Touch and Emotion in Haptic and Product Design

by

Bertina Lee

A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Doctor of Philosophy
in
Systems Design Engineering

Waterloo, Ontario, Canada, 2012

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

Abstract

The emotional experience of products can have enormous impact on the overall product experience: someone who is feeling positive is more likely to be accepting of novel products or to be more tolerant of unexpected or unusual interface behaviours. Being able to improve users' emotions through product interaction has clear benefits and is currently the focus of designers all over the world.

The extent to which touch-based information can affect a user's experience and observable behaviour has been given relatively little attention in haptic technology or other touch-based products where research has tended to focus on psychophysics relating to technical development, in the case of the former, and usability in the case of the latter. The objective of this research was therefore to begin to explore generalizable and useful relationship(s) between design parameters specific to the sense of touch and the emotional response to tactile experiences. To this end, a theoretical 'touch-emotion model' was developed that incorporates stages from existing information and emotion processing models, and a subset of pathways (the 'Affective', 'Cognitive', and 'Behaviour Pathways') was explored.

Four experiments were performed to examine how changes in various touch factors, such as surface roughness and availability of haptic (that is, touch-based) information during exploration, impacted user emotional experience and behaviour in the context of the model's framework. These experiments also manipulated factors related to the experience of touch in real-world situations, such as the availability of visual information and product context.

Exploration of the different pathways of the touch-emotion model guided the analysis of the experiments. In exploring the Affective Pathway, a robust relationship was found between increasing roughness and decreasing emotional valence (n = 36, $p \leq 0.005$), regardless of the availability of haptic or visual information. This finding expands earlier research that focused on the effect of tactile stimuli on user preference. The impact of texture on the Cognitive Pathway was examined by priming participants to think of the stimuli as objects varying in emotional commitment, such as a common mug (lower) or a personal cell phone (higher). Emo-

tional response again decreased as roughness increased, regardless of primed context (n = 27, $p \leq 0.002$) and the primed contexts marginally appeared to generally improve or reduce emotional response (n = 27, $p \leq 0.08$). Finally, the exploration of the Behaviour Pathway considered the ability of roughness-evoked emotion to act as a mediator between physical stimuli and observable behaviour, revealing that, contrary to the hypothesis that increased emotional valence would increase time spent reflecting on the stimuli, increased emotion magnitude (regardless of the positive or negative valence of the emotion) was associated with increased time spent in reflection (n = 33, $p \leq 0.002$). Results relating to the Behaviour Pathway suggested that the portion of the touch-emotion model that included the last stages of information processing, observable behaviour, may need to be revised. However, the insights of the Affective and Cognitive Pathway analyses are consistent with the information processing stages within those pathways and give support to the related portions of the touch-emotion model.

The analysis of demographics data collected from all four experiments also revealed interesting findings which are anticipated to have application in customizing haptic technology for individual users. For example, correlations were found between self-reported tactual importance (measured with a questionnaire) and age (n = 79, r = 0.28, $p \leq 0.03$) and between self-reported tactual importance and sensitivity to increased roughness (n = 79, r = -0.27, $p \leq 0.04$). Higher response times were also observed with increased age (r_{IT} = 0.49, r_{RT} = 0.48; $p \leq 0.01$).

This research contributes to the understanding of how emotion and emotion-evoked behaviour may be impacted by changing touch factors using the exemplar of roughness as the touch factor of interest, experienced multimodally and in varying situations. If a design goal is to contribute to user emotional experience of a product, then the findings of this work have the potential to impact design decisions relating to surface texture components of hand-held products as well as for virtual surface textures generated by haptic technology. Further, the touch-emotion model may provide a guide for the systematic exploration of the relationships between surface texture, cognitive processing, and emotional response.

Acknowledgements

I would like to thank my supervisor, Carolyn MacGregor, both for invaluable help in guiding me through the research process and for allowing me the freedom to pursue my interests in both engineering and psychology. I would also like to give thanks to Ian Mackenzie for his constant support in all the long days and nights that went into writing. Finally, I would like to thank my family for their constant support throughout my university career, as well as to NSERC for providing the financial assistance that made this thesis possible.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

In a visually dominated world, the importance of touch in product experience is often underestimated. At the point of purchase, for instance, the visual modality can be the source of more than 70 per cent of product experience (Fenko, Schifferstein, & Hekkert, 2009) and, touch has a strong ability to impact product experience over time (Fenko et al., 2009). Further, the increasing prevalence of haptic technology in the mass market (Coles, Meglan, & John, 2011; Jones & Sarter, 2008) suggests that there would be significant benefit to understanding the link between touch and user experience. For example, one major focus of research in haptic technology is in the creation of simulations of touch experiences (Ahmaniemi, Marila, & Lantz, 2010) and such technologies have a wide range of applications from providing touch-based feedback in medical training applications (Lederman & Jones, 2011) to making online purchasing of fabric much more feasible (Dillon et al., 2001).

Whatever the application, it is beneficial to understand not only how to generate textures but also to understand their impact on user experience, how characteristics of the application area might affect it, and also how individual characteristics could impact enjoyment. For example, research has suggested that, all else equal, smooth textures are associated with more positive experiences or adjectives than rough textures (Ekman, Hosman, & Lindstrom, 1965; Zuo, Hope, Jones, & Castle, 2004). Studies have also shown that when users are feeling more positive, they are more likely to be receptive to new ideas and technology (King, Hicks, Krull, & Del

Gaiso, 2006; Peck & Wiggins, 2006). Put together, user experience is important not only because positive experiences tend to encourage technology acceptance, but also because positive emotional states are associated with better problem-solving and holistic decision making (Gerling & Thomas, 2005).

Touch-based information may take the form of surface properties of real world products or the form of simulated haptic textures and/or forces through complex algorithms (Ahmaniemi et al., 2010; Jones & Sarter, 2008). Although some studies examine how haptic signal property of vibration pulse duration may lead to annoyance (Marshall, Lee, & Austria, 2007), or positive feelings when haptic information is made more available to shoppers in a grocery store (Peck & Childers, 2006), it is not clear how these positive or negative feelings towards multimodal touch-based information arise or translate into behaviour. Indeed, reviews of haptic technology tend not to be focused on informing the designer as to how one might use tactile information to predict user experience or satisfaction (Paneels & Roberts, 2010; Coles et al., 2011) and subsequently impact user behaviour.

Given that touch is so important to product experience (Fenko et al., 2009; Schifferstein & Cleiren, 2005) and that haptic feedback technology is rapidly developing (Jones & Sarter, 2008; Ferris & Sarter, 2010), it would be beneficial to develop a framework of understanding to link touch, emotion, and behaviour. Such a framework could allow designers to focus their efforts on certain aspects of surface properties or haptic feedback technology. For example, understanding how each sensory modality can impact emotion could direct designers to focus on improving the user experience of a specific sensory modality because that channel might be most likely to elicit positive feelings.

The purpose of this research is to begin to address the question of how multimodal touch, in various settings reflective of the real-world, can influence emotion and behaviour. The main objectives included the development and testing of a touch-emotion model that encapsulates stages of information and emotion processing. The level of available real-world visual and haptic information comprising a 'touch' experience was manipulated in each experiment using real-world objects, so that findings might be considered in the context of both real-world product and haptic technology design.

The developed touch-emotion model consists of various main information flows between perception, cognition, emotion, and behaviour. Three pathways (termed the Affective, Cognitive, and Behaviour Pathways) between each of these stages were selected for further experimental analysis. Additionally, demographics data were acquired from all experiments for the purpose of relating factors such as gender, age, and propensity for touch to user experience. The final objective of this research was to link experimental findings to potential application areas in both product design and haptic feedback technology so that designers may better understand how to manage user experience through touch properties such as surface texture.

1.1 Document Structure

This research document describes literature relevant to the concepts of touch as it pertains to emotion and behaviour in Chapter 2, and then outlines the theoretical touch-emotion model as a framework to understand how factors of touch may impact both emotion and behaviour in Chapter 3.

Four experiments and their individual analysis are then detailed in Chapters 4–7. Experiment 1 served as an exploratory study that guided the investigations undertaken in Experiments 2–4. Each experiment considered a subset of the complete list of touch factors of interest; all experiments used roughness as the controlled parameter to provide the main touch experience.

Meta analyses of data from two or more studies follows in Chapters 8–11. These analyses consider specific pathways from the proposed touch-emotion model in an attempt to verify the validity of those pathways. The combined analysis of all demographics data from all four experiments is also included here. A discussion concerning how the results from each combined analysis impacts product or haptic technology designers concludes each of Chapters 8–11.

The extent to which findings agree or disagree with the proposed theoretical model is discussed in Chapter 12. Contributions to theory, methodology, and application, assumptions and limitations of the work, and suggested next steps for future touch-related research are also discussed in Chapter 12.

Supporting documents such as experimental questionnaires, exploratory results, and detailed tables, are available in the Appendices. Finally, terms and definitions relevant throughout the document are included in the Glossary, which gives a page reference for the use of the term.

Chapter 2

Background

Much research has been conducted concerning the function and capability of haptic technology (e.g., Jones & Sarter, 2008; Ahmaniemi et al., 2010; Coles et al., 2011; Lederman & Jones, 2011). Similarly, there is much in the experimental literature that focuses on the psychophyiscal properties of touch (e.g., Lederman, 1982, 1997; Hollins & Bensmaïa, 2007; McGlone, Vallbo, Olausson, Loken, & Wessberg, 2007). With the exception of a limited number of studies (Ekman et al., 1965; Citrin, Stem, Spangenberg, & Clark, 2003; Perreault & Cao, 2006; Groot, Winter, García, Mulder, & Wieringa, 2011), there appears to be little experimental research that focuses on the impact textured product surfaces may have directly on a user's emotional experience and in turn on a user's behaviour with said product.

Since emotions have been found to have a powerful impact on how information is attended to, processed, and applied towards decision making (Bechara & Damasio, 2005; Peck & Wiggins, 2006; Cabanac & Bonniot-Cabanac, 2007), it is not surpising that the user's positive experience of the interaction with the product or technology is considered to be of significant importance (Hancock, Pepe, & Murphy, 2005; Khalid, 2006; Norman, 2004). However, recent surveys of the state of the art in haptic technology (e.g., Coles et al., 2011; Paneels & Roberts, 2010; Jones & Sarter, 2008) give very little in the way of design guidelines that would maximize user experience and performance from the perspective of changing basic touch features like surface roughness in situations reflective of the real-world. In essence, it would be insightful to investigate how immediate emotions can be predicted and by which touch-related factors, such as surface roughness or availability of touch information (see Equation 2.1). Further, it would be useful to investigate how that emotion may in turn predict measurable behaviour (see Equation 2.2).

$$Emotion(touchFactor1, touchFactor2, ...) = +ve/-ve \tag{2.1}$$

$$Behaviour(Emotion(touchFactor1, touchFactor2, ...)) = ? \tag{2.2}$$

This Chapter reviews the background literature necessary for defining emotional responses and understanding how they may be affected by touch-based experiences.

2.1 Emotion

The concept of 'emotion' and the nature of emotional response needs to be understood and defined before emotional responses to changing touch parameters can be predicted or measured. A brief history of emotion illustrates how diverse the concept can be: a definition of emotion has been tackled by philosophers, psychologists, and biologists, to name a few (Angeli & Johnson, 2004). Views on emotion vary from it being adaptive to it being disruptive (Leeper, 1948), with effects ranging from the physical to the cognitive (Plutchik, 1991).

Although there are a few qualities of emotion that can be generally agreed upon, many schools of emotion research point to the existence of two aspects of emotion: a 'feeling' state and a physiological response (James, 1884; Plutchik, 1991; Bechara & Damasio, 2005). Feeling states are contributed to by instinct, perception, cognition, and physiology, although the exact nature of feeling states is still unknown (Castelfranchi, 2000). Feeling states can be classified into groups of emotional patterns, such as fear or joy, and can also be generally classified as having positive or negative valence (fear is negative and joy is positive) (Anders, Lotze, Erb, Grodd, & Birbaumer, 2004). According to Plutchik (1991), physiological responses are of two types, sympathetic (arousal) or parasympathetic (rest). The level of arousal can be related to feelings of emotional benefit through the Wundt curve (Walker, 1980), which views emotional valence as the degree of positive or negative feelings that is an inverted 'U' function of arousal (see Appendix A). Physiological responses of either arousal or rest contribute to emotional intensity (e.g., a quickly beating heart for intense fear), so any experiment seeking to capture emotion should include a measure for intensity in addition to valence.

A second aspect of emotion that sees cross-disciplinary agreement (in psychology, neurology, and design) relates to the first, and says that emotion has two response components. According to Castelfranchi (2000) and others (Martinho, Machado, & Paiva, 2000; DiSalvo, Hanington, & Forlizzi, 2004), emotion is composed of an affective portion (which can be viewed as being associated with immediate physiological responses and is similar across normal individuals) and a cognitive portion (which can be viewed as being associated with the determination of the 'feeling state'). Affective responses are the process of non-declarative, associative, or adaptive response (Plutchik, 1982), meaning that they are likely to be the same across all individuals (e.g., the emotion of fear in response to personal threat). It happens very quickly, can often be quite visceral, and does not recruit cognitive processes (Zajonc, 1984; Angeli & Johnson, 2004) and can have subliminal effects on preference (Hilsenrat & Reiner, 2011). An example of an affective response to a product might be:

> *'It is beautiful and I like it'.*

Combining the work of Plutchik (1982) and Angeli and Johnson (2004), it would seem reasonable to suggest that since affective responses result in basic tendencies to act, they might be associated with behaviours such as 'approach' or 'avoid' behaviours. The second type of emotional response is the cognitive response, which recruits information from long or short term memory, be it knowledge or experience. An example of cognitive response might be:

'It is beautiful because it reminds me of home.'

Cognitive responses are more complex, often recruiting information from other input channels in a logical way to form a goal (Lazarus, 1984; Plutchik, 1982; Castelfranchi, 2000). Therefore, information about the context of an emotional stimulus (such as the type of product to which the stimulus belongs and the function of the product) also influences cognitive response.

In summary, emotional responses have both valence and intensity, and emotions can occur along two pathways, the 'Affective' and the 'Cognitive' Pathways. These characteristics of emotion are relevant to haptic technology or touch-based product designers in that they suggest a way to measure emotion and also suggest two information processing pathways through which to maximize user experience.

2.2 Current methods of emotional design

Current attempts to understand and predict general (non-touch-specific) user experiences from product interactions include top-down approaches such as Kansei engineering (Nagamachi, 2002) or affective engineering (Chen, Barnes, Childs, Henson, & Shao, 2009), which attempt to relate high level feelings such as 'elegant' and 'classy' to specific design parameters such as 'speed' or 'weight'. These top-down approaches tend to be product-specific, with a different set of rules for each product type. In contrast to the top-down approach, the bottom-up approach is more generalist and seeks to understand how each design parameter on each sensory modality in isolation (such as the visual experience of a surface property) can impact the entire emotional experience (Liu, 2003). This latter approach is appealing because it allows designers to iteratively improve haptic experiences by focusing on one design parameter or one modality at a time, without a new set of guidelines for each product class.

2.3 Emotion models

The framework under which the current investigation of touch as it relates to emotions and behaviour adopts the bottom-up approach discussed previously. To gain a better understanding of how information flows from touch to emotion, existing models of emotion and information processing were considered. Plutchik (1982) presents a circumplex model of emotion that offers the idea that patterns of emotions (such as anger, happiness, or sadness) vary in degree of similarity and intensity, and exist as bipolar couples (e.g., happy-sad, interested-bored). A second model put forward by Plutchik, the sequential model, is the notion that emotions arise from a pathway of processing starting with stimulus information (from either the environment or from internal thoughts) and include stages for cognition, physiological arousal, feeling state, impulses to action, and overt behaviour (see Appendix B for more details on the sequential model). The sequential model deemphasizes the need to distinguish between which components of emotion (feeling state and physiological arousal) happen first, a point of contention among psychologists (Zajonc, 1984; Lazarus, 1984). The debate can be argued to be less relevant from a practical perspective. That is, if the goal of modelling touch experiences of products or haptic technology is to have ready application in design, such a model should be more focused on the latter stages of emotion processing (impulses to action and behaviour) because these directly impact how touch-based systems are experienced and used.

The sequential theory of emotion is similar in ways to the information processing model described by Wickens and Hollands (2000), which models the stages of brain activity that occur at the onset of a stimulus and carries on through perception, cognition, all the way to decision making and behaviour (see Appendix C for more detail on the information processing model). Although emotion does not appear explicitly in the Wickens and Hollands (2000) information processing model, it nonetheless has potential to impact behaviour. Mehrabian and Russell (1974) offer the concept of environmental psychology that also supports the idea that emotions impact behaviour, as emotion is placed between the stimulus world and observed behaviour in their model of emotion processing, although it does not differentiate between the alternate paths (affective and cognitive) towards behaviour.

The existing general emotion and information processing models discussed above are for general experiences, and as such, it is unclear how a multimodal experience such as touch may predict later stages of processing. It would be useful for product or haptic technology designers to understand how touch-specific information flows through the various stages of processing to bring about user experience and behaviour.

Further, the above models do not attempt to capture the relationship between psycho-physiological processes of emotion and their effect on observable behaviour. That is, if a certain physical touch parameter is increased or decreased, current models do not suggest how emotion or behaviour can be impacted.

It would be beneficial to develop a theoretical model for understanding emotion and behaviour as it arises from touch experiences in which it is clear how each stage of the model has direct implications for design and engineering parameters. Such a model could be used by designers and researchers in the field of touch-based products or technologies for the purpose of predicting how users may be affected by specific changes in, for example, surface texture or availability of multimodal touch-based information.

2.4 The sense of touch

Some aspects of the sense of touch and associated vocabulary should be discussed. Hands are most often used in product exploration, so touch in the context of this research will refer to manual exploration of stimuli. A complete 'touch experience' is a multimodal one, involving vision and audition in addition to the haptic component (Ernst, Lange, Planck, & Newell, 2007; Suzuki, Gyoba, & Sakamoto, 2008) that is experienced via the skin and can be used to obtain information concerning surface properties such as texture, warmth, shape, and weight. Although objects can be explored by isolating touch from vision and audition, such cases happen rarely in reality (Paterson, 2007). Since haptic and visual information are more predominant in the experience of products (Schifferstein & Cleiren, 2005; Fenko et al., 2009), these two modalities will be the focus of this research.

2.4.1 Perception of haptic information

Texture is a main component of the haptic sensing of surface properties (Han & Hong, 2003), and its experience begins with four different types of cutaneous mechanoreceptors (Lederman, 1997). Haptic experiences also involve temperature receptors, proprioceptors and pain receptors (Visell, 2009), the latter of which will not be discussed. All factors that influence haptic experiences can be linked back to these receptor channels. This research looks at 'haptic information' primarily as information pertaining to surface texture, although the impact of weight and shape as they occur during active exploration is also given consideration.

2.4.2 Dimensions of texture

Research on the manual perception of surface properties have focused overwhelmingly on texture, and specifically on roughness, which is regarded as the primary dimension of texture (Lederman, 1982; D. Picard, Dacremont, Valentin, & Giboreau, 2003; Hollins & Bensmaïa, 2007). For example, in a study conducted by Bergmann Tiest and Kappers (2006) where 124 different material samples were analyzed with multidimensional scaling, it was found that the rough-smooth axis was best able (better than the next-most important axis, the hard-soft axis) to capture the space of similarities and dissimilarities between all 124 materials. In likely response to the importance of texture and roughness in the experience of touch, much research in the area of haptic technology has also focused on the algorithmic simulation of textures such as roughness (Jones & Sarter, 2008; Ahmaniemi et al., 2010; Paneels & Roberts, 2010).

Texture can also be further decomposed. Numerous studies have conducted multidimensional scaling of participants' categories of sorted textures to identify the generally agreed upon primary 'axes' of texture (D. Picard et al., 2003; Hollins & Bensmaïa, 2007). After the rough-smooth dimension, only the soft-hard dimension has been generally accepted as an independent determinant of texture (D. Picard et al., 2003). Various researchers support a number of other texture dimensions such as the dimensions of cool-warm (McGlone et al., 2007), sticky-slippery (Hollins & Bensmaïa, 2007), light-heavy (D. Picard et al., 2003), dry-wet (Chen, Shao, Barnes, Childs, & Henson, 2009; Choi & Jun, 2007) and thick-thin (D. Picard et al., 2003; Choi & Jun, 2007). While studies that examine these dimensions have found that only the rough-smooth and hard-soft dimensions may be independent axes of texture perception, some of these dimensions may contribute to the emotional response to texture in unexpected ways.

Given that roughness has been studied in such detail, it is worth considering how individuals might differ in its perception. While research on roughness has found its perception to be the most important determinant of texture regardless of product context, there is controversy in what determines its rating. Bergmann Tiest and Kappers (2007) studied the responses of 12 participants to stimuli varying in spatial density of sand particles on paper and found that the participants gave different ratings for the same stimuli, although within-individual consistency remained high. Manipulating the velocity at which a surface is contacted also appears to produce conflicting results in terms of perceived roughness (Samra, 2009), although the opposite result has been found that suggests roughness perception can be predicted by hand speed (Lederman, 1982). Vibration also seems to be important in the perception roughness, but it is unclear if it is more important than surface friction or tangential force (Bergmann Tiest & Kappers, 2007; Kyung & Kwon, 2006). Although consistent absolute ratings of roughness seem difficult to pinpoint and predict with physical parameters, studies examining the perception of changes in perceived roughness are in greater agreement. A number of studies (Ekman et al., 1965; Lederman, 1981; Lawrence, Kitada, Klatzky, & Lederman, 2007; Suzuki et al., 2008) suggest that increased roughness via varying particle spacing of abrasive paper or groove widths of a grating reliably leads to increased ratings of roughness within individuals in a 1-to-1 mapping. Ekman et al.'s (1965) study concerning roughness, smoothness and preference found that participants interacting with abrasive paper tended to prefer the smoother textures. However, participants could not see the stimuli and also provided their responses as a ratio (which subsequently underwent a log-transformation in the analysis), making results difficult to interpret and to apply to real-world (and multimodal) experiences.

These findings shed light on the importance of roughness in the experience of texture. Further, although absolute ratings of roughness can vary due to individual differences, as well as due to the kind of roughness manipulation, the finding that roughness perception can be predicted within-individual makes it an ideal candidate for investigation into how varying it can impact both emotional and behaviour responses for the average individual.

2.4.3 Multimodal touch

As previously mentioned, the natural experience of touch often occurs in conjunction with vision and audition (Paterson, 2007). This interplay between haptic, visual, and audio information in perceptual responses must be considered here because the interplay is likely to affect emotional responses as well.

In most natural settings, the sensory dominance of vision in humans is likely to interfere with the ability to report on the other senses (Gallace, Tan, & Spence, 2007). However, depending on the activity, other senses can also obtain dominance. In the particular experience of a textured surface, touch becomes the dominant input modality. The sound of the contact between the hands and the surface largely goes unnoticed (Soto-Faraco & Deco, 2009), although vision can still bias surface quality judgments (Lederman & Abbott, 1981). So when attention is called to texture, people will use both haptic and visual information strongly and audio information weakly. The term 'touch experience', in the context of this work, focuses on the combination of available haptic and visual information and does not purposefully manipulate the audio modality on the grounds that a) it has a weaker impact on the overall experience of touch-based stimuli and b) considering only the haptic and visual channels allows for greater tractability of experimental design and analysis.

Research has been conducted that examines the interaction between sensory pairs (for example, touch-vision and touch-audition). The perception of touch and vision together has been studied in greater detail. Previous work suggests that in such cases where haptic and visual input are both available, vision is used to capture macroscopic details such as shape and spatial density while haptics may be used to process microscopic details such as texture and material (Lederman & Abbott, 1981; Klatzky, Lederman, & Reed, 1987). In many cases, vision is perceived as the dominant input channel, but this is likely because of its ability to process information quickly and in parallel – for example, overall shape and colour (Whitaker, Franklin, & Newell, 2008) – while the haptic channel is limited to serial processing which often takes more time and effort (Schifferstein & Cleiren, 2005). Since attention is directed to whatever input modality provides the most reliable information for the required task, as Lederman and Abbott (1981) describes with the concepts of ecological validity and directed attention, care should be taken when defining tasks in any experiment designed to examine multimodal touch and emotion.

2.4.4 Types of touch

In terms of exploration procedure, touch is classified as being either active, involving hand movements, or passive, where the stimulus is presented to the surface of the hand (Gibson, 1962; Bolanowski, Verrillo, & McGlone, 2004). Natural product interactions most often utilize active touch (Bensmaïa & Hollins, 2005), such as picking up a mobile phone or using a haptic computer interface device like the PHANTOM® force feedback device.

There are differences in perception between the two touch procedures: under active touch, product identification and determination of size and proportion are more accurate than under passive touch (Lederman, 1982; Lederman & Klatzky, 1987). Another study revealed that under active touch, surfaces are perceived to be rougher under active touch in comparison to passive touch (Kyung & Kwon, 2006), although opposite results indicating that texture is dependent only on relative motion between skin and surface have been found (Whitaker et al., 2008). These differences must be considered in designing experiments that seek to measure the impact of touch procedure on emotional response.

2.4.5 Availability of haptic and visual information

In perception research, at least one model describes perceived roughness (PR) as the weighted (or percentage) combination of information obtained from the haptic and visual channels (Lederman & Abbott, 1981; Lederman, Thorne, & Jones, 1986), as shown in Equation 2.3. This general relationship has also been shown to apply for compliance (hard-soft) ratings (Kuschel, Di Luca, Buss, & Klatzky, 2010).

$$PR = w_{vision} * PR_{vision} + w_{haptics} * PR_{haptics} \tag{2.3}$$

$$w_{vision} + w_{haptics} = 1$$

The experimentally supported relationship of Equation 2.3 found in perception research provides a starting point to answer the question of how emotional responses may be affected by perceptual factors in touch experiences. Based on the factors apparent in Equation 2.3, preliminary questions include whether or not varying the availability of haptic or visual information can impact emotional response, and whether or not they do so in interaction.

Various amounts of available haptic and corresponding visual feedback have been used in perceptual studies before, but research is inconclusive about whether they are capable of conveying the full touch experience (Bergmann Tiest & Kappers, 2007; Cant, Large, McCall, & Goodale, 2008). It is also unclear what the impact of manipulating the availability of haptic and visual information would have on touch-evoked emotion.

The motivation for considering the availability of haptic and/or visual touch-based information on emotional response relates to the applicability of research findings in design. For example, it would be worthwhile to consider situations in which no direct haptic information of a texture is provided, reflecting on such situations as the online shopping for clothes where surface properties of material may be very important to the consumer but visual information alone is available. It would also be worthwhile to understand the emotional response to the combination of high relevant haptic[1] (in which a real object can be directly touched and handled) and high relevant visual information (in which a real-world object can be directly observed), reflecting situations such as in-store purchasing of goods. Further examples of worthwhile considerations include situations of moderate availability of relevant haptic feedback (such as restricted haptic information) and limited visual information (such as when the real object is not directly available to vision).

The above examples propose considering levels of haptic information at what might be considered a 'macro' degree of manipulation: full haptic feedback (including both proprioceptive and tactile sensing), limited exploration, or no relevant haptic information. Similarly, vision is proposed to be considered at a macro degree: real-world visual information, visual information on a screen, and no relevant visual information.

It is also possible to consider a more 'micro' degree of manipulation of the level of haptic information. For example, such a manipulation might involve using a 'limited exploration' scenario and putting tape of various thickness on the finger pad in order to restrict the amount of texture information that can be obtained (Lederman, 1982). Another method might also use a 'limited exploration' scenario

[1]Relevant haptic information refers to situations where the haptic experience is related to the stimuli; the use of a mouse to interact with an online texture does not provide 'relevant' haptic information to the experience, whereas the physical handling of a mobile device in a store does.

that instead constrains the experience of texture information to that which can be obtained through a probe (Lederman & Klatzky, 1998; Lederman, Klatzky, Morgan, & Hamilton, 2002; Lawrence et al., 2007). Similarly, 'micro' manipulations of visual information have also been considered in the study of virtual displays, where all visual information is available on a screen, and only the complexity of the visual information is changed (Artacho-Ramírez, Diego-Mas, & Alcaide-Marzal, 2008).

These 'micro' manipulations of haptic and visual information levels are equally valid, but for the purposes of design-oriented research, the 'macro' level manipulation of the availability of information was deemed more appropriate, since varying the direct availability of haptic or visual information in this 'macro' way would potentially allow for deeper understanding of the applicability and limitations of effectors on emotional response to touch in practical design and situations of typical product interaction.

2.5 Towards understanding emotional responses and changing touch parameters

Literature suggests that, unlike shape perception (the haptic and visual experience of which relies on spatial reasoning), the contributions of haptics and vision to texture perception are independent and complementary (Whitaker et al., 2008). The contribution of each of the haptic or visual modalities to a perceptual assessment, however, can depend on the question; research conducted by Lederman and colleagues (Lederman et al., 1986) shows that, for identical raised-dot stimuli, if the participant is asked to rate the 'roughness' versus 'spatial density' of the stimuli, the relative weightings of information obtained from haptics and vision will be stronger, respectively. It should be noted that in such studies, although there were differences between ratings of roughness acquired from the haptic versus visual modality, these differences tended to be small (Bergmann Tiest & Kappers, 2007).

It would be insightful to determine if similar patterns are true for emotional responses in addition to perceptual ratings. Therefore, to aid in the development of a model to link multimodal emotional responses to changing surface properties, the availability of touch-related haptic and visual information was manipulated in conjunction with the main factor of roughness.

2.6 Towards understanding cognition and emotional responses to touch

The idea that emotions act at two levels, an affective level and a cognitive level, is suggested in a number of sources: a) Plutchik's (1991) sequential model of emotion (see Section 2.1) with the concepts of physiological arousal contrasted with cognitive processing; b) work by Norman (2004) and his concepts of visceral and reflective emotions; and c) the feeling-versus-physiology debates between Zajonc (1984) and Lazarus (1984), who argue the primacy of each, respectively, on emotional response but implicitly accept that both impact it.

The notion of a 'direct' path from stimulus to emotional response was considered first by James with the notion that emotions are nothing more than the perception of changes in the body (James, 1884) and is also supported by Norman (Norman, 2004) with his 'visceral response' percept. But the idea that stimuli are perceived and then further processed cannot be ignored. The premise of Kansei Engineering posits a different set of rules for relating design parameters with qualitative descriptors for every different product group (Nagamachi, 2002). If cognitive processes drawing on the knowledge and experience of different product types had no impact on qualitative experiences and emotions, there would be no need to conduct separate Kansei Engineering analyses on cars, chairs, and so on.

Under the assumption, then, that perception precedes both the affective and cognitive processing of emotion, it is reasonable to test the hypothesis that cognition is a moderating factor between stimuli and touch-elicited emotion. That is, cognition interacts with touch-based stimuli in affecting emotion.

2.7 Towards understanding emotion and behaviour in response to touch

Immediate emotion, distinct from underlying and longer-lasting moods, can be influenced by product interactions (Khalid, 2006) and have the ability to directly impact decision making (Loewenstein & Lerner, 2003). For example, in a study conducted by Cabanac and Bonniot-Cabanac (2007), there is evidence that under conditions of time pressure, participants make decisions on a questionnaire based on maximizing the positive emotions they felt from the question items, even if those decisions are not rationally optimal. Further, by environmental psychology theory, emotions can serve to mediate between stimuli in different contextual information in the environment (such as product type) and elicited behaviour (Koufaris, 2002).

It is possible that the relationship between behaviour and emotion in the context of changing touch is a simple linear one, with more positive emotions bringing about more approach behaviours. However, in considering the Wundt curve (Walker, 1980), where emotional response is a function of an inverted U-shaped function of arousal or stimulus intensity, it might also be possible that a different axis of emotion, for example, the interest-boredom axis, best describes the relationship between behaviour and touch-elicited emotions. Both ideas can serve as a starting point to examine the relationship between emotion and behaviour.

Concentrating on the positive-negative axis as a possible main predictor of behaviour, it is reasonable to test the hypothesis of emotional valence being a mediator between stimulus and behaviour. That is, emotional valence acts as a stage between roughness stimuli and observable behaviour.

Chapter 3

Developing a Model

There have been two main thrusts of activity in this research: the development of a model that encapsulates the interactions between touch experiences, emotions, and behaviour, and the design and execution of controlled experiments to examine the manner in which touch experiences can predictably influence emotion and behaviour.

3.1 Approach

Emotional responses to products and haptic technology are made from the processing of a plethora of multimodal information. However, in keeping with the bottom-up approach developed by Liu (2003), this work focuses on understanding how the touch experience (comprised of the haptic experience and the haptic-related visual information) can impact emotional responses in situations reflective of the real-world, and how that emotion in turn might impact behaviour. Also, due to the multiple components of haptic experiences, this work will focus only on examining the impact of roughness for the reason that it is the strongest axis of texture (and thus should have the most measurable effects on emotion), and because of the existing body of roughness perception research from which parallels may be drawn. For example, Lederman's (1981) work provides insight into the relative contributions of the haptic and visual modalities in the perceptual experience of roughness, and Ekman's (1965) research looks at the unimodal (tactile) experience of roughness and preference. Further, from an application point of view, haptic technology has reached a point of simulating various textures, including roughness (Paneels & Roberts, 2010), and thus there is opportunity for application of any findings in areas of haptic feedback design as well as general product design.

3.1.1 Factors of interest

Roughness is one dimension of the experience of touch that is of interest. However, besides roughness, there are other factors which may have significant impact on the user experience of products or haptic technology. Visual fidelity of the stimuli, the amount of visual information available, and product context of the stimuli are also factors that should be considered and are discussed below.

Although haptic technology has come a long way, current technology is still limited in terms of the immersive experience of force feedback and texture simulation (Coles et al., 2011). In addition to understanding the relative contribution of the haptic and visual channels to emotional and subsequent behavioural responses in touch-based systems, it is also worthwhile to look at how the macro availability of information from each modality (haptic or vision) can impact response.

Insights into the extent to which a lower amount of available haptics can impact the emotional experience of the interaction would be applicable in understanding the experience of purchasing products online, when full visual information of a product may be available but the haptic information is not available. In a similar argument, the impact of the amount available visual information on emotional response is also relevant for touch experiences. This is true in the case where designers provide visual simulations (e.g., online visual samples of different fabrics) of touch experiences that can vary widely in terms of quality of the simulation (e.g., high-resolution digital rendering versus a photograph).

The impact of cognition on the emotional response to touch experiences should also be taken into account. From a product or haptic technology design perspective, one way to consider the impact of cognition is by considering product context that would draw from previous knowledge and experience. From the perspective of Kansei engineering and affective engineering, product context plays a considerable role in how design parameters ultimately affect the user's experience (Nagamachi, 2002). The availability of haptic and visual information along with product context, therefore, may each contribute in different ways to the overall emotional response to touch experiences.

3.1.2 Possible covariates of interest

Research has shown that age and gender both play a role in terms of touch sensitivity, which declines with age (Verrillo, 1993), and preference for touch experiences, which is purportedly higher for females (Citrin et al., 2003). An individual's propensity towards haptic experiences is also shown to have an impact on how they interact with various products (Peck & Childers, 2003; Peck & Wiggins, 2006). A final covariate of interest is ethnicity. There is evidence that ethnicity plays a role in the qualitative enjoyment of products (Han & Hong, 2003) and perhaps even in sensitivity to haptic experiences due to different skin make-up and surface sensitivity between ethnicities (Rawlings, 2006). As a result, potential covariates of interest in the study of touch-induced emotions and behaviour include age, gender, touch importance, and ethnicity.

3.2 Conceptual model

By using the approach detailed in Section 3.1, the model depicted in Figure 3.1 was developed. This figure depicts the full touch-emotion model, with considerations for the possibility of information being fed back into the system (shown by the dashed lines). This experimental research is focused on the forward pass of information (shown by the solid lines) and the particular sub-pathways of the Affective, Cognitive, and Behaviour Pathways, which are shown in Figures 3.2 – 3.4.

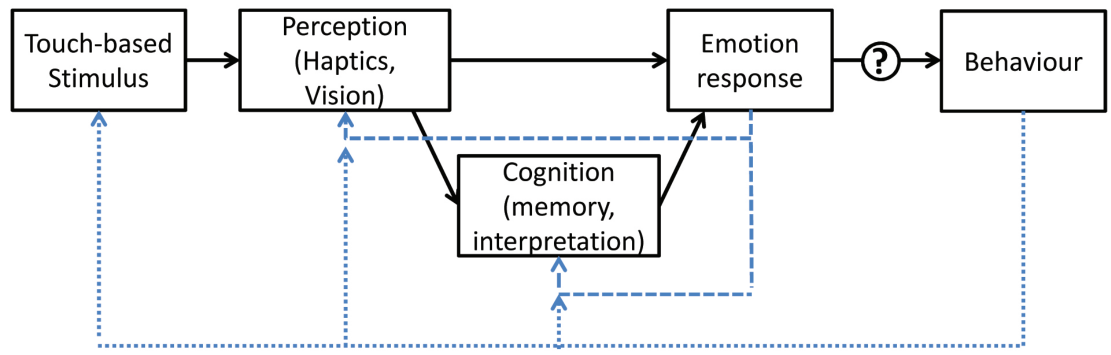


Figure 3.1: The full touch-emotion model: touch-based information flows perception through each of the applicable stages, and information may be fed back through the system. A subset of pathways in this full model is considered in this research.

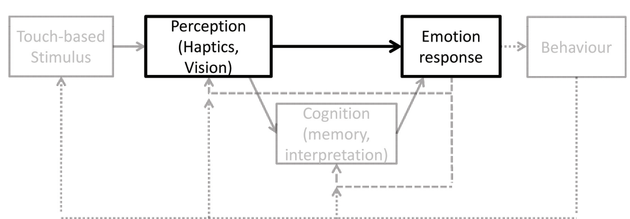


Figure 3.2: Information in the 'Affective Pathway' moves from Perception directly to Emotion.

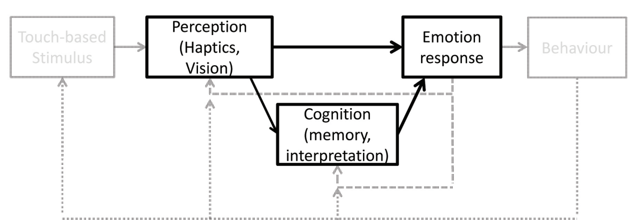


Figure 3.3: Information in the 'Cognitive Pathway' interacts with the Affective Pathway by also moving from Perception, Cognition, and on to Emotion.

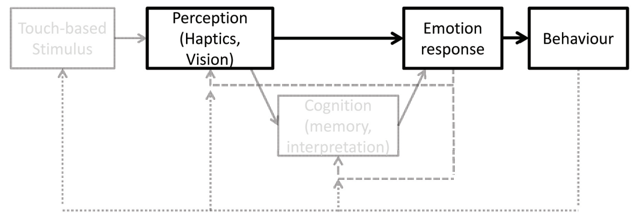


Figure 3.4: Information in the 'Behaviour Pathway' moves from the Emotion stage to the Behaviour stage.

The touch-emotion model in Figure 3.1 takes a bottom-up approach focused on practical application and is subject to a number of constraints:

1. The emotions being measured are due to physical design factors and therefore excludes emotions due to internal reflection because a) experimentally it is difficult to control internal reflection as an initiator of emotional response (e.g., thinking about a fond childhood stuffed animal and feeling happy); and b) from a practical standpoint, it is more useful for designers to understand how controllable physical parameters may impact emotion and behaviour.

2. The model captures the flow of information from the world through to behaviour as induced by touch experiences and assumes that other information (for example, auditory information or visual information not pertaining to the touch experience) would be processed such that the end results are summative, consistent with Liu's (2003) model of emotional design.

3. The model is a general model, with no specific consideration for demographics factors such as gender or age in the model itself. Since most products are used by both males and females, and many products are used across age groups and cultures, a general model was deemed to be a more useful starting point from a design perspective.

With these constraints in mind, each stage in the touch-emotion model will be described in further detail.

3.2.1 Touch-based experience

The input to the system is defined as a product that is being explored with touch. Attention is assumed to be placed on the object. Although humans are visually dominant, other senses can receive full attention depending on the situation. For example, in situations where the task is to explore surface properties, the haptic sense can have more weight than vision (Schifferstein & Cleiren, 2005).

3.2.2 Perception

Perception follows from stimulus in the world. As described in Section 2.4.4, the perception of changes in levels of touch factors (such as roughness) for simple stimuli (such as abrasive paper or surfaces with gratings) is such that there is a one-to-one correspondence between the physical stimuli and the perceived stimulus. Given these findings, the pathway between Touch in the world and Perception can be assumed to be valid. The depiction of Perception as occurring before Emotion is one that can be debated, as some scholars argue that affect and perception can happen simultaneously (the notion of 'a bad feeling' can arise spontaneously). However, if the 'world' has been defined as a product (or interface), then emotional response to the 'world' requires sensory input concerning its properties. It follows then to consider Perception as occurring before Emotion.

Perception is also depicted involving multimodal information. As discussed in Section 2.4.3, the perception of touch includes the experience of the sensory modalities of haptics and vision, which are the main contributors to touch-based experiences of products. The information from the sensory inputs does one of two things: the body spontaneously generates an affective response (which is consistent across individuals – see Section 2.1) or, the information is further reflected upon in cognition. A touch factor, say roughness, should then produce both an affective (fast, generalizable) and a cognitive (slower, knowledge- and/or experience-dependent) emotional response. The relationship between their relative contributions to the total emotional response is an open question that will be investigated.

3.2.3 Cognition

As the focus of this general model is on the touch-emotion relationship given the constraints listed in Section 3.2, cognition can be conceived to be impacted by contextual information, such as product type and personal experience. Within cognition, multimodal data can also be interpreted. The cognitive process leads to a slower, cognitive emotional response (see Section 2.6). Cognition is depicted here as a moderator of the Affective Pathway in emotion. So, for example, different levels of product context would interact with the Affective Pathway to impact emotional response.

3.2.4 Emotion

The complete emotional response to texture is predicted to be a product of both perception (affective response) and cognition (cognitive response), as discussed in Section 2. The model depicts an interaction between the two pathways, but the nature of the contribution of affect versus cognition on emotion must be determined. Consistent with Plutchik's (1991) sequential model, emotion is composed of the 'feeling' state, as well as physiological arousal, and stages in emotion can act 'backwards' on perception. For example, feeling an 'interesting' texture could direct more resources to its perception and away from, say, its colour. Emotion can also impact cognition. For example, feeling a novel, abhorrent texture could evoke emotions of avoidance, but cognitively the texture could then become interesting because it evoked those very feelings of avoidance. Given that emotion is an internal state, it cannot impact the world without a physical response – that is, without some kind of behaviour.

3.2.5 Behaviour

Behaviour in general can be an action or an absence of an action. In the context of touch-based exploration, behaviour is limited to actions of 'approach' or 'avoid' because a user either stops exploration or continues it. Both Wickens' (2000) and

Plutchik's (1982) models suggest a state ('choice' and 'impulse to action', respectively) that exists between diagnosis/emotion and behaviour. The proposed general touch-emotion model is not a decision making model, and as a result the assumption is that 'choice' and 'impulse to action' happen inseparably from the behaviour itself; users do not hesitate between being tempted to draw away from a slimy surface and actually doing so. Having drawn away from the unpleasant texture, one might reflect cognitively, turn disgust into interest, and approach it again, but only if there exists an emotional state of interest.

Behaviour can impact perception in the same way that cognition can: pausing to further examine or consider a product can highlight more touch-related features. Finally, because behaviour is external to the individual, it can impact the world: the product is no longer explored (avoidance behaviour) or the product is explored in greater detail (approach behaviour)

The proposed general touch-emotion model details specifically the emotional response to the touch experience of a product. A main assumption is that any positive emotional response to touch could only contribute to the total emotional response (due to other modalities) of the product in a positive way.

Thus the proposed model (the testing of which will be discussed in detail in Chapters 9, 10, and 11) should assist with the prediction of:

1. Changes in emotion as a function of changes in physical texture parameters (such as roughness and availability of touch-related information) in various situations.

2. Changes in emotion as a function of the application area of the product/haptic technology (such as priming participants to think of stimuli as actual products like a cell phone or a mouse).

3. Changes in behaviour as a function of emotional response to touch experiences (such as increased emotions leading to increased time spent in interaction with the stimuli).

The impact of covariates such as age and gender on user experience and behaviour, while not included in the model, will potentially have application for customizable designs of touch-based technology and products.

3.2.6 Exploring the touch-emotion model

The proposed model includes many pathways between the various stages of emotional response and behaviour. As discussed previously, this research focuses on a subset of the depicted pathways. The preliminary research questions relating to the model presented in Figure 3.1 are:

1. How does emotion change in response to manipulations of the world? How is it impacted by amounts of touch-related information available via the haptic and visual channels? (the Affective Pathway)

2. How does tapping into elements of cognition by changing product type impact emotion? (the Cognition Pathway)

3. What is the relationship between stimulus, elicited emotion, and behaviour? (the Behaviour Pathway).

To answer these questions, the touch-based experience will vary only in roughness. By addressing questions with the dominant axis of texture, it is anticipated that results may generalize to other surface properties (such as hardness and compliance).

The consistent use of roughness as the main independent variable will also allow for application-oriented questions to be answered, such as:

1. How reliable is the relationship between roughness and emotion?

2. What factors strengthen or weaken the relationship between roughness and emotion?

3.3 Common experiment and measurement procedures

The series of four experiments in this research used physical objects that varied in terms of roughness in a controlled way rather than making use of haptic technology which would simulate texture. It was felt that the use of real-world objects was the most appropriate starting point, so that findings could then be applied to general situations where surface texture (simulated haptic feedback or physical surfaces) is a key design consideration.

In each experiment, participants were also instructed to manually interact with the stimulus without specific instruction pertaining to how to do so. The open-ended instruction to explore the stimulus with the hand, similarly to work in consumer product packaging (Chen, Barnes, et al., 2009), was used in favour of more tightly controlled interactions used in perceptual touch research (Lederman & Abbott, 1981). Although it is certainly possible that such an open-ended instruction could result in different experiences of the stimuli between individuals, it is the individual's change in emotional response (and behaviour) that is of interest, and any particular form of exploration unique to an individual would not be able to explain changes in response as a result of changes roughness (which was always a within-subject factor). For the purpose of focusing on shedding light on the general touch-emotion model (which predicts later stages of processing as a result of changing physical touch-related parameters) and keeping findings generalizable to realistic product interactions, the open-ended active touch instruction was used.

Finally, an exploratory study (Experiment 1) was conducted to guide later studies (Experiments 2 to 4) towards optimized measurement of dependent variables and covariates, as well as optimal manipulations of factors of interest. The subsequent three experiments refined measures from Experiment 1, but were kept as similar to each other as possible for the purpose of allowing for combined, meta-analyses of their data.

3.4 Common experimental design

All experiments had a combination of within- and between-subject factors. Roughness was the main within-subject factor because one objective of all experiments was to understand individuals' emotional responses to increased roughness levels. All experiments were balanced on gender as closely as possible.

The number of participants for each experiment was selected to be within the range of 12-24 participants. One reason for these relatively small sample sizes, and as will be discussed in the exploratory experiment (Chapter 4), was that effects on emotion were found given even a small sample size of n = 12. The fact that the size of some of the factor effects was large enough to be detected using these small sample sizes led to the second reason of practical significance. It was deemed that if effects were significant with small sample sizes, then these are the kinds of robust effects of which designers should want to be aware.

All experiments further considered gender to be a factor. The reason for including gender was due to research indicating the existence of gender differences in the propensity to engage in touch-related experiences (Citrin et al., 2003). Thus, it made sense to include gender as a factor in the individual experiments in order to determine if it moderated any of the relationships between other touch-related predictors and the dependent variables of emotion and behaviour.

3.5 Common data analysis

Each individual experiment focused on answering more tractable questions targeted at addressing the larger research questions detailed in Section 3.2.6. As such, each of the four individual experiments was analyzed separately and findings summarized. In the chapters following those of the individual analyses, data were analyzed across experiments in order to directly address the larger research questions summarized in Section 3.2.6. A common assumption made across all of the combined data analysis of Chapters 9 to 11 was that perceived roughness, for our purposes, can be operationalized by physical roughness in the world (see Section 3.2.2 for justification). The implication is that changes in roughness (which designers have control over) can be examined in terms of impact on changes in emotions (which arise after perception).

Each analysis also utilized repeated measures analysis of variance (RM ANOVA) or linear mixed effects modelling (LME), depending on the particular goal of the analysis. RM ANOVAs were used in the individual Experiment analyses where the primary goal was to determine if there were group differences. LME modelling was used in the combined data analyses where the primary goal was to determine the coefficients for the curve fitting, thus shedding light on the direction and strength of the linear relationships[1]. With regards to the analysis of interaction effects (e.g., Roughness might interact with Haptic information availability to impact Emotion), the analysis tools available to determine the nature of the interaction in designs where there are mixed effects and continuous variables are limited. For such data, discussions with Statistics Consulting at the University of Waterloo indicated that graphical examinations of statistically significant interactions was the most effective tool for determining which interactions were different from the others and how.

It should further be noted that any experimental process assumes that the sample population produces data that is representative of the target population, as was assumed here. Additionally, findings were reported as testing with an alpha criterion set to 0.05. When 'significant' findings were reported (i.e., for a given test of an effect, p $\leq \alpha$), this was interpreted as 'given the data set acquired from this sample population, there is a probability of p that the effect is actually not there for the sample population' (Cohen, 1994). If p was found to be small, then it suggested that the null finding (that the effect is imaginary) was unlikely to be true. For this research, the concept of sample populations and the use of signifi-

[1]For both of these analysis tools, the assumption of normally distributed residuals is commonly done graphically and as such, graphical checks for the assumption of normally distributed response variables were made and the assumption of normality was deemed reasonable for all collected data.

cance testing means that: a) although ‘significant’ effects provide support for the existence of that effect, there may be gaps due to whether or not the sample population represents reality and due to the fact that there is always a chance that the null finding is true; b) the nature of significance testing rests on averages, so there may be individuals for whom the direction effects runs contrary to their individual data.

To address (a) and (b), this research first examined interesting significant effects across multiple experiments. That is, if one experiment reported a significant effect of, for example, Roughness on Emotion, then further experiments examined the same factors in the same or slightly different ways to test the robustness of the finding. If results were consistent across multiple experiments, then it increases the unlikelihood that the null hypothesis is true. This research also considered the discovered effects, which were found based on sample population averages, as guidelines for design to improve user experience. It is possible that there may be some individuals whose preferences run contrary to the average trend. However, the power of the current set of studies (where effect sizes were great enough to be found given relatively low sample sizes) is that the significant effects, when found, could be used by designers to understand how to improve user experience for the general population, even if certain individuals may not be satisfied. Similarly, the significant effects would also indicate to designers which touch-related design parameters have stronger potential to impact user experience for the general population.

Although the touch-emotion model described in this chapter is aimed at allowing findings to be applied to the general population, consideration should be given to how any findings might be impacted by demographics factors. For this reason, each Experiment analysis section included a discussion of correlations between demographics variables such as age, ethnicity, and gender, and the dependent variables. Further, as discussed in Section 3.4, since gender is a known likely moderator in the experience of touch, it was considered in the individual Experiment analysis as a factor and interactions with it were analyzed and discussed accordingly.

Since the focus of this research is on developing a general (non-gender-specific) touch-emotion model, the analysis and discussions of each Experiment Chapter are divided into two components: those effects that did not involve gender (so as to address the general touch-emotion model that does not include a gender factor) followed by those effects that included and/or interacted with gender. The combined analysis sections, focused on providing direct support for the touch-emotion model, consider gender as a covariate and control for the variance due to gender, but do not include gender as a parameter. This decision was made again due to the desire to keep results applicable for the general population.

Chapter 4

Experiment 1: Exploratory study with Haptic and Visual Availability

An exploratory study was conducted to examine the proposed touch-emotion model by first investigating the extent to which changes in roughness can impact emotion in controlled, context-free situations. In terms of the touch-emotion model, this setup corresponds to an investigation of the Affective Pathway. The ability to predict changes in emotional response through changes in roughness was seen as a necessary first step before further explorations of the touch-emotion model. That is, if the basic Affective Pathway did not exist between the touch parameter of roughness and emotion, then it would be difficult to argue the continued investigation of the later stages and pathways of the touch-emotion model. A secondary goal was to broadly examine how the multimodal touch experience is impacted by considering the amount of haptic and visual information available. By varying the amount of information available on each sensory channel, findings can be generalized to situations such as online purchasing (low relevant haptic information, high visual information) or certain kinds of in-store purchasing with limited access, as when the product is secured to the display counter (moderate haptic information, high relevant visual information).

Due to the exploratory nature of this study, analysis began with graphical depictions of the data which was followed by statistical analyses.

4.1 Participants

Sixteen upper year undergraduate or graduate students from the University of Waterloo, ages 22 to 50 years (mean = 28.7, SD = 7.79) and balanced on gender, took part in this study. The study took place in a quiet laboratory setting with normal indoor lighting. There were 4 Asians, 8 Caucasians, 2 Middle Easterners and 2 Others (ethnicity was not balanced on gender). All participants were right-handed. On a questionnaire item capturing self-rated 'tactual sensitivity', 11 participants rated themselves as 'average', 5 participants rated themselves as 'above average', and 1 participant gave their rating as 'below average'.

4.2 Stimuli and apparatus

Roughness, the main dependent variable, was manipulated via sand particle size on sheets of paper, consistent with studies in roughness perception (Ekman et al., 1965; Hollins, Bensmaïa, Karlof, & Young, 2000). From a practical standpoint, the use of sandpaper to manipulate roughness was appealing because it was low-cost and was characterized by pre-determined levels of roughness ('grit' values).

Because roughness was to be presented to the participant free of any product context, the stimuli consisted of arguably context-neutral rectangular bars, constructed from wood and finished with a specific surface roughness. Each bar had outer dimensions of 3 cm x 3 cm x 12 cm. Sand paper or smooth plastic sheets were used for the textured surface, with Roughness levels of 3, 2, and 1 corresponding to sand paper grit value 80 (very rough), sand paper grit value 220 (semi-rough), and smooth plastic covering, respectively. The use of physical blocks was considered appropriate to provide a physical substrate for the abstract concept of 'roughness' because it would have been difficult for participants to experience varying levels of roughness in a controlled way otherwise. The use of simplistic bars as stimuli (as opposed to, say, texture-covered cell phones) was done to minimize and control the extent to which participants would draw on cognitive processes via previous experience and knowledge of the stimuli. By minimizing the potential effects of the Cognitive Pathway in this way, results from Experiment 1 can shed light on the Affective Pathway.

Information level, the extent to which haptic and visual information was available, was manipulated by the construction of an apparatus that allowed the haptic and visual experience of the Roughness stimuli to be separated, in a manner similar to a study conducted by Lederman and Abbott (1981). Lederman and Abbott presented their participants with separate haptic and visual information that were of varying levels of congruence and were able to arrive at Equation 2.3 described in Section 2.5, where the perceived roughness rating was found to be a weighted sum of information from each of the haptic and visual modalities. As a first step towards examining if a similar relationship holds true for the emotional experience of roughness, the methodology used in Experiment 1 was adapted from Lederman and Abbott's (1981) study.

The amount of haptic information available had two levels. In the Moderate Haptic condition, participants could reach under a table and explore a Roughness stimulus bar mounted on a turn table. This condition is termed as 'Moderate Haptic' because the participant could rotate the stimulus on a plane but could not pick it up, and so could obtain some haptic information (such as texture and shape) but not weight. In the No Relevant Haptic condition, participants could reach under a table and experience only the scroll button on a mouse that could be used to visually explore the visual portion of the stimulus. In both conditions, the manipulation of the haptic stimulus (either by rotation of the physical stimulus or by rotation of the scroll button of the mouse) produced congruent visual behaviour.

In the present experiment, the amount of visual information ('Visual Fidelity', for short) available also had two levels. In the Lower Visual Fidelity condition, participants could see a computer model of the haptic stimulus on an LCD screen. An example of the visual stimuli in the Lower Visual Fidelity condition is shown in Figure 4.1, left. In the Higher Visual Fidelity condition, instead of an LCD screen, a turn table was positioned such that participants could see a replica of the haptic

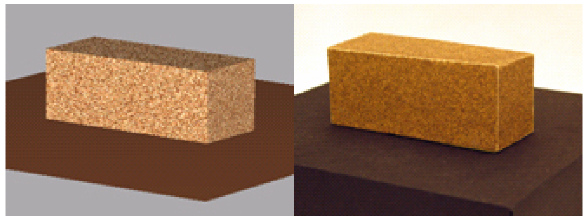


Figure 4.1: Left: visual stimulus in the Lower Visual Fidelity condition, Roughness level = 3; right: visual stimulus in the Higher Visual Fidelity condition, Roughness level = 3.

stimulus that they could feel (see Figure 4.1, right, for an example of a Higher Visual Fidelity stimulus).

An illustration of the various crossings of the Visual Fidelity and Haptic availability conditions is shown in Figure 4.2. In the Higher Visual Fidelity, Moderate Haptic condition depicted by Figure 4.2a, the user is able to manipulate a Roughness stimulus bar mounted on the nearer turn table (the haptic stimulus) and see an identical real object on the further turn table (the visual stimulus). Similarly, Figure 4.2b depicts the Lower Visual Fidelity, Moderate Haptic condition. In the context of current haptic technology, these two situations represent situations where haptic feedback is available (via simulations of texture or through restricted haptic exploration) and visual information is of varying quality. In the Lower Visual Fidelity, No Relevant Haptic condition depicted by Figure 4.2c, the user is able to manipulate a mouse for the haptic stimuli and is able to see, as the visual stimuli, an identical model on a screen that mimics the movements of the real object. The use of a mouse to manipulate objects has no relevant haptic information because the mouse does not provide haptic feedback for the touch experience. This condition is similar to what is experienced in situations such as online shopping. A screen was constructed to conceal the apparatus for setup between presentations of stimuli.

Emotional responses were recorded using the emoticon graphics developed by Desmet (2003) (see Appendix D for more details). These graphics were displayed

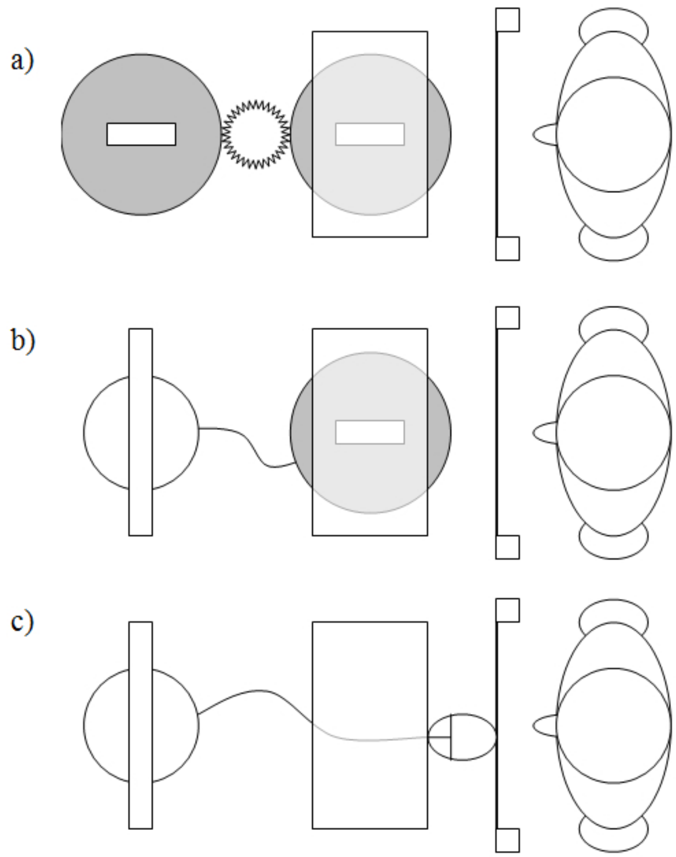


Figure 4.2: Experiment apparatus: a) Higher Visual Fidelity, Moderate Haptic condition; b) Lower Visual Fidelity, Moderate Haptic condition; c) Lower Visual Fidelity, No Relevant Haptic condition. The final condition, Higher Visual Fidelity, No Relevant Haptic, is not shown but uses the visual stimuli in a) with the mouse setup in c).

on a MSI Wind U100 laptop computer so that participants could indicate which emoticon matched their emotional response using a mouse pointer.

Response times from the start of each trial to completion of the reporting of emotion were also recorded on the laptop, rounded to the nearest millisecond. Response time was used as the operationalization of behaviour for a number of reasons. Studies in marketing and consumer research have shown that response time has been used as a measure of strength of a particular user feedback, be it a report in product involvement or a choice between products (Tyebjee, 1979; Sujan, 1985). Linking back to the touch-emotion model, response times are one way to measure the extent of approach/avoid behaviour, with longer times being associated with more involvement. Any findings concerning response time could potentially allow designers to understand how changing roughness can directly translate into one aspect of user behaviour.

4.3 Experimental and measurement procedures

Participants completed a demographics questionnaire (see Appendix E) that included questions concerning touch sensitivity. It was decided to break the concept of 'touch sensitivity' into two components, tactual sensitivity and temperature sensitivity, as a gauge for how these touch-related characteristics might affect participants' responses to touch experiences. Participants were asked to give self-ratings of tactual/temperature sensitivity as below average, average, or above average (coded as -1, 0, or 1).

Following the questionnaire, participants were asked to examine the emoticon diagram and to verbally identify each depicted emotion with a word or a phrase, for the purpose of familiarizing themselves with the diagrams. The practice trials began by asking participants to sit in front of the screened apparatus. At the start of each trial, the screen was removed and participants were able to interact with the haptic stimulus placed under the table. The screen was restored after each trial and the experimenter was able to set up the next trial. A 10-second break separated each trial.

Three practice trials were conducted in which participants were asked to manually explore stress balls with their left hand and to select the icon that matched their emotional response as quickly and as accurately as possible using their right hand. The purpose of this instruction was to attempt to capture the participant's most immediate emotional response, and the right hand (the dominant hand) was deemed to be the better hand for the task of reporting their emotional response on the provided laptop. The use of the non-dominant hand for the exploration task was considered to be realistic in real-world situations. Positive emoticons were coded as 1 and negative emoticons were coded as -1, giving a binary emotional valence response variable. It was necessary to collapse responses into binary values because there were too many categories of emotions (seven kinds of negative emotions and seven kinds of positive emotions) for the analysis that included all of them to be meaningful. The time of the total interaction, taken from the time of the presentation of stimulus to the time of successful reporting of emotional valence, was also recorded.

The actual trials proceeded similarly to the practise trials. Participants were asked to explore the stimuli and were given no information as to which product the stimuli might represent. Under the Moderate Haptic conditions, participants were asked to explore the haptic stimuli with the left hand and to record their emotional response to it with the right hand. Under the No Relevant Haptic conditions, participants were asked to use the scroll button on the mouse with their left hand and to record their emotional response to the visual stimuli with their right hand. In both conditions the participant was encouraged to visually explore the visual stimuli in addition to manually exploring the haptic stimuli.

4.4 Experimental design

A mixed effects design was used in which participants experienced both Haptic conditions and only one Visual Fidelity condition, since the Haptic manipulation was deemed to be a more subtle manipulation and less likely to produce biased responses. Therefore, participants were randomly assigned to one of the two Visual Fidelity conditions, and then within their group, experienced all Roughness levels within each Haptic level. The order in which participants experienced Haptic conditions and Roughness levels was randomized, and an equal number of males and females participated in each condition. The design was therefore a mixed $2 \times 2 \times (2 \times 3)$ model with Visual Fidelity (Higher/Lower) as the between-factor balanced on Gender (male/female), crossed with the within-factors of Haptic Levels (Moderate/Non Relevant) and Roughness (1:smooth – 3:rough).

4.5 Results

The exploratory data analysis (see Appendix F for the full exploratory analysis) first examined the effects of the independent variables (Visual Fidelity, Haptic availability, and Roughness, balanced for Gender) on the dependent variables, Emotional valence (EV) and Total interaction time (Time). Demographics variables such as age, ethnicity, and tactual/temperature sensitivity were then considered. Standard deviations were added to group means as ticks on the graphs when applicable. Consideration of the graphical relationships between variables guided the statistical analysis.

Repeated measures ANOVA (RM ANOVA) was then used as the main statistical analysis tool, with α set to 0.05. Given the exploratory nature of the study, results considered to be marginally significant ($0.05 < \alpha < 0.10$) were discussed where appropriate. Pearson's product moment correlation coefficient was used to analyze correlations between demographics variables.

The data used for all analyses underwent a removal of outliers based on Time exceeding three standard deviations from the sample mean. This resulted in the removal of 11 trials out of a total of 96 trials, leaving 85 trials in the analysis. Removal of outliers based on Time was necessary because it was deemed that participants who spent disproportionately long times before giving their response were more likely to be providing their response based on some other mechanism than a single pass of information from perception to emotion. For example, it could be that they have engaged in various feedback loops instead of providing their first response.

4.5.1 Analysis of effects on Emotional valence (EV)

General touch-emotion model:

A significant main Visual Fidelity effect was found such that the Higher Visual Fidelity condition elicited more negatively reported EV than the Lower Visual Fidelity condition [$F(1,65) = 11.5$, $p \leq 0.002$] (see Figure 4.3).

Although there was no effect of Roughness in the full model, a partial analysis of only Higher Visual Fidelity data was conducted, finding a main effect of Roughness [$F(1,33) = 4.63$, $p \leq 0.039$]. As expected, increased levels of Roughness resulted in lower EV. The exploratory data analysis shown in Figure F.1b further led to the partial analysis of only Moderate Haptic data. With this partial analysis, a main effect of Roughness on EV was also found [$F(1,32) = 5.57$, $p \leq 0.025$], again indicating that increased Roughness leads to decreased EV.

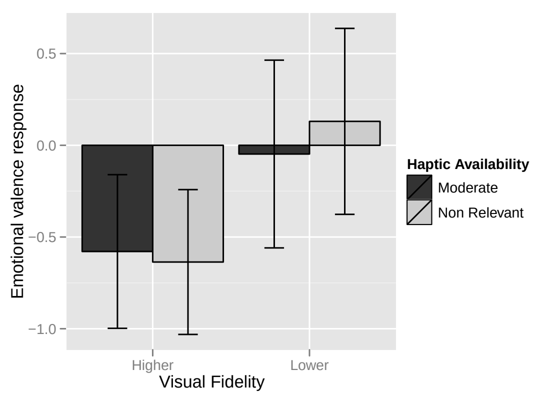


Figure 4.3: Average emotional valence by Visual Fidelity (Higher / Lower) and Haptic availability (Moderate / Non Relevant), showing a main effect of Visual Fidelity ($p \leq 0.002$).

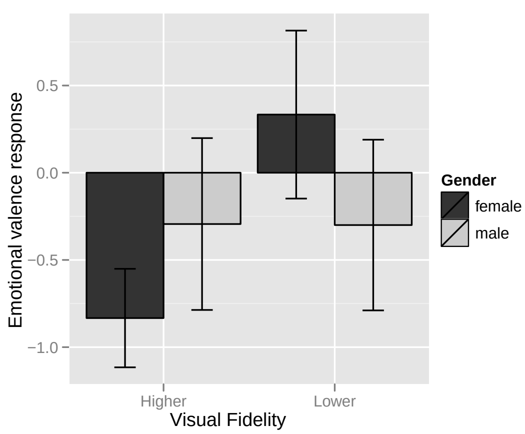
Gender effects:

A Visual Fidelity by Gender interaction on EV was found to be significant [F(1,65) = 12.3, $p \leq 0.001$], with females showing a distinct increase in EV response from the Higher Visual Fidelity to the Lower Visual Fidelity condition, and males showing little change between the conditions (see Figure 4.4a). The partial analysis of only High Visual Fidelity data also led to the finding of a main effect of Gender [F(1,33) = 5.62, $p \leq 0.024$]. Of interest is that the effect of Roughness seemed to be more pronounced for females than males (see Figure 4.4b).

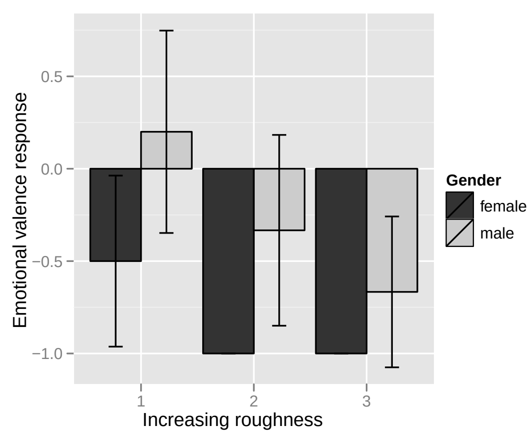
4.5.2 Analysis of effects on Total interaction time (Time)

General touch-emotion model:

The analysis revealed a Visual Fidelity by Haptics interaction effect on Time [F(1,66) = 5.13, $p \leq 0.027$], indicating that participants who had access to non-relevant haptic information and higher visual fidelity took less time to respond (see



(a)



(b)

Figure 4.4: a) examining Visual Fidelity by Gender interactions on EV ($p \leq 0.001$); b) examining effects of Gender by on EV for the Higher Visual Fidelity condition, showing a main effect of Roughness ($p \leq 0.039$) and Gender ($p \leq 0.024$).

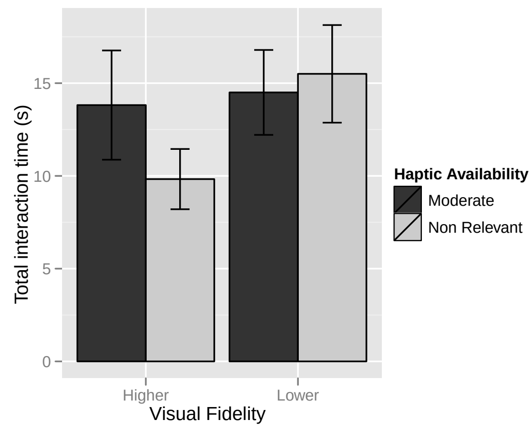


Figure 4.5: Average Total interaction time (Time) versus Visual Fidelity by Gender, showing an interaction between Visual Fidelity and Gender on Time ($p \leq 0.034$).

Figure 4.5). A main effect of Visual Fidelity on Time was also found [$F(1,66) = 4.67$, $p \leq 0.005$] such that Lower Visual Fidelity was found to increase total interaction time.

Gender effects:

A main effect of gender was also found [$F(1,66) = 4.82$, $p \leq 0.032$], with females taking less time to respond in general.

4.5.3 Analysis of demographics data

An analysis of demographics data was conducted by first collapsing the data for each individual, creating the values EV_{avg} and $Time_{avg}$. Further, in order to capture the effect of changing Roughness, a variable EV_{slope} was created for each individual such that EV_{slope} was the slope of the line of best fit of Roughness versus EV. EV_{slope} then captures the individual's emotional sensitivity to changes in Roughness, with more negative slopes indicating a greater sensitivity to the manipulation in the predicted direction (that is, it is expected that emotional response decreases with increased Roughness). $Time_{slope}$ was created similarly for each individual.

Pearson's correlation coefficient was used to analyze pairs of factors of interest after coding binary variables in the following way: ethnicity with 'Asian' = 1 and 'Caucasian' = 2; and gender with 'female' = 1 and 'male' = 2. Results are summarized in Appendix G. There was one significant positive correlation between Tactual sensitivity and EV_{slope} ($r = 0.52$, $p \leq 0.05$). There were also two marginally significant correlations: EV_{avg} was negatively correlated with Tactual sensitivity ($r = -0.49$, $p \leq 0.07$) and Gender was negatively correlated with Temperature sensitivity ($r = -0.44$, $p \leq 0.10$).

4.6 Discussion

The exploratory and statistical data analysis were conducted with the goals of a) determining how controlled factors of Roughness, Visual Fidelity, and Haptic availability impact either (or both) of emotional valence and interaction time; and b) to guide further experiments towards that end. The exploratory and statistical analyses highlighted some potential patterns, which are discussed below. Recommendations for questions to answer in subsequent experiments are also discussed. Discussions proceed within each subsection by first describing results relevant to the general touch-emotion model (which does not include a gender parameter) followed by any results that include interactions with gender (since gender was included in all ANOVA analyses).

4.6.1 Emotional valence

Considering results relating to the general touch-emotion model (with no gender factor), increased roughness levels were found to lead to decreased emotional valence when the visual stimulus was realistic or when relevant haptic information was available. This result is supported by research that suggests that rougher textures are associated with lower preference or more negative words from the experience of physical textures (Ekman et al., 1965; Zuo, 2004). From a design perspective, the present experiment indicates that multimodal roughness may be a physical parameter that can directly impact user experience, holding all else equal.

Visual fidelity was considered as a factor in the general touch-emotion model, in order to determine whether or not the visual modality had any impact on the emotional response to multimodal touch experiences. Given the tendency towards visual dominance (see Section 2.4.3), it was expected that both levels of visual fidelity (conveying roughness information) would be able to impact emotion, but it was not clear which level would have a greater impact. The effect of visual fidelity of the stimuli indicated that having the visual information displayed on a screen was better liked than having the visual information displayed as the actual physical object. It is uncertain if this is because the latter situation was slightly 'unnatural' (that is, it is more unusual to control a physical object than it is to control an object displayed on a screen), or if it is because participants found the simulated visual stimulus more interesting or enjoyable. In the latter case, designers of online shopping sites could actually benefit from having interactive 3D models of products instead of series of photographs.

When considering gender effects, the impact of visual fidelity was found to be higher for females than for males, with the more realistic visual condition producing more negative EV values for both genders. This interaction could be explained if females are more sensitive to visual touch-based information and were able to obtain more 'rough' texture information from the higher visual fidelity stimuli than from the simulated lower visual fidelity stimuli, giving rise to a generally more negative response. Alternatively, females may simply derive less enjoyment from the manipulation of a physical object than males. The finding that the level of haptic information experienced by females did not significantly impact their emotional response (regardless of the fidelity of the visual stimuli) indicates that females may have more visual dominance than males when providing responses to touch-based experiences, although further studies may be needed to confirm this speculation. From a design perspective, it may be more beneficial to user experience of both genders to focus on improving the visual texture than the haptic experience of a touch interface.

Returning to the negative effect of increased roughness on emotion to consider the gender effects, there are a number of indications that the roughness-emotion relationship may be more robust than suggested. For example, Figure 4.4b suggests that females experienced a floor effect at the higher two roughness levels. Further, based on the results of the two partial analyses, there is evidence that the condition of lower visual fidelity in combination with no relevant haptic information is the only condition under which the usual effect of roughness does not apply (which may be a good area for further investigation as to possible reasons). It is also possible that allowing participants to give more continuous emotional valence responses over a larger range would lead to a clearer relationship between roughness and emotional valence; having more controlled roughness levels would also provide more points with which to establish a trend.

4.6.2 Interaction time

When considering the effects on time in the general touch-emotion model, there was an interaction effect indicating that participants experiencing higher visual fidelity (real-world visual information) in the non-relevant haptics condition (using a mouse) tended to have lower total interaction times than in the other conditions. This could be a result of the combination of using a mouse to control a real-world object being interpreted as 'unnatural' (discussed above), resulting in participants engaging in 'avoidance' behaviour. The manipulation of the real-world object could have been considered as less 'unnatural', and thus did not elicit the same degree of 'avoidance' behaviour. This result is encouraging in that it may be reasonable to use Time as a proxy for emotion-evoked behaviour.

Considering gender effects, females tended to spend less time interacting with and responding to the stimuli, a result that can be interpreted as being consistent with the earlier finding that suggested females may be more sensitive to certain kinds of roughness-based information than males, resulting in less time required to make a judgment of emotion.

It should be noted that the interpretation of the total interaction time variable is difficult since there was no distinction between time spent interacting with the stimulus versus time spent reflecting on the emotional response. For example, some participants were observed to spend a long time exploring the stimuli, while other participants finished exploring the stimuli but took a long time to report their emotional response. It would be insightful to be able to separate the interaction time variable into two components to see how the separate time variables might be impacted by the factors of interest.

4.6.3 General discussion

There was no effect of different amounts of available haptic information; however, it may be that in situations where there is little haptic information, as in the no relevant haptic condition whereby participants used only a mouse to manipulate the object, emotional assessments made entirely via the visual channel tend to follow the same patterns as those exhibited when both haptic and visual information are available. It would be insightful to determine whether participants are actually emotionally indifferent to the level or quality of haptic information or if they are simply being internally consistent given the experimental setup.

The positive relationship between individual emotional sensitivity to roughness and tactual sensitivity is opposite to the expected result. Increased roughness was expected to lead to decreased emotional valence response, and this pattern was expected to be stronger for individuals with higher tactual sensitivity. It is possible that the observed correlation was due to the low number of roughness levels, as well as the binary emotion response variable.

The marginally significant negative relationship between individual average emotional response and individual tactual sensitivity indicates that participants with higher tactual sensitivity are more likely to report lower emotional valence. This finding is consistent with other research findings (Zuo, 2004) suggesting that rougher surfaces are less liked, since 2 of the 3 stimuli were covered in sand paper.

The finding of no relationship between gender or age and tactual sensitivity, and the finding that there was a marginally significant relationship between gender and temperature sensitivity, was unexpected and contrary to previous research that indicates the presence of gender differences in touch experience preferences (Citrin et al., 2003). It is possible, however, that the questions were too vague (participants often asked clarification questions for this portion of the demographics questionnaire) resulting in participants answering the questions in general terms, meaning that one possible interpretation could be that females are more temperature sensitive in home or office environments (as opposed to during product interactions).

A summary of key findings from Experiment 1 pertianing to the general touch-emotion model include:

1. Increased amount of visual information decreases emotional valence response ($p \leq 0.002$).

2. Increased roughness decreases emotional valence response in situations where participants have relevant haptic information or real-world visual information ($p \leq 0.039$).

3. Conditions of non-relevant haptics combined with real-world visual stimuli lead to lower response times ($p \leq 0.027$).

Addressing limitations of Experiment 1

Given the findings from this exploratory experiment, further experiments (detailed in Chapters 5–7) should focus on addressing the following points:

1. To increase statistical power and to avoid floor/ceiling effects, thereby potentially allowing the discovery of other interactions, emotional valence response should be captured as a more continuous variable.

2. To determine more conclusively the impact of haptic information availability on emotional response, more comparable haptic conditions should be used.

3. To clarify the relationship between the dependent variables and tactual sensitivity, the tactual sensitivity question should be refined to be more specific and less open to interpretation. Experiments should continue examining for potential relationships between other demographics factors, such as gender and age, on the dependent variables.

4. To better understand how behaviour is related to emotion, experiments should distinguish between types of behaviour (interaction time versus reflection time).

5. Although gender is not the main focus of the investigation, the finding that females were found to generally have lower emotional valence responses ($p \leq 0.001$) and lower response times ($p \leq 0.032$) than males in situations where visual information is presented in the real-world should be reflected upon.

Chapter 5

Experiment 2: Examining Haptic and Visual Availability

The results from Experiment 1 suggested a negative relationship between emotional response and increased roughness of stimuli and a possible effect of the amount of visual information available leading to emotional response.

Experiment 2 will verify the negative linear relationship between emotional response and increasing roughness using a continuous slider measurement method for capturing emotional valence and thus expanding the emotional response scale in order to increase the potential power of the statistical analysis. A further reason for using a continuous slider includes the avoidance of 'floor' effects observed in some emotional valence response data of Experiment 1 (e.g., Figure 4.4b). Similarly, more levels of roughness were used and roughness itself was controlled more precisely.

In Experiment 1, roughness was manipulated using three levels of 'particle spacing'. The use of off-the-shelf sandpaper had the disadvantage in that the exact distribution of particles is uncertain, thus making it more difficult to make design recommendations from findings. For instance, it could be that the particular 'grit 80' sandpaper used had more closely spaced particles than the 'grit 220' sandpaper, and this was the cause of it being less pleasing, rather than the actual grit value (which is a measure of particle size, not density). An alternative manipulation for roughness is that of varying groove spacing of a grating. Numerous studies have found that groove widths of a precisely machined grating, within certain parameters, can reliably predict increased perceived roughness when explored with the finger, a pattern that is has not been found to be different between genders (Klatzky, Lederman, Hamilton, Grindley, & Swendsen, 2003; Lederman & Abbott, 1981). For the purposes of continuing research in examining the impact of increased roughness on emotional response (a relationship supported by results from Experiment 1), a set of eight stimuli varying in roughness via changes in groove width were created.

Experiment 2 will further consider the effect of the amount of available haptic and visual information on emotion by manipulating them to consider other realistic situations. For example, Experiment 1 found that decreased visual information (providing simulated visuals instead of real-world visuals) increased emotion. Does decreasing visual information to the extreme (no relevant visual information) continue that pattern? This situation reflects interacting with products (e.g., vibration alerts) that are meant to be felt but not seen. Further, Experiment 1 offered no evidence that the availability of haptic information (either no relevant haptic information, or limited/moderate haptic information) impacted emotion. Does considering a situation where participants can pick up the stimulus for full haptic (shape, weight, and surface property) information impact emotion?

Finally, the present experiment will continue to consider behaviour as operationalized by response time. Although Experiment 1 did not give indication that changes in roughness impacted response time, it is possible that this result was due to the imprecise measure of response time. Thus, Experiment 2 will refine the measure of time in order to better examine the potential relationship between roughness and behaviour.

5.1 Participants

Twenty-four students from the undergraduate and graduate student population at the University of Waterloo participated in this study, with ages from 21 to 30 years (mean = 25.0, SD = 2.4), balanced on gender. The study took place in a quiet laboratory setting with normal indoor lighting. There were 16 Asians, 2 Caucasians, 2 Middle Easterners and 4 Others (gender was not balanced across ethnicity). All participants were right-handed. In order to more clearly specify the concept of 'tactual sensitivity', two questions were added to the questionnaire. One item captured the perceived importance of tactual information by asking 'How important are tactual experiences for you in general?'. For this item, 13 participants gave ratings as 'average', 10 as 'above average' and 1 as 'below average'. Another item captured the perceived importance of tactual information during purchases by asking 'How important are tactual experiences for you when making purchases?'. Self-reports were such that 12 participants gave ratings as 'average', 11 as 'above average' and 1 as 'below average'. Both of these questions sought to examine the potential impact on results of individual characteristics relevant to the real-world, touch-based experience of products. In general, participants were roughly evenly divided into groups that considered themselves 'average' or 'above average' on ratings capturing perceived importance of touch. Although few people rated themselves as 'below average', and the distribution is therefore skewed, there is no reason to expect that a random sample drawn from a university population would have a true sample mean that is above the population mean. That is, it was considered more likely that participants overrated themselves in providing self reports than that participants were actually significantly different from the general consumer population.

5.2 Stimuli and apparatus

The stimuli were a series of plastic rectangular bars of varying surface roughness in order to determine the extent to which the effect of carefully controlled roughness on emotional response (Ekman et al., 1965; Zuo et al., 2004; Lee & MacGregor, 2010) could be impacted by changes in the availability of haptic and visual information that makes up its experience.

Roughness was manipulated in a fashion similar to that used in roughness perception studies (Lederman & Abbott, 1981; Lawrence et al., 2007; Unger, Hollis, & Klatzky, 2011), which found that perceived roughness was dependent primarily on groove width (and not ridge width) when touching a fine grating, and that increasing inter-element spacings from 0 to roughly 2 mm leads to increased perceptions of roughness (Unger et al., 2011; Lederman & Klatzky, 1998). The stimuli for this study consisted of one set of eight rectangular bars (14 mm x 62.5 mm x 112.5 mm) machined from PVC such that a 56 mm wide strip of their surfaces were cut with grooves of varying widths (see Figure 5.1). Roughness 1, had the narrowest groove widths (representing the smoothest surface) that were 0.18 mm wide. Each Roughness level from 2-8 had grooves that increased in width by 0.14 mm such that the groove width for Roughness 8 was 1.16 mm. Ridge width was held constant at 0.25 mm for all rectangular bars. As in Experiment 1, the bars were designed to be as simplistic as possible in order to minimize the potential effects of engaging the Cognitive Pathway, and to keep emotional response focused through

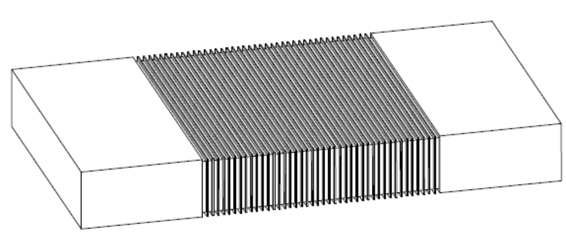


Figure 5.1: Stimulus machined from PVC, with grooves cut to specific groove widths and constant ridge widths.

the Affective Pathway.

Each Roughness stimulus was presented to the participant on a turntable inside of a wooden housing such that only one stimulus was available to the participant at any time (see Figure 5.2). The outer dimensions of the wooden housing were 63.5 cm in depth (from the participant) × 61.0 cm in width × 16 cm in height. An opaque screen (pictured in the closed position) could be closed over the viewing 'wedge' using a switch so that the turntable could be covered from the view of the participant while changing stimuli in between trials.

The factor of Haptics had two levels: High and Moderate Haptic conditions were achieved by whether or not the Roughness stimulus could be picked up. The High Haptic condition would be similar to an in-store, hand-held product interaction where full access is available. The Moderate Haptic condition provides a link with results from Experiment 1, and could also allow findings to shed light on situations where texture is important, but the product isn't usually picked up (such as a keyboard or when exploring objects that are secured to a display case). The stimuli were not permanently secured to the turntable; rather, an adjustable wooden 'frame' was secured to the turntable and the corners could be rotated

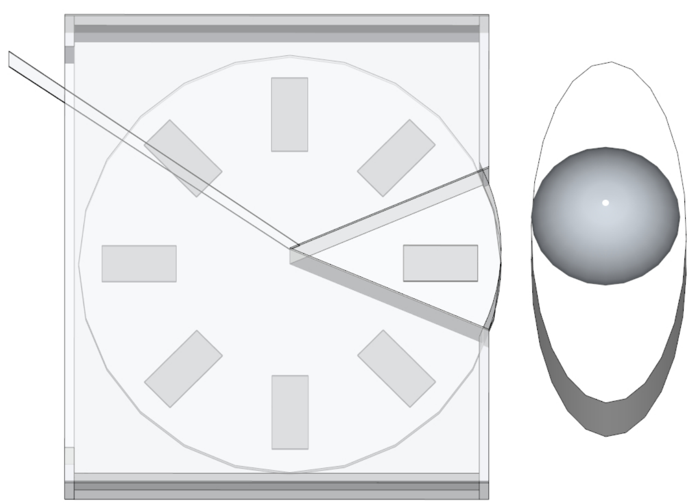


Figure 5.2: Display apparatus. A viewing wedge allows for stimuli to be presented. A switch (shown in the upper left) allows control of the viewing wedge.

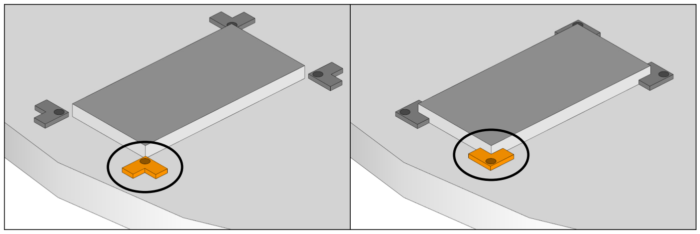


Figure 5.3: Left: illustrates the frame in a position such that the block can be picked up easily; right: illustrates the frame in a position such that the stimulus is secured and cannot be picked up easily.

around each stimulus so that the stimulus could or could not be easily picked up (see Figure 5.3), representing the High and Moderate Haptic conditions, respectively.

The factor of Visual Fidelity also had two levels: High and Non Relevant. Visual Fidelity was manipulated by attaching a piece of thick fabric onto the wooden housing over the viewing wedge in Figure 5.2 such that in the No Relevant Vision condition, participants could not see the stimulus but could reach under the fabric to touch the stimulus. In the High Visual Fidelity condition, there was no fabric and participants could easily view the stimulus.

5.3 Experiment and measurement procedures

Each trial began with the opaque screen door in the closed position. When ready, the experimenter opened the screen door and simultaneously orally cued participants that they could begin exploring the stimulus without being provided specific instructions on how to explore[1]. Participants were asked to provide their emotional response to the stimulus as quickly and as accurately as possible. Once the response was given, the opaque screen door was shut and the apparatus was set for the next trial. There was a 5 second break in between trials.

The main measure of this experiment, emotional valence response, was

[1] see Section 3.3 for justification on the use of open-ended texture exploration instructions.

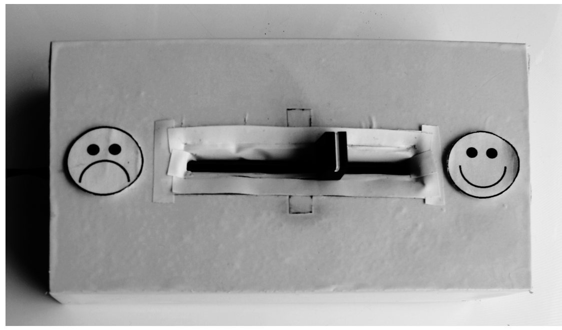


Figure 5.4: Slider similar to the one used for capturing emotional valence (left or right of centre).

recorded using a linear slider as in studies conducted by Lottridge (2008) with approximately 10 cm range of movement, constructed from a Lego RCX system. The slider was connected to a computer that recorded initial position (halfway along the slider in the 'zero' position), final position, and the times taken for both the time of interacting with the stimuli (interaction time, IT) and the movement of the slider (reflection time, RT). This breakdown of the single 'Time' measure used in Experiment 1 was selected because IT was considered to be associated with information gathering behaviour, while RT was considered to be associated with the strength of the emotion. The slider shown in Figure 5.4 had casing dimensions of 13.3 cm $\times$ 7.6 cm $\times$ 3 cm and a 6.5 cm physical sliding range. A slider similar in function and form to the one shown in Figure 5.4 was used in the Experiment 2. Experiment 2's slider was constructed from Lego building blocks and used the RCX 2.0 brick to interface with a desktop computer, but was lost during transportation during a later study. The refresh rate of the slider was once every millisecond.

The slider was positioned on the top of the wooden housing and on the side of the participant's non-dominant hand (that is, the slider was on the left side since all participants were right-handed). The minimum and maximum values on the slider were programmatically defined to be -25 and 25, respectively. The use of a slider for collecting emotion data was selected over the emoticons used in Experiment 1 because the slider allowed for a more continuous recording of emotion and was found to have high inter-trial reliability Lottridge (2008).

To shed light on how an individual's propensity for touch might affect results, two questions were devised and appended to a basic demographics questionnaire (see Appendix H) to capture self-reported importance of touch in general circumstances and when making purchases (instead of a single question for 'tactual sensitivity' used in Experiment 1). Each of these 'touch importance' questions required participants to rate themselves as 'above average', 'average', or 'below average' (coded as 1, 0, and -1, respectively).

5.4 Experimental design

Participants were randomly assigned to one of the Visual Fidelity conditions and experienced both Haptic conditions and all 8 Roughness stimuli. Participants experienced all Roughness levels in one of the Visual Fidelity conditions followed by all Roughness levels in the other Visual Fidelity condition. The order in which participants experienced each Roughness level within each Visual Fidelity condition, as well as the Visual Fidelity conditions themselves, was randomized. The design was therefore a mixed $2 \times 2 \times (2 \times 8)$ model with Haptic availability (High/Moderate) as the between-factor balanced on Gender (male/female), crossed with the within-factors of Visual Fidelity (High/Non Relevant) and Roughness (1:smooth – 8:rough).

5.5 Results

Response time data were decomposed into interaction time (IT) and reflection time (RT). Similarly to Experiment 1, all data underwent removal of outliers based on reflection time exceeding three standard deviations from the sample mean. This resulted in the removal of 14 trials out of a total of 384 trials, leaving 370 trials in the analysis.

Repeated measures ANOVA (RM ANOVA) was then used as the main statistical analysis tool, with α set to 0.05. Interesting results that approached significance ($0.05 < \alpha \leq 0.1$) were also included where applicable. Pearson's product moment correlation coefficient was used to analyze correlations between demographics variables.

The focus of the analysis will be on providing further evidence for:

1. The negative relationship between roughness and EV
2. The negative relationship between amount of visual information and EV
3. The nature of the relationship between available haptic information and EV
4. The nature of the relationship between response time (IT or RT) and the predictors
5. The relationship between covariates on EV and response time[a]

[a]As described in the common data analysis of Section 3.5.

5.5.1 Emotional valence

General touch-emotion model:

Significant main effects on EV were found for Roughness level [F(1, 350) = 11.6, $p \leq 0.001$], such that increased Roughness led to decreased EV, consistent with Experiment 1. As well, significant main effects on EV were found for Haptic availability [F(1, 350) = 14.1, $p \leq 0.001$], such that the Moderate Haptic condition produced higher average EV than the High Haptic condition.

Gender effects:

A Roughness by Haptics by Gender interaction [F(1, 350) = 5.60, $p \leq 0.019$] was also observed, such that males decreased in EV as a function of increasing Roughness when Haptic availability decreased (see Figure 5.5).

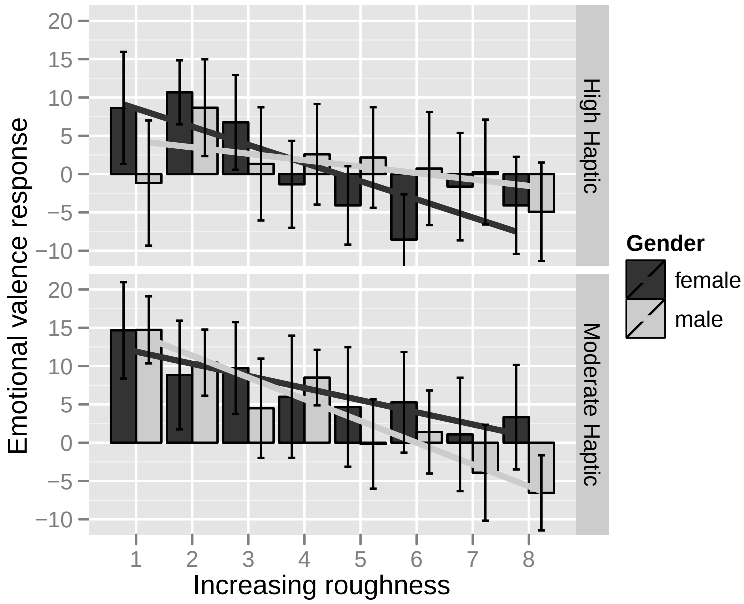


Figure 5.5: Emotional response to Roughness, broken out by Gender and Haptics, showing a three way interaction ($p \leq 0.019$).

5.5.2 Response time

General touch-emotion model (Interaction Time):

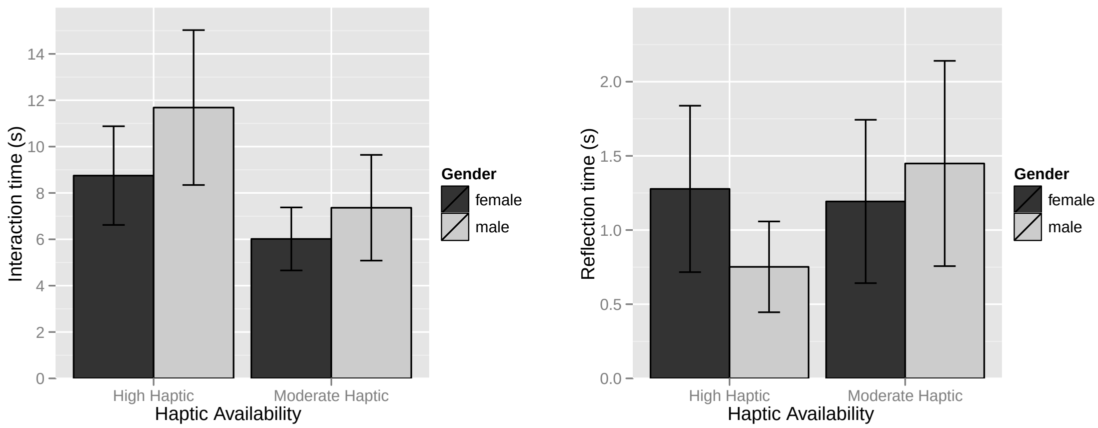
Using RM ANOVA to examine the effects on IT in the general touch-emotion model revealed a main effect of Haptic availability [$F(1, 350) = 68.69$, $p \leq 0.001$] such that the High Haptic condition led to higher IT values.

Gender effects (Interaction Time):

A significant main effect of gender on IT was found [$F(1, 350) = 14.33$, $p \leq 0.001$] such that females tended to have lower IT values than males (see Figure 5.6a).

General touch-emotion model (Reflection Time):

Similarly, looking at RT revealed a main effect of Haptic availability with [$F(1, 350) = 13.37$, $p \leq 0.001$] suggesting that participants had higher values of RT in the



(a) (b)

Figure 5.6: a) Interaction time responses broken out by Gender and Haptic availability show the main effects of Gender ($p \leq 0.001$) and Haptic availability ($p \leq 0.001$); b) Haptic availability by Gender effect on RT ($p \leq 0.003$).

Moderate Haptic condition in contrast to the High Haptic condition. A main Visual Fidelity effect approached significance [$F(1, 350) = 2.82$, $p \leq 0.095$], indicating that participants may have had higher RT in the No Relevant Vision condition.

Gender effects (Reflection Time):

There was a significant Gender by Haptics interaction [$F(1, 350) = 9.58$, $p \leq 0.003$] on RT, showing that males in the High Haptic condition had lower RTs (Figure 5.6b).

5.5.3 Demographics data

Similarly to the demographics analysis of Experiment 1, the variables of EV_{avg}, IT_{avg} and RT_{avg}, EV_{slope}, IT_{slope} and RT_{slope} were created (see Section 4.5.3 for details). The responses for the two 'tactual importance' questions used in Experiment 2 were summed to create a single variable, 'Tactual Importance Rating' (TIR), for each individual.

An analysis of demographics data proceeded using Pearson's correlation coefficient and by coding the binary variable of Gender such that ‘female’ = 1 and ‘male’ = 2. The variable Ethnicity was severely imbalanced (with more than half the participants being Asian). As a result, Ethnicity was omitted from the analysis. Results are summarized in Appendix I.

Significant correlations include that of RT_{avg} which is positively correlated with TIR ($r = 0.56$, $p \leq 0.01$). EV_{slope} was marginally and negatively correlated with age ($r = -0.40$, $p \leq 0.06$).

5.6 Discussion

One goal of Experiment 2 was to verify the negative linear relationship between increased roughness and emotional valence response under refined multimodal conditions. A second goal was to better understand the relationship between the availability of haptic and visual information and emotional valence, as well as to see if breaking up response time into two components, interaction time and reflection time, would provide insights into how emotion may affect behaviour. Further, the effects of covariates were to be clarified. The results are discussed by grouping findings by dependent variables (emotional valence, interaction time, and response time) and by covariates. As in Experiment 1, the discussion will proceed within each subsection by first describing results relevant to the general touch-emotion model followed by results that include interactions with gender, where applicable.

5.6.1 Emotion valence

When considering the general touch-emotion model, and as suggested by Experiment 1, Experiment 2 confirmed the strong negative and linear relationship between increased stimulus roughness and emotional valence response. The finding that the condition where participants were unable to pick up the stimuli actually led to higher average emotional valence is contrary to expectations (one might expect more haptic information would be better, or more liked). Although there was no evidence of an impact of haptic information availability on emotion from Experiment 1, other research studies have shown that the more that haptic stimuli is available, the more that participants tend to feel positive towards products (Peck & Childers, 2006). One possible explanation for the observed pattern in the present study is that the stimuli were slightly sharp along the edges, and that by asking participants to pick up the blocks, they were also touching the sharp edges, and this may have produced a negative emotional response. The impact of the availability of haptic information on emotional valence requires further investigation, as the results may impact the extent to which haptic technology designers concern themselves with user experience when designing haptic feedback algorithms.

When considering the effects of gender, there was an observed three-way interaction between roughness level, haptic information availability, and gender, suggesting that males became more emotionally sensitive to increased roughness, but only in the moderate haptics condition. This could be explained if the act of picking up the stimulus was distracting for males who were less able to notice the difference in roughness between stimuli. Females, being generally more sensitive to tactile information (Citrin et al., 2003) may have noticed the difference in roughness between stimuli regardless of whether or not they had to pick up the stimulus. This is consistent with the findings from Experiment 1, which suggested that females, more so than males, were sensitive to changes in visual texture information. From a practical standpoint, products or technology employing haptic features could be designed to take gender-based sensitivity into account in order to produce similar experiences of haptic feedback for all users.

5.6.2 Response time

Experiment 2 differed from Experiment 1 in that response time was broken into two components, interaction time and reflection time. The results indicate differing effects of factors on IT and RT, suggesting that the distinction between the two different types of response times was worthwhile.

Interaction time

When considering the general touch-emotion model, interaction time, the time taken by participants to explore the stimulus prior to providing their emotional valence response to it, was found to be higher when more haptic information was available. This is perhaps not surprising because the High Haptic condition required participants to spend additional time to pick up the stimulus for exploration.

When considering effects with gender, it was interesting to find that males tended to spend more time interacting with the stimuli than females. This could be explained by females being generally more attentive to touch-based information and requiring less time to acquire all the necessary information from it.

Reflection time

When considering the general touch-emotion model, reflection time, the time taken by participants to provide their emotional response to the haptic stimuli, can be interpreted as a measure of the degree of certainty that participants feel regarding the elicited emotional response. Put another way, RT is a measure of how much emotional reflection the stimulus evoked (with lower RT values indicating higher emotional intensity/certainty). The marginal main effect of visual fidelity suggested that the conditions of reduced visual information produced higher RTs is of interest as a potential relationship between behaviour (as operationalized through time) and a predictor variable. Further investigations concerning the predictor of visual information availability and time is recommended.

The gender-related results support the idea of RT being a measure of certainty. That is, given that participants were instructed to provide their emotional response to the stimuli as quickly and as accurately as possible, if RT was a measure of certainty, then it stands to reason that low levels of IT would result in high levels of

RT. The results including gender show that RT was affected by haptic information availability in the opposite direction that IT was affected, with males driving most of the difference. So, while males are spending more time gathering information about the stimulus, they are also spending less time reflecting on their emotional response. This could be explained by taking into account the finding that males in the high haptic condition are not responsive to changes in roughness (see Figure 5.5), suggesting that they may be responding to a single feature of the stimuli that is consistent throughout trials (for example, the sharp edges, or the shape), and thus do not feel the need to spend time reflecting for every trial. This finding is of interest as it may suggest that depending on the task (interaction versus reflection), information on the haptic channel may be lost or ignored.

5.6.3 General discussion

The finding that average reflection time was positively correlated with TIR is not surprising and supports the idea that individuals who generally pay more attention to touch-based information are more likely to spend time reflecting on it. However, the lack of correlation between Gender and TIR is a little surprising, although the direction of the correlation shown in Table I.1 is supported by literature indicating higher tendencies of females for valuing touch-based experiences (Citrin et al., 2003). Further data may shed light on whether or not the correlation is real.

A summary of key findings from Experiment 2 pertaining to the general touch-emotion model include:

1. The relationship between increased roughness and decreased emotional valence response was robust across groups ($p \leq 0.001$).
2. Decreased availability haptic information increased emotional valence response ($p \leq 0.001$).

Addressing limitations of Experiment 2

Looking at the results of Experiment 2 suggests further investigation into:

1. Interaction and reflection times in general did not appear to exhibit the same patterns of response, and the continued investigation of these two variables is suggested. Although gender is not the focus of this investigation, it should be noted that males and females were found to have opposite trends ($p \leq 0.003$).

2. The results surrounding the availability of visual information did not suggest any relationship between visual fidelity and emotional response (contrary to Experiment 1 which found a main effect such that decreased visual fidelity resulted in increased emotional response). Looking at response time, with marginal significance, lower amounts of visual information produced higher reflection times, again contrary to Experiment 1. The potential effects of visual fidelity on dependent variables should be examined more closely.

3. All stimuli used in Experiments 1 and 2 have thus far been designed to consider mainly the Affective Pathway by keeping the stimuli simple and minimizing their significance in memory or experience. It would be worthwhile to confirm whether such patterns of results hold once cognition is manipulated.

Chapter 6

Experiment 3: Examining Visual Fidelity and Context

The purpose of Experiment 3 was to clarify some of the questions raised in the previous two Experiments pertaining to the effect of varying the amount of visual information, to introduce a new variable of product context, and to test if the effect of changing roughness on emotion holds under the new conditions.

Experiment 1 showed that varying the amount of visual information may be able to modify emotional responses to touch experiences, such that as visual fidelity information becomes lower (e.g., visual information of a simulated stimulus available on a screen provides less visual distinction in object surface roughness than a real-world object) participant emotional response is higher. Inspection of Figure F.1b might suggest that when visual touch information is available on a screen (in contrast to in the real world), the availability of haptic information may have more of an effect on emotional valence response. However, in Experiment 2 when a more dichotomized approach to available visual information (available/non relevant) was tested and participants were able to physically touch the stimulus (either just on the object surface or by picking up the object), the presence/absence of visual information was not found to have a significant impact on emotional response. It should be remembered that in Experiment 2, when participants saw the stimuli, they were viewing the actual object (as one might in an in-store purchase situation). Thus, in order to better understand the on-line shopping case (or other on-line visual simulations of texture) Experiment 3 examined the effect of the level of visual information more closely by further setting up stimuli that could be explored by vision alone, in a setup otherwise identical to that of Experiment 2.

Finally, Experiment 3 also considered the Cognitive Pathway. In Experiments 1 and 2, the stimuli were presented as simple bars with no accompanying product context or other information concerning the stimuli. This had been done in an effort to reduce the extent to which individuals may draw upon cognitive resources when giving responses to the stimuli so that aspects of the Affective Pathway could be examined. In order to consider the Cognitive Pathway, an aspect of cognition needed to be manipulated. As described in Sections 3.1.1 and 3.2.3, cognition can be manipulated by providing a product context that would then allow participants to draw on previous experience of that product type.

Experiment 3 focused on examining the impact of vision alone (no relevant haptic information) and product context on the emotional response to changes in roughness. By varying the quality of visual information and withholding relevant tactual information, findings can be applied to situations such as the online purchase of products where texture may be important to the consumer. In this experiment, the product context of 'cell phone' was used as the experimental condition because research has shown that preferred characteristics of portable phone designs included being softer rather than rough, regardless of gender (Chuang, Chang, & Hsu, 2001). Therefore, it was expected that the experimental Product Context condition would produce more negative slopes in response to increasing roughness when compared to a product-context-free bar and/or exhibit lower mean emotional response. It should be noted that the selection of the context 'cell phone' was done because surface roughness is not part of the immediate function for this product (unlike for a product such as sandpaper). Although 'grippiness' may be related to cell phone use over time, the current experiment considers only the immediate emotional response and would thus allow findings to be applied to predicting immediate emotional response for a popular high-technology product.

Both Experiments 1 and 2 found significant relationships between increasing roughness and decreasing emotional valence. Experiment 3 will continue to examine the robustness of this relationship given the new set of manipulations.

Finally, with regards to the use of Interaction Time and Reflection Time as proxies for behaviour, Experiment 3 will continue with these measures for the purpose of providing support for the patterns of time-related results obtained from previous Experiments.

6.1 Participants

Twenty-four participants from the undergraduate or graduate student population at the University of Waterloo took part in this study, with ages from 23 to 33 years (mean = 26.3, SD = 3.46), balanced on gender. The study took place in a quiet laboratory setting with normal indoor lighting. There were 9 Asians, 9 Caucasians, 4 Middle Easterners and 2 Others (gender was not balanced across ethnicity). All participants were right-handed. On the questionnaire item capturing self-rated importance of tactual information, 17 participants gave ratings as 'average', 7 as 'above average' and 0 as 'below average'. On the questionnaire item capturing importance of tactual information during purchases, 13 participants gave ratings as 'average', 10 as 'above average' and 1 as 'below average'. There was no reason to expect that this sample's mean for importance of tactual information would differ from that of the general consumer population; the skewness of the distribution was deemed to be more likely an artifact of self reporting[1].

6.2 Stimuli and apparatus

As in Experiment 2, Experiment 3 used roughness as the main independent variable and also had Roughness levels 1–8 representing increasing roughness. How-

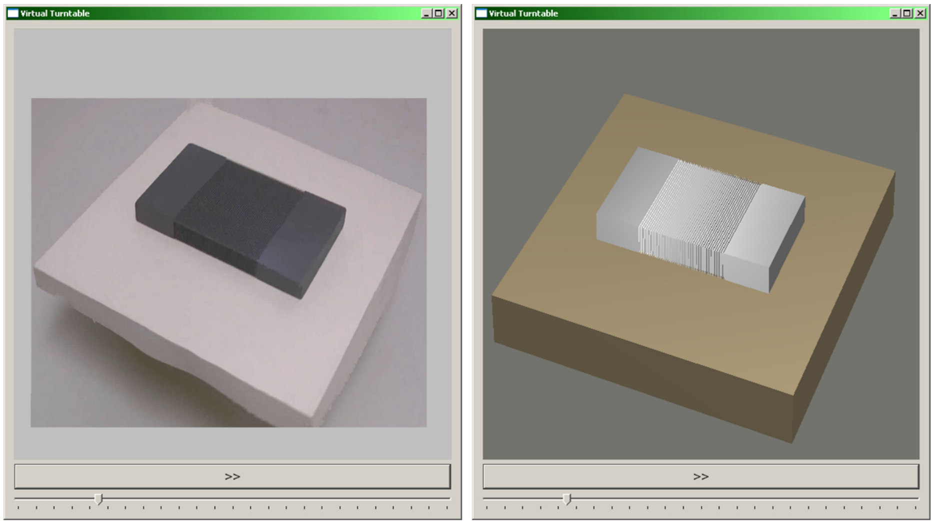
[1]see Section 5.1 for a more detailed discussion.

ever, all stimuli of varying roughness were displayed on an LCD monitor at a resolution of 1920 $\times$ 1080 dpi in order to capture the impact of the visual component of a touch experience separated from the haptic experience. Participants were able to rotate the visual component of the stimulus by using the scroll button on a mouse, thereby maximally reducing the haptic experience while still allowing participants control over exploration of the stimulus.

The visual stimuli varied in Visual Fidelity to produce two levels. In Moderate Visual Fidelity condition, to keep the visual stimulus as similar to the visual portion of stimulus in Experiment 2, videos were taken of the stimuli used in Experiment 2 mounted on a rotating platform. A total of 302 frames were captured for each Roughness stimulus to display the full 360 degree rotation of the platform in a window measuring 700 $\times$ 800 pixels, a resolution considered adequate for conveying the changes in roughness of the blocks. The visual stimuli, depicted in Figure 6.1a, could be 'manipulated' (rotated) using the scroll button on a mouse. The visual stimuli were chosen to be presented on a screen, as this paradigm is most similar to that used in many haptic applications (e.g., teleoperation) and online shopping situations.

In the Lower Visual Fidelity condition depicted in Figure 6.1b, each Roughness stimulus was instead modelled using OpenGL and displayed on a screen such that the stimulus and its platform could be rotated using the scroll button of a connected mouse. There were 302 steps to display a full 360 degree rotation of the platform in a window measuring 700 pixels $\times$ 800 pixels.

Product Context is important in understanding the degree to which any effects might be generalized beyond the current experimental setup. As a result, an additional Product Context factor was included to determine the impact, if any, of contextual information. Product Context was manipulated by either: a) simply providing instructions for each trial (the Control condition); or b) providing a scenario in addition to trial instructions where participants were asked to consider the stimuli as prototype cellphones (the Cell Phone condition). To reduce confounds, participants were merely primed to think of a product context (or none at all) in-



(a) (b)

Figure 6.1: a) Sample visual stimulus in the Moderate Visual Fidelity condition; b) Sample stimulus in the Lower Visual Fidelity condition. Both stimuli could be visually explored by using the scroll button of a mouse to rotate the object.

stead of being presented with the actual cell phone because of the anticipated difficulty in holding all other factors constant when devising stimuli appearing like actual products. For example, a mobile phone is shaped differently from an abstract block, and it could have been the change in shape (and not the different context) that led to any differences in findings. Mobile phones were selected as the experimental Product Context because research has shown that the experience of touch can be very important for mobile phone users (Seva, Duh, & Helander, 2007; Yun, Han, Hong, & Kim, 2010).

6.3 Experiment and measurement procedures

Each of 4 practice trials and 8 test trials began with a blank screen on the LCD monitor. Participants were orally cued to begin exploring the visual texture stimulus using the scroll wheel on the mouse. As participants did not have relevant haptic information to the experience with the visual textured bars, the haptic availability in Experiment is similar to that of the 'No Relevant Haptic' condition in Experiment 1. Similarly to Experiment 2, participants were asked to provide their emotional response to the texture stimulus as quickly and as accurately as possible, and once the response was given, the blank screen was restored for the next trial. The main measure of emotional valence response was captured using a slider identical to the one used in Experiment 2. There was a 5 second break in between trials.

In order to control for an individual's a priori experience with 3D models, the demographics questionnaire used in Experiment 2 was modified to include questions concerning experience with 3D games or 3D modelling (see Appendix J). There were two types of questions: the first type required participants to report the hours per week spent engaged in simulated environments (such as video games or 3D CAD models); the second type of question focused on frequency of such activities and required participants to check off a value on a 5-point Likert scale for how often certain activities, such as using gaming consoles, were done (0 = Never, 4 = Daily). Although there are existing questionnaires concerning 3D experience such as the Immersive Tendencies Questionnaire capturing a person's propensity to accept virtual environments (Witmer & Singer, 1998), the stimuli and its experience used in this experiment were not aimed at producing a convincing virtual environment. Rather, the stimuli were aimed to capture roughness on a screen and it was deemed that individuals very accustomed to seeing virtual textures, in games or through CAD work, may be more likely to exhibit greater sensitivity to the simulated roughness stimuli used in the experiment. In order to account for this possibility, experience with 3D games or 3D modelling was captured.

6.4 Experiment design

Participants were randomly assigned to one of the Visual Fidelity and Product Context conditions and experienced all 8 Roughness stimuli. The design was therefore a mixed $2 \times 2 \times 2 \times (8)$ model with Product Context (Control/Cell Phone) and Visual Fidelity (Moderate/Lower) as between subject factors balanced on Gender (male/female), crossed with the within-factors of Roughness (1:smooth – 8:rough).

6.5 Results

As in Experiment 2, response time data were decomposed into interaction time (IT) and reflection time (RT) and all data underwent removal of outliers based on reflection time exceeding three standard deviations from the sample mean. This resulted in the removal of 6 trials out of a total of 192 trials, leaving 186 trials in the analysis.

The potential effect of 3D modelling experience on participant response was checked by analyzing its correlations with all independent and dependent variables. There were no significant correlations, suggesting that the 3D experience of participants did not unduly affect emotional response to the stimuli in the present study; therefore, 3D experience was not included as a covariate in the analysis. Thus, the analysis proceeded using RM ANOVA with the full model for all controlled independent variables.

Results and analysis from Experiments 1 and 2 provided improved understanding of factors involved in affecting emotion via changing roughness. As a result, a more formal hypothesis testing approach was adopted for Experiment 3. The focus of the analysis will be on examining:

1. E3–$H1_0$: means of different Visual Fidelity groups are not significantly different in terms of EV

   E3–$H1_1$: means of different Visual Fidelity groups are significantly different, with the Lower Visual Fidelity group having higher EV (as in Experiment 1)

2. E3–$H2_0$: means of different Visual Fidelity groups are not significantly different in terms of RT

   E3–$H2_1$: means of different Visual Fidelity groups are significantly significantly different in terms of RT, with the Lower Visual Fidelity group having higher RT (as suggested by a marginal effect in Experiment 2)

3. E3–$H3_0$: means of different Roughness groups are not significantly different in terms of EV

   E3–$H3_1$: means of different Roughness groups are significantly different, with the higher Roughness levels having lower EV (as in Experiments 1 and 2).

4. E3–$H4_0$: means of different product context groups are not significantly different in terms of EV

   E3–$H4_1$: means of different product context groups are significantly different, with Product Context interacting with Roughness level such that the Cell Phone group has lower EV

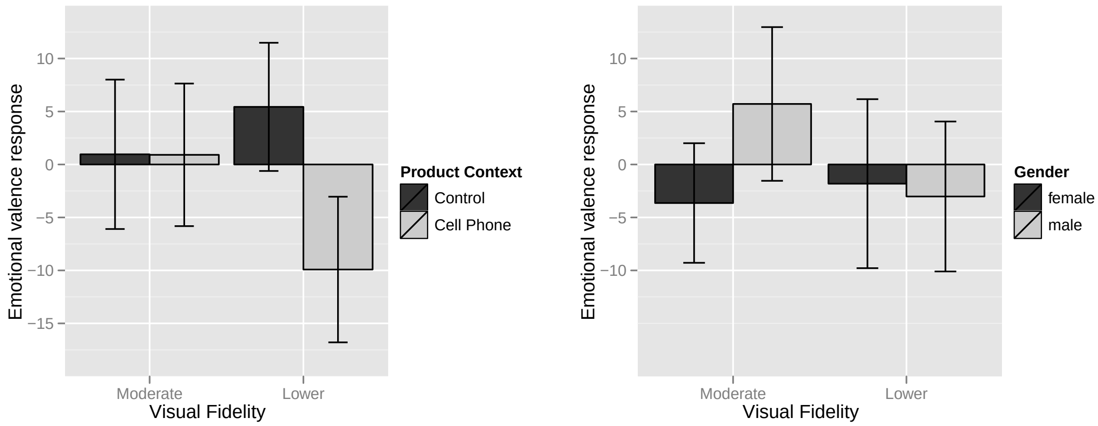
6.5.1 Emotional valence

General touch-emotion model:

A Visual Fidelity by Context interaction was significant [$F(1, 168) = 19.1$, $p \leq 0.001$] with participants in the Product Context Control condition showing increased EV when Visual Fidelity was decreased and participants in the Cell Phone condition showing the reversed trend (see Figure 6.2a). As per the interaction, a main effect on EV was found for Product Context [$F(1, 168) = 16.6$, $p = 0.001$] but no main effect on EV was found for Visual Fidelity suggesting that Product Context is the driving force in the interaction.

Gender effects:

EV was affected by a Gender by Visual Fidelity interaction [$F(1, 168) = 7.80$, $p \leq 0.006$] (see Figure 6.2b), such that increased Visual Fidelity led to a more pronounced increase in EV for males than for females. A main effect of Gender was also found (but no main Visual Fidelity effect), such that females had generally lower EV responses than males [$F(1, 168) = 4.83$, $p \leq 0.030$], making Gender a likely driving source of the Gender by Visual Fidelity interaction.



(a) (b)

Figure 6.2: a) Visual Fidelity by Product Context interaction on EV ($p \leq 0.001$); b) Visual Fidelity by Gender interaction on EV ($p \leq 0.006$).

A Product Context by Gender interaction was found to be marginally significant [$F(1, 168) = 3.27$, $p \leq 0.072$], suggesting that for females, the Cell Phone Context led to a more pronounced decrease in EV when compared to the Control condition while males show less of a shift in EV (collapsed over Roughness, see Figure 6.3)

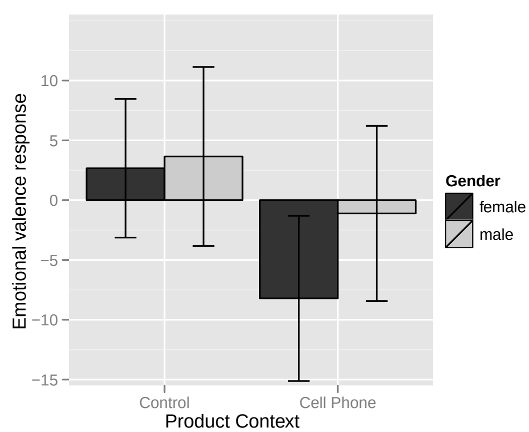


Figure 6.3: Marginally significant Product Context by Gender interaction on EV ($p \leq 0.072$)

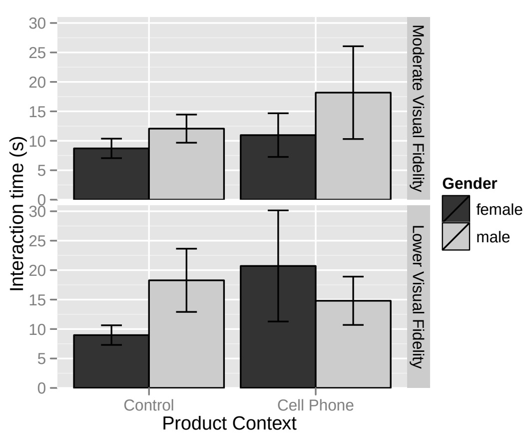
6.5.2 Response time

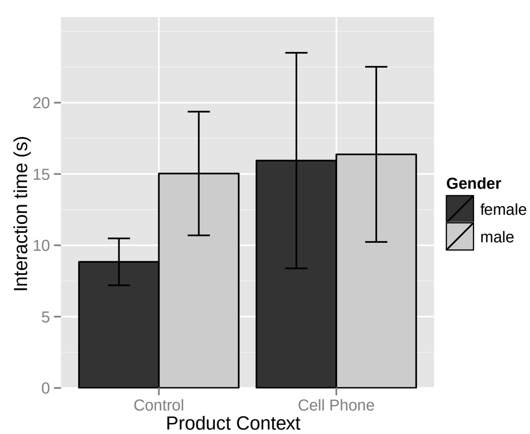
General touch-emotion model (Interaction Time):

Using RM ANOVA to examine the effects on IT in the complete model revealed a main effect of Product Context [$F(1, 168) = 7.57$, $p \leq 0.007$] such that the Cell Phone Condition led to higher IT. A main effect of Visual Fidelity was also significant [$F(1, 168) = 4.66$, $p \leq 0.033$], suggesting that Lower Fidelity led to higher IT values.

Gender effects (Interaction Time):

A three-way Product Context by Visual Fidelity by Gender interaction [$F(1, 168) = 8.95$, $p \leq 0.004$] found that the Product Context conditions produced a greater difference in IT values for females in the Lower Visual Fidelity condition (see Figure 6.5a). A two-way Product Context by Gender interaction [$F(1, 168) = 3.95$, $p \leq 0.049$] suggested that females had lower IT values only for the Control Product Context condition (see Figure 6.4b). The main effect of Gender on IT [$F(1, 168) = 4.38$, $p = 0.038$] showed that males generally had higher IT values.





(b)

(b)

Figure 6.4: a) Context by Gender by Visual Fidelity interaction on IT ($p \leq 0.004$); Product Context by Gender interaction on IT ($p \leq 0.049$).

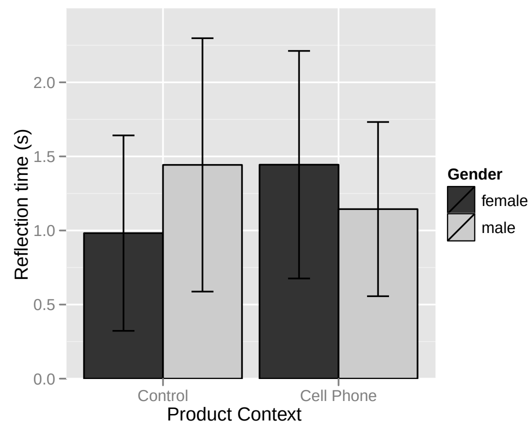


Figure 6.5: Marginally significant Product Context by Gender interaction on RT ($p \leq 0.077$).

General touch-emotion model (Reflection Time):

RT in the complete model revealed no statistically significant main effects or interactions that did not involve Gender.

Gender effects (Reflection Time):

A Product Context by Gender interaction was marginally significant [$F(1, 168) = 3.17$, $p \leq 0.077$], indicating that females tended to have lower RTs in the Control Product Context condition and that the reverse was true for males (see Figure 6.5).

6.5.3 Demographics data

As in Experiments 1 and 2, the variables of EV_{avg}, IT_{avg}, RT_{avg}, EV_{slope}, IT_{slope} and RT_{slope} were created (see Section 4.5.3 for details). The responses for the two 'tactual importance' questions were again summed to create a single variable, 'Tactual Importance Rating' (TIR), for each individual (see Section 5.5.3 for details).

An analysis of demographics data proceeded using Pearson's correlation coefficient and by coding the binary variable of Gender such that 'female' = 1 and 'male' = 2. The variable Ethnicity was balanced for Asians (n = 9) and Caucasians (n = 9), so only these two groups were included in any Ethnicity correlations (Asian = 1; Caucasian = 2). Results are summarized in Appendix K.

Significant correlations included a negative correlation between EV_{avg} and TIR ($r = -0.46$, $p \leq 0.03$), EV_{slope} and TIR ($r = -0.42$, $p \leq 0.05$) and IT_{avg} and Ethnicity ($r = -0.47$, $p \leq 0.05$). Correlations that approached significance included positive correlations between IT_{avg} and Age ($r = 0.37$, $p \leq 0.08$); RT_{avg} and Age ($r = 0.35$, $p \leq 0.10$); and Age and TIR ($r = 0.39$, $p \leq 0.06$).

6.6 Discussion

The purpose of Experiment 3 was to address the effect of the fidelity of visual information on emotional and time responses. Further, the question of the impact of different product contexts on response patterns was also considered towards the end of shedding light on the Cognition Pathway. As before, discussions will proceed within each subsection by first describing results relevant to the general touch-emotion model followed by results that include interactions with gender.

6.6.1 Emotional valence

When considering the general touch-emotion model, results from Experiment 3 by way of a 2-way interaction of Visual Fidelity $\times$ Product Context (as depicted in Figure 6.2; $p \leq 0.001$) provided support for E3–$H1_1$, the hypothesis that lower visual fidelity information leads to higher emotional valence response in the control product context condition (as anticipated based on results from Experiment 1). The results do not provide support for E3–$H4_1$, the hypothesis that priming participants to think of cell phones would lead to lower emotional valence in response to increased Roughness. It is, however, interesting to note that priming participants to think of cell phones did have a negative effect when moving from moderate (video of stimuli) to lower levels (3D model of stimuli) of visual information, indicating that perhaps those in the cell phone context needed more visual information that was simply not available in the 3D models.

The significant interaction between Visual Fidelity and Product Context found that participants reported similar emotional responses regardless of product context when the visual fidelity was moderate (video visual stimuli). However, when visual fidelity was lower (computer generated 3D model), product context drove different response patterns with the 'cell phone' context generating more negative emotional valence responses (as compared to the moderate visual fidelity condition) and the 'no product' control context generating more positive emotional valence responses (when compared to the cell phone condition). The pattern of the 3D model visual information eliciting more positive feedback than more 'real' visual information in conditions of no product context is consistent with findings from Experiment 1 (which varied visual information by presenting it either on a screen or as an actual object). It seems, then, that the addition of a product context decreases emotional response when visual information is presented as a 3D model of the product. From an application perspective, this finding may mean that computer generated 3D models may not be the ideal form for visual presentation of touch-based information.

It is worth noting that under the conditions tested in Experiment 3, E3–$H3_0$ (changing levels of roughness has no significant effect on emotional valence) was supported, regardless of whether or not participants were primed to think of a product context. Closer inspection of results from Experiment 1 suggest that the availability of haptic information may be the key – which may not be surprising. As a reminder, Experiment 1 found that roughness level impacted emotional valence responses only for those conditions when haptic information was available (see Section 4.5) but not under the condition when visual information appeared on a screen and no relevant haptic information was available. Considering findings from Experiments 1–3, it appears that when participants are asked to provide emotional valence responses to touch-based information by utilizing visual information only, their emotional valence response pattern cannot be as robustly predicted by altering physical parameters (such as roughness). Further, when touch-based stimuli are experienced via directly available haptic information, the effect of roughness on emotional response is generally robust. From a designer's perspective this finding is particularly relevant because it provides support for research into practical ways to incorporate haptic feedback interfaces to enhance touch-based interactions (such as online shopping). By providing haptic information to a touch-based experience, designers can more reliably improve user experience when making purchases of tactile products because certain rules of thumb (for example, increasing roughness leads to decreased emotional valence) have stronger effect when experienced through the haptic channel.

When considering the effects of gender on emotional valence, the marginally significant finding that females have less positive responses than males in the moderate (video of the stimuli) fidelity condition is consistent with findings from Experiment 1. The high visual fidelity condition of Experiment 1 was presented by a physical rough object (instead of an object on a screen), and so it was possible that females did not feel as positive about engaging with the apparatus as much as males did. In Experiment 3, this possibility is ruled out because both the moderate and lower visual fidelity conditions were presented on a screen, and manipulation of the viewed object was done via a non-relevant haptic experience (i.e., through a computer mouse). The increasing of visual fidelity, therefore, does in fact appear to have opposing effects on females in contrast to males, with females generally experiencing less shift in emotional valence response. From an applied perspective, it is worth considering that increasing visual fidelity may not increase user emotional experience when viewing an online product that is targeted primarily at females.

6.6.2 Response time

Interaction time

When considering interaction time for the general touch-emotion model, priming participants to think of cell phones resulted in higher interaction times, indicating that the manipulation was producing some behavioural effect and that participants were perhaps examining the stimuli more like they would if they were, for example, viewing a cell phone in a glass case in a store.

Once gender is considered as a factor on Interaction Time, a significant 3-way interaction was found between visual fidelity, product context and gender (Figure 6.4a; $p \leq 0.004$). While participants generally had higher interaction times in the phone condition, parsing the data by gender revealed that females were the main drivers of the pattern. That is, females spent significantly less time interacting with stimuli when not primed to think of a product context. Males showed no difference. These results are congruent with the findings from Experiment 2 (which did not prime participants to think of any context) that indicated that males had higher average interaction times. The interaction between product context and gender in Experiment 3 is evidence that introducing a product context increases interaction time for females but makes no difference for males. That is, when the stimulus is viewed as a product, females are more likely to spend more time interacting with it. This is consistent with consumer research indicating that providing touch-based stimuli to shoppers in a store (with meaningful stimuli) caused females more so than males to spend more time in the store (Hornik, 1992).

It is interesting that interaction time is affected by so many factors. It would be insightful to shed more light on the nature of the interactions that bring about higher or lower interaction times in order for applications in design to be clearer. This could be done, for example, by recording the types of physical interactions that subjects make with the stimuli during exploration.

Reflection time

When considering reflection time in the general touch-emotion model, Experiment 3 provided no evidence for E3–$H2_1$, which hypothesized that the lower visual fidelity group would produce higher RT (as was suggested by a marginally significant finding in Experiment 2). It is possible to reconcile results from both Experiments 2 and 3, since Experiment 2 varied visual information in a binary fashion (no visual information or complete visual information) and Experiment 3 varied visual information by having two levels of visual fidelity available on a screen. In light of the results of Experiment 3, the results for Experiment 2 can be interpreted to suggest that in situations where touch-based visual feedback is not available, people will rely on the haptic channel, which is slower at gathering information than vision (Schifferstein & Cleiren, 2005). Experiment 3 suggests that when visual information is available for touch-based responses but no corresponding relevant haptic information is available, assessments can be made with equal swiftness regardless of visual fidelity. This explanation implies that visual fidelity alone does not increase the reflection time, although visual fidelity may increase or decrease emotional response, as discussed previously.

When considering gender effects, product context and gender were found to marginally ($p \leq 0.077$) impact reflection time such that females tended to have higher reflection times when primed to think of a cell phone prior to manipulating the stimulus, whereas males tended to have higher reflection times when not primed to think of a product context, although the difference for males between product context conditions is lower. The pattern is similar to that of the effect of product context and gender on interaction time, although further investigation on the effect of product context is warranted to determine whether or not males truly experience a difference in reflection time between context conditions.

6.6.3 General discussion

The finding that emotional sensitivity is significantly correlated to self-ratings of tactual importance is supported by the trend observed in the demographics analysis of Experiment 2 (see Appendix I for the demographics analysis of Experiment 2). Individuals with higher self-ratings of tactual importance do appear to be more emotionally sensitive to increasing roughness – that is, the rougher that the stimuli become, the less that individuals high in tactual importance enjoy the stimuli. There is also strong evidence that average interaction time is higher for Asians than it is for Caucasians, a relationship hinted at in the correlation analysis of Experiment 1 (see Appendix G for the demographics analysis of Experiment 1). The marginally significant correlations between reflection time and age, as well as between interaction time and age, seem to suggest that as age increases, more time is needed to obtain touch-based information and to respond to it. Further, with increased age, it is more likely that participants report higher tactual importance, at least within the narrow range of age (23 to 33 years) represented in this experiment. It is interesting to note that gender was not correlated with tactual importance ratings, even though research suggests that females may consider touch to be more important than men (Hornik, 1992; Citrin et al., 2003). However, given that more than half of participants rated themselves as 'average' in terms of tactual importance ratings, the results from the present experiment are not definitive.

A summary of significant findings from Experiment 3 pertaining to the general touch-emotion model include:

1. Increasing visual fidelity for simplistic stimuli appears to decrease emotional valence in the cell phone context and increase emotional valence in the no product context condition ($p \leq 0.001$).

2. Priming participants to think of cell phones appears to increase interaction time ($p \leq 0.007$).

3. Lower visual fidelity appears to increase interaction time ($p \leq 0.033$).

Addressing limitations of Experiment 3

Experiment 3 sheds light on various effects of product context in interaction with other factors, but further questions remain, and are summarized below.

1. In order to provide more insight into the nature of the various effects on interaction time, further studies need to document the kind of physical exploration behaviours that people make while interacting with stimuli and provide more detailed behaviour measures.

2. In order to examine whether or not the product context effects observed under conditions of no relevant haptic information apply to conditions of directly available haptic information, further studies should include product context and allow for haptic exploration of the stimuli.

3. In order to examine the nature of the contribution of haptic and visual modalities to the emotional response to roughness, a further analysis of data from Experiments 2 and 3 is suggested (see Chapter 9).

Chapter 7

Experiment 4: Continuing examination of the effect of Product Context

Experiment 4 focused on examining the effects of Product Context in situations where both haptic and visual information are available, such as in-store purchase settings. It fills some of the gaps in data created by Experiment 2, which considered the multimodal touch experience without a primed product context, and by Experiment 3, which considered a vision-based experience of roughness with a single primed context contrasted with a control (context-free) condition. Experiment 4 considered the multimodal touch experience with four primed contexts, manipulations that may more readily allow results to be applied to situations of real-world shopping. Experiment 4 was also designed to clarify the impact of primed context on the emotional response to changes in roughness by having the Product Context factor (described in Experiment 3) be within-subjects in order to control between-subject variability. Finally, the absence of clear and consistent patterns of results concerning the time-based behaviour measures used thus far motivated a more detailed measure for behaviour. While interaction and reflection times were preserved for continuity in data, new measures were taken through video recordings to investigate the possibility that different types of physical interactions could be predicted by changes in roughness.

7.1 Participants

16 participants from the undergraduate or graduate student population at the University of Waterloo originally took part in the study. One participant was removed from the analysis because of a large number of missing data due to hardware failure, resulting in n = 15, with 7 females and 8 males in ages ranging from 18 to 22 (mean = 19.9, SD = 1.48). There were 5 Asians, 6 Caucasians and 4 Others. All participants were right-handed. On the questionnaire item capturing self-rated importance of tactual information, 8 participants gave ratings as 'average', 5 as 'above average' and 2 as 'below average'. On the questionnaire item capturing importance of tactual information during purchases, 6 participants gave ratings as 'average', 7 as 'above average' and 2 as 'below average'. As with Experiments 2 and 3, there was no reason to expect that this sample's mean for importance of tactual information would differ from that of the general consumer population; the skewness of the distribution was deemed to be more likely an artifact of self reporting[1].

Unlike previous studies, which recruited participants from a mailing list and invited them to the laboratory to partake in the experiment, Experiment 4 was located in the Student Life Centre (SLC) of the University of Waterloo. The SLC has a large common area and fairly steady traffic flow of students throughout the day. Participants were offered a candy bar for their participation in the 10-minute study, in an attempt to simulate in-store situations where ambient noise and other minor ambient distractions are present. The change in the choice of setting was done so that any results could be applied to these more general product shopping situations.

[1]See Section 5.1 for a more detailed discussion.

7.2 Stimuli and apparatus

As in Experiment 2, Experiment 4 used Roughness as the main independent variable and used the same set of rectangular prisms as stimuli and the same apparatus (see Section 5.2 for more details regarding the apparatus). A cardboard mini-stall was created to limit visual distractions during interaction with the stimuli. The cardboard stall was 70 cm in height and formed three walls around the apparatus, extending towards the participant a further 30 cm in order to obstruct peripheral vision.

In order to manipulate Product Context, participants were primed to think of one of four objects prior to and during each trial via a card that was displayed on top of the wooden housing. Participants were instructed to think of the object written on the card while exploring the stimuli. The first object, 'Mug', was designed to be the control condition. In contrast to Experiment 3 (in which verbal product context was given only at the start of a set of stimuli, and only for the between-subject Cell Phone condition), the visual cards used to cue participants into thinking about within-subject product contexts necessitated a control object in order for the conditions to be as similar as possible. 'Mug' was considered to be a quasi-control condition because it, like mobile phones, is something that needs to be picked up in order to be used but, unlike mobile phones and other technologies, has not been shown to elicit strong and consistent feelings from users about textures (Schifferstein, 2006; Chuang et al., 2001). The other three objects, Cell Phone, Keyboard, and Mouse, were selected because they all primarily interface with the hand and based on research linking high technology products and the importance of touch, these objects were more likely to evoke feelings regarding texture (Schifferstein, 2006; Fenko et al., 2009). It should be noted that product context in Experiment 4 represents a nominal variable as all conditions have some associated priming, as opposed to Experiment 3 where product context was an ordinal variable with one condition having no priming.

The main measure was again emotional response valence, which was captured using a slider similar to the one used in Experiment 2, but implemented using Lego NXT parts (the second generation Lego programmable microprocessor). This change in hardware was made because the original slider apparatus was no longer available for use. The NXT-based slider was built to replicate the dimensions and function of the original and on testing it performed comparably. A video recording was also taken of the interactions.

The basic demographics questionnaire used in this experiment was identical to that used in Experiment 2 (see Appendix H) for the reason that, unlike Experiment 3, there was no need to include questions to capture experience with 3D graphics since all stimuli in Experiment 4 were real physical objects.

7.3 Experimental and measurement procedures

Participants were instructed to keep their non-dominant hand on the slider and to use their dominant hand to explore the stimuli by looking at it and touching it. During each of four practice trials and before the set of actual trials, all participants were instructed to provide their emotional response valence to the physical stimulus as quickly and as accurately as possible. There were four sets of test trials (for each of the four Product Context conditions). Within each of the four sets, participants experienced all 8 Roughness stimuli in random order. Participants also experienced Product Context conditions in random order.

Each trial began with the viewing wedge closed. The participant was cued by the experimenter to begin at the same time that the viewing wedge blind was opened. Participants could touch the stimulus in any way that they desired but could not pick up the stimulus (and thus the haptic condition was similar to the 'Moderate' conditions used in Experiments 1 and 2). Participants were instructed to verbally inform the experimenter when they had finished with giving their emotional response, at which point the screen closed again. Each participant experienced all 8 Roughness stimuli in a random order. A 5-second break separated each trial. The experiment lasted 10 minutes and video was taken of the entire experiment for each participant.

7.4 Experimental design

Participants experienced all 8 Roughness stimuli and all 4 Product Context levels. The order in which participants experienced each Roughness level within a given Product Context condition, as well as the order in which Participants experienced each Product Context, was randomized. The design was therefore a mixed $2 \times (8 \times 4)$ model with Gender (male/female) crossed with the within-factors of Roughness (1:smooth – 8:rough) and Product Context (Cell Phone, Keyboard, Mouse, Mug).

7.5 Results

Response time data were decomposed into interaction time (IT) and reflection time (RT), as in Experiments 2 and 3. An additional time measure, video time (VT), was also used. Similar to previous experiments, all data underwent removal of outliers based on reflection time exceeding three standard deviations from the population mean. This resulted in the removal of 14 trials out of a total of 480 trials, leaving 466 trials in the analysis.

Repeated measures ANOVA was then used as the main statistical analysis tool, with α set to 0.05. Interesting results that approached significance ($0.05 < \alpha \leq 0.1$) were also included where applicable. Pearson's product moment correlation coefficient was used to analyze correlations between demographics variables.

Video analysis was completed by two independent raters, with variables for video time (VT), vertical motion (VM), horizontal motion (HM), multiple motions (MM) and small motions (SM) coded for each trial[2]. VT was taken as the difference between the time when participants began touching the stimuli and the time when

[2] Inter-rater reliability was calculated using Pearson's correlations. The two raters had very high correlations on variables of VM, HM, and MM ($r > 0.60$, $p \leq 0.001$). The two ratings for SM had a coefficient of $r = 0.39$, $p \leq 0.001$, and the ratings for VT had a coefficient of $r = 0.11$, $p \leq 0.001$.

participants ceased contact with the stimuli. VM was coded as 1 if participants stroked[3] the stimulus at least once at an angle less than or equal to 45 degrees to the length-wise edge of the stimulus, and 0 otherwise. Likewise, HM was coded as 1 if participants stroked the stimuli at least once at an angle greater than 45 degrees to the length-wise edge of the stimulus, 0 otherwise. MM was coded as 1 if participants' hand movement changed direction at least once, 0 otherwise. SM was coded as 1 if participants' hand movements were too small to be reliably coded as either VM or HM. A combined metric intended to capture the amount of tactual interaction the participant engaged in was calculated such that Tactual Interaction = VM + HM + MM - SM. SM is subtracted because it was assumed to be an indication of low tactual interaction.

The results below are discussed by looking at the dependent variables of emotional valence, response time (IT, RT, VT), and behaviour (VM, HM, MM, SM). Given findings from previous experiments, the focus of the current analysis will be on examining:

1. E4–$H1_0$: means of different roughness groups are not significantly different in terms of EV
   E4–$H1_1$: at least one of the means of different roughness groups is significantly different from the rest, with the higher roughness levels having lower EV (as in Experiments 1 and 2).

2. E4–$H2_0$: means of different product context groups are not significantly different in terms of EV
   E4–$H2_1$: at least one of the means of product context groups is significantly different from the rest (as in Experiment 3).

As this is the first study with video data, the analysis of the various behaviours will include exploratory data analysis. In addition to understanding how patterns of stimulus exploration can be predicted by controlled factors, the analysis of video

[3] A stroke is defined as the act of running finger(s) across the surface to the stimulus.

data will also shed light on whether or not the use of video analysis is recommended for future studies.

7.5.1 Emotional valence

General touch-emotion model:

The RM ANOVA revealed a significant main effect of Roughness [$F(1,456) = 33.4$, $p \leq 0.001$] on EV in the expected direction, with increased Roughness leading to decreased EV.

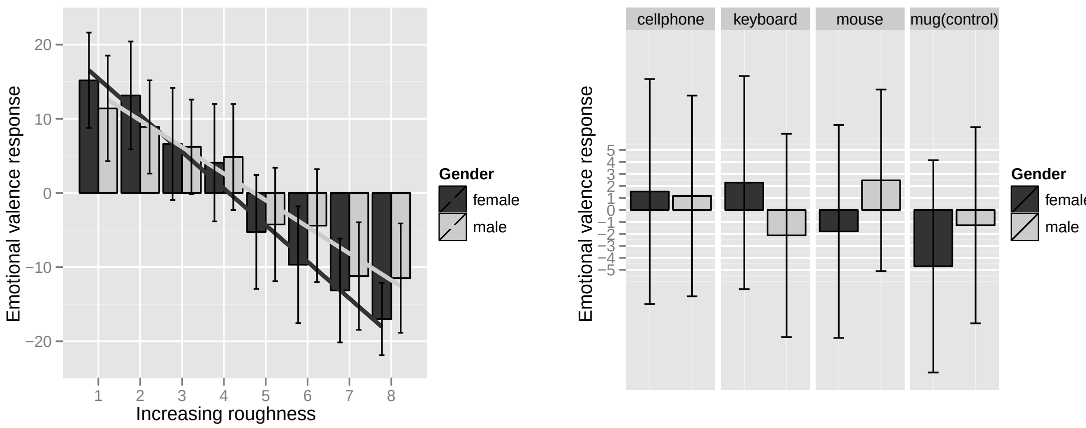
Gender effects:

A two-way Roughness by Gender interaction on EV was found [$F(1,456) = 5.38$, $p \leq 0.021$] indicating that females respond with a greater range of emotional valence when Roughness increases (see Figure 7.1a). A two-way Product Context by Gender interaction [$F(3,456) = 2.65$, $p \leq 0.049$] was also found, suggesting that females respond with lower EV than males in the Mouse and Mug Contexts, but with higher EV in the Keyboard Context (see Figure 7.1b). A partial analysis on Product Context reveals a marginally significant main effect of Gender in the Keyboard Context [$F(1,114) = 3.56$, $p \leq 0.062$] and Mouse Context [$F(1,114) = 3.12$, $p \leq 0.081$]. The apparent differences in EV for females and males in the Mug and Cell Phone Contexts were not significant.

7.5.2 Response time

General touch-emotion model (Interaction Time):

RM ANOVA revealed a marginally significant main effect of Product Context indicating that the Keyboard Context had higher IT values than the other conditions [$F(1,448) = 2.17$, $p \leq 0.091$] (see Figure 7.2).



(a) (b)

Figure 7.1: a) Average EV broken out by Roughness and Gender, showing an interaction ($p \leq 0.021$); b) average EV broken out by Gender and Product Context, showing a 2-way Gender by Product Context interaction ($p \leq 0.049$).

Gender effects (Interaction Time):

A main effect of Gender on IT was found, indicating that males had higher IT values than females [$F(1,448) = 7.02$, $p \leq 0.009$].

General touch-emotion model (Reflection Time):

A marginally significant Roughness by Product Context interaction suggests that the Cell Phone Context produced larger changes in RT values as Roughness increased [$F(1,448) = 2.45$, $p \leq 0.063$] (see Figure 7.3).

Gender effects (Reflection Time):

A main effect of Gender on RT was found, with males tending to have lower RT values [$F(1,448) = 5.27$, $p \leq 0.022$].

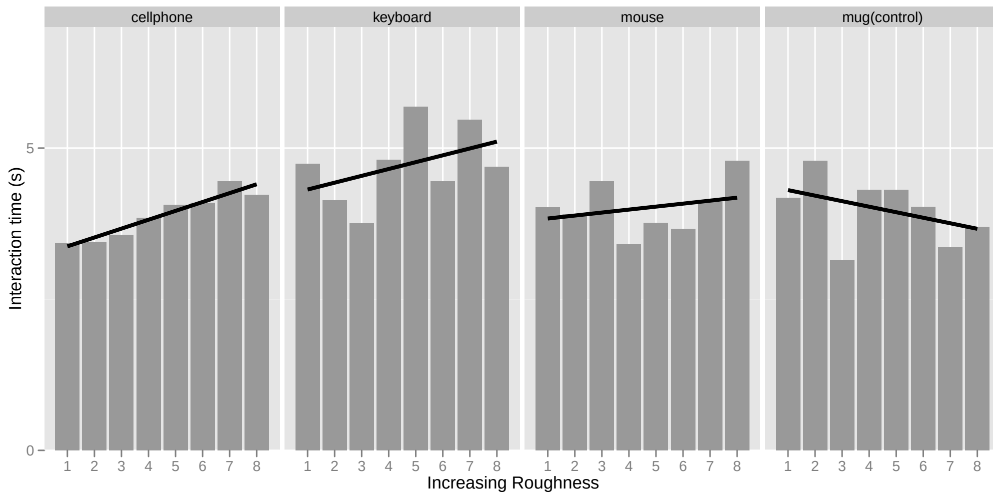


Figure 7.2: A Roughness by Product Context interaction on IT suggesting that the Cell Phone Context produces a different pattern in response to Roughness for IT values ($p \leq 0.091$).

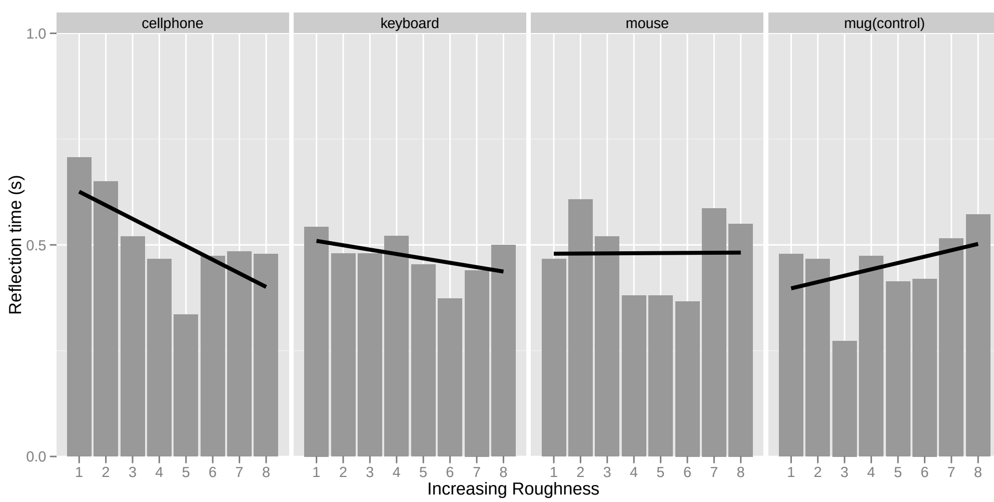


Figure 7.3: A Roughness by Product Context interaction on RT suggesting that the Cell Phone Context produces a different pattern in response to Roughness for RT values ($p \leq 0.063$).

General touch-emotion model (Video Time):

VT in the complete model revealed no statistically significant main effects or interactions that did not involve Gender.

Gender effects (Video Time):

Considering Gender, the analysis of VT revealed a marginally significant main effect of Gender, indicating that males had higher values of VT [$F(1,448) = 3.49$, $p \leq 0.066$].

7.5.3 Behaviour

The analysis of the different types of behaviour began with an exploratory data analysis in order to shed light on the effectiveness of the new measurement procedure. The first graphical analysis was aimed at examining whether or not Product Context had an effect on the various types of behaviours, shown in Figure 7.4. This graphic suggests that participants are more likely to engage in MM and VM than either HM or SM. Further exploratory analysis considered the impact of gender on observed behaviour, shown in Figure 7.5. Figure 7.5 suggests that females are less likely to engage in SM than males and that both genders engage in the other types of behaviours approximately equally.

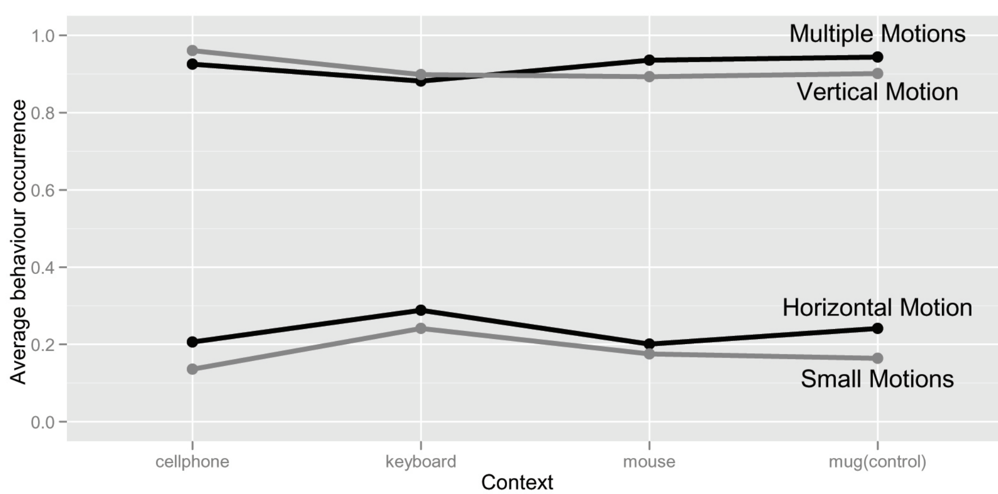


Figure 7.4: Average occurrence of each type of behaviour plotted over each of the four Product Contexts (1 = type of exploration behaviour occurred; 0 = behaviour did not occur).

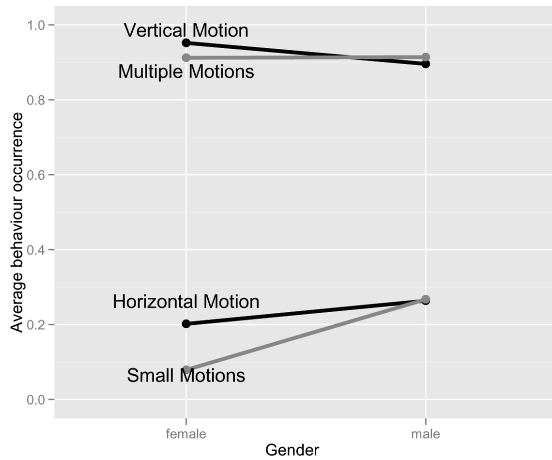


Figure 7.5: Average occurrence of each type of behaviour plotted over Gender (1 = type of exploration behaviour occurred; 0 = behaviour did not occur).

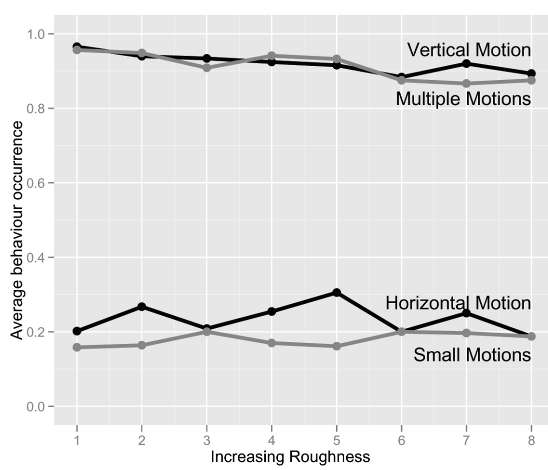


Figure 7.6: Average occurrence of each type of behaviour plotted over Roughness levels (1 = type of exploration behaviour occurred; 0 = behaviour did not occur).

Considering the impact of Roughness on behaviour produced Figure 7.6, in which an interesting pattern of decreasing average tendency to engage in VM and MM as a function of increasing Roughness was observed. HM showed no response to roughness, and SM slightly increased in response to increased Roughness. Figure 7.7 explores the potential patterns relating each behaviour type with Roughness and Gender. While VM and MM appear to decrease as a function of increased Roughness for both genders, HM and decreases with increased Roughness only for females (males increase HM with increased Roughness), and females increase SM in response to increased Roughness (males do not appear to exhibit a difference in SM with increased Roughness).

General touch-emotion model:

The RM ANOVA on the summary behaviour variable of Tactual Interaction did not find any significant effects. However, the exploratory graphic of Figure 7.6 prompted the analysis of the combined dependent variable of (VM + MM), since both variables seem to decrease with increased Roughness. This analysis revealed a main effect of Roughness [$F(1, 447) = 4.01$, $p \leq 0.046$] such that increased Roughness led to decreased average (VM + MM), as can be seen in Figure 7.6.

Gender effects:

The summary behaviour variable of Tactual Interaction was affected by Gender such that females had higher Tactual Interaction values than males [$F(1, 447) = 5.33$, $p \leq 0.022$]. There were no other effects on Tactual Interaction. Consideration of the exploratory graphic shown in Figure 7.5 prompted the analysis of the dependent variable HM and found that it was affected by a marginally significant Gender by Roughness interaction, such that males had higher tendency to engage in HM while Roughness increased and females tended to have lower tendency to engage in HM as Roughness increased [$F(1, 447) = 3.04$, $p \leq 0.082$] (see Figure 7.6, third row). HM was also affected by a main effect of Gender such that males had a

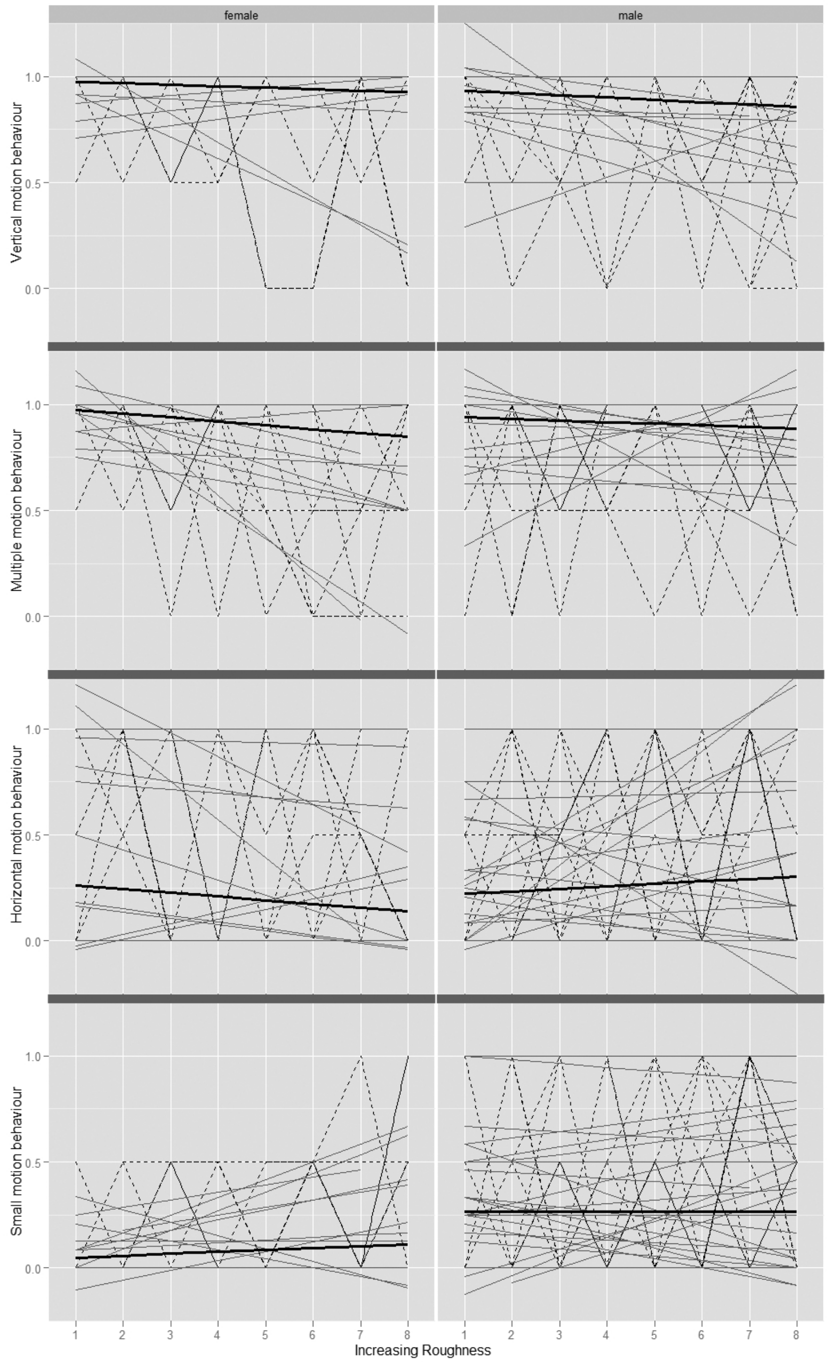


Figure 7.7: Average occurrence for each type of behaviour plotted over Roughness levels by Gender. Dashed lines: individual subject profiles; Solid thin lines: individual subject best fit lines; thick black lines: group average best fit lines.

higher tendency to engage in HM [$F(1, 447) = 4.19$, $p \leq 0.042$] (see Figure 7.5). Finally, SM was significantly impacted by a Product Context by Gender interaction that suggested that males engaged in more SM but only for the Keyboard Context [$F(3, 447) = 3.17$, $p \leq 0.024$]. SM was also impacted by a main Gender effect on SM [$F(1, 447) = 38.15$, $p \leq 0.001$], suggesting that Gender was the main driver of the Product Context by Gender interaction (see Figure 7.5).

7.5.4 Demographics data

As in previous experiments, the variables of EV_{avg}, IT_{avg}, RT_{avg}, EV_{slope}, IT_{slope} and RT_{slope} were created (see Section 4.5.3 for details). Additional values, VT_{avg} and VT_{slope}, were similarly created to capture the individual-averaged VT and the individual sensitivity of VT to increasing Roughness. The responses for two 'tactual importance' questions were again summed to create a single variable, 'Tactual Importance Rating' (TIR), for each individual. As before, females were coded as 1 and males as 2. Ethnicity was balanced across Asians and Caucasians (9 individuals in each group), with Asians coded as 1 and Caucasians coded as 2.

Statistically significant correlations included a positive correlation between TIR and RT_{slope} ($r = 0.52$, $p \leq 0.05$). Marginally significant correlations included a positive correlation between RT_{slope} and Age ($r = 0.45$, $p \leq 0.09$), a negative correlation between RT_{avg} and Ethnicity ($r = -0.54$, $p \leq 0.09$), and a negative correlation between EV_{slope} and the summary behaviour variable Tactual Interaction ($r = -0.49$, $p \leq 0.08$). See Appendix L for the full correlation table.

7.6 Discussion

The purpose of Experiment 4 was to continue the investigation into the effects of changing roughness in a new environment considered to be more representative of real-world touch experiences. Further, Experiment 4 was designed to more closely examine the effects of varying product contexts on emotion response while experiencing multimodal touch. Lastly, Experiment 4 included new measures for behaviour in response to questions raised by earlier experiments. The analysis of Experiment 4 data allowed for the consideration of the effectiveness of these detailed measures of behaviour based on the level of insight that they were found to provide. As before, discussions will proceed within each subsection by first describing results relevant to the general touch-emotion model followed by any results that include interactions with gender.

7.6.1 Emotional valence

When considering the general touch-emotion model, the main effect of surface roughness on emotional valence response was found to be robust (and consistent with findings from Experiments 1 and 2), thus supporting $E4–H1_1$. This result was strongly significant ($p < 0.001$) even in the presence of random ambient noise and potential distractions as afforded by the Student Life Centre and given multiple product contexts. The robustness of the roughness-emotion relationship suggests that it may apply even in store/shop settings where there may be similar ambient factors (e.g. random noise) that could distract from the touch-based stimulus. Thus the roughness-emotion relationship is compelling under both controlled laboratory and less controlled but arguably more realistic settings.

When considering gender effects, a significant interaction was found between surface roughness and gender indicating that females were more emotionally sensitive to increases in roughness than males, a relationship suggested in Experiment 3 ($p \leq 0.072$). This finding complements literature suggesting that females are more interested in touch-based experiences (Hornik, 1992; Citrin et al., 2003). It is consistent, then, that the present findings indicate that the preference for touch-based experiences is also correlated with increased emotional sensitivity to changes in its physical parameters. Turning to the consideration of the impact of product context and $E4–H2_1$, the current experiment provides tentative support for the hypothesis that product context serves to simply shift the Affective Pathway response curve up or down, although the effect may depend on demographic factors. Evidence for this relationship includes the marginally significant finding that females have generally increased emotion in the keyboard condition and decreased emotion in the mouse condition. Combining the results from Experiments 3 and 4, it appears that providing product context for a haptic experience does not change the pattern of emotional response to changing roughness. In other words, the magnitude of the impact of decreased or increased roughness on emotional response does not appear to be significantly influenced by a suggestion to imagine a product context for that touch experience.

7.6.2 Response time

When considering response time in the general touch-emotion model, there were no significant effects that did not involve gender. Although marginally significant, interaction time was found to be higher when participants were primed to think of a keyboard, but it is unclear what may have contributed to this particular result. During the experiment, it was noted that some participants began 'imaginary typing' on the stimulus surface, which could have increased the interaction time. It is possible that another unmeasured covariate, such as typing speed, was the cause of this marginally significant primed product context effect on IT. For example, individuals who are slow typists could have been driving the observed increased interaction time when they interacted with the stimuli. However, it should be noted that participants were asked to give their response to the stimuli as quickly and as accurately as possible; they were not asked to interact with the stimuli as if it were actually the primed product type. It might be insightful for future studies that choose to manipulate context through priming to include a measure for 'imagination'; for example, persons with higher imaginative ability might tend to take longer in interacting.

Although not significant, a visual inspection of Figure 7.2 and 7.3 reveals an interesting pattern of IT and RT slopes as a function of roughness trending consistently in opposite directions for each product context category, as suggested in Experiment 2 when looking at gender effects on interaction and reflection time. One interpretation is that the longer participants spend interacting with the object, regardless of surface roughness, the faster they are able to give an emotional response. It is apparent, then, that roughness alone does not drive response times, and this result opens the door for emotion to serve as a mediator of response times.

When considering the effects of gender, gender significantly impacted interaction time and marginally significantly impacted video time in the same way observed in Experiments 2 and 3. That is, males were found to have generally higher interaction and (and here, video time) than females, regardless of other factors. That both IT and VT exhibited the same pattern in gender is not surprising, since video time may be thought of as a different way to measure interaction time (via video coding instead of a computerized 'stopwatch').

Reflection time was significantly impacted by gender, with males having lower reflection times than females. The marginally significant interaction between product context and roughness may indicate that priming participants to think of the stimulus as a cell phone leads to greater changes in reflection time as roughness increased (that is, higher roughness led to lower reflection times). This pattern might be explained by the rougher stimuli generating higher arousal, which in turn led participants to give their responses without need for lengthy reflection.

7.6.3 Behaviour

When considering the general touch-emotion model, there were some patterns in behaviour that were independent of gender. For instance, the results indicate that vertical motion perpendicular to the groove length and multiple distinct movements were both impacted by roughness, such that increased roughness led to fewer of both types of activity ($p \leq 0.046$). This finding supports the existence of the Behaviour Pathway depicted in the touch-emotion model (see Section 3.2), since increased roughness decreases emotional valence, which might be thought of to lead to decreases in the amount of these two types of behaviour. Also, the hypothesis that small motions are related to lower tactual engagement is supported in that small motions are more likely to occur as the roughness of the stimuli increases, which again, has already been shown to lead to decreased emotion.

In considering the effects of gender, analysis of the combined Tactual Interaction variable revealed that females tended to engage in more touch behaviours than males ($p \leq 0.022$), although a breakdown of the different types of motion indicates that the relationship is not entirely simple. Small motions (motions that could not be classified as either horizontal or vertical motions due to their short distance of finger movement) were found to be impacted by gender, such that males engaged in more small motions during stimulus exploration than females.

That horizontal motions (movements parallel to the groove lengths) did not produce a conforming pattern is perhaps not unsurprising (there was a marginally significant product context by gender interaction), given that the surface roughness of the stimuli cannot be experienced with this type of movement. It might be worthwhile, in future studies, to limit the type of interaction so that participants experience the texture manipulation in a more controlled manner.

To summarize, the analysis of the detailed behaviour measures has led to insights into the types of behaviour that might be elicited if stimuli are smooth or rough, and may allow prediction of behaviour depending on whether user experience is positive or negative. Although the tendency for participants to engage in each behaviour appears to change little as a function of product context or roughness (as in Figure 7.4 and 7.6), video coding is recommended because, as discussed here, it may tease out behaviours indicative of product texture exploration strategies that may be impacted by emotional response.

7.6.4 General discussion

The demographics analysis revealed a positive correlation between reflection time slope (to increased roughness) and tactual importance ratings, meaning that individuals higher in tactual importance ratings tended to spend more time thinking about the emotional response that they report. Since it was found that roughness is not generally the sole predictor of response times, this correlation may indicate that tactual importance is a contributor to the relationship between surface roughness and response time. With regards to the negative correlation between emotional valence slope (as a function of increased roughness) and Tactual Interaction, it is possible that people with high sensitivity to surface roughness (i.e, they have a greater tendency to experience decreased emotional valence with increased roughness) also tend to engage in fewer types of touch (vertical motion, horizontal motion, multiple motions) because these individuals are better able to discern haptic information with fewer interactions.

Marginally significant correlations included the positive correlation between reflection time slope (as a function of increased roughness) and age, suggesting that the people who spend more time reflecting on stimuli that increase in roughness tend also to have higher age (keeping in mind the relatively narrow sample age range of 18 to 22). For any single individual, one might expect that the opposite would be true. That is, rougher surfaces are more arousing (in a negative way), and thus reflection times should decrease with increased roughness (less reflection is necessary). Further analysis of this correlation given findings from previous experiments is recommended.

Finally, the negative correlation found between average reflection time and ethnicity such that individuals who spend more time reflecting on stimuli also tended to be Asian, could be related to the finding by Han and Hong (2003) that Americans are more likely to consider surface roughness to be more important in overall product satisfaction than are Koreans. Thus, Caucasians may be more accustomed to providing responses to roughness and to linking it with user experience. If Asians are less experienced with providing emotional response to changing levels of roughness, it would stand to reason that they may also require more time to provide that response. A more complete discussion follows in the combined demographics analysis, Chapter 8.

Like previous experiments, the demographics analysis of Experiment 4 data uncovered a number of interesting findings. It would be worthwhile to analyze all demographics data collected across studies to determine which correlations are better supported than others.

A summary of key findings from Experiment 4 pertaining to the general touch-emotion model include:

1. Increased roughness decreased emotional response, regardless of primed product context ($p \leq 0.001$).

2. Increased roughness tended to decrease the tendency to engage in physical interaction (through vertical/multiple exploration movements) with stimuli ($p \leq 0.046$).

Addressing limitations of Experiment 4

The discussion of results from Experiment 4 indicated value in including more detailed measures for behaviour. That males and females were often found to engage in different types of physical exploration under different conditions is a fascinating discovery and had there been more data (for example, from other studies) with which to compare findings, stronger statements with regards to how males and females engage in touch interactions could have been made. The drawbacks of such detailed measures includes the extremely time consuming nature of video coding (which was why video coding was not employed in Experiments 1 to 3 until it became clearer that time measures for behaviour were likely not capturing the whole picture). Future studies, perhaps employing actual force feedback haptics systems that can capture and code movements automatically, should continue investigating the effects of gender and product context, to name but two relevant factors, on both emotional response and behaviour.

The discussion of Experiment 4, while considering results from the previous three Experiments, motivates the following areas of investigation:

1. The patterns of results surrounding observed physical behaviour suggests different tendencies of behaviour for varying levels of gender and roughness. Future work should continue to examine and clarify how physical behaviour is influenced by these and other factors.

2. In order to shed light on which of the many correlations discussed in the Experiments so far are consistent, an analysis of combined demographics data is suggested (see Chapter 8).

3. In order to examine the nature of the contribution of the perception of the stimulus (roughness) and cognition (product context) to emotional response, a further analysis of data from Experiments 3 and 4 is suggested (see Chapter 10).

4. In order to examine the nature of how perception and emotion might lead to response time behaviour, a further analysis of data from Experiments 3 and 4 is also suggested (see Chapter 11).

Chapter 8

Analysis: Demographics

From the standpoint of developing the touch-emotion-behaviour framework, an analysis of the effect of covariates such as age and gender provides a basis for understanding their effects when relationships between roughness, emotion, and behaviour are modelled. These potential covariates, gathered from demographics questionnaires, were collected from all experiments, although the questionnaire items from Experiments 2–4 were the most comparable.

As a result, the demographics analysis proceeded by using only data from Experiments 2–4, collapsing participant data such that each participant was represented by one row of data. Given that the analysis included time-related dependent variables, outliers were removed prior to collapsing the data on the basis of reflection time (RT) being greater than three standard deviations from the experiment population mean (see Section 4.5 for details). 24 participants were included from Experiment 2, 24 participants were included from Experiment 3, and 15 participants were included from Experiment 4 (as before, one participant was dropped due to too much missing data). There were 31 females and 32 males, coded as 1 and 2, respectively, for a total of 63 participants ages 18 to 33 (mean = 24.16, SD = 3.62). The two Ethnicities which had the most participants identified were the Asian Ethnicity (n=30) and the Caucasian Ethnicity (n=17), coded as 1 and 2, respectively.

If enough correlations analyses are performed, randomness is bound to produce a few correlations that are significant. In order to determine the reliability of findings from the combined and individual experiment demographics analyses, correlations from each individual Experiment were compared with the combined correlation analysis. Significant relationships from the combined analysis in which the correlation coefficients differed in sign from findings from individual Experiments were investigated more thoroughly. By conducting such a meta analysis, it is possible to be more confident of reported significant correlations.

8.1 Results

As with the analyses in Experiments 2–4, the variables of EV_{avg}, IT_{avg}, RT_{avg}, EV_{slope}, IT_{slope} and RT_{slope} were created (see Section 4.5.3 for details). The responses for two 'tactual importance' questions were again summed to create a single variable, 'Tactual Importance Rating' (TIR), for each individual.

Statistically significant correlations include the positive correlation between IT_{avg} and Age, RT_{avg} and Age, and Age and TIR (with *r* at 0.49, 0.48, and 0.28, respectively, and $p \leq 0.03$). Significant negative correlations were found between EV_{slope} and TIR (*r* = -0.27, $p \leq 0.04$).

Marginally significant correlations ($0.05 < p \leq 0.1$) were found between EV_{avg} and Ethnicity, IT_{avg} and Ethnicity, RT_{avg} and Ethnicity, EV_{slope} and Age, IT_{slope} and Age, and Gender and TIR (with *r* at -0.27, -0.23, -0.28, 0.23, -0.21 and -0.22, respectively). Results are summarized in Appendix M.

8.1.1 Analysis of inconsistent correlations across experiments

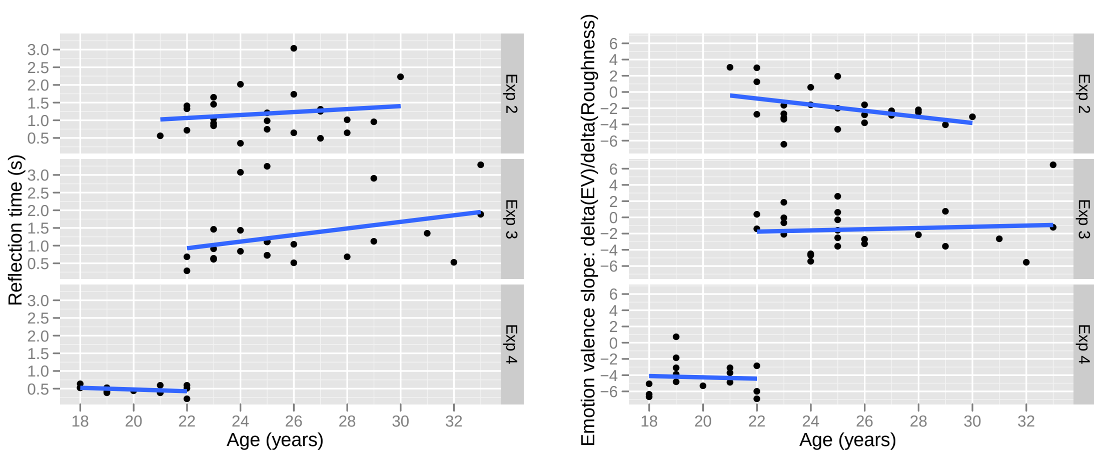
Each significant correlation discussed previously was further analyzed to determine whether or not the correlation obtained from combining data from Experiments 2–4 was consistent with the findings from individual demographics analyses (from Sections 5.5.3, 6.5.3, 7.5.4). If the directions of the correlations in the combined analysis were the same as in the individual Experiment demographic analyses (regardless of the significance in the individual analyses), then we can be more confident of the relationship. Otherwise, further investigation and discussion may be necessary.

TIR

All significant and marginally significant correlations of the combined analysis shown in the first column of Table M.1 were found to be in the same direction as the individual Experiment demographics analyses, providing strong support for the positive correlation between TIR and Age and the negative correlations between TIR and EV_{slope} and TIR and Gender.

Age

The significant correlation between Age and IT_{avg} in the combined analysis was supported by correlations in the same direction by all Experiments. The significant correlation between Age and RT_{avg} was supported by all Experiments except Experiment 4. Closer inspection of the graphical representation of the data as shown in Figure 8.1a revealed that one possible explanation for the opposite correlation



(a) (b)

Figure 8.1: a) Correlation between Age and RT_{avg} broken down by Experiment; b) correlation between Age and EV_{slope} broken down by Experiment.

in Experiment 4 between Age and RT_{avg} is the limited range of ages available in Experiment 4. That is, the narrow span of ages have a weaker ability to comment on age-related trends. Therefore, the positive correlation between Age and RT_{avg} and the negative correlation between Age and IT_{slope} remain convincing.

The marginally significant positive relationship between Age and EV_{slope} is not well supported (see Figure 8.1b). Part of the reason is due to Experiment 3, which had a reasonably large representation of ages but did not provide support for the negative relationship between age and emotional valence slope. One possible explanation for the different pattern of Experiment 3 may be that, unlike the other Experiments, it did not provide participants with information on the haptic channel. Although Experiment 1 was exploratory in nature, we look to its results in order to shed light on the direction of correlation between Age and EV_{slope}. Examination of Figure F.7a from the exploratory data analysis of Experiment 1 revealed that EV_{slope} more likely shares a negative relationship with Age.

Lastly, the negative correlation between Age and RT_{slope} was also poorly supported by the analysis from individual studies, with only a single other study providing supporting evidence.

Gender

Inspection of the correlation table in Appendix M revealed no statistically significant correlations concerning Gender and any other variable not previously discussed. This finding is also consistent with the findings from individual Experiment demographic analyses.

Ethnicity

Comparison of combined results with the individual experiment demographics analyses involved looking only at Experiments 3 and 4, since Ethnicity was not a variable in Experiment 2 due to heavily imbalanced Ethnicity data. The marginally significant negative correlations between Ethnicity and EV_{avg} and Ethnicity and

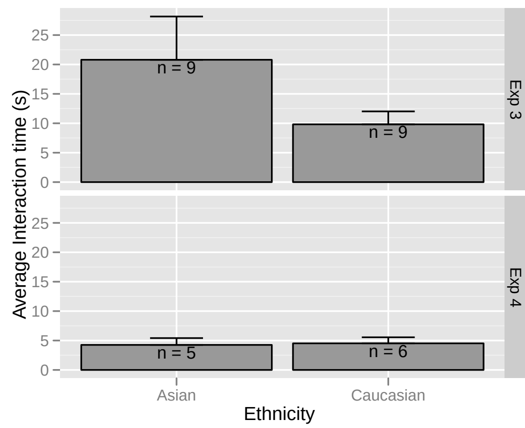


Figure 8.2: Correlation between Ethnicity and IT_{avg} broken down by Experiment.

RT_{avg} were supported by both the individual analyses. However, the Ethnicity and IT_{avg} correlations were in differing directions for Experiments 3 and 4. Graphical inspection of Figure 8.2 suggests that the negative correlation between the two variables observed in the combined demographics analysis is driven by data from Experiment 3 and that data from Experiment 4 suggests no correlation between the variables. The low variance from the data in Experiment 4 indicates that perhaps the strong pattern from Experiment 3 is caused by a third variable, such as Visual Fidelity. The negative correlation between Ethnicity and RT_{avg} is uncertain.

8.2 Demographics discussion

The purpose of the combined demographics analysis was to determine which, if any, of the covariates of interest are consistently correlated with the response variables. Reliable patterns can be directly applied in the design of products with touch elements for the purpose of improving user experience and performance based on individual characteristics such as age and gender, and they can also indicate the need to control for covariates in subsequent modelling of relationships between roughness, emotion, and behaviour. It should be noted that all correlations related to age should be considered in light of the fact that all participants were drawn from the university-age population.

Looking first at TIR, the finding that emotional sensitivity to roughness increases as TIR increases makes sense given that increased roughness leads to decreased emotional valence. It also follows that the negative effects of increased roughness would be stronger for individuals who are more sensitive to touch-based information. TIR and age were found to be positively correlated, suggesting that as individuals increase with age they are more likely to pay more attention to tactual information. Finally, the finding that females are more likely to have higher TIRs than males is consistent with literature suggesting that females generally have higher self-reported need for touch (Citrin et al., 2003).

Looking at age and its relationships with covariates revealed a strong positive correlation between both average reflection and interaction time and increased age. This could be explained by literature that suggests that skin sensitivity decreases starting as early as age 20 (Verrillo, 1993), meaning that as age increases, more time may need to be spent in both handling the touch-based stimuli and providing an emotional response to it. It is interesting that there is evidence for a negative relationship between age and EV_{slope}, indicating that as age increases, increased roughness produces a more negative effect on emotion – that is, an increased emotional sensitivity to decreased roughness.

Finally, the negative relationship between ethnicity and both interaction and reflection times suggests that Caucasians spend less time interacting with and reflecting on touch-based experiences than do Asians, even though there is no evidence of a relationship between ethnicity and TIR. In a study in user satisfaction across cultures conducted by Han and Hong (2003), cross-cultural differences were observed between the importance that American versus Korean participants placed on surface roughness of audio/visual products. The observed differences suggested that Americans, not Koreans, were more likely to consider roughness to be an important contributor to user satisfaction. The findings in the present research could possibly be explained if Caucasians have more practice with parsing and responding to texture information and are thus faster at doing it than are Asians.

It should be noted that the negative correlation between Ethnicity and RT_{avg} was not supported by the two experiments that contributed to the finding, so it is possible that the observed Ethnicity effect on reflection time is a product of another covariate. Further studies can shed more light on the Ethnicity effect on response times by balancing groups on Ethnicity and by framing the ethnicity demographics questionnaire item to query for 'culture most identified with'[1], which allows for findings to be truly attributed to the characteristics of a culture/ethnicity, as opposed to physical appearance. Despite these limitations, the findings observed in this research suggest with fair consistency that there may be culture-based tendencies to interact more or less with touch-based stimuli.

A summary of key significant findings from the combined demographics analysis include:

1. Increasing roughness leads to more negative emotional responses for individuals with high tactual importance ratings (r = -0.27 $p \leq 0.04$).

2. Tactual importance is positively correlated with age (r = 0.28, $p \leq 0.03$).

3. Interaction and reflection times are higher with increased age (r_{IT} = 0.49, $p \leq 0.01$; r_{RT} = 0.48, $p \leq 0.01$).

[1] In all questionnaires used for this research, participants were asked to fill out all items and were given minimal guidance. The ethnicity section provided a list of ethnicities that the participant could choose from, or they could write their own.

Chapter 9

Analysis: Affective Pathway

The Affective Pathway analysis was conducted to examine the extent to which emotional response could be predicted by changing physical surface properties, as well as to examine how much the haptic and vision information channels can impact that relationship. The model outlined in Section 3.2 depicts emotional response as being dependent on a perceived touch experience, with the haptic and visual modalities both contributing to the emotional response (but in an unknown fashion). This 'Affective Pathway' is highlighted in Figure 9.1 and in essence suggests that it is possible to predict emotion by changing roughness, and that the haptic and visual modalities may differentially impact this pattern.

To examine this pathway, a subset of data from all experiments needed to be selected to meet the requirements that a) the manipulations included varying the

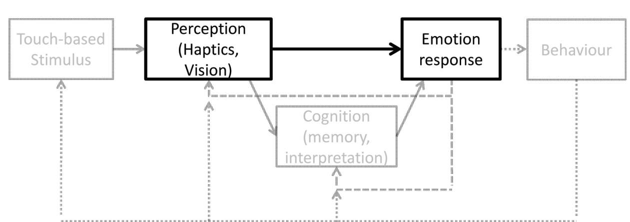


Figure 9.1: The Affective Pathway as a path between perceived roughness and roughness-evoked emotion.

availability of haptic and/or visual information; b) the cognitive aspects of the stimuli were minimized; and c) the experimental design was otherwise identical. Experiment 1, with only 3 levels of Roughness instead of 8, was ruled out as a source of data. Experiment 4 was ruled out because all stimuli were given a product context. The experimental setups used in Experiments 2 and 3 manipulated haptic and visual information availability, and all of the participants in Experiment 2 and half the participants in Experiment 3 were exposed to stimuli free of product context, so the combined analysis of data from these two studies can be used together to analyze the impact of multimodal touch on emotion. It should be noted that one assumption made was that perceived roughness, for our purposes, can be operationalized by actual roughness (see Sections 2.4.2 and 3.5 for more detailed justifications).

9.1 Analysis procedure

Analysis of how emotion may be predicted by a multimodal touch experience proceeded using LME analysis with data from Experiments 2 and 3, both of which examined factors of Haptics and Visual information availability.

A number of data operations needed to be performed before data across these two experiments could be analyzed. First, due to the large between-subject variance in range of emotional response (some participants were 'high responders' and tended to use the extremes of the slider, while others were 'low responders' and tended to use only the mid-ranges of the slider), all emotional response data were normalized (producing EV_{norm}) for each individual in order to capture how different levels of available haptic and visual information can cause changes in emotional response within individuals. Second, and as mentioned before, only a subset of data from Experiments 2 and 3 was selected for analysis on the basis of having comparable data sets. Within these two experiments, Experiment 2 was within-subjects on Visual Fidelity (High and Non Relevant) and between-subjects on Haptic information availability (High and Moderate). In order to be comparable with data from Experiment 3, which was between-subjects on both Haptic and Visual Fidelity factors, data from Experiment 2 was filtered first.

From Experiment 2, 6 participants were randomly selected from the Moderate Haptic condition and only the No Relevant Vision data were considered. The remaining 6 participants from the Moderate Haptic condition had only their High Vision condition data considered. The same selection process was repeated for the participants in the High Haptic condition such that ultimately all data from Experiment 2 was between-subject on Haptic and Visual Fidelity factors. The second filter applied to data from Experiment 3. Experiment 3 included factors for Visual Fidelity and Product Context. In order to keep the Cognition Pathway controlled, only data from the 'Control' context (where participants were not primed to think of a product) were considered in order to be consistent with the data collected using the context-free stimuli in Experiment 2. Since Experiment 3 presented visual information on a screen, and there was no relevant haptic information, all data used from Experiment 3 were considered as 'Moderate Vision' and 'No Relevant Haptic'.

Following the application of the aforementioned filters, data from a total of 36 participants (24 from Experiment 2 and 12 from Experiment 3) were included in the analysis. Participants were aged 21 to 33 years (mean = 25.3, SD = 2.95). The data were balanced on all conditions by gender (18 females and 18 males).

9.2 Results

The design of the data was within-subjects on Roughness and between-subjects on Haptic and Visual availability. As a result, the design was a partial mixed $3 \times 3 \times (8)$ model with Haptic availability (High/Moderate/Non Relevant) and Visual Fidelity (High/Moderate/Non Relevant) as the between-factors balanced on gender, crossed with the within-factor of Roughness (1:smooth – 8:rough). Cells representing High Haptic/Moderate Visual Fidelity, Moderate Haptic/Moderate Visual Fidelity, Non Relevant Haptic/High Visual Fidelity, and Non Relevant Haptic/Non

Relevant Visual Fidelity were not investigated by Experiment 2 or 3. Gender was included in this analysis as a covariate to be controlled for, since the purpose of the analysis of the Affective Pathway was to address the impact of multimodal touch on emotion in the general touch-emotion model.

A backward elimination process for LME modelling process was used, beginning with a full model and reducing until all p-values were less than α or a more complete model was a better fit. Maximum likelihood comparisons were used to determine the best fit model[1].

Both factors of Haptic and Visual Fidelity could not be included in a complete model owing to the incomplete design of the data when considered across the Experiments. As a result, partial analyses of these two factors were conducted. As shown in Equation 9.1, regressing Roughness and Haptic availability on EV_{norm} revealed that EV_{norm} was predicted by a Roughness by Haptic availability interaction (β = -0.13, p $\leq$ 0.021) and by Roughness (β = -0.11, p $\leq$ 0.005). The interaction indicates that moderate conditions of Haptic information, more so than High and Non Relevant levels of Haptic information, affected emotional response valence (see Figure 9.2).

$$\mathrm{EV}_{norm} = \beta_{R_H}\mathrm{Roughness} + \beta_{R\times H_{moderate}}\mathrm{Roughness} \times \mathrm{Haptic}_{moderate} + \mathrm{k}_H \quad (9.1)$$

As shown in Equation 9.2, regressing Roughness and Visual information availability on EV_{norm} revealed that EV_{norm} is predicted by Roughness only (β = -0.16, p $\leq$ 0.001). Visual inspection of Figure 9.3 shows the main effect of Roughness (and no Roughness by Visual Fidelity interaction) in that the slopes of all three trend lines are non-zero and similar.

$$\mathrm{EV}_{norm} = \beta_{R_V}\mathrm{Roughness} + \mathrm{k}_V \quad (9.2)$$

A graphical examination[2] of both the Haptic and Visual Fidelity factors is shown in Figure 9.4. Here there are suggestions that the effect of Roughness on EV_{norm} is

[1]See (Faraway, 2002) for more details on the backward elimination process.

[2]See Section 3.5 for justification of using graphical methods to comment on interactions.

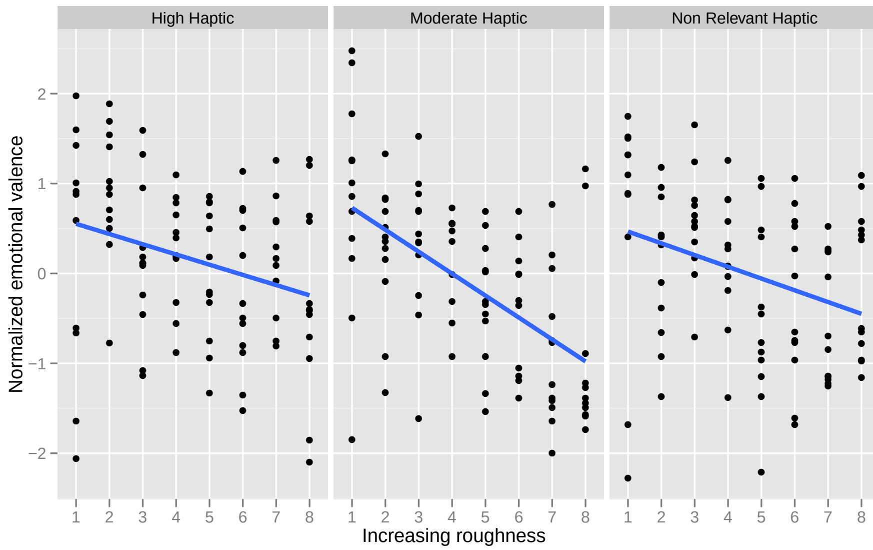


Figure 9.2: Normalized emotional response to Roughness, broken out by Haptic information availability.

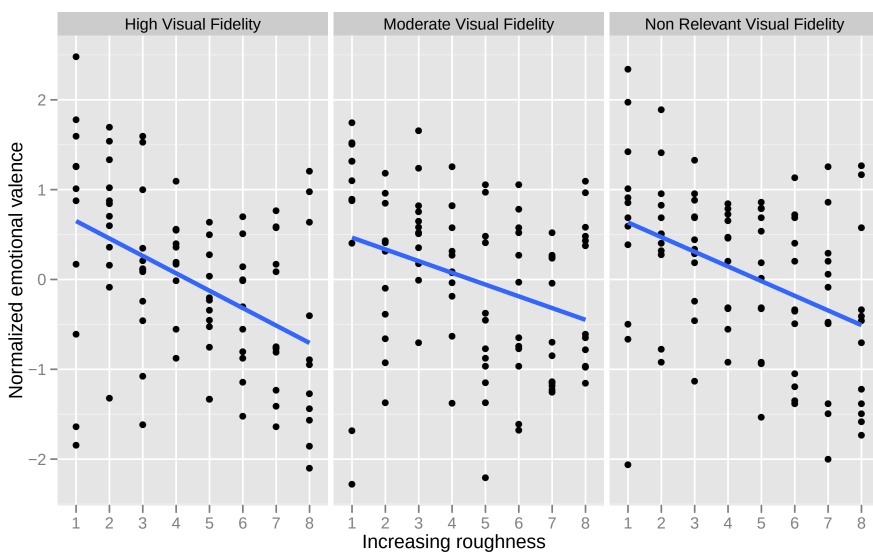


Figure 9.3: Normalized emotional response to Roughness, broken out by Visual information availability.

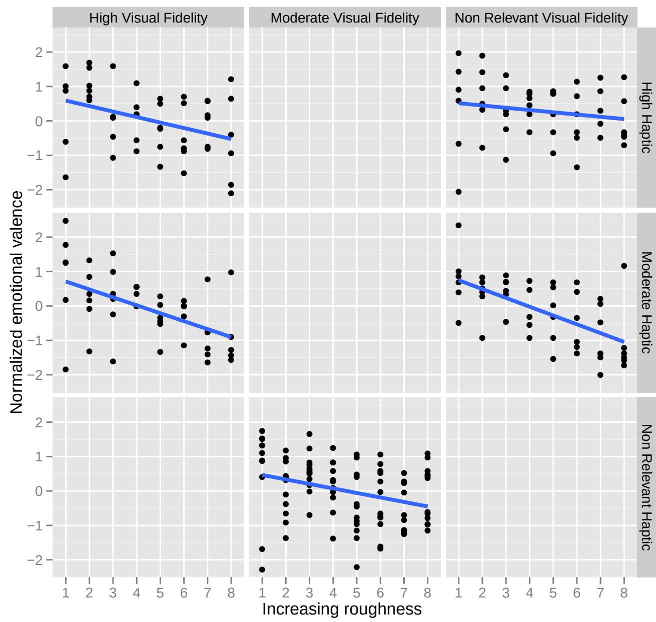


Figure 9.4: Normalized emotional response to Roughness, broken out by Haptic and Visual information availability.

high for the High Haptic/High Visual Fidelity, Moderate Haptic/High Visual Fidelity, and Moderate Haptic/Non Relevant Visual Fidelity conditions. The effect of Roughness appears lower in the High Haptic/Non Relevant Visual Fidelity condition.

9.3 Affective Pathway discussion

The first purpose of this study is to verify, based on results from Experiment 1, that the relationship between emotional response and increasing roughness (increasing gap spacing) is a negatively sloping linear line. In other words, the Affective Pathway exists (and predicts that emotion valence decreases as roughness increases in multimodal situations). Given that roughness was found to significantly predict emotional response, regardless of the amount of haptic or visual information available, the linear relationship between changing physical parameter and corresponding emotional response is confirmed.

The linear nature of the relationship between changing roughness and emotional response is an interesting one, given that perceptual ratings of roughness have been found to be exponentially related to linear changes in physical roughness (Unger et al., 2011; Lawrence et al., 2007). One possible explanation is that participants are providing emotional responses directly from the stimuli via a fast, cognitive-independent 'affective' channel (Norman, 2004; Plutchik, 1982) and are thus responding only to the differences between physical stimuli, regardless of the absolute magnitude of their actual roughness values. This explanation is also supported in part by the lack of an influence of product context in the present analysis. The practical value of this finding is that the change or improvement of user experience may not be directly proportional to the change in the surface property of a touch-based product. That is, making a surface twice as smooth may result in only slightly improved emotional response.

The second purpose of this combined analysis was to examine whether the perceptual availability of haptic and visual input have a differential effect on the total emotional response to the stimuli. Graphical inspection of Figure 9.1 indicated that the total emotional response to changing roughness is contributed to by both the availability of haptics and the availability of visuals. It is interesting to note that in the partial analysis, varying the availability of haptic information has an impact on the strength of the Affective Pathway, whereas varying levels of visual information does not (see Figure 9.3). A closer inspection of the interaction between haptics and vision (see Figure 9.4) revealed no notable interactions between the two variables, except in the case where participants could not see the stimulus but were required to pick it up for exploration. It would seem that participants who could not see the stimuli in the condition where they had to pick up the stimuli became less emotionally sensitive to changes in roughness (shallower negative slope). As mentioned in the discussion of Experiment 2, this may be the result of the physical properties of the stimuli, which had some sharp corners, and this feature may have dominated the experience of the stimuli (making roughness less salient).

Varying haptic information availability had an impact in that the 'moderate' haptic condition, where participants could touch the surface of the stimuli but could not pick it up, actually increased sensitivity to roughness (that is, higher roughness levels decreased emotional valence more than in the other haptic conditions). One possible explanation is that in the moderate haptic condition, all of the participant's attention was focused on the texture information of the stimuli and therefore was more sensitive to changes in its surface properties, while in the high haptic condition, some of the participant's attention was diverted to manipulating the stimulus, and so the changes in surface properties became less noticeable. Participants in the non relevant haptic condition were completely reliant on vision as the input channel, which has been shown to be less accurate than the haptic channel at discerning surface properties such as roughness (Whitaker et al., 2008).

It is interesting that changing the direct availability of touch information had more impact on emotional response than changing the availability of vision, although both the haptic only and vision only conditions were able to produce the linear roughness-emotion relationship. That is, increased stimulus roughness predictably decreases emotional valence, regardless of whether the change in stimulus is perceived with only visuals, with haptics and visuals, or with only haptics. This finding appears consistent with perceptual research conducted by Lederman and colleagues (Lederman et al., 1986; Lederman & Abbott, 1981) in which the independent variable was roughness and roughness ratings were the main measures. In these studies, it was expected that the tendency for visual dominance in humans would bias roughness judgments towards that of stimuli perceived on the visual channel in situations where the haptic and visual stimuli were discrepant. It was discovered that visual dominance only occurred if, instead of roughness ratings, participants were asked to supply estimates of spatial density (a task more reliant on the parallel processing ability of vision). Similarly, the findings from the current combined analysis suggest that there is no visual dominance in reporting emotional response valence to the present stimuli, and that the emotional response to touch-based stimuli is a type of processing that is sensitive to roughness information perceived on either haptic or visual channels.

The setup of the stimuli used in Experiment 3 was different from that of Experiment 2 in that the visual stimuli was displayed on a screen in order to allow for findings to be generalized to typical applications of haptic technology in which the visual stimuli is viewed through a screen. The results from both studies combined suggest that the visual channel alone can be used to impact the emotional response to touch-based information. That is, there is evidence that it is possible to increase the positive user experience of haptic technology by simply improving parameters of the corresponding visual stimulus, a strategy currently used in online shopping websites. However, it should also be noted that by providing actual haptic information (as in the moderate haptic condition), it may be possible to increase the reliability of the predicted impact of texture feedback. That is, if the objective of the designer is to improve user experience by decreasing the surface roughness of a particular product, emotional response will more likely actually increase if the user can experience the change both haptically and visually.

The findings from the combined Affective Pathway analysis do have limitations. First, the independent variable in both studies was roughness. As previously mentioned, there are many axes of touch where the impact on emotional response could conceivably be different. However, given studies in compliance that indicate patterns in perception similar to those observed for roughness (Kuschel et al., 2010), there is evidence that the emotional response to other changes in surface properties should show similar patterns to those discussed here. Also, the incomplete crossing of the availability of haptic and visual information meant that the full interaction between the two could not be evaluated. It is anticipated that a high visual fidelity (looking at real objects) and non relevant haptic cell would appear very similar to the moderate vision (looking at real objects via a screen) and non relevant haptic cell (see Figure 9.4). It is also expected that the moderate visual fidelity / high haptic and moderate visual fidelity / non relevant haptic cells would appear alike to the corresponding high visual fidelity data cells, since it is expected that the quality of visuals will not have an effect on the sensitivity of the roughness-emotion relationship[3]. Despite these limitations, however, it is still possible to use the findings, so long as the limitations are considered.

9.3.1 Potential applications

Research in Multiple Resource Theory and haptics have shown that care must be taken when attempting to maximize information throughput by presenting types of information across modalities (Ferris & Sarter, 2010). One potential application of the findings of the combined Affective Pathway analysis is that positive (or negative) user experience to a touch stimulus can be impacted equally well on either the haptic or visual channel, which may be counterintuitive given that one might assume that user experience to touch might be better impacted via the haptic modality alone (for example, a 'comfortable' feeling mouse may be more enjoyable than a 'good-looking' mouse). So, in order to maximize both function and positive experience, designers may wish to pair enhanced user experience changes (such as reducing roughness where possible) on the channel where there is minimal chance that modifications made for the sake of user experience will inadvertently degrade the function of the product or the performance of the user.

Another application of findings can be found in current research in the use of haptics during training, either for medical or vehicle driving situations. Research in these areas are concerned with the loss of performance between training (with haptic feedback) and retention phases (without haptic feedback) (Yannier, Basdogan, Tasiran, & Sen, 2008; Groot et al., 2011). Results from a recent study conducted by Groot et al. (2011) using a lane-keeping driving task suggested that the decrease in performance following haptic feedback can be mitigated if haptic feedback is used more sparingly. With regards to the findings of the current analysis, it is also possible that customizing the amount of haptic feedback required to elicit certain emotional states (and thus impact the user) could improve performance. For example, if haptics are used to enhance drivers' performance by aiding them in lane

[3]See Results and Discussion of Experiment 3, whereby visual fidelity was not found to either directly impact emotional response or interact with roughness to do so.

tracking, understanding the emotional impact of the level of feedback could mean minimizing negative emotion (which otherwise could inadvertently contribute to increased road rage and decreased performance).

Further, the widespread use of haptics through vibro-tactile interfaces has so far been to convey fairly one-dimensional messages (such as alerts) (Jones & Sarter, 2008; Ferris & Sarter, 2010). However, it may also be possible to piggyback the expected elicited emotional response as a characteristic of, for example, a vibratory alert signal. By incorporating knowledge of how to improve or decrease user experience into the design of alerts, it may be possible to generate alert signals that both notify the user without causing annoyance (negative emotion). This kind of alert might signal a low priority alert because users may not be compelled to tend to it immediately. Alternatively, alert signals could be generated that both notify the user and cause annoyance. This kind of alert (the haptic equivalent of an audio fire alarm) could convey a high priority alert. The idea of using expected elicited emotional response in addition to perception of haptic signals to convey information taps into concerns about information transfer rates of the haptic modality (Tan, Member, Reed, & Durlach, 2010) and the findings from this combined analysis contribute to shedding light on its feasibility.

Chapter 10

Analysis: Cognition Pathway

The purpose of Cognition Pathway analysis was to determine the extent to which cognition, as operationalized by product context, is a moderator between touch-based stimuli and emotional response (either valence or time). The model outlined in Section 3.2 depicts two pathways from stimulus to emotion: an Affective Pathway (a direct path from perception to emotion) and a Cognitive Pathway (an alternative path to emotion). By minimizing the extent to which participants associated other information, such as product context, with the stimuli, it was possible to collect data along the Affective Pathway. Similarly, by introducing a product context to which participants can relate and draw from previous experience, it was possible to consider the effect of the Cognitive Pathway. These two pathways are highlighted in Figure 10.1.

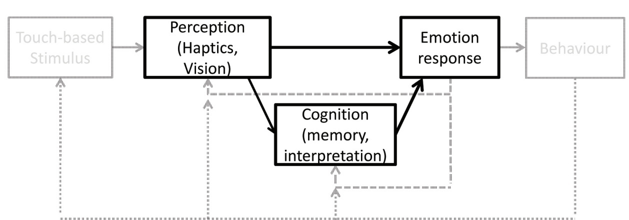


Figure 10.1: The Cognition Pathway (lower solid arrow) as a moderator with the Affective Pathway (upper solid arrow).

The relationship between the two pathways and emotional response are depicted such that the Cognition Pathway is a moderator to the effect of the Affective Pathway on emotional response. That is, the model suggests that there is an interaction between the two pathways in producing an emotional response[1]. In other words, the Cognition Pathway as shown indicates that, depending on the product context provided, participants will be more or less emotionally sensitive to perceived Roughness.

To examine the Cognition Pathway, only data from experiments that manipulated Product Context were used (that is, only data from Experiments 3 and 4 were considered). For the purposes of this analysis, only data from the Control and Cell Phone conditions will be used from both experiments. The Cell Phone condition was selected since research has shown that surface properties of phones are perceived to be of importance to users (Yun et al., 2010).

This combined analysis was conducted on the assumption that product context, which relies on short and long term memory, is a relevant operationalization of cognition. As before, a further assumption is that perceived roughness, for our purposes, can be operationalized by actual roughness (see Sections 2.4.2 and 3.5 for more detailed justifications).

10.1 Analysis procedure

A number of data operations needed to be performed before data across experiments could be analyzed. First, filters for the data were applied because the analysis of the Cognition Pathway included only factors of Roughness (1:smooth – 8:rough) and Product Context (Control / Cell Phone) with realistic accompanying visual information. As a result, the data from Experiment 3, containing a Visual Fidelity factor, was filtered so that only data of participants in the Moderate Visual Fidelity condition (where the visual stimuli was realistic video of the same stimuli that were used in Experiment 4, the latter of which provided all participants

[1]See Baron and Kenny (1986) for more details regarding moderation (versus mediation) testing.

with High Visual Fidelity). Further, because Experiment 4 was within-subjects on Product Context, in order to have comparably structured data with Experiment 3 (which was between-subjects on Product Context), only the data for the Control Product Context was kept for the first 8 participants, and only the data for the Cell Phone Context was kept for the next 7 participants. In this way, Experiment 4 data were also between-subjects on Product Context.

Special note should be made of what was considered to be 'Control Context' data. In reality, the control condition from Experiment 3 was truly a 'control' (in that no product context at all was provided), whereas the 'control' condition from Experiment 4 actually had a product context (Mug). The 'Mug' context was selected because the product context of Mug had not been found in any previous research to be one in which texture was considered important. Whether or not the Mug context was actually different from the true Control context should be checked.

Following the application of the aforementioned filters, data from a total of 27 participants (12 from Experiment 3 and 15 from Experiment 4) were included in the analysis. Participants were aged 18 to 33 years (mean = 22.6, SD = 3.93). There were 11 females and 12 males.

To test the moderating effect of Product Context on emotional response, RM ANOVA was the main analysis tool. The model detailed in Section 3.2 suggested that Product Context plays a moderating role between stimuli and emotional response valence. From a statistical perspective, a moderator role would be apparent if Product Context (the Cognitive Pathway) is shown to interact with Roughness (the Affective Pathway) in affecting emotional response. Besides examining the impact of Product Context on EV, it would also be insightful to examine whether or not Product Context had an impact on behaviour as operationalized by interaction time (IT) or reflection time (RT). If Product Context was found to have a moderating role on either types of behaviour without a corresponding effect on EV, then the model of Section 3.2 would need to revisited.

10.2 Results

The design of the data was within-subjects on Roughness and between-subjects on Product Context, with dependent variables of EV, IT and RT. The combination of the two control conditions from both Experiments 3 and 4 in the analysis assumed no difference between the two data sets. To shed light on whether the 'Control' conditions from both experiments were comparable, an RM ANOVA was conducted to determine if, considering only the Control data from Experiment 3 and the Mug data from Experiment 4, there are any differences between the Control and Mug contexts in terms of EV. The RM ANOVA with the between-factor Product Context (E3:Control / E4:Mug) $\times$ within-factor Roughness (1–8) revealed no significant main effects or interactions between these factors on EV, suggesting that the assumption of 'Mug' as a reasonable 'control' condition was an acceptable one.

Returning to the combined data analysis, the design of the data was then a mixed 2 $\times$ (8) model with Product Context (Control / Cell Phone) as the between-factor crossed with the within-factor of Roughness (1:smooth – 8:rough). Gender was included in this analysis as a covariate to be controlled.

The RM ANOVA revealed a significant main effect of Roughness [$F(1, 306) = 10.29$, $p \leq 0.002$] on EV and a marginally significant main effect of Product Context on EV [$F(1, 306) = 3.18$, $p \leq 0.076$], suggesting that increased Roughness produced lower EV values and that the Cell Phone Context condition led to higher EV values (see Figure 10.2 for a graphical depiction). There were no interactions between Product Context and Roughness. Further, considering both IT and RT revealed no main effects or interactions of Product Context or Roughness on either variable.

10.3 Cognition Pathway discussion

The combined analysis of data from Experiments 3 and 4 suggests that the Cognition Pathway as depicted may not be accurate since cognition (as operationalized

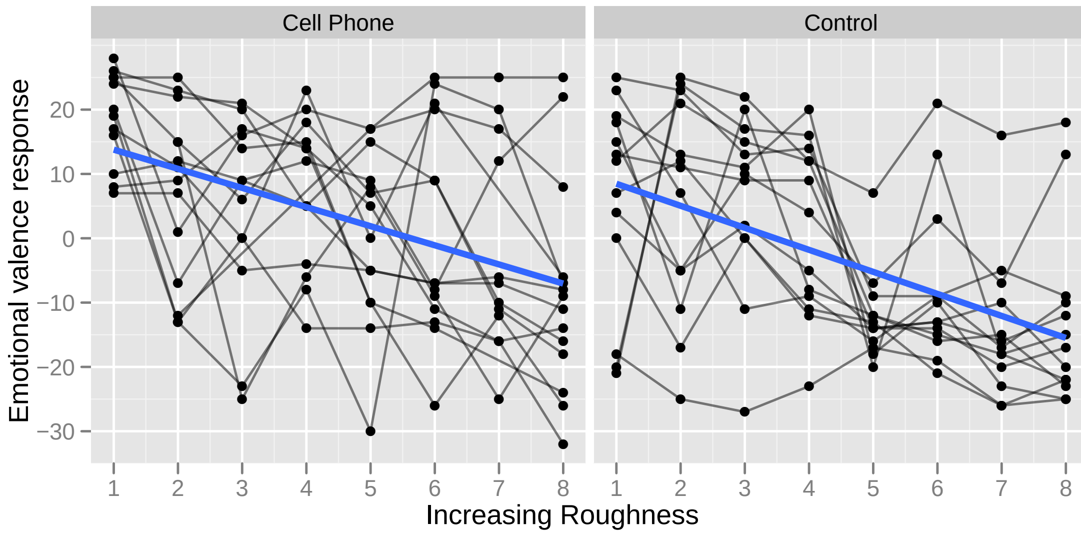


Figure 10.2: Main effects of Roughness ($p \leq 0.002$) and Product Context ($p \leq 0.076$) on EV .

by Product Context) was not found to significantly interact with the Affective Pathway (operationalized by Roughness) in the touch-emotion model of Section 3.2. The main effect of product context suggests that perhaps the effect of the Cognition Pathway is more accurately depicted as additive with the Affective Pathway. That is, by drawing on previous knowledge of the given product context, the experience of a meaningful touch event is simply that of the experience of a more abstract touch event (product context-free) offset by an amount dependent on the product context of the touch event.

One limitation of the current analysis includes the fact that in the cell phone context conditions, participants never handled an actual cell phone; rather, they were asked to imagine that the stimuli were cell phones. It would be insightful to determine to what extent a participant's ability to visualize could impact results, a factor not considered in the experimental methods used. Another limitation is the fact that a limited number of product contexts were employed. Future work should examine other types of product contexts, in order to determine more definitively if product context truly serves only to offset the roughness-emotion relationship (instead of interacting with it).

The main findings, however, are still meaningful because they report average responses across individuals, regardless of their propensity for visualization. Further, findings are particularly relevant to the design of hand-held high technologies, which includes a large variety of products.

10.3.1 Potential applications

The summative relationship between the Cognitive and Affective Pathways has significant applications in design because it suggests that the effect of product context on the user's experience of touch is merely to offset the individual's emotional response to a raw surface property (be it roughness or perhaps even compliance and stickiness). That is, in order to improve the user experience of a touch experience, designers may be able to focus on understanding how a limited number of raw surface properties – irrespective of a potentially infinite space of product contexts – can positively impact user experience.

Chapter 11

Analysis: Behaviour Pathway

The analysis of the Behaviour Pathway aimed to examine whether or not the emotion stage detailed in the touch-emotion model of Section 3.2 is accurate. If the depicted flow of information is true, it implies that it is possible to predict observable behaviour by affecting emotion. The pathway of interest is highlighted in Figure 11.1. The relationships between the variables of Roughness, Emotion, and Behaviour as shown in Figure 11.1 suggest that touch-evoked emotion is a complete mediator between Roughness and Behaviour. In other words, emotion serves as an intermediary stage of processing between perception and behaviour.

In order to focus the analysis on the Behaviour Pathway, the Cognition Pathway was held constant by considering only data collected from participants experiencing stimuli presented without product context. Further, the examination of this

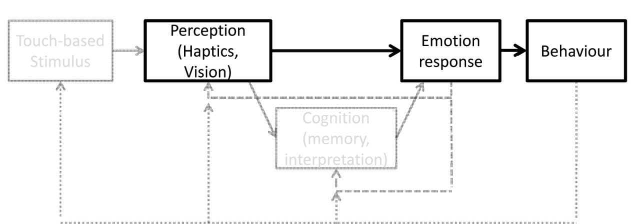


Figure 11.1: The Behaviour Pathway (from stages of Touch/Perception, through Emotion to Behaviour) with emotion as a mediator between perceived roughness and observed behaviour.

pathway is essentially determining if emotion is a mediator between Perception and Behaviour. Mediation relationships can be tested using LME modelling and a three-step mediation analysis process.

It should be noted that this combined analysis was conducted on the assumption that reflection time, the time taken to provide an emotional response to a touch-based stimulus using a slider, is a measure of approach or avoid behaviour as a result of emotion. Reflection time, as opposed to interaction time, was used as the main dependent variable because reflection times capture the emotion-related behaviour. Interaction time, by contrast, can be argued to include general exploratory interaction with the stimuli that does not necessarily relate to felt emotion. As before, a further assumption is that perceived roughness, for our purposes, can be operationalized by actual roughness (see Section 2.4.2 and Section 3.5 for more detailed justifications).

11.1 Analysis Procedure

To test the mediating effect of EV on RT, LME modelling was the main tool. Mediation analysis proceeds with three steps[1]:

1. Showing that EV is predicted by Roughness (ignoring RT)
2. Showing that RT is predicted by Roughness (ignoring EV)
3. Including both EV and RT in the model and showing that RT is predicted by EV and that the effect of Roughness on RT with EV in the model is lessened when compared to the model in Step 2 (i.e., the coefficient for Roughness is a smaller magnitude)

As in the previous two meta analysis Chapters, in order to conduct a combined analysis of data collected across experiments, a number of data operations needed to be performed first. The goal was to obtain a data set such that the Behaviour

[1]See Baron and Kenny (1986) for more details regarding mediation (versus moderation) testing.

Pathway, as it is affected by a single variable of Roughness, could be analyzed while keeping results as general as possible. As such, filters were applied on the data collected from Experiments 2–4 such that a) the level of physical interaction was low; b) the visual information was realistic; and c) the level of cognitive processing was minimized. So, from Experiment 2, only data from participants who could see the real-world stimuli but not pick it up were used (Moderate Haptic condition). From Experiment 3, only data from participants who could see the realistic depictions of the stimuli in the Control Product Context (no context) were used. Although data from Experiment 3 were all collected under the 'Non Relevant Haptic' condition, this was deemed comparable to the 'Moderate Haptic level' condition in terms of amount of time spent in exploration (since picking up the stimulus takes more time than either not picking it up or simply using a mouse to explore). From Experiment 4, only data from participants in the Control Context (primed to think of common mugs) were used[2] (all participants in Experiment 4 could see real-world visual stimuli). A summary of the filters applied is shown in Table 11.1.

Following the application of the aforementioned filters, data from a total of 33 participants (12 from Experiment 2, 6 from Experiment 3, and 15 from Experiment 4) were included in the analysis. Participants were aged 18 to 32 years (mean = 23.2, SD = 3.90). The data were balanced as closely as possible by gen-

Table 11.1: Subset of data used from each of Experiments 2–4.

	Factor		
Experiment	Haptic availablity	Visual Fidelity	Product Context
2	Moderate Haptic	High (real-world stimuli)	No product context
3	Non Relevant Haptic	Moderate (video on a screen)	No product context
4	Moderate Haptic	High (real-world stimuli)	Mug product context

[2]As described in Section 10.2, the Mug context did not impact emotion differently from the Control Context (no product context) of Experiment 3.

der (16 females and 17 males).

Finally, all emotional response and response time data were normalized per individual, creating EV_{norm} and RT_{norm}. The reason for doing so was due to the observation that some individuals tended to be high responders (using only the extremes of the slider) while others tended to be low responders (using only the middle of the slider). In order to be able to meaningfully compare changes in individual emotional responses and response times to changing stimuli, both measures were normalized to the individual.

11.2 Results

The design of the data was within-subjects on Roughness (1:smooth – 8:rough), with dependent variables of EV_{norm} and RT_{norm}. Initial graphical consideration of the data, as shown in Figure 11.2, indicated that RT is unlikely to be a simple linear function of EV and there may be good reason to include an indicator variable for the sign of the emotional valence response. As a result, an indicator variable, E_{sign} was created such that $E_{sign} = 0$ for all reported normalized emotional valences that

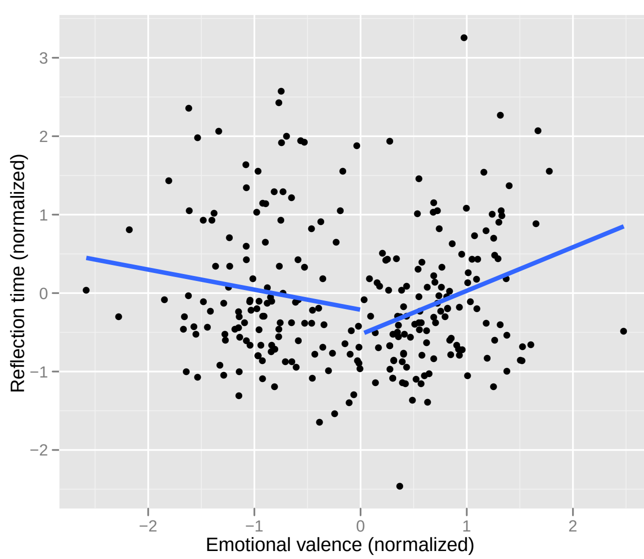


Figure 11.2: Individual EV_{norm} versus Individual RT_{norm}.

Table 11.2: Regression coefficients for testing whether Emotion is a mediator between Roughness and Reflection time.

	D.V. =	Roughness		+	E_{sign}		+	EV_{norm}		+	$EV_{norm} \times E_{sign}$	
Step		β_R	$p \leq$		β_{EV}	$p \leq$		β_{EV}	$p \leq$		$\beta_{EVxEsign}$	$p \leq$
1	EV_{norm} =	-0.093	0.001		1.520	0.001		--	--		--	--
2	RT_{norm} =	0.050	0.050		n.s.	n.s.		--	--		--	--
3	RT_{norm} =	0.080	0.105		n.s.	n.s.		n.s.	n.s.		0.660	0.002

were negative and E_{sign} = 1 for all reported normalized emotional valences that were positive or zero. This variable was included in all mediation analyses.

The LME analysis of Step 1 in Section 11.1, which regressed EV_{norm} on Roughness (and E_{sign}), revealed that Roughness is a significant predictor of EV_{norm} (see Table 11.2, Step 1). E_{sign} was also a predictor, as it should be expected given its definition relative to the dependent variable. Removing E_{sign} as a regressor gave EV_{norm} as a function of Roughness only [β = -0.25, p $\leq$ 0.001].

In Step 2, regressing RT_{norm} on Roughness and E_{sign}, revealed that Roughness is also a predictor of RT_{norm}, albeit in a different direction (see Table 11.2, Step 2). Here, E_{sign} is not a predictor.

Finally, in Step 3, regressing RT_{norm} on Roughness, EV_{norm}, and E_{sign}, revealed that RT_{norm} is predicted by both Roughness and an interaction between EV_{norm} and E_{sign}. Notably, the effect of Roughness on RT_{norm} has not decreased (see β_R values in Step 2 and Step 3 of Table 11.2).

In order to check if the physical act of sliding the switch of the slider to the extrema was the cause of the correlation between emotion and response time, a Pearson correlation analysis between raw RT and EV magnitudes was conducted on the same set of data. This correlation analysis revealed a correlation of 0.11 (p $\leq$ 0.09), an r value far below the standard 0.3 cutoff for 'weak correlation', suggesting that something other than the physical geometry of the measuring tool for emotion is causing the observed relationship between emotion and reflection time.

11.3 Behaviour Pathway discussion

The goal of the analysis of the Behaviour Pathway was to determine the extent to which emotional response (operationalized by emotional response valence) served as a mediator between perceived roughness and touch-evoked behaviour (operationalized by refection time). That is, to what extent is the Behaviour Pathway as depicted in Figure 11.1 a reflection of human information processing when a touch stimulus is involved? Towards this end, results of this combined analysis suggest that the Behaviour Pathway may need some revision.

A number of modifications were made to a standard mediation analysis. The first concerned the inclusion of a fourth variable (in addition to roughness, emotional valence, and reflection time): emotion sign. An initial exploratory analysis of the relationship between emotion and reflection time suggested that reflection time was a positive linear function of positive emotions, and a negative linear function of negative emotions (see Figure 11.2). As such, the indicator variable emotion sign was included in the mediation analysis in order to capture the impact of the sign of the emotion response on behaviour.

A second deviation from a standard mediation analysis included the normalization of all dependent variables. This normalization was done in order to better understand how individual changes in emotion may result in changes in behaviour. Results are discussed in terms of what these transformed variables mean.

The results of the mediation analysis can be considered in three stages, corresponding to the three steps of the analysis. First, and as expected given the results from Chapter 9, normalized emotion valence was strongly predicted by roughness. That is, on average, a given individual's emotional response to rougher stimuli was less than that individual's mean response (and vice versa for smoother stimuli). The emotion sign indicator variable was a significant predictor of emotional response, although it is not a meaningful one since it was derived from emotional valence.

The second result of this analysis addressed the question of whether reflection time was predicted by roughness. Although the effect size is relatively small, it was found that as roughness increased, a given individual tended to spend more time reflecting than that individual's average reflection time for rougher stimuli and less time for smoother stimuli. By itself, this result may be counterintuitive because it suggests that negative emotions (associated with rougher stimuli) lead participants to spend more time in reflection whereas one might expect that participants would want to avoid spending time reflecting on things they didn't like. The results from Step 3, discussed next, offer some clarification.

The third result of this analysis considered whether or not reflection time was predicted by both emotional valence and roughness. The analysis found that the strongest predictors of reflection time (the parameters with the highest magnitude coefficients) were normalized emotional valence and the interaction between normalized emotional valence and emotion sign. Together, the two coefficients indicate that a given individual tended to spend more time (i.e., longer than their average) when their emotional response was greater than their average, and that this effect was much less if their emotional response was less than their average.

The mediation analysis allowed for the following comments to be made. First, changes in emotion by itself did not appear to be a predictor of changes in reflection time, particularly since Step 2 suggests a positive (albeit small) effect of increasing roughness on reflection time, whereas increasing roughness had a negative effect on emotion valence. However, it is interesting to note that in Step 3, changes in emotion crossed with the sign of the emotion led to changes in reflection time. In particular, it seemed that the larger the magnitude of the emotional valence response, the more likely that individuals responded by taking longer reflection times. One possible explanation is that, in general, extreme values of emotion may tend to take longer to physically report on the emotion measurement device of the slider (i.e., reporting a neutral emotional response requires little slider movement whereas reporting an extreme emotional response requires greater slider movement). If physical movement of the slider was the cause of the pattern observed in Step 3, then a correlation analysis between reflection time and the magnitude of raw emotion should reveal a high correlation coefficient. The results of this combined analysis found that this correlation was weak or non-existent (the Pearson correlation coefficient between reflection time and the magnitude of raw emotion was 0.11 with $p \leq 0.09$). The correlation analysis ignored which data belonged to which individual, suggesting that the finding that reflection time is predicted by the magnitude of emotion (as opposed to its valence) truly reflects trends experienced within an average individual.

Since changes in reflection time were strongly predicted by the magnitude of emotion – and not emotion valence – it may be too early to say that emotion isn't a mediator between perception and behaviour (it could also be possible that behaviour is a mediator to emotion). The suggestion that the magnitude of emotion (in response to a multimodal roughness-based touch event) is more strongly correlated with reflection time than the valence of the emotion is supported by combining Mehrabian and Russell (1974) environmental psychology concepts of approach (good) and avoid (bad) with the Wundt curve, which views good (correlated with approach behaviour) and bad (correlated with avoid behaviour) emotions as functions of the interest-boredom axis of emotion (Walker, 1980).

The main finding of this combined analysis suggests that designers of haptic technology utilizing both haptic and vision modalities should be cognizant that, in the creation of real or virtual textures such as roughness, the amount of time that a user will be inclined to reflect on an interface or product may be better predicted by the interest-boredom emotion axis than the positive-negative emotion axis. This speculation has yet to be explored experimentally.

It should be noted that this study focused only on the axis of roughness out of all other surface properties, and that further studies should be conducted to consider how the emotional response to, for example, compliance might affect behaviour. Also, here 'behaviour' was taken to be the time that participants took to provide their emotional response. It would be insightful to examine whether or not the time spent interacting with the stimulus also increased, as this might shed some light on whether greater time spent interacting with the product actually results from higher emotional responses.

One assumption that this analysis makes is that behaviour follows from emotion, and not the other way around. Given that emotional response could not be directly manipulated, the direction of the aforementioned relationship between emotion magnitude and reflection time is inconclusive. It is possible that increased reflection time leads individuals to report higher emotion because they are satisfying the need to be internally consistent. It could also simply be that increased reflection time causes higher emotion responses through some other mechanism. The assumption that behaviour follows from emotion is based on literature indicating that felt emotions lead to 'action impulses' or states of 'action readiness' (Plutchik, 1982; Frijda, 1988; Heilman, Blonder, Bowers, & Crucian, 2000) and influence decision making by directing attention to certain features or not (Loewenstein & Lerner, 2003). That is, emotions affect observable actions. As described in Plutchik's sequential theory of emotion, those actions may in turn feed back and affect emotions (for example, the action taken to pick up a product in a store because it is visually appealing may result in additional information about its texture that could feed back into a stronger positive emotional state). However, the simplicity of the stimuli in Experiments 2, 3 and 4, as well as the setup and procedure, were designed such that participants should have had minimal opportunity for their behaviour to affect their emotional response in a feedback loop. Whether or not behaviour was truly able to impact emotion (instead of the other way around), is something that should be further investigated.

Besides the uncertainty surrounding the presence or absence of feedback loops between emotion and behaviour, the results presented in this study are also conflicted in terms of whether or not emotion is a mediator between changing roughness and reflection behaviour. The mediation analysis revealed that changes in stimuli do not have a strong impact on changes in reflection time. Further study, perhaps considering stimuli that are expected to evoke only positive or only negative emotions, is recommended in order to shed light on the mediational role of emotion between stimulus and behaviour in the context of touch experiences.

Comment should also be made on the setup and procedure of each Experiment contributing data to this Behaviour Pathway analysis and how each may be applied to real-world settings. In Experiment 3, roughness was manipulated digitally on a screen and the participant was given no opportunity to physically touch the object. This scenario reflects current online shopping situations, as well as some minimally invasive surgery solutions, where visual information is provided instead of a full haptics experience. The setup in Experiments 2 and 4 used real physical blocks and may reflect on situations where haptic technology simulates texture feedback, for example, in the simulation of roughness via control algorithms of a magnetic levitation device (Unger et al., 2011) or through vibration (Ahmaniemi et al., 2010). Such feedback would be used in applications such as minimally invasive surgery, e-commerce, or woodworking (Lederman & Jones, 2011). Further, Experiment 4 was conducted in the UW Student Life Centre which had a significant amount of ambient noise when compared to the quiet conditions of the laboratory. The experimental environment of Experiment 4 might also reflect conditions more commonly found when browsing products at a retail outlet. Taken together, the results of the meta analysis of data from all three Experiments have the potential to generalize to a variety of real-world situations.

11.3.1 Potential applications

The idea that emotion-evoked behaviour may be a better function of the interest-boredom emotion axis than the positive-negative emotion axis must be applied with caution. The findings do not suggest that designers should create highly interesting and stimulating haptic experiences in an effort to create a larger emotional response; increased duration of a vibration may actually lead to greater annoyance (Jones & Sarter, 2008). However, in situations where longer reflection times are needed, for example, in the use of haptic technology in training for clinical breast examinations (Gerling & Thomas, 2005), this analysis provides evidence that simply amplifying target signals may not be enough to encourage greater reflection. Rather, creating novel target signals could increase reflection because it would increase emotional interest.

Chapter 12

Conclusions

The main purpose of this research was to provide a framework for understanding the link between touch and touch-evoked emotion and behaviour. Towards this end, a number of concluding remarks can be made.

12.1 Revisiting the touch-emotion model

A primary activity of this research was the experimental exploration of various human information processing flows within the touch-emotion model detailed in Section 3.2. Three flows in particular were identified as points of interest: the Affective Pathway, the Cognitive Pathway, and the Behaviour Pathway.

Experimental results support the existence of the Affective Pathway, in that decreased roughness, experienced through haptics and vision, reliably predicts increased emotion, extending previous work (Ekman et al., 1965) by including multimodal stimuli in various situations (on screen or reality), product contexts (cell phone, keyboard, mouse, and mug) and settings (in laboratory and out of laboratory). However, the depiction of cognition (operationalized by product context) as a moderator between the stages of perception and emotion may be inaccurate. The main product context effects on emotion observed in Experiments 3 and 4, as well as the Cognition Pathway meta analysis, may suggest instead that a more appropriate model appears as in Figure 12.1, with cognition serving to generally increase

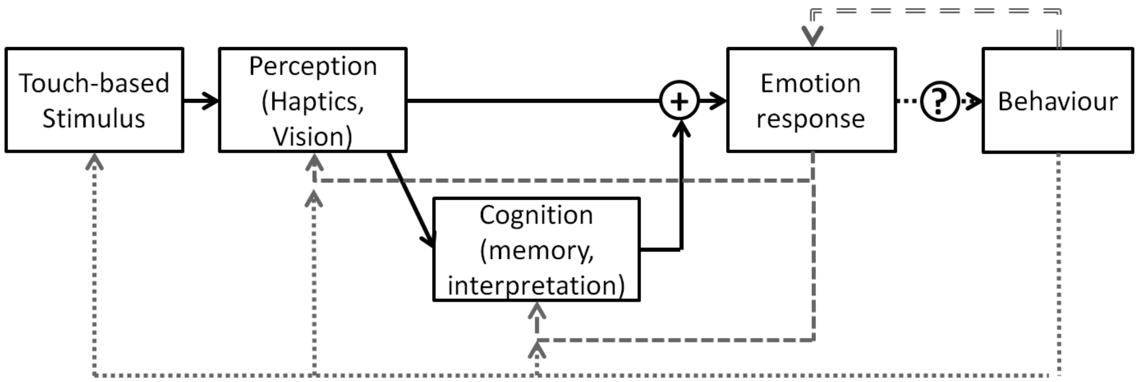


Figure 12.1: A revised touch-emotion model including a) the updated Cognition Pathway, such that product context serves to generally increase or decrease the impact of the Affective Pathway on Emotion; and b) an additional feedback loop between Behaviour and Emotion.

or decrease emotional response, without interacting with the impact of perception on emotion.

A further revision of the touch-emotion model concerns the Behaviour Pathway, which initially asserted that emotion mediates between the perceptual stage and the behaviour stage. Results here suggested that although emotion valence (a signed variable going from -25 to 25) may not be a mediator, it may be possible that emotion magnitude does serve as a mediator between changes in roughness and changes in response times. Further, given the difficulty of establishing causality between felt emotion and observed behaviour, a feedback loop between behaviour and emotion has also been added to the touch-emotion model. Until more is known concerning the link between emotion and behaviour, the Behaviour Pathway as depicted in Figure 12.1 should be considered as a possible relationship between touch-evoked emotion and behaviour that is consistent with the findings within this research.

12.2 Limitations

This research puts forward a theoretical model that shows the relationship between changes in physical roughness and later information processing stages such as cognition, emotion, and observable behaviour. It is important to make note of the limitations of the experiments that explored and provided evidence for the model, in order to understand the limitations of the model's potential applications.

One limitation of the experiments pertains to the dependent measure of emotional response that was taken to be the response on a slider given 'as quickly and as accurately as possible'. It is important to note that since all of the responses were self-report, the measure of emotion may or may not reflect actual immediate emotional response. Future work may avoid this issue by using complementary measures for emotion, such as electroencephalography. However, in the current work, increases in roughness experienced through haptics and vision were consistently found to lead to decreases in emotional response. Regardless of whether not the actual reported emotional response is identical to the felt emotional response, it is reasonable to assume that at a minimum, the direction of change of emotional response valence as a function of increased roughness is true.

Another limitation of the experiments stemmed in part from the general nature of the touch-emotion model, in that demographic factors such as self-rated tactual importance, age, and ethnicity were never balanced during data collection and subsequent analysis. The fact that representative tactual importance, age, and ethnicity ranges were never achieved in each experiment meant that the extent to which they may impact the proposed general model may be called into question. For example, since the majority of participants were either Asian or Caucasian, it is difficult to infer that the proposed model applies for the general person, including, for example, African individuals. Other demographics factors, such as hand size (which is likely correlated with gender), were not measured and may also impact findings. People with large hands may explore stimuli inherently differently and experience roughness differently as a result. Although all results were obtained from limited demographics ranges, the results themselves are of interest and provide a case for further investigations into the true generalizability of the proposed model. That is, the current touch-emotion model guided a number of experimental explorations that revealed interesting demographics-related findings which, in turn, allow further investigations to begin to consider whether or not it makes sense to include a gender or ethnicity factor somewhere in the model. Further, if such demographics factors should explicitly appear in the touch-emotion model, consideration should also be given as to whether they should occur at the point of perception of the stimuli or at the point of generation of the emotional response.

The choice of manipulation of the factors of haptic and visual information availability may also be considered a limitation. The selection for the three levels of available information (no relevant, moderate, high) of haptic and visual information was based on being able to relate results to real-world situations such as a mouse-controlled online shopping experience or an in-store shopping experience. However, from a theoretical perspective, it would also be insightful to know how the continuous manipulation of haptic and visual information quality affects the emotional response to changes in roughness. Doing so might also allow for a full crossing of the two factors of haptic and vision levels, which would then enable a more thorough investigation of potential interactions. There is also a practical reason to consider a manipulation of, for example, simulated texture and varying levels of simulated visuals. This combination of factors would have application for designers of many teleoperation systems (such as dentistry simulators, or minimally invasive surgery systems) and allow understanding of what combination of texture and visual simulations produce the best user experience while maintaining task performance (the latter of which was not investigated here).

The manipulation of all stimuli through roughness, and specifically, through the change in groove widths of a grating, also limits the generalizability of findings. In reality, surface roughness is likely to be experienced in a variety of different ways (e.g., bumps on a sheet of rubber or cracks in leather) and in concert with other properties, such as compliance, as both may contribute to 'grippiness'. Until further manipulations of roughness are considered and in conjunction with manipulations of other surface properties, the touch-emotion model remains untested in terms of whether varying two surface properties simultaneously (e.g., roughness and compliance) will produce the same patterns as when varying just one. Further, do other manipulations of roughness (for example, via sand paper, or by an array of raised dots of varying density) produce similar patterns as observed by this research? Although the current studies are limited in their ability to answer these questions, the studies again provide a starting point and a direction for further investigations into the robustness of the roughness-emotion relationship.

The manipulation of cognition by varying primed product context also poses a limitation, in that results may be different if participants are presented with actual cell phones or actual mugs. As discussed in Chapter 6, the advantage of requiring participants to imagine the product after being primed with 'cell phone' or 'mug' is that differences between groups may be more easily attributed to the manipulation of product context, and not some other confound like shape or weight. The results from the present research suggests that when product context is manipulated in isolation, it may simply offset emotion, regardless of roughness. This finding should be tested with other methods of manipulating cognition, for example, by loading working memory or having participants engage in a goal-oriented task while experiencing changing texture.

Finally, the Behaviour Pathway of the touch-emotion model was examined primarily by using response time as the measure of behaviour. As was mentioned in Experiment 4, the limitation of considering only response time is that specific behaviours and physical interaction styles are completely ignored. However, as discussed in Section 4.2, one advantage of considering response time as a proxy for behaviour includes the research finding that response times can be a measure of engagement with a stimulus, and engagement is generally a positive outcome from the perspective of product designers. Still, the interesting patterns observed in Experiment 4 pertaining to the recording of 'vertical motions' or 'small motions' during stimulus interaction suggests that it would be worthwhile to continue using alternative measures of behaviour (other than time) to see how they may be affected by changes in stimulus texture properties.

12.3 Contributions

This research sought to increase understanding of how to predict emotional and subsequent behavioural responses to touch-based stimuli that exist in haptics technology and numerous products today. In order to maintain both tractability and thoroughness of the investigation, only the texture component of the sense of touch was considered, and only the dimension of roughness was experimentally manipulated. However, texture is a major component of the sense of touch, and roughness is the main dimension of texture, so there is high potential that the contributions detailed below will be applicable to many situations involving touch, keeping in mind the limitations discussed previously.

12.3.1 Theoretical contributions

The development of the touch-emotion model allowed for a conceptualization of how various stages of information processing could combine to predict emotional response and emotion-evoked behaviour. The contribution of such a model allowed for a series of experiments to be designed to test its validity and predictive power. In testing the various pathways of the touch-emotion model, it was discovered that roughness and roughness-evoked emotion are related (increasing roughness decreases emotion) when considering multimodal (haptic and visual) stimuli presented using various methods and in various physical situations. Cognition, as operationalized by imagined product context, does not appear to interact with roughness to impact emotional response but rather generally increases or decreases the effect of roughness. Meanwhile behaviour, as operationalized by response time, appears to be a function of emotion magnitude such that the extreme emotion values, regardless of sign, predict increased reflection time.

12.3.2 Methodological procedures

Through each of the experiments, the measure for response time (physical behaviour) became progressively refined. The discussion from Experiment 1 indicated that a single measure for response time was inadequate for interpretation. Experiments 2 and 3 included two variables for response time: the time taken before initializing the report of emotional response, and the time taken to give the emotional response itself. This breakdown of response time into two phases, the 'interaction time' and the 'reflection time', allowed for better interpretation of results. For example, it was found that the time spent interacting with the stimulus and the time spent reporting the emotional response trended in opposite directions. That is, individuals with high interaction time tended to have lower emotional response reporting time. It is recommended that future experiments in touch and emotion maintain this distinction in recording response times.

The video recording procedure was a further contribution to the study of touch-evoked emotion. Although time consuming, the video recordings provided insight into the kinds of exploration behaviour associated with high or low emotional response, and high or low response times. By including video recordings in behaviour measures, as yet unforeseen relationships between stimulus and behaviour may be discovered.

12.3.3 Applications

The strong link between increased roughness and decreased emotion is applicable for designers in the sense that, given a choice for the type of haptic feedback or the type of surface finish, they should be aware that choosing rough-feeling signals or rougher surface finishes is likely to decrease user enjoyment for the average person. The finding that roughness sensitivity was highest in the condition of limited surface exploration might also have ready application. For example, in situations where providing force feedback is a key component of the technology, corresponding simulated surface textures may be less attended to by the user.

In terms of understanding which design features and user characteristics might impact the touch-emotion experience, this research has contributed a number of applicable findings:

1. **Increasing roughness leads to more negative emotional responses:** Provided there is relevant haptic information, this relationship was confirmed in three experiments and holds across various multimodal (haptic and visual) feedback formats, a number of individual characteristics, and in different experimental settings ($p \leq 0.05$).

2. **Tactual importance tended to be correlated with an increase in the negative emotional sensitivity to roughness:** designers should understand whether their users are touch-sensitive or not, since individuals with high tactual importance may experience significantly lower enjoyment than others for the same roughness level (r = -0.27, $p \leq 0.04$).

3. **Tactual importance is positively correlated with age:** designers should be aware of the average age of their target users, as increased age is correlated with increased sensitivity to touch-based features (r = 0.28, $p \leq 0.03$).

4. **Interaction and reflection times are higher with increased age:** designers should be aware of the average age of their target users, since increased age is correlated with more time spent interacting with the interface, product, or technology if touch-based information is provided (r_{IT} = 0.49, $p \leq 0.01$; r_{RT} = 0.48, $p \leq 0.01$).

Each of these findings might serve as a starting point for a rule of thumb, or as a guideline, for designers of touch-based emotional experiences. These relationships can serve to build a list of demographics questionnaire items to be used during the product design stage of consideration of user needs and requirements, which is a key stage in usability design engineering (Preece, Rogers, & Sharp, 2002). Following is a list of marginally significant findings that raise interesting questions and, once thoroughly investigated, may also have the potential for application in design:

5. **Increased roughness may have more negative emotional response with increased age:** designers should be aware of the average age of their target users, since increasing age may increase the magnitude of negative responses to increased roughness (r = -0.23, p $\leq$ 0.07).

6. **Asians may have higher average emotional response than Caucasians:** designers should be aware of the ethnicity of their target market, as ethnicity may impact the extent to which users attend to touch-based features (r = -0.27, p $\leq$ 0.07).

7. **Asians may spend more time interacting with and reflecting on touch-based experiences than do Caucasians:** designers should be aware of the culture of their target users, since the texture or haptic feedback in a product used in North America may have more impact on enjoyment than the same qualities in a product used in an Asian country (r_{IT} = -0.23, p $\leq$ 0.08; r_{RT} = -0.27, p $\leq$ 0.06).

12.4 Future work

As mentioned previously, roughness served as the main dimension of haptic experience in all experiments within this work. The first goal of future work should be to establish if each of the pathways predicting emotion and behaviour exhibit similar patterns for other dimensions of touch. For example, if all stimuli varied instead on the dimension of hardness, would the Affective Pathway still hold predictive power over emotion, and if so, would the relationship between measured changes in hardness and measured emotion response also be linear? The generalizability of the developed touch-emotion model would be increased through these tests.

The impact of product context appeared to be to shift the abstract (context-free) emotional response patterns up or down, depending on the product context. This main effect of product context was found instead of the expected interaction between product context and roughness levels (one might expect less roughness sensitivity for something like a mug and more roughness sensitivity for something more personal like a cell phone). Further work should attempt to replicate and build upon this marginally significant finding, perhaps with a wider range of hand-held products. The implications for designers could be profound in the sense that if it is true that product context simply provides an upward or downward shift of touch-evoked emotions (that is, it does not interact with product context), then increasing roughness will always decrease emotion. However, if product context in fact interacts with roughness, then the design decisions surrounding the physical texture of products is more complex. For example, it could be that changing roughness makes no impact on user experience for certain types of products.

It is also possible that the operationalization of cognition by priming participants to think of product context may not be the complete story. For example, other elements of cognition, such as working memory, may also affect emotional response. If participants are distracted or engaged in a secondary task while interacting with surfaces of changing roughness, the emotional sensitivity to roughness could also decrease. Future studies should consider other aspects of cognition in order to better understand and model its impact on emotion.

The results of this research also suggest that behaviour, measured as various response times, might be better predicted by the magnitude of emotional response, or even that emotional response is predicted by response time. Since it was not possible to assign an emotional response, this research could only identify a correlation between the two variables. It would be insightful to determine if higher or lower emotion-evoked response times translates to performance, since designers of haptic technology that performs a specific function (such as alerting drivers that are deviating from a laneway; Groot et al. (2011)) would find it very useful to know whether enjoyment improves performance. If the reverse was true and longer response times predict emotion, response time would be a useful behavioural measure for emotional response in future touch-emotion research.

In addition to the three pathways (the Affective, Cognitive, and Behaviour Pathways) explored in this research, the full touch-emotion model described includes feedback pathways. If these feedback pathways exist, for example, from emotion back to perception, then it would add credence to strongly considering user experience in the design of haptic technology, as more enjoyable experiences might impact the perception of feedback signals in a virtuous circle that could impact performance.

From a more methodological standpoint, future research into examining the nature of the relationship between emotion and emotion-evoked behaviour should consider measures of behaviour in addition to time, for example, types of interaction behaviour as Experiment 4 started to do. These studies might also benefit from a more natural setting, similar to that found in stores, so that participants are under no obligation to interact with the stimuli for any amount of time. Such studies would need to consider how to capture emotion, which might be achieved through image processing of facial expressions as is done in research in affective computing (R. Picard, 2003). It would be of great benefit for product designers to know if specific touch-based parameters such as roughness or hardness can be shown to influence behaviour in natural settings.

The continued use of video recordings in touch-emotion research could eventually lead to findings that allow designers to understand what kinds of interactions are most likely to happen, given certain product touch properties. Future work should also consider how to capture not only observable interaction styles, but could also include measures for force of exploration. Just as broad vertical strokes of the physical surface of the stimuli in this research corresponded with higher emotional response (and lower roughness), it might also be true that certain surface properties evoke certain emotions that are correlated with stronger or weaker applied force during exploration. Understanding fully how surface properties can elicit emotion and behaviour would allow designers to design products that are not only enjoyable to use, but likely to be interacted with in the way that the designer intended.

It would also be insightful to continue the investigation into how various levels of available haptic information can impact emotional response. Across all experiments within this research, there were three conditions: no relevant haptic information (interaction with stimulus was done through a mouse), moderate haptic information (interaction was limited to surface exploration), or high haptic information (interaction was not limited and the stimulus could be picked up). It was notable that emotional sensitivity to roughness was highest in the limited surface exploration case, but a further question would be: within the category of limited haptic feedback, how does the quality of the feedback impact user experience? For example, haptic feedback can be provided via tactors (Groot et al., 2011) or via a rotating brush (Samra, 2009), to name but two methods. Although both could be used to convey varying levels of texture information, does one technique evoke greater ranges of emotional experience than the other? Answering this question could provide justifications for designers to choose one type of haptic feedback over another if both allow for equal performance.

In a similar fashion, this research also considered various conditions of visual information of roughness and their impact on emotional response. Although this research suggests that the availability of visual information has less ability to predict emotion, it is still uncertain as to what extent visual fidelity can impact emotional response. Does lower quality visual feedback (perhaps in the form of simulated models) that corresponds with directly available, relevant haptic feedback evoke a better user experience than excellent quality visual feedback but lower amounts of available haptic feedback? Answering such questions could direct designers of multimodal haptic technology to focus on the refinement of information in one modality or another.

This research begins the investigation of key questions regarding the relationship between multimodal touch and emotion in product and haptic design. The impact of some individual characteristics (such as gender, age, and tactual importance) was found to have a number of interesting interactions with touch factors of interest, making it worthwhile to continue to investigate whether or not they should be included in the general touch-emotion model. Future work can focus on a number of areas, theoretical, methodological, and applied, in order to further develop the touch-emotion model.

12.5 Summary

In summary, as discussed in preceding sections, the purpose of this research was to address the question of how multimodal touch can influence emotion and behaviour in various settings. By developing a touch-emotion model that was subsequently explored in four experiments, this research found that a) touch experiences, as operationalized by surface roughness, can predict changes in emotion under various conditions; b) contrary to expectations, cognition (as operationalized by cognitive priming of product context) does not appear to significantly interact with perception to impact emotion; and c) behaviour, as operationalized by response times, appears to be better predicted by emotion magnitude than by emotion valence. These findings, in addition to demographics findings linking age, gender, and tactual importance to the experience of touch, have the potential to have application in product and haptic technology design because they highlight various ways by which designers may impact or predict user experience. The research area of understanding touch and touch-evoked emotion is an area that has significant potential to improve user experience for all touch-based products presented to the user in virtual applications or in the real world.

References

Ahmaniemi, T., Marila, J., & Lantz, V. (2010, October). Design of Dynamic Vibrotactile Textures. *IEEE Transactions on Haptics*, *3*(4), 245–256.

Anders, S., Lotze, M., Erb, M., Grodd, W., & Birbaumer, N. (2004, December). Brain Activity Underlying Emotional Valence and Arousal: A Response-Related fMRI Study. *Human brain mapping*, *23*(4), 200–209.

Angeli, A. de, & Johnson, G. I. (2004). Emotional intelligence in interactive systems. In D. McDonagh, P. Hekkert, J. van Erp, & D. Gyi (Eds.), *Design and emotion* (pp. 262–266). New York, New York, USA: Taylor & Francis.

Artacho-Ramírez, M., Diego-Mas, J., & Alcaide-Marzal, J. (2008, November). Influence of the mode of graphical representation on the perception of product aesthetic and emotional features: An exploratory study. *International Journal of Industrial Ergonomics*, *38*(11-12), 942–952.

Baron, R. M., & Kenny, D. A. (1986, December). The moderator-mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology*, *51*(6), 1173–1182.

Bechara, A., & Damasio, A. R. (2005, August). The Somatic Marker Hypothesis: A Neural Theory of Economic Decision. *Games and Economic Behavior*, *52*(2), 336–372.

Bensmaïa, S., & Hollins, M. (2005, July). Pacinian representations of fine surface texture. *Perception & Psychophysics*, *67*(5), 842–854.

Bergmann Tiest, W. M., & Kappers, A. M. L. (2006, January). Analysis of haptic perception of materials by multidimensional scaling and physical measurements of roughness and compressibility. *Acta psychologica*, *121*(1), 1–20.

Bergmann Tiest, W. M., & Kappers, A. M. L. (2007, February). Haptic and Visual Perception of Roughness. *Acta Psychologica*, *124*(2), 177–189.

Bolanowski, S., Verrillo, R., & McGlone, F. (2004, January). Passive, active and intra-active (self) touch. *Behavioural Brain Research*, *148*(1-2), 41–45.

Cabanac, M., & Bonniot-Cabanac, M.-C. (2007, January). Decision Making: Rational or Hedonic? *Behavioral and Brain Functions*, *3*(45), 1–8.

Cant, J. S., Large, M.-E., McCall, L., & Goodale, M. A. (2008). Independent processing of form, colour, and texture in object perception. *Perception*, *37*(1), 57–78.

Castelfranchi, C. (2000). Affective appraisal versus cognitive evaluation in social emotions and interactions. In A. Paiva (Ed.), *Affective interactions: towards a new generation of computer interfaces* (pp. 76–106). Berlin: Springer.

Chen, X., Barnes, C., Childs, T., Henson, B., & Shao, F. (2009, December). Materials Tactile Testing and Characterisation for Consumer Products Affective Packaging Design. *Materials & Design*, *30*(10), 4299–4310.

Chen, X., Shao, F., Barnes, C., Childs, T., & Henson, B. (2009). Exploring Relationships between Touch Perception and Surface Physical Properties. *International Journal*, *3*(2), 67–76.

Choi, K., & Jun, C. (2007, January). A systematic approach to the Kansei factors of tactile sense regarding the surface roughness. *Applied ergonomics*, *38*(1), 53–63.

Chuang, M. C., Chang, C. C., & Hsu, S. H. (2001, April). Perceptual factors underlying user preferences toward product form of mobile phones. *International Journal of Industrial Ergonomics*, *27*(4), 247–258.

Citrin, A. V., Stem, D. E., Spangenberg, E. R., & Clark, M. J. (2003, November). Consumer Need for Tactile Input An internet Retailing Challenge. *Journal of Business Research*, *56*(11), 915–922.

Cohen, J. (1994). The earth is round (p ¡ .05): Rejoinder. *American Psychologist*, *49*(12), 997–1003.

Coles, T. R., Meglan, D., & John, N. W. (2011, January). The Role of Haptics in Medical Training Simulators: A Survey of the State of the Art. *IEEE Transactions on Haptics*, *4*(1), 51–66.

Desmet, P. (2003). Measuring emotions. In M. A. Blythe, K. Overbeeke, A. F. Monk, & P. C. Wright (Eds.), *Funology: from usability to enjoyment* (pp. 111–124).

Dillon, P., Moody, W., Bartlett, R., Scully, P., Morgan, R., & James, C. (2001). Sensing the Fabric: to Simulate Sensation Through Sensory Evalaution and in Response to Standard Acceptable Properties of Specific Materials Viewed as a Digital Image. *Lecture notes in computer science*, *2058*, 205–218.

DiSalvo, C., Hanington, B., & Forlizzi, J. (2004). An accessible framework of emotional experiences for new product conception. In D. McDonagh, P. Hekkert, J. van Erp, & D. Gyi (Eds.), *Design and emotion* (pp. 251–261). New York, New York, USA: Taylor & Francis.

Ekman, G., Hosman, J., & Lindstrom, B. (1965). Roughness, smoothness, and preferences: a study of quantitative relations in individual subjects. *Journal of Experimental Psychology*, *70*(1), 18–26.

Ernst, M. O., Lange, C., Planck, M., & Newell, F. N. (2007). Multisensory Recognition of Actively Explored Objects. *Canadian Journal of Experimental Psychology*, *61*(3), 242–253.

Faraway, J. J. (2002). *Practical Regression and Anova using R*. Julian J. Faraway.

Fenko, A., Schifferstein, H. N. J., & Hekkert, P. (2009, January). Shifts in sensory dominance between various stages of user-product interactions. *Applied Ergonomics*, *41*(1), 34–40.

Ferris, T. K., & Sarter, N. (2010). When Content Matters: The Role of Processing Code in Tactile Display Design. *IEEE Transactions on Haptics*, *3*(3), 199–210.

Frijda, N. H. (1988, May). The Laws of Emotion. *American Psychologist*, *43*(5), 349–358.

Gallace, A., Tan, H. Z., & Spence, C. (2007, December). The Body Surface as a Communication System: The State of the Art after 50 Years. *Presence: Teleoperators and Virtual Environments*, *16*(6), 655–676.

Gerling, G. J., & Thomas, G. W. (2005, October). Augmented, Pulsating Tactile Feedback Facilitates Simulator Training of Clinical Breast Examinations. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *47*(3), 670–681.

Gibson, J. J. (1962, November). Observations on active touch. *Psychological Review*, *69*(6), 477–491.

Groot, S. de, Winter, J. C. F. de, García, J. M. L., Mulder, M., & Wieringa, P. A. (2011, December). The Effect of Concurrent Bandwidth Feedback on Learning the Lane-Keeping Task in a Driving Simulator. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *53*(1), 50–62.

Han, S. H., & Hong, S. W. (2003). A systematic approach for coupling user satisfaction with product design. *Ergonomics*, *46*(13-14), 1441–1461.

Hancock, P. A., Pepe, A. A., & Murphy, L. L. (2005). Hedonomics: The Power of Positive and Pleasurable Ergonomics. *Ergonomics in Design*, *Winter*, 8–14.

Heilman, K. M., Blonder, L. X., Bowers, D., & Crucian, G. P. (2000). Neurological Disorders and Emotional Dysfunction. In J. Borod (Ed.), *The neuropsychology of emotion* (pp. 367–412). Oxford, New York: Oxford University Press.

Hilsenrat, M., & Reiner, M. (2011). The impact of subliminal haptic perception on the preference discrimination of roughness compliance. *Brain Research Bulletin*, *85*, 267–270.

Hollins, M., Bensmaïa, S., Karlof, K., & Young, F. (2000, November). Individual differences in perceptual space for tactile textures: evidence from multidimensional scaling. *Perception & Psychophysics*, *62*(8), 1534–1544.

Hollins, M., & Bensmaïa, S. J. (2007). The Coding of Roughness. *Canadian Journal of Experimental Psychology*, *61*(3), 184–195.

Hornik, J. (1992, December). Tactile Stimulation and Consumer Response. *Journal of Consumer Research*, *19*(3), 449–458.

James, W. (1884). What is an Emotion? *Mind*, *9*, 188–205.

Jones, L. A., & Sarter, N. B. (2008, February). Tactile Displays: Guidance for Their Design and Application. *Human Factors: The Journal of the Human Factors and*

Ergonomics Society, *50*(1), 90–111.

Khalid, H. M. (2006, July). Embracing Diversity in User Needs for Affective Design. *Applied ergonomics*, *37*(4), 409–418.

King, L. A., Hicks, J. A., Krull, J. L., & Del Gaiso, A. K. (2006, January). Positive Affect and the Experience of Meaning in Life. *Journal of Personality and Social Psychology*, *90*(1), 179–196.

Klatzky, R. L., Lederman, S. J., Hamilton, C., Grindley, M., & Swendsen, R. H. (2003). Feeling textures through a probe: Effects of probe and surface geometry and exploratory factors. *Perception & psychophysics*, *65*(4), 613–631.

Klatzky, R. L., Lederman, S. J., & Reed, C. (1987). There's More to Touch Than Meets the Eye: The Salience of Object Attributes for Haptics With and Without Vision. *Journal of Experimental Psychology: General*, *116*(4), 356–369.

Koufaris, M. (2002, June). Applying the Technology Acceptance Model and Flow Theory to Online Consumer Behavior. *Information Systems Research*, *13*(2), 205–223.

Kuschel, M., Di Luca, M., Buss, M., & Klatzky, R. L. (2010, October). Combination and Integration in the Perception of Visual-Haptic Compliance Information. *IEEE Transactions on Haptics*, *3*(4), 234–244.

Kyung, K.-U., & Kwon, D.-S. (2006). Multi-sensory Perception of Roughness: Empirical Study on Effects of Vibrotactile Feedback and Auditory Feedback in Texture Perception. In *Icat 2006* (pp. 406 – 415). Hangzhou, China: Springer-Verlag Berlin Heidelberg.

Lawrence, M. A., Kitada, R., Klatzky, R. L., & Lederman, S. J. (2007). Haptic roughness perception of linear gratings via bare finger or rigid probe. *Perception*, *36*(4), 547–557.

Lazarus, R. S. (1984). On the primacy of cognition. *American Psychologist*, *39*(2), 124–129.

Lederman, S. J. (1981). The Perception of Surface Roughness by Active and Passive Touch. *Bulletin of the Psychonomic Society*, *18*(5), 253–255.

Lederman, S. J. (1982). The perception of texture by touch. In *Tactual perception: A* *sourcebook* (pp. 130–167). New York, New York, USA: Cambridge University Press.

Lederman, S. J. (1997). Skin and Touch. In *Encyclopedia of human biology, volume 8* (2nd ed.). Academic Press.

Lederman, S. J., & Abbott, S. G. (1981, August). Texture Perception: Studies of Intersensory Organization Using a Discrepancy Paradigm, and Visual Versus Tactual Psychophysics. *Journal of Experimental Psychology: Human Perception and Performance*, *7*(4), 902–915.

Lederman, S. J., & Jones, L. A. (2011). Tactile and Haptic Illusions. *IEEE Transactions on Haptics*, *4*(2), 1–22.

Lederman, S. J., & Klatzky, R. L. (1987). Hand Movements: A Window into Haptic Object Recognition. *Cognitive Psychology*, *19*(3), 342–368.

Lederman, S. J., & Klatzky, R. L. (1998). Feeling Through a Probe. In *Dsc-vol. 64, proceedings of the asme dynamic systems and control division* (pp. 127–131). Anaheim, California: ASME 1998.

Lederman, S. J., Klatzky, R. L., Morgan, T., & Hamilton, C. (2002). Integrating Multimodal Information about Surface Texture via a Probe: Relative Contributions of Haptic and Touch- Produced Sound Sources. In *10th annual meeting of haptic interfaces for teleoperator and virtual environment systems. satellite meeting of the annual ieee vr '02 meeting.* (pp. 97–104). Orlando, FL, USA: IEEE.

Lederman, S. J., Thorne, G., & Jones, B. (1986). Perception of Texture by Vision and Touch: Multidimensionality and Intersensory Integration. *Journal of Experimental Psychology. Human Perception and Performance*, *12*(2), 169–180.

Lee, B., & MacGregor, C. G. (2010). The Emotional Impact of Surface and Prototyping Properties in Product Design. In *Human factors and ergonomics society annual meeting proceedings* (pp. 1757–1761(5)). San Francisco, CA, USA.

Leeper, R. (1948). A motivational theory of emotion to replace emotion as a disorganized response. *Psychological Review*, *55*(1), 5–21.

Liu, Y. (2003). Engineering Aesthetics and Aesthetic Ergonomics: Theoretical Foundations and a Dual-Process Research Methodology. *Ergonomics*, *46*(13-

14), 1273–92.

Loewenstein, G. F., & Lerner, J. S. (2003). The role of affect in decision making. In R. J. Davidson, K. R. Scherer, & H. H. Goldsmith (Eds.), *Handbook of affective sciences* (pp. 619–642). Oxford: Oxford University Press.

Lottridge, D. (2008). Emotional Response As a Measure of Human Performance. In *Chi ea '08.* Florence, Italy.

Marshall, D. C., Lee, J. D., & Austria, P. A. (2007, February). Alerts for In-Vehicle Information Systems: Annoyance, Urgency, and Appropriateness. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *49*(1), 145–157.

Martinho, C., Machado, I., & Paiva, A. (2000). A cognitive approach to affective user modeling. In *Affective interactions: towards a new generation of computer interfaces* (pp. 64–75). Berlin: Springer.

McGlone, F., Vallbo, A. B., Olausson, H., Loken, L., & Wessberg, J. (2007). Discriminative touch and emotional touch. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale*, *61*(3), 173–183.

Mehrabian, A., & Russell, J. A. (1974). *An approach to environmental psychology*. Cambridge, MA: MIT Press.

Nagamachi, M. (2002, May). Kansei Engineering As a Powerful Consumer-Oriented Technology For Product Development. *Applied ergonomics*, *33*(3), 289–94.

Norman, D. (2004). *Emotional Design: Why We Love (Or Hate) Everyday Things*. New York, New York, USA: Basic Books.

Paneels, S., & Roberts, J. C. (2010, April). Review of Designs for Haptic Data Visualization. *IEEE Transactions on Haptics*, *3*(2), 119–137.

Paterson, M. (2007). *Senses of Touch*. Oxford, New York: Berg.

Peck, J., & Childers, T. (2006, June). If I touch it I have to have it: Individual and environmental influences on impulse purchasing. *Journal of Business Research*, *59*(6), 765–769.

Peck, J., & Childers, T. L. (2003). Haptic judgments of curvature by blind and sighted humans. *Journal of Marketing*, *67*, 35–48.

Peck, J., & Wiggins, J. (2006, October). It Just Feels Good: Customers' Affective Response to Touch and Its Influence on Persuasion. *Journal of Marketing*, *70*(4), 56–69.

Perreault, J. O., & Cao, C. G. L. (2006, September). Effects of Vision and Friction on Haptic Perception. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *48*(3), 574–586.

Picard, D., Dacremont, C., Valentin, D., & Giboreau, A. (2003, October). Perceptual Dimensions of Tactile Textures. *Acta Psychologica*, *114*(2), 165–184.

Picard, R. (2003, July). Affective computing: challenges. *International Journal of Human-Computer Studies*, *59*(1-2), 55–64.

Plutchik, R. (1982, July). A Psychoevolutionary Theory of Emotions. *Social Science Information*, *21*(4-5), 529–553.

Plutchik, R. (1991). *The emotions*. Lanham, MD: University Press of America.

Preece, J., Rogers, Y., & Sharp, H. (2002). *Interaction design: beyond human-computer interaction*. New York, New York, USA: J. Wiley & Sons.

Rawlings, A. V. (2006, April). Ethnic skin types: are there differences in skin structure and function? *International journal of cosmetic science*, *28*(2), 79–93.

Samra, R. (2009). *Tactile haptics: a study of roughness perception in virtual environments*. Waterloo, ON: University of Waterloo.

Schifferstein, H. N. J. (2006, January). The perceived importance of sensory modalities in product usage: a study of self-reports. *Acta psychologica*, *121*(1), 41–64.

Schifferstein, H. N. J., & Cleiren, M. P. H. D. (2005, March). Capturing product experiences: a split-modality approach. *Acta psychologica*, *118*(3), 293–318.

Seva, R. R., Duh, H. B.-L., & Helander, M. G. (2007, November). The marketing implications of affective product design. *Applied ergonomics*, *38*(6), 723–31.

Soto-Faraco, S., & Deco, G. (2009, January). Multisensory contributions to the perception of vibrotactile events. *Behavioural brain research*, *196*(2), 145–54.

Suzuki, Y., Gyoba, J., & Sakamoto, S. (2008, November). Selective effects of auditory stimuli on tactile roughness perception. *Brain research*, *1242*, 87–94.

Tan, H. Z., Member, S., Reed, C. M., & Durlach, N. I. (2010). Optimum Information Transfer Rates for Communication through Haptic and Other Sensory Modalities. *IEEE Transactions on Haptics*, *3*(2), 98–108.

Unger, B., Hollis, R., & Klatzky, R. (2011). Roughness Perception in Virtual Textures. *Small*, *4*(2), 122–133.

Verrillo, R. T. (1993). The effects of aging on the sense of touch. In R. T. Verrillo (Ed.), *Sensory research: multimodal perspectives* (pp. 285–298). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Visell, Y. (2009, January). Tactile sensory substitution: Models for enaction in HCI. *Interacting with Computers*, *21*(1-2), 38–53.

Walker, E. L. (1980, June). Berlyne's theoretical contributions to psychology. *Motivation and Emotion*, *4*(2), 105–111.

Whitaker, T. A., Franklin, C. Simões, & Newell, F. N. (2008, November). Vision and Touch: Independent or Integrated Systems for the Perception of Texture? *Brain research*, *1242*, 59–72.

Wickens, C., & Hollands, J. (2000). *Engineering psychology and human performance*. Upper Saddle River, N.J.: Prentice-Hall.

Witmer, B. G., & Singer, M. J. (1998, June). Measuring Presence in Virtual Environments: A Presence Questionnaire. *Presence*, *7*(3), 225–240.

Yannier, N., Basdogan, C., Tasiran, S., & Sen, O. (2008, July). Using Haptics to Convey Cause-and-Effect Relations in Climate Visualization. *IEEE Transactions on Haptics*, *1*(2), 130–141.

Yun, M. H., Han, S., Hong, S., & Kim, J. (2010). Incorporating user satisfaction into the look-and-feel of mobile phone design. *Ergonomics*, *46*(13-14), 1423–40.

Zajonc, R. B. (1984). On the primacy of affect. *American Psychologist*, *39*(2), 117–123.

Zuo, H. (2004). Exploration into formal aesthetics in design : (material) texture. *Design*, 1–11.

Zuo, H., Hope, T., Jones, M., & Castle, P. (2004). Sensory Interaction with Materials. In D. McDonagh, P. Hekkert, J. van Erp, & D. Gyi (Eds.), *Design and emotion* (pp. 223–227). New York, New York, USA: Taylor & Francis.

Appendix A

Wundt Curve

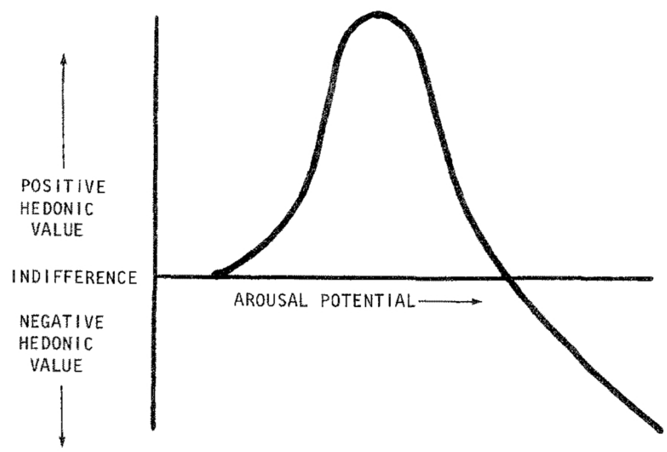


Figure A.1: The Wundt curve. Berlyn (1971, adapted from Berlyne, 1960, and from Wundt, 1874).

The Wundt curve illustrates the relationship between arousal and emotional valence, such that medium levels of arousal due a stimulus are more pleasing than low or high levels of arousal (Walker, 1980).

Appendix B

Sequential Model of Emotion

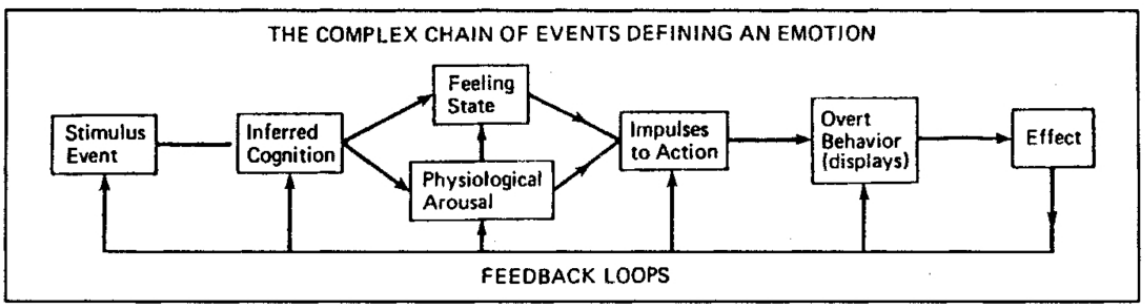


Figure B.1: The sequential model of emotions developed by Plutchik (1982).

Emotions in the sequential model are part of a circular feedback system such that stimulus events (either external or internal) trigger an emotion process. The model suggests that following cognition, a feeling state occurs simultaneously with physiological arousal, which then leads to impulses to action, such tendencies to as innervate muscles towards facial expressions or approaching / avoiding. Overt behaviours are then those tendencies made manifest into physical actions. The effect of those actions can then feedback to the process (Plutchik, 1982).

Appendix C

Information Processing Model

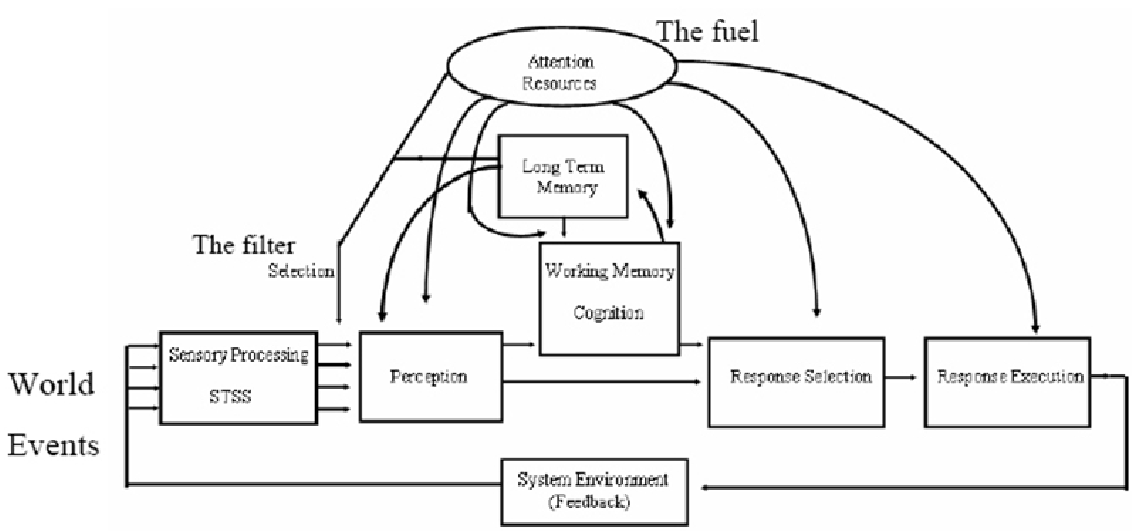


Figure C.1: Wicken's (2000) information processing model.

Each stage of the information processing model is defined as follows. Sensory processing is typically auditory or visual. Perception of those senses is the immediate understanding of the meaning of sensory information based on that information (bottom-up processing) and on past experience stored in long term memory (top-down processing). Response (action) selection is either rapid and automatic or is a deliberative decision (skill-based, rule-based or knowledge based). Response execution involves the motor cortex and the muscles and impacts the world. Working memory is what cognition, thinking and situation awareness require in order to take place. Working memory is also required for conscious rehearsal, problem solving and imaging. It is temporary and very vulnerable. Long term memory, on the other hand, is where 'permanent' (but forgettable) information is stored, such as facts, procedures, skills. Long term memory drives and supports perception in a top-down manner (Wickens & Hollands, 2000).

Appendix D

Emoticon Graphics

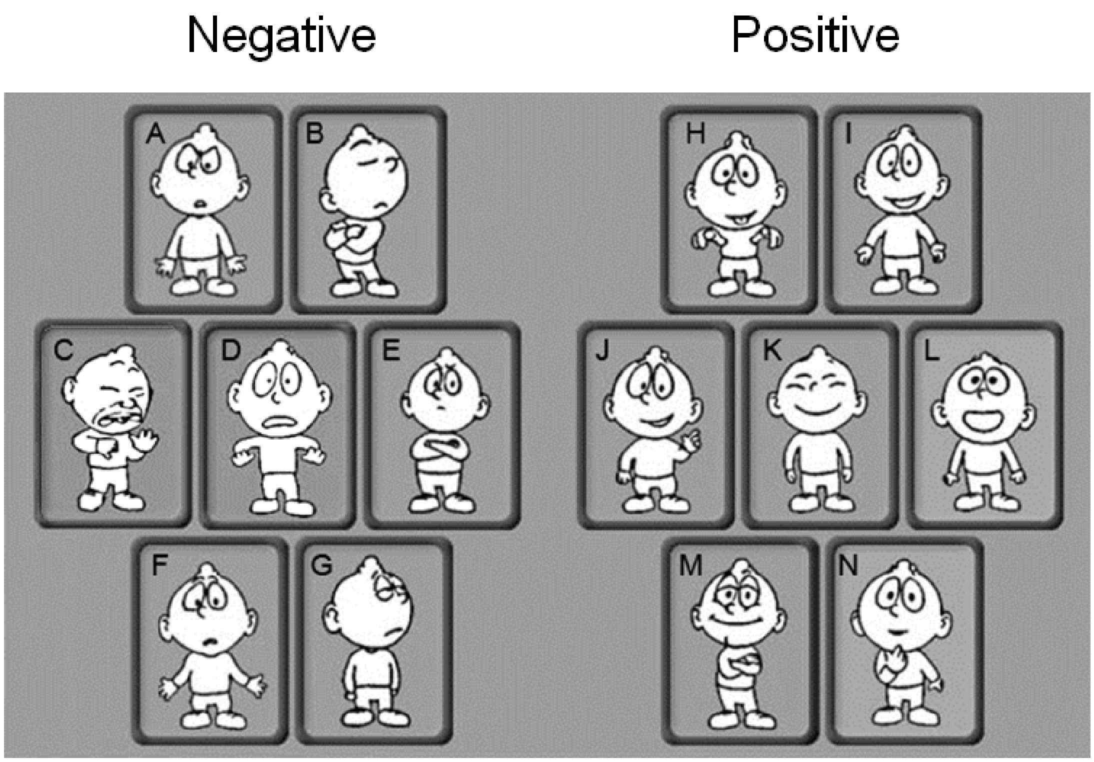


Figure D.1: Emoticons developed in a study by Desmet (2003), used in the exploratory experiment to collect emotional valence.

Appendix E

Experiment 1 Questionnaire

Before we begin, please answer the following questions:

1) What is your age (years): ______
2) What is your gender: ________
3) What is your program of study? ____________________________________
4) How many hours a week do you play video games? ________
5) Please check how often you use these controllers:

	0	1	2	3	4
	Never	Rarely	Occasio nally	Often	Very often
Mouse (for gaming)					
Joystick					
Regular console controller (PS, Xbox, etc)					
Wii hand controller					
Nintendo DS					
Guitar					
Drums					
Other: ______________________________					

Figure E.1: Questionnaire used for Experiment 1.

6) What is your ethnicity?
    a. Asian
    b. Black
    c. Caucasian
    d. Hispanic
    e. Native American
    f. East Indian
    g. Other: If Other, please specify: ________

7) Please check which applies most to you:

	Below Average	Average	Above Average
How tactually sensitive are you? (How easily can you detect differences in texture?)			
How temperature sensitive are you? (How easily can you detect differences in temperature?)			

Figure E.2: Questionnaire used for Experiment 1 (continued).

Appendix F

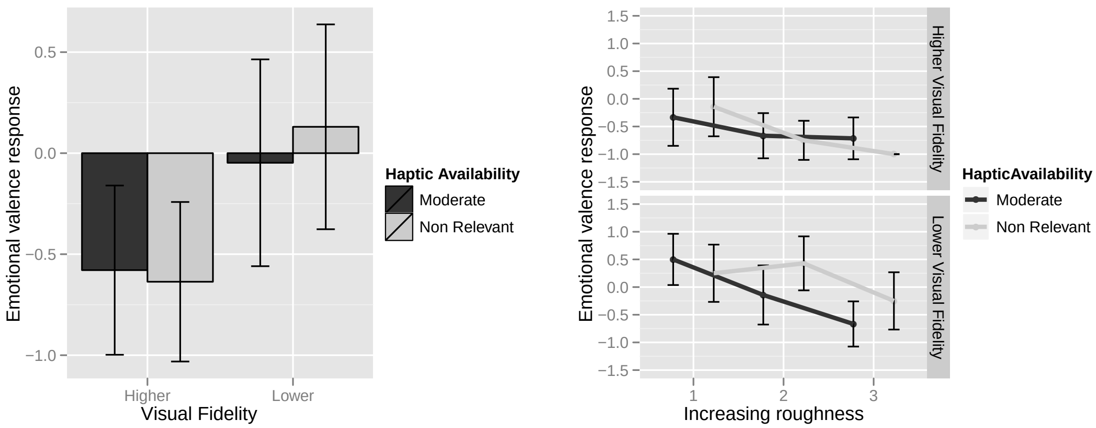
Experiment 1 Exploratory Data Analysis

F.1 Potential effect of Predictors on Emotional Valence and Total Interaction Time

Examining first the potential relationship between the predictors (Haptic and Visual information availability) and Emotional valence (EV) yielded the graphical representation of the data as presented in Figure F.1a and b. Visual inspection of these graphics reveals that the High Visual Fidelity condition produces lower EV, that the effect of Haptic availability on EV is relatively weak, and that increased Roughness leads to decreased EV.

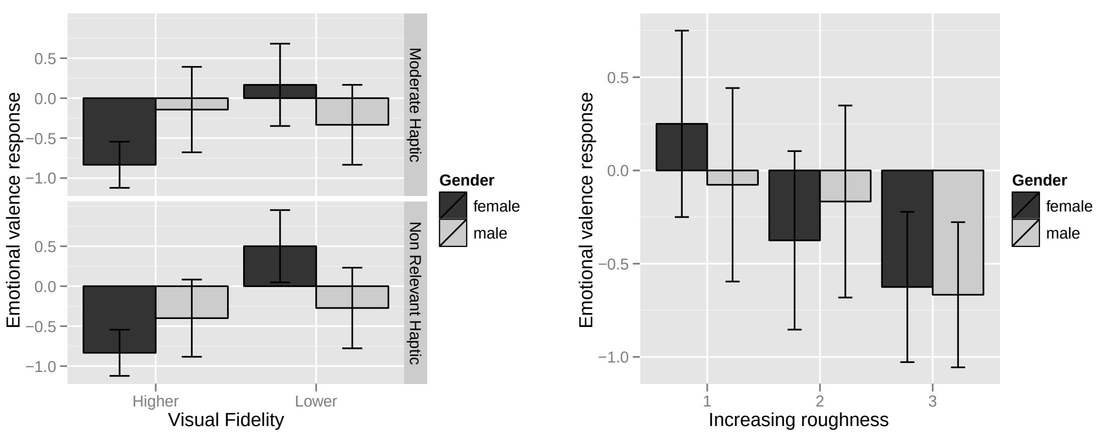
The graphical representations of the effects of Gender on EV are shown in Figure F.2a and b. The graphs suggest that females are more likely to report changes in emotions to changing Visual Fidelity conditions, and that females are also more likely than males to be emotionally responsive to changes in Roughness.

The consideration of the relationship between the independent variables and Time produced the visual representation of the data seen in Figure F.3a and b. Visual inspection of Figure F.3 reveals that in the Moderate Haptic condition, there is likely no effect of Visual Fidelity level, but in the Non Relevant Haptic condition,



(a) (b)

Figure F.1: a) Examining potential Visual Fidelity by Haptic availability interactions on EV; b) examining potential effects of Roughness on EV.

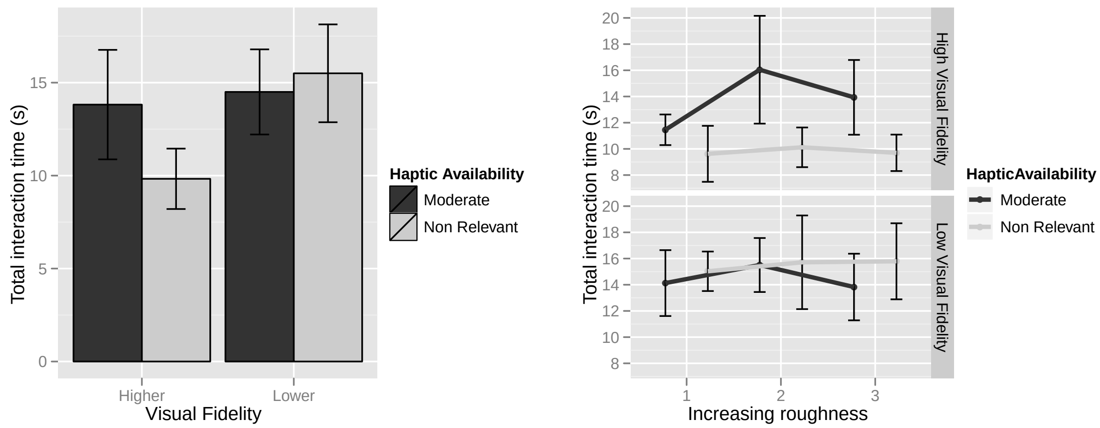


(a) (b)

Figure F.2: a) Examining potential Visual Fidelity by Haptic availability by Gender interactions on EV; b) examining potential effects of Gender by Roughness on EV.

participants appear to spend less time interacting with the stimulus in the High Visual Fidelity condition. Further, there may be a weak influence of Roughness on Time such that increasing Roughness results in slightly increased Time.

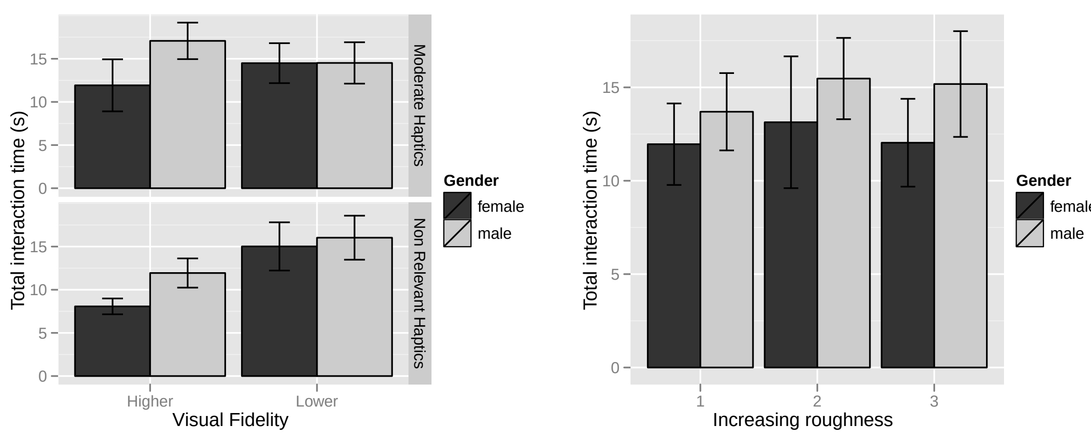
Considering the effect of Gender on Time yielded Figure F.4. It is possible that



(a) (b)

Figure F.3: a) Examining potential Visual Fidelity by Haptic availability interactions on Time; b) examining the effect of Roughness on Time.

decreasing Visual Fidelity level leads to increased Time for females, and that Time is generally higher for males, though these effects may be small.



(a) (b)

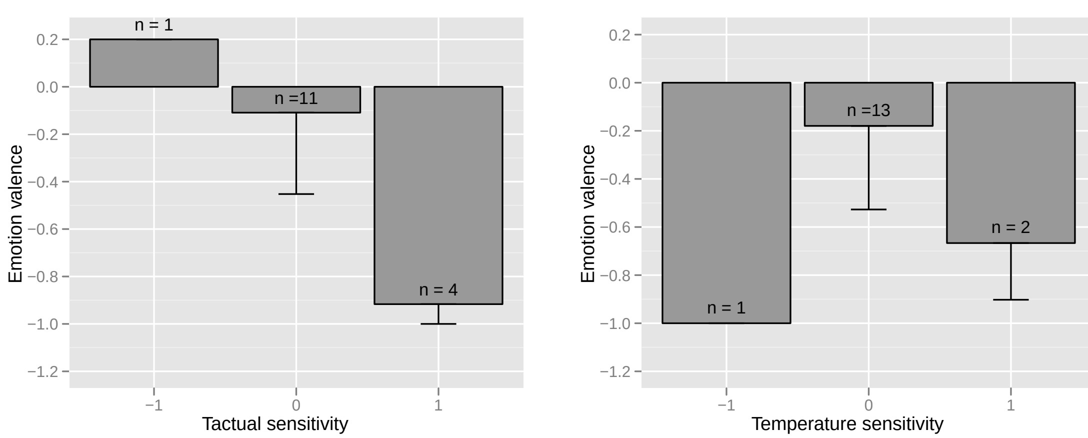
Figure F.4: a) Examining potential Visual Fidelity by Haptic availability by Gender interactions on Time; b) examining the potential effect of Gender by Roughness on Time.

F.2 Potential demographics relationships

An analysis of demographics data was conducted by first collapsing the data for each individual, creating the values EV_{avg} and $Time_{avg}$. Further, in order to capture the effect of changing Roughness, a predictor variable EV_{slope} was created for each individual such that EV_{slope} was the slope of the line of best fit of Roughness versus EV. EV_{slope} then captures the individual's emotional sensitivity to changes in Roughness, with more negative slopes indicating a greater sensitivity to the manipulation in the predicted direction (that is, it is expected that emotional valence decreases with increased Roughness). $Time_{slope}$ was created similarly for each individual.

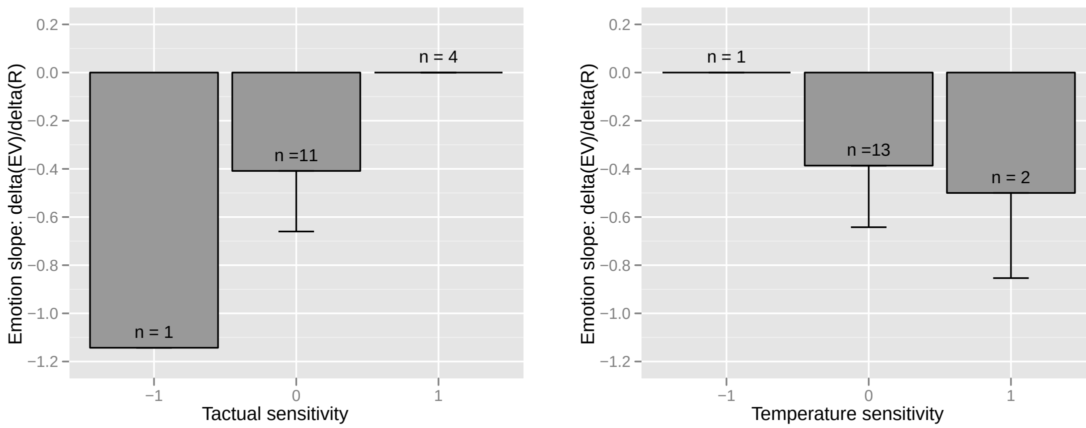
Considering tactual and temperature sensitivity and their correlations with EV_{avg} yielded Figure F.5. Tactual sensitivity appears to be negatively correlated with EV_{avg}.

Considering tactual and temperature sensitivity and their correlations with EV_{slope} yielded Figure F.6. Tactual and Temperature sensitivity appear to have opposite effects on EV_{slope}: increases in the former correlated with increased EV_{slope}



(a) (b)

Figure F.5: Examining potential relationships between tactual sensitivity (a) and temperature sensitivity (b) and EV_{avg}.

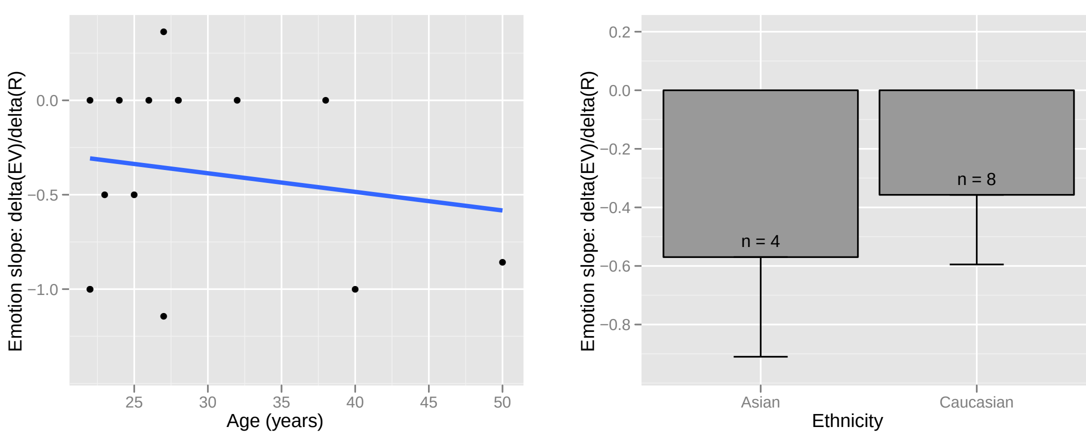


(a) (b)

Figure F.6: Examining potential relationships between Tactual sensitivity (a) and Temperature sensitivity (b) and EV_{slope}.

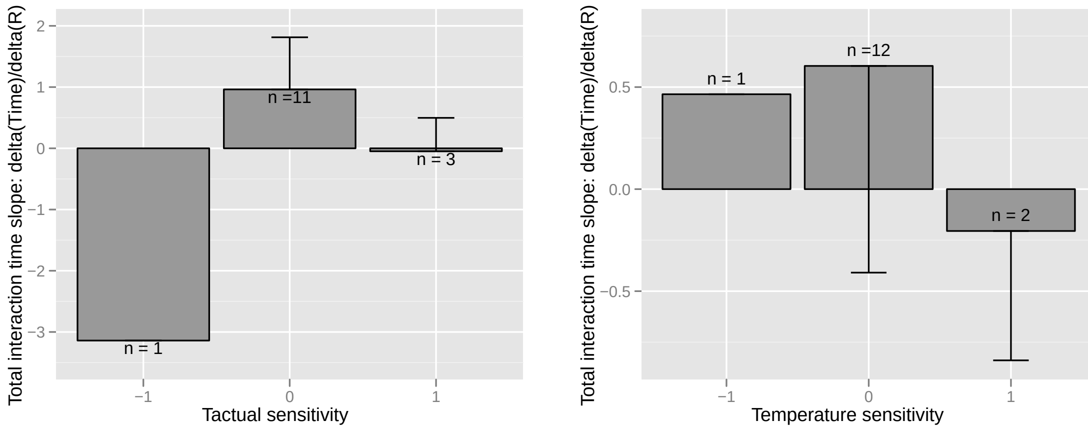
while increases in the latter correlated with decreased EV_{slope}.

Further demographics analysis considered the patterns of Age and Ethnicity in relation to EV_{slope}, shown in Figure F.7. There is a suggestion that Age is negatively correlated with EV_{slope}, and that Asians may have more negative EV_{slope} values



(a) (b)

Figure F.7: Examining potential relationships between Age (a) and Ethnicity (b) on EV_{slope}.

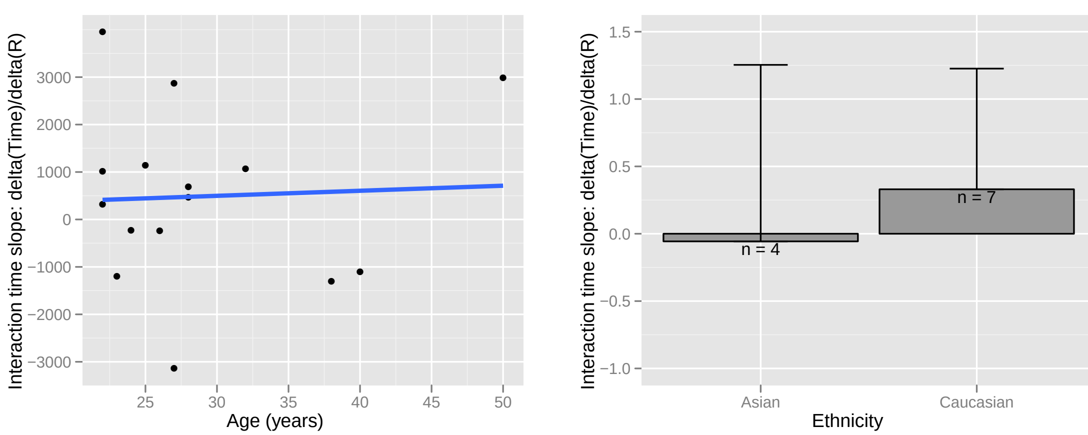


(a) (b)

Figure F.8: Examining potential relationships between Tactual sensitivity (a) and Temperature sensitivity (b) and Time_{slope}.

than Caucasians.

Similarly, considering the patterns between Tactual and Temperature sensitivity and Time_{slope} produced Figure F.8. It can be seen here that Tactual sensitivity and Temperature sensitivity appear to be correlated positively and negatively, re-



(a) (b)

Figure F.9: Examining potential relationships between Age (a) and Ethnicity (b) and Time_{slope}.

spectively, with Time_{slope}.

Inspection of the potential relationships between age and ethnicity on Time_{slope} produced Figure F.9. There was no convincing evidence for a correlation between Age and Time_{slope} or Ethnicity and Time_{slope}.

Appendix G

Experiment 1 Demographics Correlation Table

Table G.1: Pearson correlation coefficient table for demographics data of Experiment 1. ** denotes significant correlations (p $\leq$0.05); * denotes marginally significant correlations (0.05 $<$ p $\leq$ 0.1).

	Tactual Sensitivity		Temperature Sensitivity		Age		Gender		Ethnicity	
	r	*p* ≤	*r*	*p* ≤	*r*	*p* ≤	*r*	*p* ≤	*r*	*p* ≤
EV_{avg}	-0.49	0.07 *	-0.02	0.95	0.26	0.36	0.01	0.98	-0.45	0.17
$Time_{avg}$	-0.14	0.60	-0.26	0.33	0.12	0.67	0.41	0.12	-0.10	0.77
EV_{slope}	0.52	0.05 **	-0.19	0.49	-0.16	0.58	0.13	0.64	0.12	0.72
$Time_{slope}$	0.15	0.60	-0.11	0.69	0.05	0.88	0.14	0.63	0.20	0.56
Age	0.16	0.58	0.22	0.44	--	--	--	--	--	--
Gender	0.02	0.95	-0.44	0.10 *	--	--	--	--	--	--
Ethnicity	0.44	0.18	-0.42	0.21	--	--	--	--	--	--

Appendix H

Experiments 2 and 4 Questionnaire

Before we begin, please answer the following questions:

1) What is your age (years): ______
2) What is your gender: ________
3) What is your program of study? _______________________________________
4) What is your ethnicity?
   a. Asian
   b. Black
   c. Caucasian
   d. Hispanic
   e. Native American
   f. East Indian
   g. Other: If Other, please specify: ________

Figure H.1: Questionnaire used for Experiments 2 and 4.

5) Compared to the average person, please check which applies most to you:

	Below Average	Average	Above Average
How tactually sensitive are you? (How easily can you detect differences in texture?)			
How temperature sensitive are you? (How easily can you detect differences in temperature?)			
How important are tactual experiences for you in general?			
How important are tactual experiences for you when making purchases?			

Figure H.2: Questionnaire used for Experiments 2 and 4 (continued).

Appendix I

Experiment 2 Demographics Correlation Table

Table I.1: Pearson correlation coefficient table for Experiment 2. ** denotes significant correlations (p $\leq$0.05); * denotes marginally significant correlations (0.05 < p $\leq$ 0.1).

	TIR		Age		Gender	
	r	*p* ≤	*r*	*p* ≤	*r*	*p* ≤
EV_{avg}	0.11	0.62	-0.05	0.82	-0.10	0.66
IT_{avg}	-0.09	0.67	0.16	0.45	0.25	0.24
RT_{avg}	0.56	0.01 **	0.17	0.44	-0.08	0.72
EV_{slope}	-0.31	0.14	-0.40	0.06 *	0.03	0.89
IT_{slope}	-0.14	0.52	-0.23	0.28	-0.18	0.41
RT_{slope}	-0.12	0.59	-0.20	0.36	-0.05	0.82
Age	0.24	0.26	--	--	--	--
Gender	-0.23	0.29	--	--	--	--

Appendix J

Experiment 3 Questionnaire

Before we begin, please answer the following questions:

1) What is your age (years): ______
2) What is your gender: ________
3) What is your program of study? ____
4) What is your ethnicity?
    a. Asian
    b. Black
    c. Caucasian
    d. Hispanic
    e. Native American
    f. East Indian
    g. Other: If Other, please specify: ________
5) How many hours a week do you play video games? ________
6) How many hours a week do you deal with 3D models? ________

Figure J.1: Questionnaire used for Experiment 3.

7) Please check how often you use these:

	0 Never	1 Once a month	2 Once a week	3 More than once a week	4 Daily
PC (for gaming)					
PC (for 3D modelling)					
Consoles (Ex, PS3, Xbox)					

8) Compared to the average person, please check which applies most to you:

	Below Average	Average	Above Average
How tactually sensitive are you? (How easily can you detect differences in texture?)			
How temperature sensitive are you? (How easily can you detect differences in temperature?)			
How important are tactual experiences for you in general?			
How important are tactual experiences for you when making purchases?			

Figure J.2: Questionnaire used for Experiment 3 (continued).

Appendix K

Experiment 3 Demographics Correlation Table

Table K.1: Pearson correlation coefficient table for Experiment 3. ** denotes significant correlations (p $\leq$0.05); * denotes marginally significant correlations (0.05 < p $\leq$ 0.1).

	TIR		Age		Gender		Ethnicity	
	r	*p* ≤	*r*	*p* ≤	*r*	*p* ≤	*r*	*p* ≤
EV_{avg}	-0.46	0.03 **	0.23	0.28	0.38	0.13	-0.35	0.17
IT_{avg}	-0.09	0.68	0.37	0.08 *	0.21	0.33	-0.47	0.05 **
RT_{avg}	-0.12	0.57	0.35	0.10 *	0.11	0.63	-0.35	0.16
EV_{slope}	-0.42	0.05 **	0.09	0.67	0.14	0.51	-0.20	0.42
IT_{slope}	0.11	0.61	-0.18	0.40	0.12	0.58	-0.29	0.25
RT_{slope}	0.13	0.55	0.15	0.48	-0.22	0.32	0.31	0.21
Age	0.39	0.06 *	--	--	--	--	--	--
Gender	-0.28	0.19	--	--	--	--	--	--
Ethnicity	0.37	0.13	--	--	--	--	--	--

Appendix L

Experiment 4 Demographics Correlation Table

The correlation table between touch factors of Tactual Importance Rating, Age, Gender, Ethnicity, and Tactual Interaction generated from participant demographics data from Experiment 4 appears on the following page.

Table L.1: Pearson correlation coefficient table for Experiment 4. ** denotes significant correlations ($p \leq 0.05$); * denotes marginally significant correlations ($0.05 < p \leq 0.1$).

	TIR		Age		Gender		Ethnicity		Tactual Interaction	
	r	*p* ≤	*r*	*p* ≤	*r*	*p* ≤	*r*	*p* ≤	*r*	*p* ≤
EV_{avg}	-0.12	0.67	-0.30	0.28	0.28	0.41	-0.05	0.89	0.19	0.51
IT_{avg}	0.12	0.67	0.11	0.71	0.30	0.29	0.19	0.58	-0.16	0.59
RT_{avg}	0.15	0.59	-0.33	0.23	-0.30	0.28	-0.54	0.09 *	-0.07	0.82
VT_{avg}	-0.19	0.51	0.06	0.84	0.30	0.29	0.19	0.58	0.02	0.96
EV_{slope}	-0.26	0.35	-0.06	0.84	0.35	0.21	-0.12	0.72	-0.49	0.08 *
IT_{slope}	-0.17	0.54	0.35	0.20	-0.11	0.69	0.32	0.34	0.43	0.13
RT_{slope}	0.52	0.05 **	0.45	0.09 *	0.24	0.39	-0.05	0.88	0.06	0.84
VT_{slope}	0.07	0.82	0.28	0.32	-0.35	0.21	-0.06	0.86	0.10	0.73
Tactual Interaction	0.44	0.12	0.42	0.14	-0.14	0.63	0.40	0.26	--	--
Age	0.36	0.19	--	--	--	--	--	--	--	--
Gender	-0.15	0.60	--	--	--	--	--	--	--	--
Ethnicity	0.02	0.97	--	--	--	--	--	--	--	--

Appendix M

Experiments 2–4 Demographics Correlation Table

Table M.1: Pearson correlation coefficient table for combined correlation analysis of data from Experiments 2–4. ** denotes significant correlations (p $\leq$0.05); * denotes marginally significant correlations (0.05 < p $\leq$ 0.1).

	TIR		Age		Gender		Ethnicity	
	r	$p \leq$	r	$p \leq$	r	$p \leq$	r	$p \leq$
EV_{avg}	-0.15	0.26	0.09	0.50	0.11	0.47	-0.27	0.07 *
IT_{avg}	-0.04	0.78	0.49	0.01 **	0.15	0.24	-0.23	0.08 *
RT_{avg}	0.15	0.25	0.48	0.01 **	0.00	1.00	-0.28	0.06 *
EV_{slope}	-0.27	0.04 **	0.23	0.07 *	0.12	0.37	-0.01	0.95
RT_{slope}	0.06	0.65	-0.01	0.96	-0.12	0.35	0.21	0.16
IT_{slope}	0.01	0.93	-0.21	0.10 *	0.03	0.83	0.06	0.67
Age	0.28	0.03 **	--	--	--	--	--	--
Gender	-0.22	0.08 *	--	--	--	--	--	--
Ethnicity	0.11	0.45	--	--	--	--	--	--

Glossary

Affective Pathway The flow of information from the Touch/Perceptual stages directly to Emotion., 23

Behaviour Pathway The flow of information from the Touch/Perceptual stages, through Emotion, and then to Behaviour., 23

Cognition Pathway The flow of information from the Touch/Perceptual stages, through Cognition, and then to Emotion., 23

Emotional response The stage of information processing that includes both emotional valence response and arousal response to a stimulus., 8

Emotional valence The degree of positive or negative feelings., 6

EV The participant's emotional valence response to a stimulus., 42

EV$_{avg}$ Average of EV values calculated for each individual., 45

EV$_{slope}$ Calculated per individual, it is the slope of the linear line through each subject's EV vs. Roughness data points, measuring the individual's emotional sensitivity to changes in Roughness., 45

Haptic information availability Manipulation groups in which the availability of the haptic stimulus is changed by considering different real-world situations of non-relevant haptic information, moderate haptic information, and full haptic information., 37

HM Horizontal motion is the behaviour coding for stimulus exploration movements in the direction of side to side relative to the participant., 91

IT Distinct from Time, Interaction time is the time participants spend interacting with the stimulus (does not include Reflection time)., 58

IT$_{avg}$ Average of IT values calculated for each individual., 62

IT$_{slope}$ Calculated per individual, it is the slope of the linear line through each subject's IT vs. Roughness data points, measuring the individual's IT sensitivity to changes in Roughness., 62

MM — Multiple motion is the behaviour coding if participants physically explore the stimulus with more than one clear movement., 91

Product Context — An operationalization of cognitive resources, product contexts are manipulation groups in which participants are primed to think of some kind of product type (or none at all)., 70

Roughness — Refers to a set of stimuli that vary by increasing levels of roughness., 36

RT — Distinct from IT and Time, Reflection time is the time that participants take to provide EV., 58

RT$_{avg}$ — Average of RT values calculated for each individual., 62

RT$_{slope}$ — Calculated per individual, it is the slope of the linear line through each subject's RT vs. Roughness data points, measuring the individual's RT sensitivity to changes in Roughness., 62

SM — Small motions is the behaviour coding if participants physically explore the stimulus with movements that are too small to code as either Vertical motions or Horizontal motions., 91

Tactual Interaction A measure of interaction in the touch experience in Experiment 4, defined as the sum of VM, HM, MM, and -SM., 91

Time Total interaction time, equal to the sum of IT and RT., 42

Time$_{avg}$ Average of Time values calculated for each individual., 45

Time$_{slope}$ Calculated per individual, it is the slope of the linear line through each subject's Time vs. Roughness data points, measuring the individual's Time sensitivity to changes in Roughness., 45

TIR Tactual importance rating; the sum of two items on a questionnaire measuring the individual's self-reported importance of tactual information., 62

Touch experience A multimodal experience comprised of both haptic and visual components., 10

Visual Fidelity Manipulation groups in which the availability or quality of the visual stimulus is altered to include such conditions as non-relevant visuals, moderate visuals (presented on a screen), and real-world visuals., 37

VM Vertical motion is the behaviour coding for stimulus exploration movements in the direction of towards and away from the participant., 91

VT Video time is the time participants spend in physical contact with the stimulus., 91

$\mathbf{VT}_{avg}$ Average of VT values calculated for each individual., 98

$\mathbf{VT}_{slope}$ Calculated per individual, it is the slope of the linear line through each subject's VT vs. Roughness data points, measuring the individual's VT sensitivity to changes in Roughness., 98