudate/Caudate body	R	-	22	-15	22	373	N, U	*n.s.*
Lentiform nucleus/Putamen	L	-	-21	4	12	421	U	
Thalamus	L	-	-6	-34	10	319	N, U	*n.s.*
Occipital								
Middle occipital gyrus/Fusiform gyrus	L	19	-38	-69	-10	603	U	
Fusiform gyrus/Declive	R	19	21	-84	-15	528	N, U	*n.s.*
Cuneus/Lingual gyrus	L	17	-13	-90	8	602	N, U	U>N*
Cerebellum								
Inferior semi-lunar lobule	L	-	-27	-64	-40	390	U	
Declive of Vermis/Declive	R	-	1	-76	-16	539	-	
Uvula/Inferior semi-lunar lobule	L	-	-7	-81	-34	537	N, U	*n.s.*
Cerebellar Tonsil/Culmen	L	-	-23	-35	-29	297	-	
Culmen	R	-	15	-43	-16	535	-	

Note. Table particulars are as previously stated. Response Type: N=natural, U=unnatural. *$p < 0.05$.

To investigate the relationship between Response Type ('natural', 'unnatural') and Exploration Modality (touch only, vision only, bimodal), a voxelwise 2×3 ANOVA was performed. The centre of mass for each of the clusters eliciting either a main effect for response type or exploration modality or an interaction between these two factors, as revealed by the critical comparisons is reported in Table 5.3. Subsequent *t*-tests comparing activation in these regions to a baseline of zero activation change were conducted to clarify the significance of the activation level for each condition. A main effect of response type was observed in the left lingual gyrus, left MCC, and right MOG. Within the left MCC, activation was significant when stimuli were perceived as 'natural' only, whereas for the left lingual gyrus and right MOG, activation was significant when stimuli were perceived as 'unnatural' only.

A main effect of exploration modality was observed in the left parahippocampal gyrus, and the right middle temporal gyrus. Activation in the left parahippocampal gyrus was greater in the vision only condition than in the touch only ($p<0.05$) or bimodal condition ($p<0.05$); the touch only and bimodal conditions were both significantly deactivated, and did not differ from each other. In contrast, for the right middle temporal gyrus, activation was greater in the vision only and touch only condition than in the bimodal condition ($p<0.05$ and $p<0.05$ respectively); the bimodal condition was again significantly deactivated. An interaction was observed between the two main factors in right precuneus, such that activation specifically when stimuli were perceived as 'natural' in the touch only condition, and as 'unnatural' in the vision only condition.

Table 5.3. *Brain regions eliciting significant activation for 'natural' and 'unnatural' response types across exploration modality (voxelwise ANOVA analysis, $p<0.05$ corrected).*

				Centre of Mass			Vol.			
Effect	Anatomical Structure	Side	BA	x	y	z	µl	F(1,15)	>0	Contrast
Response Type	Lingual gyrus	L	18/19	-19	-71	-3	1139	62.06**	U	-
	Cingulate gyrus	L	24	-21	-16	31	567	63.53**	N	-
	Middle occipital gyrus	R	19	44	-58	-4	492	29.49**	U	-
Exp. Modality	Parahippocampal gyrus	L	19	-32	-44	1	724	12.59**	T, V, B	V>T, B
	Middle temporal gyrus	R	21	50	-31	-6	469	10.72**	T, V, B	T, V>B
Interaction	Precuneus	R	-	21	-54	31	509	15.82**	TN, VU	-

Note. Table particulars are as previously stated. Response Type: N='natural', U='unnatural', Exploration Modality: T=touch only, V=vision only, B=bimodal. **$p<0.001$

5.4 Discussion

The aim of this study was to examine the cortical correlates of "naturalness" in a controlled empirical fashion, using material surfaces as stimuli. While naturalness as a concept has received much attention in the literature, a gap exists in the understanding the brain processes that may underlie this perception. At a behavioural level, it was observed that there was a significant distinction between the perception of natural and unnatural stimuli. Furthermore, there was no significant difference in perception across the modality conditions. This result is not surprising, as stimuli were chosen from a prior pilot study such that no exploration condition was given an advantage. In this way, we maximised the potential of observing a dichotomy between natural and unnatural perception in the functional analysis.

In the initial whole-brain analysis of the functional data activation was observed in a number of clusters along the cingulate and anterior insula for the natural-unnatural stimulus contrast during the bimodal exploration of the wood stimuli. Notably, using the block-design method of analysis, there was only one cluster that reached significance for the touch only condition (i.e. in the cerebellum), while no clusters met the required level of significance for the vision only exploration condition. This finding may imply that the physical properties of the natural and unnatural stimuli recruit similar processes in the brain during the unimodal exploration conditions. In order to clarify whether this is the case, a later neuroimaging study (see Chapter 6) utilised an event-related method of presentation so that natural and unnatural stimulus categories could be examined independently. It is particularly interesting that a network of regions were activated for natural compared to unnatural stimuli during bimodal exploration, despite a lack of clusters being observed for the unimodal conditions. While bimodal performance was not significantly different to unimodal performance in the behavioural results, the functional

results suggest that simultaneous tactile and visual exploration of a texture stimuli invokes processes beyond that of unimodal exploration. These areas, which demonstrated greater activation for natural than unnatural stimulus blocks, have been strongly implicated in the coordination of sensory information with affective responses (e.g. Berridge & Kringelbach, 2007; Rolls, et al., 2003). Additionally, activation in the bilateral MOG was observed for the natural-unnatural contrast, a region that has been implicated in other texture-related studies (e.g. Stilla & Sathian, 2008). In general, previous behavioural and functional studies suggest that touch and vision act independently for the perception of texture (see Chapter 2). However, given that very few studies have investigated visuo-tactile sensory integration in texture perception from a functional perspective, further studies are needed to unravel how vision and touch behave during the simultaneous exploration of a texture.

On closer examination of participants' responses it was noted that in some cases, participants were inconsistent in categorising a given sample as 'natural' or 'unnatural'. In light of this, a subsequent whole-brain analysis of the functional data compared activations corresponding to 'natural' and 'unnatural' response types across modality conditions. This analysis revealed a number of areas that were activated above baseline for both 'natural' and 'unnatural' responses including the fusiform, parahippocampal, MOG and lingual gyri. These regions have been reported in a number of visual texture perception and scene preference studies, and lie along the proposed surface-property pathway of the ventral stream (e.g. Beason-Held, et al., 1998; Biederman & Vessel, 2006; Cant & Goodale, 2007; Yue et al., 2007). Activation was also observed in the posterior insula and inferior frontal gyrus for the task. These regions may reflect the cognitive and evaluative processes involved in tactile texture perception (Kitada, et al., 2005; Stilla & Sathian, 2008). Furthermore, activation was observed in multiple locations along the cingulate cortex, a

region that reflects the affective processing of sensory information (Berridge & Kringelbach, 2007; Rolls, et al., 2003).

Using a voxelwise ANOVA approach it was observed that perceiving a stimulus as 'unnatural' significantly activated clusters in the lingual gyrus and MOG, areas that have been observed in visual texture perception studies (e.g. Beason-Held, et al., 1998; Cant & Goodale, 2007). Additionally, activation in the MCC was yielded when stimuli were perceived as 'natural'. Although this region is posterior to the well-known affective region of the ACC, it has recently been shown to be activated when classifying a stimulus according to its desirability (Kawabata & Zeki, 2008).

A number of regions demonstrated differences in activation across exploration modality condition independent of response type. Specifically, the left parahippocampal gyrus showed greater activation in the vision only condition than in either the touch only or bimodal condition, whereas activation in the right middle temporal gyrus was greater in the vision only and touch only condition than in the bimodal condition. The visual dominance seen in the left parahippocampal gyrus is consistent with studies that indicate this area in the visual perception of texture (e.g. Beason-Held, et al., 1998; Cant & Goodale, 2007) and in visual scene preference (e.g. Biederman & Vessel, 2006; Yue et al., 2007). The right middle temporal gyrus (BA 21) has been indicated to play a role in language, and has been implemented in the silent generation of words (Indefrey & Levelt, 2000; Sevostianov, et al., 2002). In this case, it is plausible that participants were labelling stimuli internally while exploring the samples.

Taking an overview of the functional results, this study indicated a wide network of sensory and evaluative regions were involved in the task. Despite using a set of ecological stimuli that were variable in nature, many areas that have been observed in the perception of tactile and visual texture were replicated; the fusiform, parahippocampal, MOG and

lingual gyri (e.g. Beason-Held, et al., 1998; Cant & Goodale, 2007), and the posterior insula and inferior frontal gyrus (Kitada, et al., 2005; Stilla & Sathian, 2008). Notably, the left lingual gyrus elicited significantly more activity when perceived as 'unnatural' relative to 'natural', while the left fusiform, and bilateral parahippocampal gyrus were significantly activated for 'unnatural' only. These findings add to the dissociations observed in these areas in a living/nonliving semantic categorisation task (e.g. Chao, et al., 1999; Mahon, et al., 2009; Mahon, et al., 2007; Noppeney, et al., 2006; Wierenga, et al., 2009), and give an indication that semantic processing is involved in the perception of naturalness.

These findings give us a glimpse into the affective evaluation that is involved in the naturalness perceptual task. Given the suggestion that humans have a preference for naturalness across many domains (Ode, et al., 2009; Purcell & Lamb, 1998; Rozin, 2005, 2006; Rozin, et al., 2004), further investigation is necessary to clarify the affective relationship that we have with natural materials, and the brain processes that are involved in this perception of these stimuli.

CHAPTER 6

ELUCIDATING THE CORTICAL CORRELATES OF NATURALNESS PERCEPTION

PART II - FROM WOOD TO FABRIC TEXTURES

Authorship

This chapter is currently being prepared for journal submission:

Whitaker, T. A., Simões-Franklin, C., & Newell, F. N. (in prep). An fMRI investigation of the cortical areas underlying the visual and tactile perception of "naturalness" in wood and fabric textures. *Manuscript in Preparation, title TBC.*

6.1 Introduction

In Chapter 5 an examination of whether naturalness (either physical or perceived) influenced changes in the BOLD response using wood textures was presented. It was demonstrated that a wide network of regions were activated during the bimodal exploration of natural compared to unnatural stimuli, for example, the left ACC, bilateral PCC and left MOG regions. Furthermore, the perception of naturalness of wood textures recruited a large array of cortical areas including many regions along the cingulate gyrus, ventral visual stream and posterior parietal area. In order to clarify whether these areas are recruited during the perception of wood textures specifically, or whether the findings could be generalised beyond one stimulus category, a consecutive fMRI investigation was conducted on the perception of naturalness using both wood and fabric stimuli.

6.1.1 Outline of experiment

This study sought to extend the scope of the investigation presented in Chapter 5 by including a set of fabric together with wood textures. Using an event-related design, an examination was conducted on whether the brain processes involved in the perception of naturalness were stimulus-specific, or could be generalised across material type. Furthermore, an investigation of whether the cortical areas recruited in the naturalness perception of a stimulus varied as a function of exploration modality (touch or vision) was carried out. It was predicted that any material-specific differences would be primarily apparent in sensory regions, whilst decisions based on the perception of a stimulus being either 'natural' or 'unnatural' may recruit not only cortical regions involved in decision-making, but also those implicated in affective processes.

6.2 Method

6.2.1 Participants

Sixteen right-handed undergraduate and postgraduate students (9 female, mean age 20.5 years, age range 18-26) of Trinity College Dublin participated in this study for nominal pay or research credits. All participants reported normal or corrected-to-normal vision, no tactile impairments, no history of neurological or psychological disorders, and no particular experience with either wood or fabric materials (either professionally or otherwise). Following a briefing on the experimental protocol and fMRI method, participants gave written consent to take part in the study.

6.2.2 Stimuli and apparatus

Stimuli

The stimuli consisted of 24 unique material surfaces (12 wood and 12 fabric, half natural). These particular stimuli were taken from a larger pool of wood and fabric samples, which were used in a previous behavioural pilot study on naturalness perception (see Chapter 3). The wood stimuli comprised of six natural stimuli, consisting of tiger oak and cognac oak samples, which had different finishes: raw, weathered, waxed, and oiled. The unnatural wood stimuli consisted of hard and soft vinyl, and high-quality photocopy. The fabric stimuli comprised of six natural stimuli, consisting of different combinations of wool and cotton; and six unnatural stimuli, consisting of different combinations of acrylic and polypropylene. Fabrics were woven in either a coarse or fine weave.

During presentation, the orientation of the stimuli was constrained such that the grain of wood consistently lay along the y-axis, and the warp of the fabric weave lay consistently along the x-axis relative to the participant. Each stimulus was fixed behind a plastic frame using an epoxy adhesive. The frame had an 80 x 80 mm window through

which the sample could be viewed or touched. Some of the thinner samples required a firm backing, which was achieved by fixing Plexiglas behind these samples. For visual presentation of each stimulus, a high-resolution image was captured using a 10-megapixel Nikon camera, within a DigiEye System (VeriVide Ltd.) under a diffuse uniform light setting that imitated daylight. Each image was cropped to 850 x 850 pixels using Photoshop® (Adobe Systems, version 10.0.1, San Jose, CA), and was centrally displayed on a blank background (grey, RGB: 126, 126, 126).

Apparatus

The experiment took place in a Philips Intera Achieva 3.0 Tesla MR system (Best, The Netherlands). Each mounted stimulus was fixed to a custom-built MR-compatible tactile apparatus (Lyons, et al., in prep). The apparatus consisted of a conveyor belt mechanism, which was rotated using an attached handle so that each stimulus was presented underneath the participant's hand and thus avoided any unnecessary movement of the participant's arm. Visual images and cueing instructions were presented via a mirror system that reflected a 1280 x 1024 pixel display, projected on a panel placed behind the participant's head outside the magnet. The mirror was mounted on the head coil in the participant's line of vision. Responses were recorded using a two-button fibre-optic response pad (Cambridge research systems), which was placed directly underneath the participant's left hand during the experiment. The participant used their index and middle fingers to respond to each trial during the study. Stimulus presentation was controlled using Presentation® software (www.neurobs.com), which was synchronised with trigger pulses from the MR scanner.

6.2.3 Experimental design

The experiment was based on a three-way factorial design with material type (wood, fabric), stimulus category (natural, unnatural) and exploration modality (touch only, vision only) as within-subjects factors. Perceived naturalness was the dependent variable measured (response type: 'natural', 'unnatural').

The experimental protocol was based on a binary decision task where participants were required to categorise each explored stimulus as either 'natural' or 'unnatural'. The experiment consisted of six runs of trials, with stimuli explored using one exploration modality type per run, thus there were three separate runs for each exploration modality condition. The order of these runs was counterbalanced across participants. Within each run, trials were presented in an event-related fashion, with each stimulus presented once per run in a pseudo-randomised order. In all, each of the 24 stimuli was presented three times per exploration modality, a total of 144 trials.

6.2.4 Procedure

Within the context of this experiment, the term 'natural' was defined to each participant as a texture surface that was "derived from nature". Exploration of the stimuli in the touch only condition was practised prior to testing: participants completed three clockwise rotations on the surface using their right index finger under limited timing such that each rotation took approximately one second, resulting in three seconds of exploration per stimulus. This type of exploration reflects the 'lateral motion' exploratory procedure described by Lederman and Klatzky (1987), but was circular to take into account that the materials may have different information available to touch along the horizontal and vertical axes. During each trial in the vision only condition, a stimulus image was presented for three seconds.

An illustration of the temporal sequence of events during a typical trial in each of the exploration modality conditions is displayed in Figure 6.1. In all exploration conditions, participants were cued to begin exploration by the disappearance of a fixation cross on the visual display. In the tactile only condition, the visual display remained blank (grey; RGB: 126, 126, 126) for the duration of exploration. In the visual only condition, the exploration hand (right) remained still. Once exploration was complete, a question mark symbol appeared on the visual display for one second, which acted as a cue to respond. The participant was then required to categorise the stimulus as 'natural' or 'unnatural' by pressing the relevant button on a two-button response pad using their left hand. Following the response cue, a fixation-cross appeared on screen until the beginning of the next trial. The length of the fixation period was jittered between four and ten seconds.

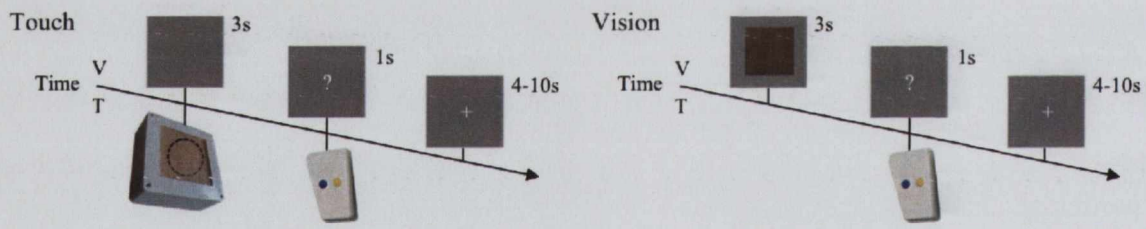


Figure 6.1. Illustration of the sequence of events in a trial. In the touch only condition, a tactile stimulus was presented while the screen was blank. In the vision only condition, an image appeared on screen while no tactile stimulus was presented.

6.2.5 Data acquisition

Scanning started with 31.5 seconds of standard scout images to adjust head positioning, followed by a reference scan to resolve sensitivity variations. Imaging used a parallel SENSitity Encoding (SENSE) approach (Pruessmann, et al., 1999) with a

reduction factor of 2. A high-resolution T1-weighted MP-RAGE anatomical sequence was acquired for each participant (180 oblique-axial slices, field of view 230 mm, slice thickness 0.9 mm, voxel size 0.9 x 0.9 x 0.9, total duration 5.43 minutes) to allow subsequent activation localization and spatial normalization.

Functional data of the entire brain were collected using a T2* weighted echo-planar imaging sequence: 32 non-contiguous (10% gap) 3.5-mm axial slices, echo time 35 ms, TR 2000 ms, field of view 224 mm, matrix 64 x 64 mm in Fourier space. Each one of the six functional scans had a duration of 5.22 minutes. The spontaneous changes in frequency were automatically corrected by the Intera Achieva by means of a dynamic stabilization (real time frequency adjustment) after each TR.

6.2.6 Data analysis

All analyses were conducted using Analysis of Functional NeuroImages software (AFNI, http://afni.nimh.nih.gov; Cox, 1996). After image reconstruction, the functional and structural data were aligned (Saad, et al., 2009). The time-series data were then linearly de-trended and motion-corrected using 3D volume registrations (least-squares alignment of three translational and three rotational parameters), concatenated (i.e. the three functional runs of each exploration modality type), and warped onto the standard stereotaxic Talairach space (Talairach & Tournoux, 1988). Activation outside the brain was removed using an edge-detection algorithm.

Stimulus-based analysis

The initial analysis of the functional data was based on stimulus category (natural, unnatural), and included data acquired during all trials, i.e. including also those trials where participants categorised the naturalness of the stimulus incorrectly (see 'response-based analysis' for an analysis of the perceptual-related data). For each participant, a

haemodynamic response model was generated for each of the four stimulus types (wood natural, wood unnatural, fabric natural, fabric unnatural) for each exploration modality type (touch only, vision only) based on the convolution of the corresponding time series with a gamma function (Cox, 1996). The time series data was constructed such that an event of interest corresponded with the exploration of a stimulus. A regression analysis followed for each exploration modality type, comprising of the four stimulus-related regressors and the motion-corrected time-series files were accommodated for nuisance variance. The boxcar regression parameter values for each of the time series were converted into %AUC scores (Murphy & Garavan, 2005), which served as the event-related activation measures. Individual activation maps were spatially blurred using a Gaussian kernel with 3 mm r.m.s. isotropic deviation.

Response-based analysis

Following consideration of the behavioural responses, a second functional analysis was conducted based on the response of each participant to each stimulus as 'natural' or 'unnatural' and included data acquired during all trials, i.e. including also those trials where participants categorised the naturalness of the stimulus incorrectly (see 'stimulus-based analysis' for an analysis of the stimulus-related data). For each participant, a haemodynamic response model was generated according to their response per trial for each material type (wood, fabric) for each exploration modality type (touch only, vision only) based on the convolution of the corresponding time series with a gamma function (Cox, 1996). The time series data was constructed such that an event of interest corresponded with the exploration of a stimulus. A regression analysis followed for each exploration modality type, comprising of the four response-related regressors ('natural' and 'unnatural' across material type) and the motion-corrected time-series files were accommodated for nuisance variance. The boxcar regression parameter values for each of the time series were

converted into %AUC scores (Murphy & Garavan, 2005), which served as the event-related activation measures. Individual activation maps were spatially blurred using a Gaussian kernel with 3 mm r.m.s. isotropic deviation.

Thresholding and statistical parameters for functional analysis

Prior to a group analysis the individual activation maps (for both the stimulus- and response-based analyses) were determined with single-sample *t*-tests against the null hypothesis of zero activation change (i.e. no change relative to tonic task-related activity). Significant voxels passed a voxel-wise statistical threshold ($t = 4.07$, $p < 0.001$) and were required to be part of a larger 141 µl cluster of contiguous significant voxels. Thresholding parameters were determined through a Monte Carlo simulation and resulted in a 5% probability of a cluster surviving due to chance. In order to conduct statistical comparisons between natural and unnatural (for both the stimulus- and response-based analyses) across exploration modality, the activation maps were combined for all conditions. These maps, normally referred to as an 'OR-map' (like the Boolean 'OR' operator), include the clusters that were significantly activated by any of the conditions.

To further investigate the relationship between naturalness (stimulus or perceived) and exploration modality, separate voxelwise analyses were conducted using a three-factor ANOVA on wood and fabric stimuli for both the stimulus- and response-based data. For the stimulus-based ANOVAs, stimulus category (natural, unnatural) and exploration modality (touch only, vision only) were entered as fixed factors and participant (16 levels) as a random factor. For the response-based ANOVAs, response type ('natural', 'unnatural') and exploration modality (touch only, vision only) were entered as fixed factors and participant (16 levels) as a random factor. Unlike the OR-map approach, this voxelwise ANOVA only reveals the brain areas that show a main effect for either factor, or the interaction between these factors. Furthermore, it levels out any brain area that is

equally activated by the different conditions, i.e. any cluster that is mutually activated across the levels of a fixed factor would not be apparent. For this analysis, significant voxels passed a voxel-wise statistical threshold ($t = 8.68$, $p < 0.01$) and were required to be part of a larger 439 µl cluster of contiguous significant voxels. Thresholding parameters were determined through a Monte Carlo simulation and resulted in a 5% probability of a cluster surviving due to chance.

6.3 Results

6.3.1 Behavioural results

While the main focus of this research is the perception of naturalness, and not accurate categorisation of a stimulus in terms of naturalness *per se*, it is noteworthy that categorisation of the stimuli was above chance (50%) for all exploration modality conditions. For wood, stimuli were on average correctly categorised 72.90% in the touch only condition and 57.47% in the vision only condition. For fabric, stimuli were correctly categorised 62.72% in the touch only condition and 85.24% in the vision only condition. As the study was interested in examining perception rather than accuracy, the behavioural analyses reported were conducted on the perception of naturalness across participants.

Perceiving naturalness across materials and exploration type

For each participant, the percentage of 'natural' responses for each condition was calculated and was used for analysis. In order to examine whether perceived naturalness varied as a function of material type and exploration modality, a 2 x 2 x 2 factorial ANOVA with Material Type (wood *vs.* fabric), Stimulus Category (natural *vs.* unnatural) and Exploration Modality (touch only *vs.* vision only) as within-subjects factors was performed on participant's mean percentage of 'natural' responses for each condition. Posthoc analyses reported in this chapter were conducted using the Bonferroni criterion. A

significant main effect of Stimulus Category was observed, $F_{(1, 15)} = 138.61$, $p < 0.001$, such that the natural stimuli were significantly more likely to be categorised as 'natural' than the unnatural stimuli. There were no other significant main effects.

A significant two-way interaction was observed between Material Type and Stimulus Category, $F_{(1, 15)} = 4.08$, $p < 0.05$ (see Figure 6.2), however using the Bonferroni posthoc criterion, these contrasts did not reach significance. All other two-way contrasts were not significantly different.

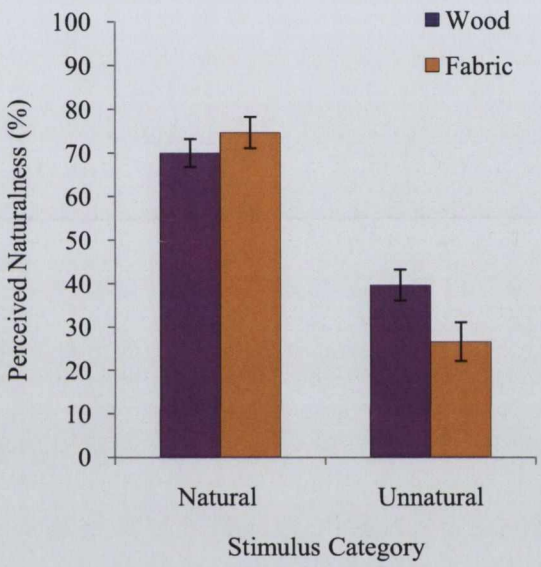


Figure 6.2. Illustration of the 2-way interaction between material type and stimulus category. Error bars represent ±1 SE from the mean.

A significant three-way interaction was observed between Material Type, Stimulus Category and Exploration Modality, $F_{(1, 15)} = 27.66$, $p < 0.001$ (see Figure 6.3). There was a significant difference in naturalness perception across material types in the unnatural stimulus category ($p < 0.01$), such that wood stimuli explored using vision only ($M = 52.08$) were more likely to be categorised as 'natural' than fabric stimuli explored using vision only ($M = 14.58$). All other contrasts were not significantly different.

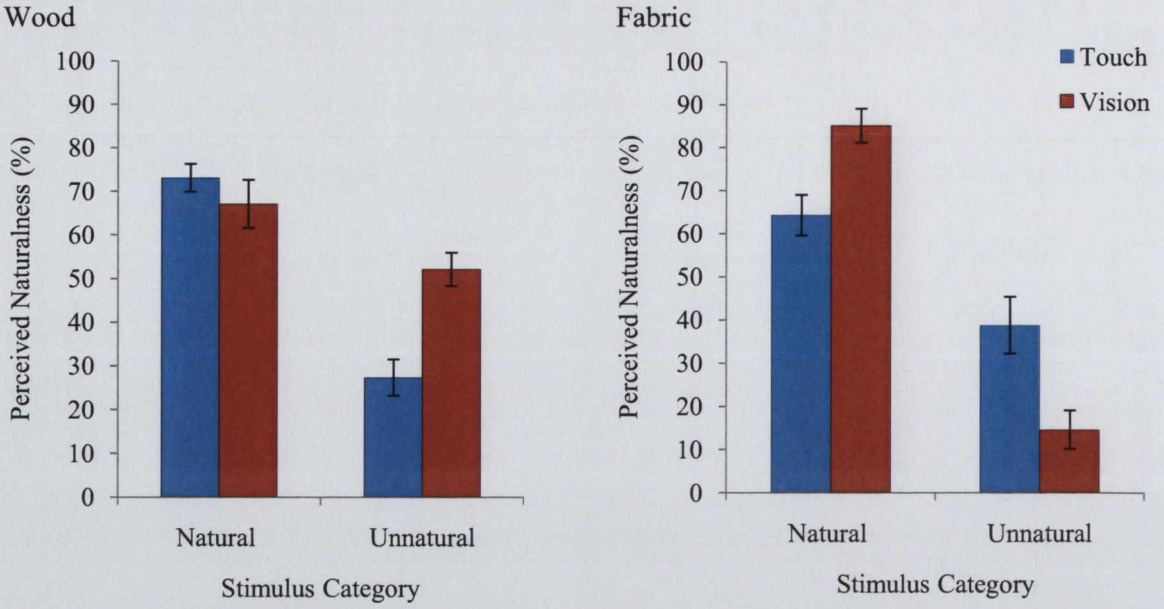


Figure 6.3. Illustration of the 3-way interaction between material type, stimulus category and exploration modality, separated by material type. Error bars represent ±1 SE from the mean.

Examination of a response bias in naturalness categorisation

In order to examine whether there was a bias in participants' naturalness categorisation responses, a 2 x 2 x 2 factorial ANOVA with Material Type (wood *vs.* fabric), Stimulus Category (natural *vs.* unnatural) and Exploration Modality (touch only *vs.* vision only) as within-subjects factors was performed on the percentage of total 'natural' or 'unnatural' responses for each condition (see Figure 6.4). There were no significant main effects nor interactions observed, suggesting that there was no bias in responding either 'natural' or 'unnatural' across material type or exploration modality.

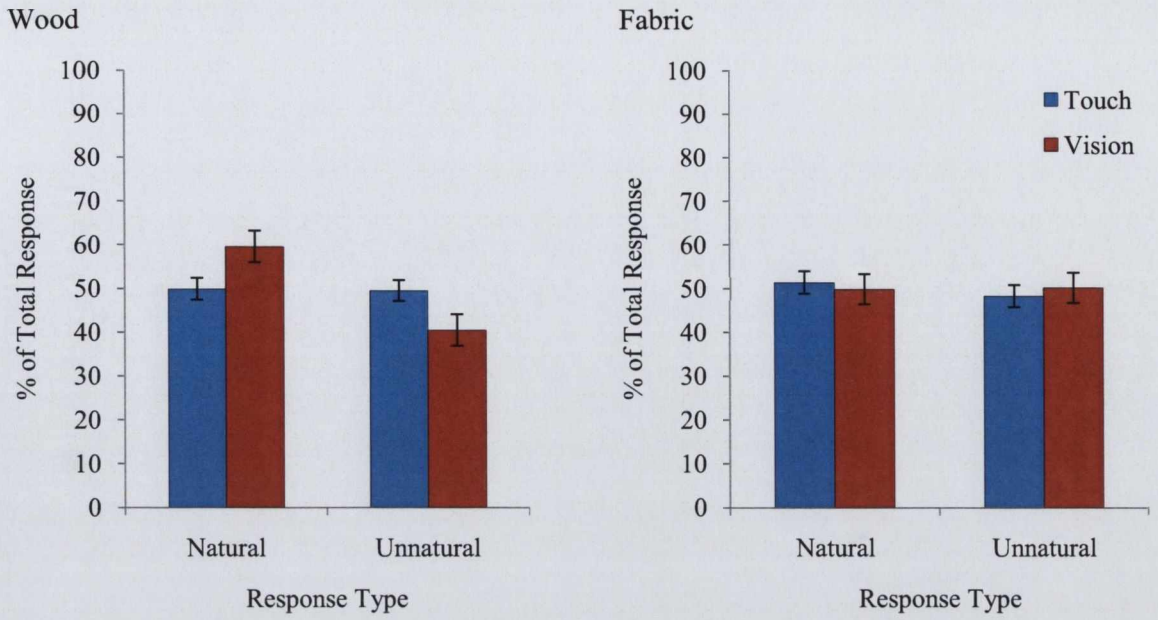


Figure 6.4. Illustration of the percentage of 'natural' and 'unnatural' responses given across exploration modality, separated by material type. Error bars represent ±1 SE from the mean.

6.3.2 Functional results

Stimulus-based analysis

The initial whole-brain analysis (OR-map) investigated the activation associated with natural and unnatural stimulus categories across each exploration modality per material type. As illustrated below, exploring natural and unnatural stimuli activated a wide network of brain regions.

For wood stimuli, a number of overlapping areas of activation were observed across stimulus category (see Figure 6.5) including the bilateral lingual and fusiform gyri (BA 17 & 18), bilateral somatosensory cortex and inferior parietal lobule (BA 2 & BA 40), bilateral posterior insula (BA 13), bilateral medial frontal gyrus (BA 6), right MCC (BA 24 & BA 31) and right superior temporal gyrus (BA 22). Furthermore, there were a number of regions that showed stimulus-specific activation for either natural or unnatural wood stimuli. For example, exploration of natural wood stimuli elicited activation in the left inferior temporal gyrus, right ACC (BA 10, BA 32 & BA 24), right Amg, right thalamus and bilateral uvula. In contrast, exploration of unnatural wood stimuli elicited activation in

the left thalamus, left cerebellum, left ACC (BA 10 & BA 32), left MCC (BA 31), left middle temporal gyrus (BA 21), right MOG, right inferior temporal gyrus (BA 20), right caudate and right lentiform nucleus.

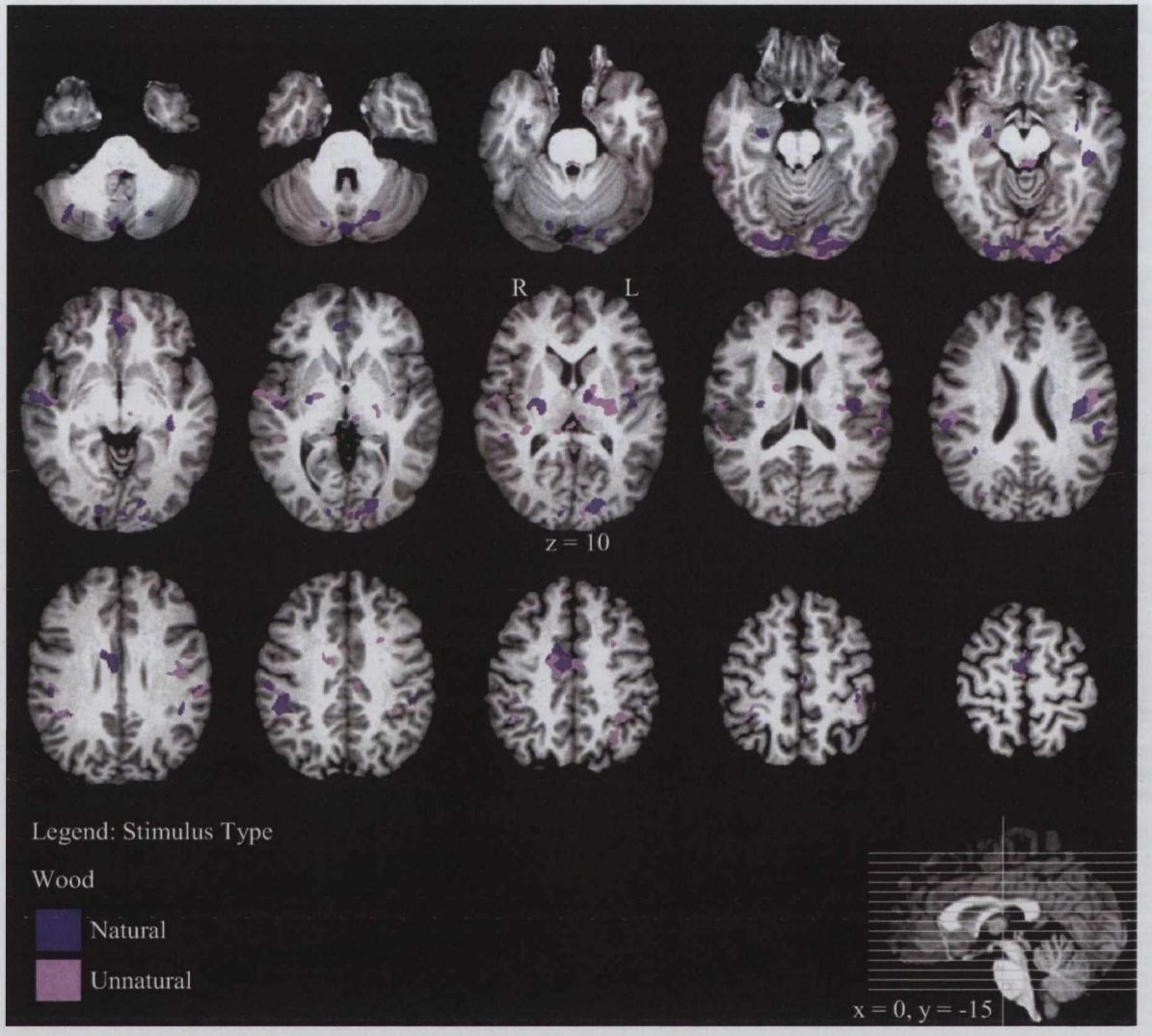


Figure 6.5. Axial views of the brain of an individual participant with superimposed significant activation associated with natural and unnatural stimulus categories across exploration modality for wood stimuli (whole-brain analysis, $p<0.05$ corrected).

For fabric stimuli, a number of overlapping areas of activation were observed across stimulus category (see Figure 6.6) including the bilateral uvula and pyramis cerebellar regions, bilateral lingual and fusiform gyri (BA 17 & 18), bilateral somatosensory cortex and inferior parietal lobule (BA 2 & BA 40), right MCC (BA 24 & BA 31), right precentral gyrus (BA 3) and right posterior insula (BA 13). Furthermore, there were a number of regions that showed stimulus-specific activation for either natural or unnatural fabric stimuli. For example, exploration of natural stimuli elicited activation in the left medial frontal gyrus (BA 6), left MCC (BA 31) and left precentral gyrus (BA 4). In contrast, exploration of unnatural stimuli elicited activation in the left posterior insula (BA 13), right ACC (BA 10 & BA 32), right supramarginal gyrus, right middle temporal gyrus (BA 21), right MOG (BA 18) and right Amg.

Comparing the regions associated with natural and unnatural stimuli across material type, a number of regions were commonly activated for both wood and fabric stimuli. Specifically, sensory areas within both the somatosensory cortex and within the visual cortex, such as the lingual and fusiform gyri along with the right MCC and right posterior insula were activated across stimulus type and material type. Surprisingly, there were a number of common regions activated across materials but were differentially activated across stimulus category. For example, while activation in the right ACC and right Amg was associated with exploration of natural wood stimuli, activation in these areas was elicited during the exploration of unnatural fabric stimuli. Conversely, while activation in the left MCC was associated with exploration of unnatural wood stimuli, activation in this area was elicited during the exploration of natural fabric stimuli.

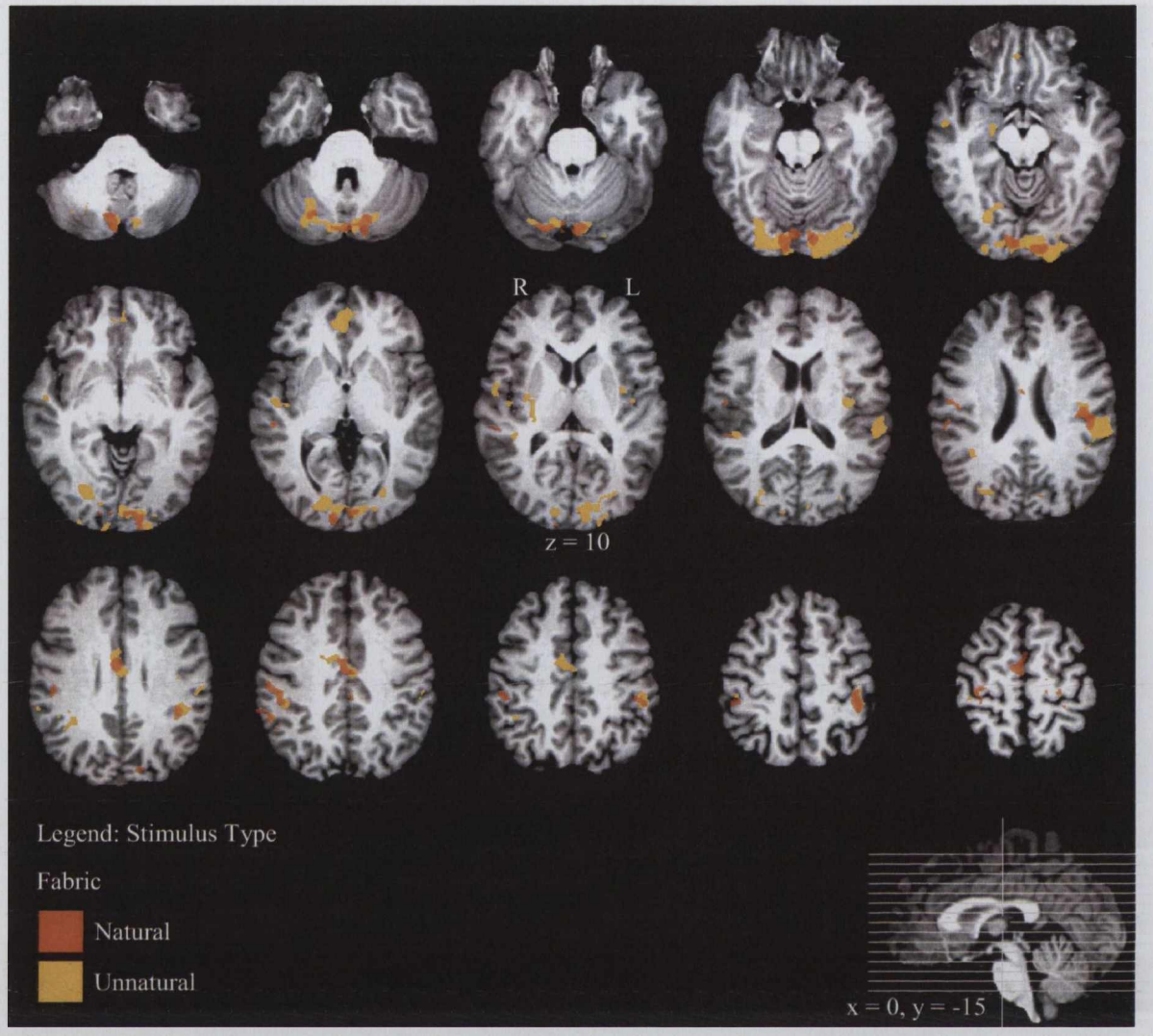


Figure 6.6. Axial views of the brain of an individual participant with superimposed significant activation associated with natural and unnatural stimulus categories across exploration modality for fabric stimuli (whole-brain analysis, $p<0.05$ corrected).

To investigate the relationship between Stimulus Category (natural, unnatural) and Exploration Modality (touch only, vision only), separate voxelwise 2×2 ANOVAs were performed for wood and fabric stimuli. The centre of mass for each of the clusters eliciting either a main effect for stimulus category or exploration modality or an interaction between these two factors, as revealed by the critical comparisons in the 2×2 ANOVA was recorded. Subsequent *t*-tests comparing activation in these regions to a baseline of zero activation change were conducted to clarify the significance of the activation level for each condition.

A main effect of exploration modality, i.e. activation independent of stimulus category, was observed in a large array of cortical areas including tactile and visual sensory regions (see Table 6.1 for wood stimuli, Table 6.2 for fabric stimuli). For both wood and fabric stimuli, there were no clusters detected that met the adopted statistical threshold corresponding to neither a main effect of stimulus type nor an interaction between stimulus type and exploration modality.

Table 6.1. *Brain regions eliciting significant activation for natural and unnatural stimulus types across exploration modality for wood stimuli (voxelwise ANOVA analysis, $p<0.05$ corrected).*

					Centre of Mass			Vol.			
Material Type	Effect	Anatomical Structue	Side	BA	x	y	z	µl	$F_{(1,15)}$	>0	Contrast
Wood	Stimulus Category	*No clusters found*									
	Exp. Modality	Postcentral gyrus/Inferior parietal lobule	L	2	-41	-25	28	46431	72.15**	T	-
		Thalamus/Medial dorsal nucleus	L	-	-5	-19	9	1636	23.97**	T	-
		Fusiform gyrus	L	20	-40	-10	-25	973	15.13**	T	-
		Posterior insula	R	13	31	-26	26	666	18.79**	T	-
		Inferior frontal gyrus	L	-	-43	24	19	662	22.54**	T	-
		Cingulate gyrus	L	-	-16	3	24	620	18.18*	T	-
		Putamen	R	-	21	-2	16	1023	20.30**	T	-
		Inferior/Middle occipital gyrus	L	18	-34	-89	-10	3042	21.37**	V	-
		Inferior/Middle occipital gyrus	R	18	35	-86	-9	1444	15.81***	V	-
		Lingual gyrus/Cuneus	R	18	12	-101	-4	483	12.79*	V	-
		Inferior temporal gyrus	L	20	-60	-29	-26	448	18.79**	V	-
		Postcentral gyrus/Superior temporal gyrus	R	40	56	-26	16	21614	43.08**	T, V	T>V**
		Inferior temporal gyrus/Fusiform gyrus	R	20	57	-30	-18	6457	35.34**	T, V	T>V**
		Precentral/Postcentral gyrus	R	4/3	27	-28	52	451	43.07**	T, V	T>V**
		No clusters found									

Note. Hemispheric location (side) and corresponding Brodmann area (BA; where appropriate) are reported. The coordinates are given within the framework of the standardized stereotaxic brain atlas of Talairach and Tournoux (1988). Positive values for *x*, *y*, and *z* denote, respectively, locations to the right, anterior and superior of the anterior commissure. Exploration Modality: T=touch, V=vision. *$p<0.01$, **$p<0.001$

Table 6.2. *Brain regions eliciting significant activation for natural and unnatural stimulus types across exploration modality for fabric stimuli (voxelwise ANOVA analysis, $p<0.05$ corrected).*

Material Type	Effect	Anatomical Structure	Side	BA	Centre of Mass			Vol.	$F_{(1,15)}$	>0	Contrast
					x	y	z	µl			
Fabric	Stimulus Category	*No clusters found*									-
	Exp. Modality	Medial frontal gyrus	L	4	-16	-21	57	463	17.05*	T	-
		Inferior occipital gyrus	L	18	-33	-90	-7	5373	20.96*	V	-
		Middle frontal gyrus	R	18/19	33	-89	5	3279	19.05*	V	-
		Superior frontal gyrus	R	19	38	-83	30	565	16.42*	V	-
		Postcentral gyrus/Inferior parietal lobule	L	2	-48	-33	44	9248	31.66*	T, V	T>V**
		Inferior semi-lunar lobule	R	-	8	-68	-46	737	24.96*	T, V	T>V**
	Interaction	*No clusters found*	-	-	-	-	-	-	-	-	-

Note. Table particulars are as previously stated. Exploration Modality: T=touch, V=vision. **$p<0.001$

Response-based analysis

A subsequent whole-brain analysis (OR-map) investigated the activation associated with 'natural' and 'unnatural' response types across each exploration modality and material type. As illustrated below, perceiving a stimulus as 'natural' and 'unnatural' activated a wide network of brain regions.

For the wood stimuli, a number of overlapping areas of activation were observed across response type (see Figure 6.7) including as the bilateral lingual and fusiform gyri (BA 17 & 18), bilateral somatosensory cortex and inferior parietal lobule (BA 2 & BA 40), the right superior temporal gyrus (BA 41), right anterior MCC (BA 23 & BA 24), bilateral ACC (BA 32) and bilateral middle frontal gyrus (BA 10). Furthermore, there were a number of regions that showed response-specific activation for either 'natural' or 'unnatural' responses to wood stimuli. For example, perceiving a stimulus as 'natural' elicited activation in cerebellar regions such as the bilateral uvula, in the right parahippocampal gyrus (BA 30), right inferior temporal gyrus (BA 20), bilateral posterior insula (BA 13) and left thalamus. In contrast, perceiving a stimulus as 'unnatural' elicited activation along the right collateral sulcus, right middle occipital gyrus (BA 19), the left superior parietal area (BA 7) and the left middle frontal gyrus (BA 6).

For fabric stimuli, a number of overlapping areas of activation were observed across response type (see Figure 6.8) including in cerebellar regions such as the bilateral uvula, bilateral cuneus, lingual and fusiform gyri (BA 17 & 18), bilateral postcentral gyrus and inferior parietal lobule (BA 2 & BA 40), left posterior insula (BA 13), right Amg and right anterior MCC (BA 23 & BA 24). Furthermore, there were a number of regions that showed response-specific activation for 'unnatural' responses to fabric stimuli, for example, the right CoS, left middle temporal gyrus, right posterior MCC (BA 23), left middle frontal gyrus (BA 10) and left ACC (BA 32).

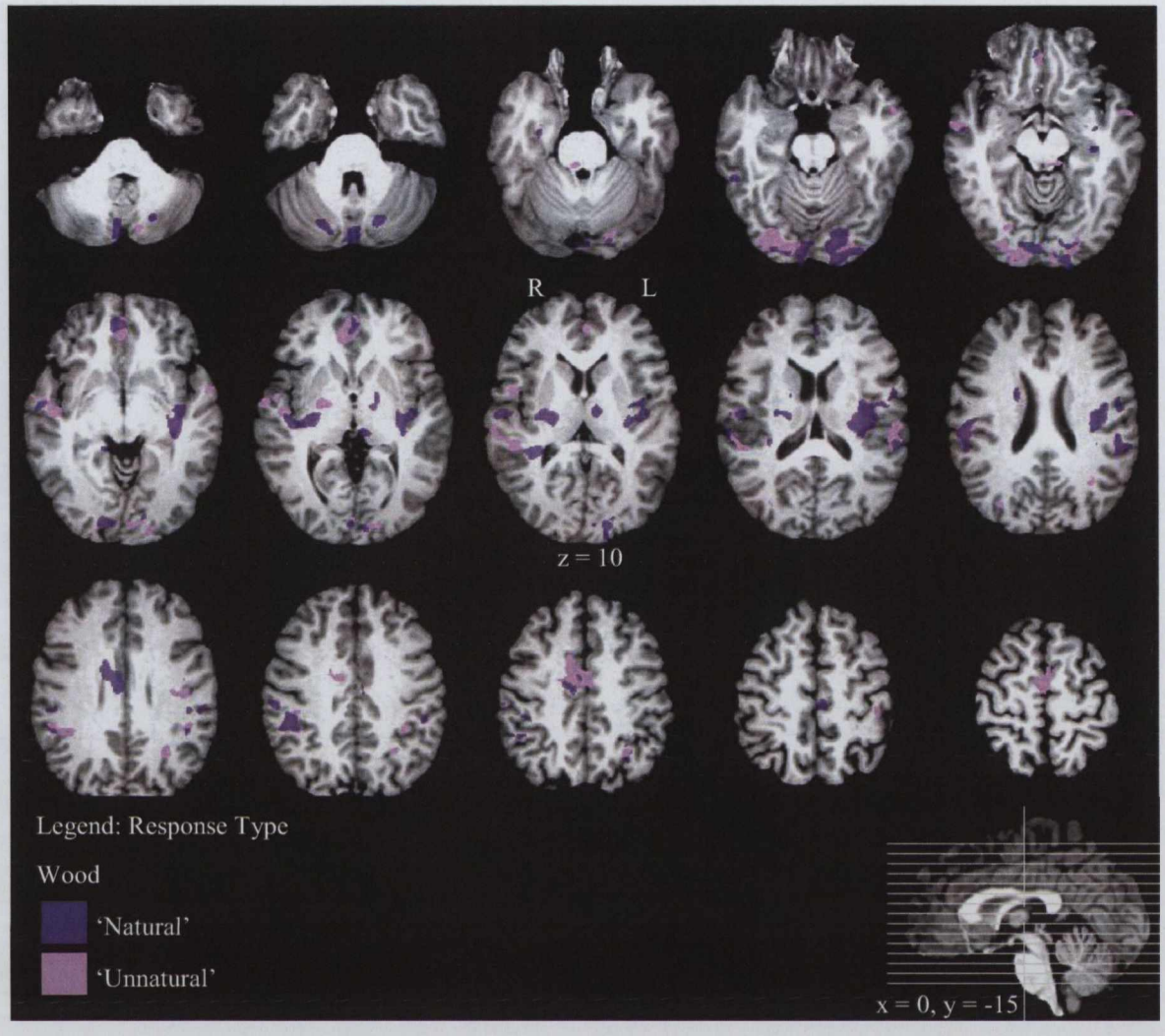


Figure 6.7. Axial views of the brain of an individual participant with superimposed significant activation associated with 'natural' and 'unnatural' response types across exploration modality for wood stimuli (whole-brain analysis, $p<0.05$ corrected).

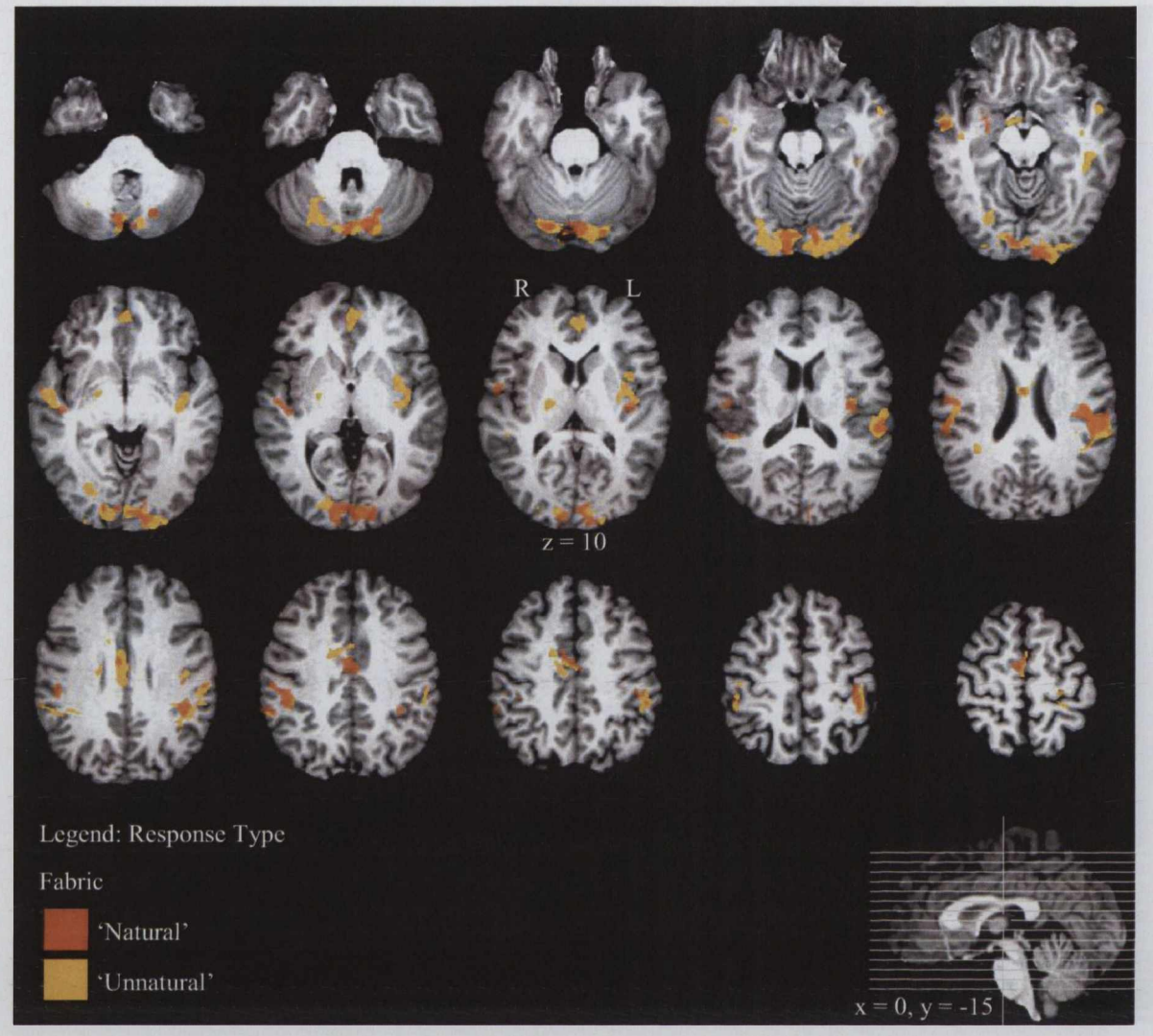


Figure 6.8. Axial views of the brain of an individual participant with superimposed significant activation associated with 'natural' and 'unnatural' response types across exploration modality for fabric stimuli (whole-brain analysis, $p<0.05$ corrected).

Comparing the regions associated with 'natural' and 'unnatural' response types across material type, a number of regions were commonly activated for wood and fabric stimuli. For example, sensory areas within both the somatosensory cortex and within the visual cortex, such as the lingual and fusiform gyri along with the right anterior MCC were activated across response type and material type. There were also a number of regions that were commonly activated by the wood and fabric materials but differentially activated for response types for these materials. For example, while activation in the bilateral ACC and middle frontal gyri was associated with 'natural' and 'unnatural' responses for wood

stimuli, activation in these areas was associated with 'unnatural' responses for fabric stimuli, and was left lateralised. Conversely, while activation in the left posterior insula was associated with 'natural' and 'unnatural' responses for fabric stimuli, activation in this region was associated with 'natural' responses for wood stimuli, and was bilateral.

To investigate the relationship between Response Type ('natural', 'unnatural') and Exploration Modality (touch only, vision only, bimodal), a voxelwise 2×2 ANOVA was performed for wood and fabric stimuli. The centre of mass for each of the clusters eliciting either a main effect for response type or exploration modality or an interaction between these two factors, as revealed by the critical comparisons was recorded. Subsequent *t*-tests comparing activation in these regions to a baseline of zero activation change were conducted to clarify the significance of the activation level for each condition.

For the wood stimuli, a main effect of exploration modality, i.e. activation independent of response type, was observed in a number of regions including the left cingulate gyrus, and bilateral fusiform gyrus (see Table 6.3). An interaction between response type and exploration modality was also observed in a number of regions. For example, activation specific to wood stimuli perceived as 'natural' that were explored through vision was observed in the left precuneus. Furthermore, wood stimuli that were perceived as 'natural' elicited activation in the right Somatosensory cortex and left lentiform nucleus when explored using touch, relative to perceived 'unnatural' stimuli. It is plausible that this finding of ipsilateral activation being elicited in the primary somatosensory cortex is related to emotional valence, i.e. that a stronger button press was used when categorising stimuli as 'natural' rather than 'unnatural'.

Table 6.3. *Brain regions eliciting significant activation for 'natural' and 'unnatural' response types across exploration modality for wood stimuli (voxelwise ANOVA analysis, $p<0.05$ corrected).*

					Centre of Mass			Vol.			
Material Type	Effect	Anatomical Structue	Side		x	y	z	µl	$F_{(1,15)}$	>0	Contrast
Wood	Response Type	*No clusters found*									
	Exp. Modality	Cingulate gyrus	L	-	-12	-26	26	68143	54.01**	T	-
		Cingulate gyrus	L	-	-15	3	26	656	15.65**	T	-
		Thalamus	L	-	-4	-20	9	2147	22.97**	T	-
		Inferior occipital gyrus	L	18	-34	-89	-12	2921	21.36**	V	-
		Inferior/Middle occipital gyrus	R	18	33	-87	-5	574	13.48*	V	-
		Fusiform gyrus	L	20	-37	-12	-21	1078	14.43*	T, V	T>V**
		Fusiform/Inferior temporal gyrus	R	20	55	-29	-18	6415	30.29**	T, V	T>V**
	Interaction	Inferior semi-lunar lobule/Uvula	L	-	-11	-66	-36	1778	19.42*	T_N, V_U	$T_N = V_U$
		Precuneus/Cuneus	L	31/7	-6	-64	28	1715	21.40**	V_N	-
		Inferior/Middle frontal gyrus	L	47	-21	21	-18	874	16.10*	T_N, V_U	$T_N = V_U$
		Lentiform nucleus/Putamen	L	-	-33	-21	-1	656	13.13*	T_N, T_U	$T_N > T_U$
		Middle occipital gyrus	L	-	-30	-77	1	457	12.06*	-	-
		Cerebellar lingual/Culmen	R	-	9	-45	-12	2625	19.77**	T_N	-
		Parahippocampal gyrus/Uncus	R	34	19	4	-18	1724	19.65**	T_N, V_U	$T_N = V_U$
		Inferior/Middle frontal gyrus	R	47	23	34	-6	1283	14.28*	T_U, V_N	$T_U = V_N$
		Postcentral gyrus	R	-	42	-16	32	1179	20.12**	T_N, T_U	$T_N > T_U$
		Fusiform gyrus	R	19/37	42	-65	-15	674	11.16*	T_U	-
		Fusiform/ Parahippocampal gyrus	R	20/36	39	-32	-16	603	12.56*	T_N	-
		Superior/Inferior temporal gyrus	R	38	34	20	-22	530	15.72*	V_U	-

Note. Table particulars are as previously stated. Exploration Modality: T=touch, V=vision. Stimulus Category: N=natural, U=unnatural *$p<0.01$, **$p<0.001$

Table 6.4. *Brain regions eliciting significant activation for 'natural' and 'unnatural' response types across exploration modality for fabric stimuli (voxelwise ANOVA analysis, $p<0.05$ corrected).*

Material Type	Effect	Anatomical Structure	Side	BA	Centre of Mass			Vol.	$F_{(1,15)}$	>0	Contrast
					x	y	z	µl			
Fabric	Response Type	Middle/superior temporal gyrus	R	39/19	55	-64	19	1110	17.82*	U	-
		Precuneus	L	7	-8	-63	41	873	18.62*	-	-
	Exp. Modality	Posterior insula/Postcentral gyrus	L	13	-39	-18	24	1088	16.17*	T	-
		Middle temporal gyrus	L	21	-55	-21	-9	874	16.20*	T	-
		Claustrum/Caudate/Posterior insula	L	13	-37	-26	-2	506	15.16*	T	-
		Medial frontal gyrus	L	-	-14	-15	62	463	17.55*	T	-
		Inferior semi-lunar lobule	R	-	8	-67	-42	2058	38.12**	T	-
		Supramarginal gyrus/Inferior parietal lobule	R	40	60	-40	34	964	17.33*	T	-
		Middle/superior temporal gyrus	R	21	63	-7	-4	909	19.67**	T	-
		Superior/medial frontal gyrus	R	9	30	48	30	473	17.79*	T	-
		Middle occipital gyrus	R	18/19	29	-90	13	793	21.81**	V	-
		Inferior parietal lobule	L	40	-49	-33	40	11848	40.11**	T, V	T>V**
		Inferior/middle occipital gyrus	L	18	-33	-90	-8	5212	22.05**	T, V	V>T**
		Superior temporal gyrus	R	22/42	65	-34	12	463	16.08*	T, V	T>V**
	Interaction	*No clusters found*									

Note. Table particulars are as previously stated. Exploration Modality: T=touch, V=vision. Stimulus Category: N=natural, U=unnatural. *$p<0.01$, **$p<0.001$

For fabric stimuli, a main effect of response type, i.e. activation independent of exploration modality, was observed in the right middle temporal gyrus when stimuli were perceived as 'unnatural' (see Table 6.4). A main effect of exploration modality, i.e. activation independent of response type, was observed in a number of regions including the left somatosensory cortex, left parietal lobule and bilateral MOG.

6.4 Discussion

The aim of this study was to examine the cortical correlates of "naturalness", using ecological material textures as stimuli. While naturalness as a concept has received much attention in the literature, few studies have used materials as stimuli and as such a gap exists in the understanding of the brain processes that may underlie the perception of naturalness in materials.

At a behavioural level, it was observed that there was a significant distinction between the perception of natural and unnatural stimuli. Furthermore, there were no significant main effects of exploration modality or material type, suggesting that overall no exploration condition was given a particular advantage or bias in terms of whether they were perceived stimuli as 'natural' or 'unnatural'. An interesting 3-way interaction was observed in the behavioural results such that for wood stimuli, unnatural stimuli were more likely to be perceived as 'natural' following visual than tactile exploration. This finding suggested that for this stimulus set, the unnatural wood stimuli were better imitations of their natural counterpart in terms of their visual properties.

Given that there was a small level of uncertainty in participants' responses, a dual-analysis method was adopted such that naturalness was examined at both a sensory (i.e. derived from natural or unnatural materials) and perceptual (i.e. perceived as 'natural' or 'unnatural' irrespective of sensory properties) level. For both types of analysis, a large network of cortical regions were activated across stimulus category and material type. For

example, within the occipital lobe, the fusiform, MOG and lingual gyri were activated across material type, and in some cases for both tactile and visual exploration. These regions have been reported in a number of visual texture perception studies, and lie along the proposed surface-property pathway of the ventral stream (e.g. Beason-Held, et al., 1998; Cant & Goodale, 2007). In addition, well-known tactile regions, i.e. somatosensory cortex and inferior parietal lobule were elicited independently of stimulus category or material type. Furthermore, the posterior insula and inferior frontal gyrus were activated across stimulus category and in some cases across material type. These regions may reflect the cognitive and evaluative processes involved in tactile texture perception (Kitada, et al., 2005; Stilla & Sathian, 2008). Notably, with the exception of activation within the middle temporal gyrus, which was elicited when fabric stimuli were perceived as 'unnatural', there were no regions in which changes in the BOLD response were associated with a main effect of stimulus category or response type, i.e. independent of exploration modality. This suggests that the perception of naturalness in materials is modality-dependent. Furthermore, rather than distinct regions being involved for natural than unnatural stimuli, common areas that are implicated in texture perception and evaluation play a key role in this task.

Despite the many similarities in the cortical regions activated across material type, the associated activation patterns in a number of regions differed for wood and fabric stimuli. For example, in areas such as the ACC, Amg, posterior insula and MCG, changes in BOLD were different across stimulus category and material type. These regions have been implicated in reward processing (e.g. Berridge & Kringelbach, 2007; Rolls, et al., 2003), and suggest the presence of an affective evaluation of the sensory information that was presented.

Taking an overview of the functional results, this study indicated that a wide network of sensory and evaluative regions were involved in the task. Using a more ecological stimulus set than in previous studies on texture perception, which comprised of both wood and fabric textures, this study replicated and extended the previous findings (see Chapter 5) and those observed in the tactile and visual texture perception literature. This study found the same cortical regions activated during the wood-specific task as reported in Chapter 5, namely the CoS, fusiform, parahippocampal, MOG and lingual gyri, and the posterior insula and inferior frontal gyrus. Furthermore, multiple sub-regions were significantly activated along the cingulate cortex, for both wood and fabrics perceived as 'natural' and 'unnatural'. This activity gives us a glimpse into the affective evaluation that is involved in the naturalness perceptual task. Given the suggestion that humans have a preference for naturalness across many domains (Ode, et al., 2009; Purcell & Lamb, 1998; Rozin, 2005, 2006; Rozin, et al., 2004), further investigation is necessary to clarify the affective relationship that we have with natural materials, and the brain processes that are involved in this perception of these stimuli. These functional studies suggest that the evaluation of naturalness recruits not only sensory texture-related networks, but relies on affective and evaluative regions of the cortex.

CHAPTER 7

GENERAL DISCUSSION

The concept of naturalness is an exciting and emerging topic of investigation and has recently received considerable attention across many domains of literature, from food and medicinal preferences, to the impact on health and well-being. While manufacturing industries continue to invest in generating imitation materials that are cheaper to produce and purchase, there remains a booming market for 'organic', '100% natural' and unsynthesised products. Despite this, a gap in the literature remains on whether people can discriminate natural from unnatural materials, whether natural materials are preferred, and if so, how these preferences are manifested in behavioural decisions. Moreover, a preference for natural over synthetic mimics depends on the ability to discriminate these materials. Once these are discernible, then an open question is what cortical processes underlie the perception of naturalness of these materials. These topics of study were the focus of the present thesis.

7.1 Visuo-tactile contributions to texture perception

In order to perceive the material properties of surface, we encode information received at our senses and use this information to facilitate discrimination, identification and exploration of the stimulus. In the review of the background literature (see Chapter 2), the evidence for the role of vision and touch in the perception of texture was discussed with the particular aim of evaluating whether these systems contribute information to texture perception in either an independent or integrated manner. Although texture information is efficiently encoded by both vision and touch, several behavioural and neuroimaging studies have suggested that texture information is processed in qualitatively different ways for these modalities, such that the type of information encoded and the manner in which it is encoded differs across these sensory systems. Furthermore, vision and touch perceive different aspects of texture information with vision the more appropriate modality for discriminating texture boundaries and touch the more appropriate

modality for discriminating stimulus roughness and compliance. Differences also exist in the neural structures and functions which primarily underlie these systems, further suggesting independence of these modalities in the perception of texture. Accordingly, recent evidence suggests that behavioural tasks involving texture perception do not benefit from integration across the senses (e.g. Lederman & Abbott, 1981; Jones & O'Neil, 1985), suggesting that qualitatively different information is represented across vision and touch which cannot be combined to enhance perceptual performance. Research using more familiar objects, however, does suggest a role for sensory integration in texture perception (e.g. Stilla & Sathian, 2008), although these effects may be due to more cognitive influences rather than basic sensory encoding. In summary, previous studies on texture perception suggest that unlike shape perception, vision and touch contribute information to the perception of texture in an independent but complementary manner. The following discusses the overall findings that were observed in the empirical chapters reported here, and evaluates the results in light of previous literature on naturalness and texture perception.

7.2 Perceiving naturalness in material textures

In the behavioural studies reported here (see Chapter 3) and in the behavioural performance during the neuroimaging studies (see Chapters 5 and 6) it was observed that participants were adept at perceiving a distinction between natural and unnatural wood and fabric stimuli. This ability to discriminate between stimulus categories within each material type is remarkable given that participants had no in-depth (professional or otherwise) expertise with these materials, they were not provided with any particular information on the composition of the materials, and the experimental environment was sometimes moderately controlled in terms of ambient information such as lighting and sound (particularly in the experiments conducted in the Science Gallery, see Chapter 4).

However, these findings based on experiments conducted in less-controlled environments have since been replicated by another group of researchers using stricter experimental conditions (see Overvliet & Soto-Faraco, in prep), and thus appear to be invariant to experimental context.

The behavioural results suggested that discrimination of naturalness seemed to depend on the type of material and the sensory modality that was exploring the material. For example, naturalness categorisation was more efficient using touch for wood, and using vision for fabric. This finding suggested that for naturalness categorisation, touch and vision appeared to encode and represent qualitatively different information. This observation is consistent with the wider texture perception literature (see Chapter 2), which suggests that touch and vision behave in an independent manner for the perception of texture, and expands this to the domain of ecological texture surfaces. One plausible explanation for the performance differences observed in these studies would be that the physical properties of wood and fabric are considerably distinct, and that touch or vision may be better suited to encode information from one material over another.

Given that the textures used were ecological materials that can be encountered in everyday living, it may also be the case that when synthetic materials are manufactured, the features which are most emphasised are those which are optimally encoded by the most appropriate sensory modality. So for example, it may be the case that imitation wood flooring surfaces are created to be more visually appealing, rather than being realistic to touch, since tactile exploration of floors occurs relatively rarely. Therefore, in order to render a synthetic wood floor more 'natural', it makes sense that greater effort be placed on the visual appearance of the wooden surface, making imitation surfaces more difficult to discern from afar. On the other hand, if emphasis is put on the visual rather than tactile features, then tactile exploration can easily discriminate natural from synthetic wood

surfaces. For fabrics, our typical experience is with clothing and as such it seems appropriate that the tactile feel of a fabric be of greater importance than its visual appearance when creating an imitation and close visual inspection may reveal differences between natural and unnatural fibres that touch would not. Thus, the results found here that the efficient perception of naturalness is both modality-specific and material-dependent may simply reflect the manufacturing bias in the sensory features most emphasised. An important follow-up to these studies would be to examine the perception of naturalness in ecological materials which are equally appealing to both touch and vision.

7.3 Naturalness perception: A multidimensional evaluation

The results presented in Chapter 4 suggested that the perception of naturalness in materials is a complex process that involves a number of evaluative dimensions above and beyond the discrimination of texture by each of the sensory modalities. In an attempt to elucidate what characteristics play a role in the perception of naturalness in fabric materials, a multi-scale rating task was conducted. Here it was observed that fabrics that were rated as more natural were also rated as more harsh, expensive and liked. The harshness characteristic was the dominant predictor of perceived naturalness across exploration modality (touch, vision, bimodal), indicating the important role of physical properties in the perception of naturalness in materials. Furthermore, the presence of a positive relationship between hedonics and value with perceived naturalness was particularly interesting as it suggested the possible existence of an affective relationship with natural materials. Considering the observation that a preference exists for naturalness in foods, medicines (e.g. Rozin, 2005, 2006; Rozin, et al., 2004) and landscapes (e.g. Ode, et al., 2009; Purcell & Lamb, 1998), it is likely that such a preference would be apparent in materials.

A limitation of the study presented in Chapter 4 is that the investigation was restricted to fabric stimuli. This was purposely done as the stimuli were created such that they varied in actual naturalness along a continuum (in 25% intervals), and as such it could be expected that the perceived naturalness of these stimuli would be gradient in fashion. A further complication of the data was that the stimuli were presented in groupings of six such that participants had the opportunity to compare stimuli against another. The primary reason for this presentation method was due to the nature of the experimental context, i.e. the investigation was conducted in a public exhibition. However, in a follow-up study to address these issues, researchers at the Universitat de Barcelona investigated the relationship between perceived naturalness and perceived hedonics for a wider set of stimuli consisting of wood, fabric, and stone textures (Overvliet et al., in prep). Initial analysis of these results indicated a strong positive relationship across materials such that the more natural a stimulus was perceived, the more liked it was. Notably, although the presentation method used here may have been an initial concern, the findings yielded were consistent with those observed for fabrics in the follow-up study.

Together, the behavioural studies indicated the primary role of sensory information in the perception of naturalness of a textured material, suggesting the importance of bottom-up feature-driven influences in the discrimination and identification of a texture. Considering the observation that for fabric stimuli, perceived naturalness was related to other dimensions such as value and hedonics, and the recent results indicating a positive relationship between hedonics and naturalness in a wider texture set (Overvliet et al., in prep), it is fruitful to hypothesise what drives these relationships. For example, it is difficult in these studies to unravel whether judging a stimulus as more liked is made following a conscious discrimination of the naturalness of a stimulus, or whether there is something inherent in the natural stimulus that is liked more. It is likely that both bottom-

up and top-down processes are involved in the perception of naturalness in materials, and an investigation that attempts to unravel the influences of these factors would be profitable.

7.4 Examining the cortical correlates of naturalness

The investigation of an abstract and multi-dimensional concept such as naturalness is challenging. Naturalness as an evaluation could be considered to involve many dimensions, invoking mechanisms pertaining to sensory encoding, pleasure, moral evaluation and motivation (e.g. consumer behaviour). As a complement to the behavioural investigations, a set of neuroimaging studies (see Chapters 5 and 6) were conducted in order to investigate the brain processes that are involved in the evaluation of naturalness. These investigations sought to examine whether exploring ecological stimuli elicited naturalness-specific differences in the BOLD response. Furthermore, by utilising both tactile and visual exploration conditions, these studies investigated whether activation associated with evaluating naturalness differed as a function of exploration modality.

The investigations of the neural processes underlying naturalness demonstrated a wide network of regions including those associated with sensory, perceptual and cognitive decision-making, that were associated with the evaluation of wood and fabric stimuli. While both stimulus and response-based analyses were conducted, a number of regions were elicited independently of analysis type. For instance, occipito-temporal regions such as the fusiform and lingual gyri, parietal regions such as the Somatosensory cortex and inferior parietal lobule, frontal regions such as the middle frontal gyrus and many sites along the cingulate gyrus were observed across studies and material types. The presence of these sites across these studies indicates that the evaluation of naturalness involves not only sensory and decision-making processes, but also suggests the involvement of affective processes. Given that perceived naturalness has been observed to be positively related to hedonic ratings in materials (see Chapter 4; Overvliet, et al., in prep), the activations

observed along the middle frontal gyrus, cingulate gyrus, inferior parietal lobule and ventral visual stream, are in keeping with literature that has revealed these regions in the aesthetic evaluation of art (e.g. Vartanian & Goel, 2004a, 2004b), scene preference (e.g. Biederman & Vessel, 2006; Yue et al., 2007) and other moral evaluative judgements (e.g. Greene, Nystrom, Engell, Darley, & Cohen, 2004; Greene, Sommerville, Nystrom, Darley, & Cohen, 2001). Moreover, the activity that was consistently observed in the MOG and along the visual ventral stream were in line with a number of recent texture-related studies (e.g. Cant & Goodale, 2007; Stilla & Sathian, 2008).

While many common areas of activation were observed across studies, and material types, there were a number of notable individual findings. In the event-related study (see Chapter 6), exploration of natural wood stimuli and unnatural fabric stimuli elicited activation in the right Amg, and right ACC. This finding is difficult to interpret; however, given the observation that the Amg has been implicated in negative evaluative judgements (e.g. Cunningham et al., 2003), this suggests that these stimuli may represent the extremes of our naturalness evaluation. For instance, it is possible that the natural wood stimuli and unnatural fabric stimuli were perceived as quite unpleasant to explore (given the roughness of the raw wood, and the plastic-ness of the fabric). Furthermore, in the perceptual analysis of this data, activation in the left posterior insula was associated with 'natural' responses for wood stimuli, while it was elicited across response type for fabric stimuli. This region has been implicated in the evaluation of sensory reward (e.g. Berridge & Kringelbach, 2007; Rolls, et al., 2003), and hints at the presence of an affective evaluation of these stimuli in these conditions. In order to clarify the role of the Amg and posterior insula in this study, it would be necessary to look at the relation between naturalness and affective evaluation in more detail.

Over the course of the functional studies, a number of regions were yielded which demonstrated differences in activation across exploration modality condition independent of stimulus or response type. In the initial examination of the perception of naturalness in wood textures (see Chapter 5), the left parahippocampal gyrus showed greater activation in the vision only condition than in either the touch only or bimodal condition, whereas activation in the right middle temporal gyrus was greater in the vision only and touch only condition than in the bimodal condition. In the subsequent functional study (see Chapter 6), visual exploration of the wood stimuli (across stimulus- and response-based analysis) elicited activation in bilateral MOG, while tactile exploration of these stimuli involved the left Somatosensory cortex, as well as the left cingulate and thalamus. Notably, some clusters were elicited for both tactile and visual exploration in the right Somatosensory cortex, and bilateral fusiform gyrus, but were significantly greater for the touch only condition. For fabric stimuli, visual exploration elicited activation bilaterally along the occipital gyrus; while modality-specific activation was elicited for tactile exploration in the bilateral middle temporal gyrus, and left medial frontal gyrus. These findings, along with the behavioural results suggest that the modalities of touch and vision make distinct (albeit complementary) contributions to the perception of texture. Given that modality-specific activations were observed across stimulus category and response types it is likely that these sensory systems are encoding qualitatively distinct information during the texture perception task. Notably, unlike Stilla and Sathian (2008) who observed mutual activity in the MOG for touch and vision in a texture-related task, activation in this region was observed throughout these studies for vision only. However, activity along the visual ventral stream was observed for both touch and vision suggesting that the evaluation of the stimuli recruited similar regions in a distinct manner.

These functional studies of naturalness mark the beginning of a potentially fruitful avenue of research which falls within the realm of neuro-aethetics, reward and moral evaluation literature. If we suppose that an ideational motivation exists for natural things (Rozin, et al., 2004; Spranca, 1992), this implies that our preference for naturalness will generalise from food and landscapes to the domain of texture materials. If this preference is an evolutionary process, as suggested by the biophilia hypothesis (Kellert & Wilson, 1993; Wilson, 1984), then one could anticipate that the evaluation of naturalness would be observable by distinct mechanisms in the brain. Furthermore, given a preference for natural materials over unnatural imitations (see Chapter 4; Overvliet, et al., in prep), it is plausible that the evaluation of naturalness not only involves sensory processes but also affective as well as evaluative processes in the brain.

7.5 Implications of the findings

These findings, that the evaluation of naturalness in materials was multi-dimensional and that the perception of naturalness across materials differed for touch and vision, have particular implications for product production. Considering the observation that vision was less efficient at perceiving the naturalness in wood stimuli, it would seem appropriate that the development of imitation wood flooring would continue to focus on the visual characteristics of the surface but also invest in implementing more realistic tactile surface characteristics. Conversely, touch was less efficient at perceiving naturalness in fabric stimuli, suggesting that there were more similarities between the tactile properties of the natural and unnatural fabric stimuli than between the visual properties across stimulus category. Given the observed positive relationship between perceived naturalness, value and hedonics, and the potential differences across the senses in perceiving naturalness, it seems largely beneficially to consider these findings in the production of imitation textiles. Further studies are needed to investigate the relationship

between physical, affective and cognitive dimensions of material textures, in particular relating to those textiles that are commercially available.

7.6 Suggestions for future research

On consideration of these studies, a number of potential modifications for future research are apparent. Given the pioneering nature of these set of studies, it was beyond the scope of the project to include a larger stimulus set. Although a considerable foundation in the investigation of the perception of naturalness in materials has been made, there remains an opportunity to extend these findings by utilising a much larger range of materials by including a variety of wood and fabrics, and extending to stone, edibles (i.e. fruit and vegetables), plants, and skin (i.e. for application in prosthetics). While the use of ecological textures is becoming more popular in the literature (e.g. Ballesteros, et al., 2005; Guest & Spence, 2003a, 2003b; Picard, 2007), the dimensions that underlie the perception of naturalness and other higher-order evaluations are still largely unexplored.

Throughout these studies, the exploration used in the tactile condition was restricted to three clockwise rotations on a surface using the index fingertip. The purpose of this was to control the level of information received across participants and trials, and to avoid a confounding variable of exploration in the functional data. Although this type of lateral exploration is considered optimal for exploring texture information (Lederman & Klatzky, 1987), it may be the case that more multi-dimensional tasks, such as discriminating the naturalness of a texture surface, may involve other exploratory strategies. For instance, the presence of a disturbance in a surface pattern (e.g. a knot) may change the method of exploration of a wood surface, or a fabric material may be best explored using a thumb and forefinger. The exploration duration of three seconds utilised across the studies was considered appropriate for the categorisation tasks that were conducted. It would however be interesting to examine the influence of timing on the

perception of naturalness of these textures. An investigation of whether naturalness categorisation performance is affected by limited exploration would help unravel the contribution of implicit processes in the perception of naturalness.

In light of the growing literature on the affective and aesthetic processes in the brain (see Chapter 1), it may be expected to find activations associated with the perception of naturalness in frontal regions such as the orbitofrontal cortex. As these studies were explorational in nature, they sought to gain insight into the brain regions relating to the naturalness evaluation in general, and so used a whole-brain method when recording the data. As a consequence of this method, an unfortunate signal drop-out in the orbitofrontal region was suffered. Despite this, many clusters were activated in regions such as the cingulate cortex and posterior insula. This activity gives us a glimpse into the affective evaluation that is involved in the evaluation of naturalness in materials. Given the findings of Rozin and others (Ode, et al., 2009; Purcell & Lamb, 1998; Rozin, 2005, 2006; Rozin, et al., 2004) that we have a natural preference for foods, medicines and landscapes, further investigation is necessary to clarify the affective relationship that we have with natural materials, and the brain processes that are involved in this perception of these stimuli. Utilising specific sequence parameters when recording the functional data so that the orbitofrontal region is captured would be beneficial to such an investigation.

These investigations focussed on the explicit evaluation of naturalness in a set of material stimuli. While this approach was considered to be the most appropriate for the initial exploration of naturalness perception, it would also be interesting to examine whether the perceived naturalness of a material is subject to cognitive manipulation. In light of recent studies that demonstrate a cognitive modulation of the experience of pleasure (McCabe et al., 2008; Plassman et al., 2007), it would be fascinating to explore the influence of top-down information on the perception of naturalness in a material. For

example, the semantic or verbal labelling describing the hedonics or value of a texture stimulus could be manipulated in order to assess how these factors influence the perceived naturalness of a stimulus. If such a possibility exists, this would have critical implications for the advertising industry.

The functional studies conducted here demonstrated that a network of sensory, decision-making and affective regions were involved in the naturalness categorisation task. In order to unravel whether the areas observed here are generalisable to the perception of naturalness i.e. across different stimuli and as an abstract concept, it would be fruitful to conduct further investigations using multiple methodologies and stimulus types. Future functional studies that examine the implicit evaluation of naturalness, for example, using passive presentation of stimuli, attentional tasks or cognitive manipulation, or tasks that require participants to make other aesthetic, categorical, or hedonic evaluations of these stimuli would help elucidate how the perception of naturalness relates or differs from other aesthetic or perceptual decision-making tasks.

7.7 Final conclusions

The studies reported in this thesis contribute to a new and emerging field of investigation, which focuses on the neural processes underlying pleasure, aesthetics and moral evaluations in the brain. While a preference for naturalness has been implicated across many domains, the perception of naturalness in texture materials has been limited.

The work presented in this thesis aimed at unravelling whether naturalness perception is a sensory, affective or cognitive process. Considering the behavioural and neuroimaging results together, it appears that the perception of naturalness in materials is a multi-dimensional process that is primarily reliant on a sensory evaluation, but that also contains affective and cognitive evaluations. The behavioural studies demonstrated that people are adept at categorising wood and fabric stimuli in terms of naturalness in the

absence of any external information such as labelling. Furthermore, for fabric stimuli, the perception of naturalness is positively related to judgements of harshness, value and hedonics. The neuroimaging results indicate that the evaluation of naturalness in materials invokes a network of regions that have been previously implicated in texture-related perceptual tasks, along with decision-making, and moral and affective evaluation centres. Together the results highlight the complex mechanisms that underlie the evaluation of naturalness in materials. Further investigations examining the perception of naturalness across a wider stimulus set, using a number of methodological modifications, should focus on attempting to unravel the relationship between naturalness and other sensory and higher-order dimensions. This future work will help elucidate the importance of naturalness for the consumer, and will have critical implications within the manufacturing and advertising industries.

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APPENDICES

Appendix A

Ethics Approval Letter

School of Psychology
University of Dublin, Trinity College
Dublin 2, Ireland

Tel: +353 1 896 1886
Fax: +353 1 671 2006

F.A.O. Aisling Whitaker

School of Psychology Research Ethics Committee

1 March 2007

Dear Aisling,

Following clarification of the duration of fMRI scanning and the procedure for dealing with possible consequent anomalous findings, I am pleased to inform you that your application entitled "A neuroimaging investigation of naturalness" has been approved by the School of Psychology Research Ethics Committee.

Yours sincerely,

Kevin Thomas, PhD
Chair,
School of Psychology Research Ethics Committee

Appendix B

Behavioural Forms

Behavioural Information Sheet

Title of Project: *Title changed as appropriate*

Research Team: T. Aisling Whitaker, Cristina Simões-Franklin, and Fiona Newell
Multisensory Research Group, Trinity College Dublin

Information about the project:

We instinctively know whether something is natural, or a synthetic mimic. But the key factors responsible for this perception have yet to be identified: This is the primary objective of this project. We are interested in investigating how information obtained by the different senses contributes to the perception of naturalness. Additionally, we plan to examine the brain processes involved in the perception of naturalness.

In this study, you will be asked to explore a number of surfaces, one at a time, and to respond whether you think the surface is natural or not. **By natural we mean derived from nature**. The completion of this study will take approximately 1 hour.

The data collected will be kept in the strictest confidence and will be retained after the study is completed. It will not be used in future unrelated studies without further specific permission being obtained. If at any time during the research you wish to withdraw from the study then you may, without prejudice.

We would like to thank you for your attention and we would be very grateful if you decide to participate in our study.

If, at any time, you have any questions regarding this research, please feel free to contact T. Aisling Whitaker on whitaket@tcd.ie, Dr. Cristina Simões-Franklin on Cristina.Simoes@tcd.ie or Dr. Fiona Newell on Fiona.Newell@tcd.ie.

Behavioural Consent Form

Title of Project: *Title changed as appropriate*

Participation in the study is entirely voluntary and if you agree to participate you have the following rights:

1. The information from this study will be kept strictly confidential and will not be made available to any other people.
2. We will aim to publish our results in scientific journals but any information we have will be completely anonymous and presented as a group.
3. As participation is completely voluntary, you are free to withdraw from the study at any time, without prejudice.
4. Participants will be each assigned an identification code, and thus their data will not be identifiable. For this reason the Freedom of Information Act does not pertain to our study.

I, the undersigned, give my informed consent to participate in "*Title changed as appropriate*" conducted by the Multisensory Research Group, TCD at the Trinity College Institute of Neuroscience.

Full Name: _____

Signed: _____

Date: _____

T. Aisling Whitaker
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Appendix C

Edinburgh Handedness Inventory

Participant Code: _____

Please indicate your preference in the use of hands in the following activities *by putting* + *in the appropriate column.* Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, *put* ++. If in any case you are really indifferent *put* + in both columns.

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all questions, and only leave a blank if you have no experience of the object or task.

		LEFT	RIGHT
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife (without fork)		
7	Spoon		
8	Broom (upper hand)		
9	Striking match (match)		
10	Opening box (lid)		
i	Which foot do you prefer to kick with?		
ii	Which eye do you use when using only one?		

Appendix D

Fabric Stimuli

Table D.1. *Description of the fabric stimuli used in Chapter 4*

Stimulus	Fabric Type	Finish	Naturalness %
1	100% Wool	Fine	100
2	100% Cotton	Fine	100
3	75% Cotton 25% Wool	Fine	100
4	50% Wool 50% Cotton	Fine	100
5	100% Wool	Coarse	100
6	100% Cotton	Coarse	100
7	75% Wool 25% Cotton	Coarse	100
8	75% Cotton 25% Wool	Coarse	100
9	50% Wool 50% Cotton	Coarse	100
10	75% Wool 25% Acrylic	Fine	75
11	75% Cotton 25% Acrylic	Fine	75
12	75% Wool 25% Poly	Fine	75
13	75% Cotton 25% Poly	Fine	75
14	75% Wool 25% Acrylic	Coarse	75
15	75% Cotton 25% Acrylic	Coarse	75
16	75% Wool 25% Poly	Coarse	75
17	75% Cotton 25% Poly	Coarse	75
18	50% Wool 50% Acrylic	Fine	50
19	50% Cotton 50% Acrylic	Fine	50
20	50% Wool 50% Poly	Fine	50
21	50% Cotton 50% Poly	Fine	50
22	50% Wool 50% Acrylic	Coarse	50
23	50% Cotton 50% Acrylic	Coarse	50
24	50% Wool 50% Poly	Coarse	50
25	50% Cotton 50% Poly	Coarse	50
26	25% Wool 75% Acrylic	Fine	25
27	25% Cotton 75%Acrylic	Fine	25
28	25% Wool 75% Poly	Fine	25
29	25% Cotton 75% Poly	Fine	25
30	25% Wool 75% Acrylic	Coarse	25
31	25% Cotton 75%Acrylic	Coarse	25
32	25% Wool 75% Poly	Coarse	25
33	25% Cotton 75% Poly	Coarse	25
34	100% Acrylic	Fine	0
35	100% Poly	Fine	0
36	75% Acrylic 25% Poly	Fine	0
37	75% Poly 25% Acrylic	Fine	0
38	50% Poly 50% Acrylic	Fine	0
39	100% Acrylic	Coarse	0
40	100% Poly	Coarse	0
41	75% Acrylic 25% Poly	Coarse	0
42	50% Acrylic 50% Poly	Coarse	0

Note. Poly refers to polypropylene

Appendix E

Rating Scales

Table E.1. *Rating scales used in Chapter 4*

Characteristic	Scale	
Naturalness	0	Extremely unnatural
	1	Very unnatural
	2	Slightly unnatural
	3	Neither unnatural nor natural
	4	Slightly natural
	5	Very natural
	6	Extremely natural
Value	0	Extremely cheap
	1	Very cheap
	2	Slightly cheap
	3	Neither cheap nor expensive
	4	Slightly expensive
	5	Very expensive
	6	Extremely expensive
Hedonics	0	Extremely dislike
	1	Dislike very much
	2	Slightly dislike
	3	Neither dislike nor like
	4	Slightly like
	5	Like very much
	6	Extremely like
Roughness	0	Extremely rough
	1	Very rough
	2	Slightly rough
	3	Neither rough nor smooth
	4	Slightly smooth
	5	Very smooth
	6	Extremely smooth
Harshness	0	Extremely harsh
	1	Very harsh
	2	Slightly harsh
	3	Neither harsh nor soft
	4	Slightly soft
	5	Very soft
	6	Extremely soft

Table continues

Characteristic	Scale	
Pleasantness	0	Extremely unpleasant
	1	Very unpleasant
	2	Slightly unpleasant
	3	Neither unpleasant nor pleasant
	4	Slightly pleasant
	5	Very pleasant
	6	Extremely pleasant
Familiarity	0	Extremely unfamiliar
	1	Very unfamiliar
	2	Slightly unfamiliar
	3	Neither unfamiliar nor familiar
	4	Slightly familiar
	5	Very familiar
	6	Extremely familiar

Note. For half of the participants, scales were presented in reverse order to avoid order effects

Appendix F

MRI Forms

MRI Information Sheet

Title of Project: *Title changed as appropriate*

Research Team: T. Aisling Whitaker, Cristina Simões-Franklin, and Fiona Newell
Multisensory Research Group, Trinity College Dublin

Information about the project:

We instinctively know whether something is natural, or a synthetic mimic. But the key factors responsible for this perception have yet to be identified: This is the primary objective of this project. We are interested in investigating how information obtained by the different senses contributes to the perception of naturalness.

The present experiment aims to identify which areas of the brain are involved in the perception of naturalness. During the task you will either see or feel a selection of wood and/or fabric samples, one at a time, and your task is to respond whether you think the sample is of a natural or unnatural material. **By natural we mean derived from nature.** Throughout the entire task, your brain activity will be measured using Magnetic Resonance Imaging and prior to scanning, you will be trained on the task.

The study will take place at the MRI facility located at Trinity College Dublin. The session (including the MRI scanning) will take maximum 2 hours. If at any time during the research you wish to withdraw from the study then you may do so. All information gathered during the course of this research will be held in confidence and it is available to you upon request. Please do not hesitate to ask the researcher any questions you may have. If you are happy to be involved in this study, then please complete this consent form and make it available to the researcher.

We would like to thank you for your attention and we would be very grateful if you decide to participate in our study. If at any time you have any questions regarding this research, please feel free to contact T. Aisling Whitaker on whitaket@tcd.ie, Dr. Cristina Simões-Franklin on Cristina.Simoes@tcd.ie or Dr. Fiona Newell on Fiona.Newell@tcd.ie.

What is MRI?

The purpose of functional MRI scanning is to determine which brain regions are activated as someone performs certain tasks. In the MRI scanner there is a very large magnetic field. This magnetic field and radio signals which are transmitted in the scanner measure the concentration of water particles within the body, allowing brain functioning relating to behaviour to be measured in terms of blood flow to the brain. The person who is going to be scanned lies on a bed where their head is placed into a device which has the appearance of a large helmet. When the person has been safely and comfortably secured in this device, the bed is moved slowly into the scanner. When the person's head is in the middle of the magnetic field, radio frequency pulses and magnetic fields are switched on and off to produce a signal which we use for measuring blood flow.

Individual MRI test runs will last no longer than 10 minutes to minimise fatigue and the entire testing session will be completed within 60 minutes. It is very important that you keep still and, in particular, do not move your head while we are taking an image of your brain. For some images, you will be doing a cognitive task that you will have practiced outside of the scanner. For other images, you will just lie still and relax while we take high-resolution images of your brain. We will explain exactly what you need to do before we start each MRI test run.

What will I be asked to do while I am in the MRI scanner?

You will be asked to perform cognitive tasks that you will have already practiced with one of the researchers prior to the scanning session. During scanning, we will tell you what task to do before each scan by communicating through the intercom system.

What are the risks associated with MRI?

When operated by appropriately qualified individuals, MRI presents virtually no risk, as there is NO exposure to x-rays or radioactivity with this procedure. The noise produced by an MRI exam can be very loud and you will be issued with protective headphones or earplugs to prevent damage to your hearing. The noise produced by the exam has been reported to produce temporary threshold shifts (i.e., decreased ability to hear quiet sounds) in a small percentage of people. Given the confines of an MRI machine, a small percentage of people in the past have reported feeling claustrophobic (fear of being closed in a tight space) when placed into an MRI scanner. Please let us know if you have experienced claustrophobia in the past. During MRI scanning, you will be in contact with the MRI operator via an auditory communication system. This will be

used to regularly check your comfort and to allow you to inform us of any problems or concerns. You will also have a "panic button" which you may press at any time to indicate that you wish to stop the scanning procedure.

As the MRI involves a large magnetic field, it is essential that NO METAL BE BROUGHT INTO THE SCANNER WITH YOU.

Items that must be removed by individuals before entering the MRI facility include:

- Purse, wallet, money clip, credit cards, cards with magnetic strips;
- Electronic devices such as beepers or cell phones;
- Hearing aids;
- Metal jewellery (in all parts of the body), watches;
- Pens, paper clips, keys, coins;
- Hair barrettes, hairpins;
- Any article of clothing that has a metal zipper, buttons, snaps, hooks, underwire bras, or metal threads;
- Shoes, belt buckles, safety pins.

Other objects that may be hazardous include:

- Metallic spinal rod
- Plates, pins, screws, or metal mesh used to repair a bone or joint
- Joint replacement or prosthesis
- Metal jewellery such as that used with body piercing.
- Some tattoos or tattooed eyeliner (these alter MR images, and there is a chance of skin irritation or swelling; black and blue pigments are the most troublesome)
- Bullet, shrapnel, or other type of metal fragment
- Metallic foreign body within or near the eye (such an object generally can be seen on an x-ray; metal workers are most likely to have this problem)
- Dental fillings (while usually unaffected by the magnetic field, they may distort images of the facial area or brain; the same is true for orthodontic braces and retainers)

If you have any of these items, please inform us immediately.

There may be additional or unknown risks associated with MRI. For example, in very rare cases, the strong magnetic field can induce nerve stimulation (e.g., switching the strong magnetic field gradients during imaging has been reported to cause twitching in the neck

muscles). Also, in very rare cases, the radio signals have been reported to cause burns. There may be other risks associated with imaging that are not yet known.

Who shouldn't undergo the MRI procedure?

- Research participants who have the following items should not undergo an MRI procedure:
- Cardiac pacemaker or an implanted defibrillator
- Catheter that has metal components that may pose a risk of a burn injury
- A metal clip placed to prevent bleeding from an intra-cranial aneurysm
- A medication pump (such as that used to deliver insulin or a pain-relieving drug)
- A cochlear (inner ear) implant

It is essential that you inform the MR operator if you have any metal items in any of the above lists.

Pregnancy and MRI

For female participants it is also important that you tell us if there is any possibility that you are pregnant. To date there are no known risks of MRI during pregnancy, however as a precautionary safety measure pregnant individuals will not be included in the study. To participate in the current study women of child-bearing potential must be using one of the following acceptable methods of birth-control:

a. oral or transdermal contraceptives
b. barrier (diaphragm or condom) with spermicide
c. intrauterine progesterone contraceptive system
d. levonorgestrel implant
e. medroxyprogesterone acetate contraceptive injection
f. complete abstinence from sexual activity

What if the brain imaging finds some abnormality in my brain?

The brain images that we acquire are obtained for research purposes and are not the kind that would necessarily be prescribed for clinical diagnosis. Therefore, not all abnormalities, which might be detected with other MRI scans, will be detected by the scans done during this study.

The images of your brain will be checked by a radiologist. In the unlikely event of an irregularity being found by the radiologist, the radiologist will contact you GP and if advised to by the radiologist, the GP shall endeavour to contact you to arrange a meeting

with a radiologist. We will ask you, in a separate form, for your GP details prior to scanning. It is policy of the Trinity College Institute of Neuroscience to contact the GPs of ALL participants in MRI studies informing them of the participants' involvement. We will contact you GP, but we will provide NO details on the particular study in which you are involved but will inform them that you are undergoing magnetic resonance imaging and that your brain scans will be read by a radiologist.

Although a significant abnormality is extremely unlikely, you should be aware that if such an abnormality is detected and you are informed, then this knowledge might have consequences for you. Please take the time to consider carefully what it would mean to you if we told you of an abnormality in your brain which might, or might not, affect you later in life. Knowledge of an abnormality may affect your ability to work in certain professions, obtain life or health insurance and other facets of daily living. If you do not want to know, then it is better not to participate in this study.

MRI Consent Form

Title of Project: *Title changed as appropriate*

By providing my consent I agree that:

I have been informed of the discomforts and risks that I may reasonably expect to experience as part of this study. I have been informed that if a brain abnormality is observed, that I will be contacted for a meeting with a radiologist. I have been informed that when used on appropriately qualified individuals, MRI presents virtually no risk. There will be no exposure to x-rays or radioactivity in this study. I understand that noise produced by this exam could be very loud, and that I will wear earplugs or headphones to prevent damage to my hearing. Even with earplugs, the noise produced by the exam may produce temporary threshold shifts (i.e., decreased ability to hear quiet sounds). I have been informed that I may experience some discomfort from lying in the MRI scanner such as claustrophobia (fear of being closed in a tight space) or tight sensations from having my head restrained to prevent movement. I have been informed that I will also be asked to perform some tasks that I have been trained on, prior to the MRI procedure, which should not cause undue distress.

I have been informed that other risks of injury due to MRI include damage to implanted electronic devices (such as pacemakers), haemorrhage if aneurysm clips are present and trauma if ferrous metal objects are brought too close to the scanner. However, these risks are minimal in a properly administered site. I do not have any of these items in my body.

I understand these risks and am agreeing to volunteer to participate in this research. I understand that I can withdraw at any time from the study.

Participant	Witness
Name:_____	Name:_____
Signed:_____	Signed:_____
Date:_____	Date:_____

MRI Checklist

Do you have any of the following?

Cardiac Pacemaker: Yes No
Have you ever had any surgical procedures? Yes No
If yes, what type and where?_____

The following items may be harmful to you during your MR scan or may interfere with the MR examination. You must provide a "yes" or "no" for every item. Please indicate if you have or have had any of the following:

Yes	No	
____	____	Any type of electronic, mechanical, or magnetic implant Type:
____	____	Cardiac pacemaker
____	____	Aneurysm clip
____	____	Implanted cardiac defibrillator
____	____	Neurostimulator
____	____	Biostimulator Type:
____	____	Any type of internal electrodes or wires
____	____	Cochlear implant
____	____	Hearing aid
____	____	Implanted drug pump (eg, insulin, Baclofen, chemotherapy, pain medicine)
____	____	Halo vest
____	____	Spinal fixation device
____	____	Spinal fusion procedure
____	____	Any type of coil, filter, or stent Type:
____	____	Any type of metal object (eg, shrapnel, bullet, BB)
____	____	Artificial heart valve
____	____	Any type of ear implant
____	____	Penile implant
____	____	Artificial eye
____	____	Eyelid spring
____	____	Any type of implant held in place by a magnet Type:
____	____	Any type of surgical clip or staple
____	____	Any IV access port (eg, Broviac, Port-a-Cath, Hickman, Picc line)
____	____	Medication patch (eg, nitroglycerine, nicotine)
____	____	Shunt
____	____	Artificial limb or joint What and where:
____	____	Tissue expander (eg, breast)
____	____	Removable dentures, false teeth, or partial plate
____	____	Diaphragm, IUD, Pessary Type:
____	____	Surgical mesh Location:
____	____	Body piercing Location:
____	____	Wig, hair implants
____	____	Tattoos or tattooed eyeliner
____	____	Claustrophobia

Handedness: Right / Left

Native Language: _____

I have read and understood this form, and consent to my study being used for research. I have had a chance to ask any questions.

My contact phone number is: _____

My contact address is: _____

_____

_____

Signed (Volunteer): _____

Parent or Guardian if under 18: _____

Witnessed (Researcher/MR staff): _____

Date: _____

Hazard Checklist for MRI Personnel

Yes	No	
____	____	Endotracheal tube
____	____	Swan-ganz catheter
____	____	Extra ventricular device
____	____	Arterial line transducer
____	____	Foley catheter with temperature sensor and/or metal clamp
____	____	Rectal probe
____	____	Esophageal probe
____	____	Tracheotomy tube
____	____	Guidewires

Comments:

MRI Pregnancy Form

There are no known risks of MRI during pregnancy. However as a precautionary safety measure pregnant individuals will not be included in this study.

It is essential that female participants tell us if there is any possibility that they are pregnant.

To participate in the current study women of child-bearing potential must be using one of the following acceptable methods of birth-control:

a. oral or transdermal contraceptives
b. barrier (diaphragm or condom) with spermicide
c. intrauterine progesterone contraceptive system
d. levonorgestrel implant
e. medroxyprogesterone acetate contraceptive injection
f. complete abstinence from sexual activity

I confirm that I am using one of the methods of birth control listed above and can confirm that I am not pregnant.

Name: _____

Signed: _____

Date: _____

MRI Data Consent Form

Trinity College Institute of Neuroscience, (TCIN) is performing research, utilising an MRI scanner at Trinity College, Dublin 2. These research scans, although not full clinical scans, will be read by a radiologist.

In the unlikely event of an irregularity being found, the radiologist, [Dr William Torreggiani of The Adelaide and Meath Hospital Incorporating the National Children's Hospital (AMNCH), Tallaght] will inform the participants GP, that a proper clinical scan may be required to determine whether or not an irregularity is of clinical significance.

To enable us to perform the research scans the participant agrees to give consent/ permission for:

i. TCIN to conduct the MRI scan and store MRI scan data of participant;
ii. TCIN or Principal Investigator, (PI) to contact participants GP;
iii. TCIN radiographer to send MRI scan data to radiologist acting for TCIN;
iv. Radiologist to store data in a hospital system with same care as other patient data ensuring participants confidentiality;
v. Radiologist/ Clinician (acting for TCIN) to contact participants GP;
vi. TCIN to store data on the study for a period of at least 5 years or as specified in the specific consent form.

A dated standard letter signed by the appropriate Principal Investigator will be sent to all participants GP's, it is the responsibility of the Principal Investigator to ensure that this is sent at least two days before scanning to allow for postal delays. The principal investigator is responsible for their project at all times.

The TCIN designated radiologist will be sent data in a form that allows identification so that if a response is required he can act quickly (a copy of this is also held at TCIN). This will be stored in the hospital system with the same rigour and attention to confidentiality as all other medical data, as per the rules of that institution; a copy of this data will also be stored at TCIN. The raw scan data will be stored at TCIN in anonymous form for research purposes as agreed on the consent form of the specific research project.
I agree to the above points and understand that my data will be treated carefully at TCIN and in the hospital system.

Participant Name and Address: _____

_____

_____

Signed by Participant: _____

MRI Study Summary

Name: _____

Phone: _____

Sex: Male [ ] Female [ ]

Date of Birth: _____

Weight: _____kg

Please provide us with the details of another person (e.g., next-of-kin) should we need to contact you in the future.

Name of contact person: _____

Phone: _____

Study: _____

Time in: ____:____ Time Out: ____:____

Investigator: _____

