# Creating affective touch with soft robotics

Designing affect-enabling interactive artefacts using an affect-, material-, and interaction-led (AMI-led) design framework

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of the requirements of the Royal College of Art
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This thesis represents partial submission for the degree of Doctor of Philosophy at the Royal College of Art. I confirm that the work presented here is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

During the period of registered study in which this thesis was prepared the author has not been registered for any other academic award or qualification. The material included in this thesis has not been submitted wholly or in part for any academic award or qualification other than that for which it is now submitted.

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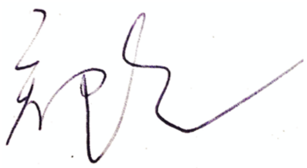

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# Abstract

Physically-bodied artefacts made with interactive materials, when affording an affective experience, can unlock tremendous design opportunities to significantly improve user experience and benefit physical and mental well-being. Yet such potential has rarely been exploited within the emergent space of affective interaction design. Designing artefacts with interactive materials that enable affective experience poses challenges, both in relation to the emergent nature of affect and in navigating the unfolding properties of materials in their physical and temporal forms and their interactive gestalt. In this cross-disciplinary space, it is difficult for designers to tackle the challenges within one specific domain of expertise, and there is a lack of design knowledge to support the form-giving process of creating affect-enabling interactive artefacts.

My research initiated an effort to address this gap. It asked:

> How can we design artefacts using interactive materials that enable affective experience?

To address this question, I combined knowledge and approaches from three domains – an interactional approach, fashion practice and material-centred interaction design – to formulate the affect-, material- and interaction- (AMI)-led design framework which guided my practice. This framework is grounded in the affect theories proposed by Barrett and Massumi to consider affect as an event, an emergence that can only be enabled through interaction.

Focusing on one type of interactive material – silicone pneumatic soft robotic (SPSR) material – my research took a Research through Design approach and followed the methods of studio practice, co-exploration and assessment.

In order to develop an artefact with an affect-enabling outcome, my practice progressed through three phases of exploration. The initial exploration focused on the designability

and affective affordance of the silicone pneumatic soft robotic (SPSR) material. A further exploration, with a broad focus, investigated designing for a positive affective touch experience. The third exploration, with a defined focus, was about creating and evaluating the final artefact – a soft robotic device (S-CAT device) which delivers a gentle stroking touch. With the evaluation results I showed that touch delivered by the S-CAT device elicited a pleasant sensation, and that it can modulate a subjective response that is similar to that elicited by the touch of a human hand or a soft brush.

My research makes an original contribution to both theory and practice within the space of affective interaction design. Through a practice-based design exploration, I demonstrated one possible pathway to creating an affect-enabling artefact with SPSR material, applying the affect-, material-, and interaction-led (AMI-led) design framework. This framework and its associated methods of studio practice, co-exploration and assessment can potentially be applied for generative, analytical, communication and educational purposes in design practice and research within the space of affective interaction design. The S-CAT device has demonstrated that it is possible for soft robotic material to produce an affective touch, which opens up the field for the exploration of further design opportunities, including those in healthcare. The research produced practical design knowledge of how to design affective touch stimulation.

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All graphs not otherwise identified are by the author.

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# Acknowledgement

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# Definition of terms

There are several key terms used in this thesis, which I specify below in alphabetical order.

**AMI-led design framework**

Affect-, material- and interaction- led design framework was formulated through my research. At the start of my practice, this framework was considered a conceptual one as it was developed theoretically through the literature review and aimed to provide a system of concepts that supported and guided my practice (Maxwell, 2013, p.39), as detailed in section 3.1. At the end of my research this framework evolved and is now considered a methodological one (Wiberg, 2013), as I expanded the framework to include the methods applied in my research, and, I critically discussed its wider implications in section 7.1.

**Artefact (s)**

The artefact or artefacts mentioned in this thesis refer to interactive artefacts that I have made in my practice. They are made with interactive materials, and normally include a physical interface made from analogue material, actuation mechanics, a micro-controller which includes a physical control board and software to digitally programme the controls.

**CT-optimal touch**

This is a term in neuroscience to refer to a gentle stroking type of touch. CT refers to CT afferents, C tactile (CT) neurons, which is a class of low-threshold C neurons that innervate the human skin (Olausson et al., 2002). A gentle stroking or caressing touch at a speed of 1-10cm/s, an indentation force between 3-0.25mN and at approximately skin temperature most optimally excites the CT afferents and is thus called CT-optimal touch (McGlone et al., 2007, Löken et al., 2009).

**S-CAT device**

S-CAT refers to soft robotic CT-optimal affective touch. The S-CAT device is the final artefact that I created in this research.

**SPSR material**

Silicone pneumatic soft robotic material. In my research it is considered as one type of interactive material.

These terms are not all established within conventional academic discourse but were developed through this research to describe particular attributes and processes. Specifically, artefacts were the objects that I designed in this research. SPSR material was the main material employed to design them. Following this, the AMI-led design framework was formulated and used to guide my practice. In my practice with a defined focus, I used SPSR material to simulate the attributes of a CT-optimal affective touch, to deliver a gentle stroking touch. I called the stroking touch delivered by the SPSR material soft robotic CT-optimal affective touch (S-CAT), which is delivered by an S-CAT device. For ease of reading, I have assigned acronyms to these terms which I use frequently throughout this thesis. They are introduced in full in the introduction to each chapter, as well as when they first appear in the text of each chapter

# Chapter 1 Introduction

In this chapter, I first introduced the background to this research and the context it sits in. I then explained the personal journey that have led me to the central topic of this research. I presented the main research question and identified the aims and objectives. I then outlined the methodological approach of this work before specifying the positioning of audience for this research. Finally I presented the structure of this thesis.

## 1.1 Background

'As interactive technologies find their way into new areas of use, new intersections between areas of expertise are being opened'(Vallgårda and Redström, 2007, p.514). My research is situated in the emergent space of affective interaction design. Sitting at the intersection of an interactional approach, fashion practice and the material-centred interaction design, my practice has brought these areas together. Rather than seeking a transfer of knowledge between static disciplines, my research seeks to synthesise in order to forge new knowledge and expertise that contribute to the generation of an emerging field revolving around creating physically-bodied interactive artefacts that enable affective experience.

In his seminal book *Emotional Design: Why We Love (or Hate) Everyday Things* (Norman, 2007), Norman argued that the emotional aspect of a designed object is instrumental to a product's success. Such considerations of affect have been introduced into the design of interactive technologies, to supplement a practice that traditionally focuses on functionality and efficiency (Hayashi and Baranauskas, 2013; Zhang and Li, 2005). Designing technologies that are relevant to human emotional experience, or affective interaction design (Lottridge et al., 2011), is an emergent space. The design recommendations for the work in this area are predominantly focused on the kind of practice that engages digital materials, or information technologies for the outcome of screen based virtual interfaces. In a parallel space, interactive materials, or computational composites (Vallgårda and

Redström, 2007; Vallgårda, 2014) are being introduced as materials for design. This trend has brought together expertise from material design, such as fashion and textile practices, and interaction design (Vallgårda, 2014; Genç et al., 2018), to form a 'material-centred interaction design approach' (Wiberg, 2018). Physically-bodied artefacts, made from interactive material, when affording an affective experience such as that described by Norman, can unlock tremendous design opportunities to significantly improve user experience and benefit physical and mental well-being. Yet such potential has rarely been exploited within the space of affective interaction design, as there is a missing link – the application of affect-enabling qualities to material-bodied interactive artefacts. My research initiated this link.

Regarding the practices within this design space, the dominant paradigm is still a computational one, which does not concern the experiential qualities of physical material design. This paradigm is led by Affective Computing (Boehner et al., 2007, Jung, 2017), which refers to 'computing that relates to, arises from, or influences emotions.' (Picard, 1995, p.1). In the Affective Computing approach, the aim of the design is usually the success of an algorithm, and the subject of design is computational models of affect-sensing and responsive behaviours. This has met with criticism for being too goal oriented and its inadequacy to support rich and complex human experience (Sengers et al., 2002; Boehner et al., 2005; Höök, 2013). As a counter-reaction to Affective Computing, researchers and practitioners such as Boehner, Höök and Fritsch (Boehner et al., 2005; Boehner, DePaula, et al., 2007; Höök, 2008, 2009; Fritsch, 2009, 2018) developed the interactional approach to emotion. The interactional approach refers to a practice that sees emotion as interaction (Boehner, DePaula, et al., 2007, p.280), and rather than sensing and transmitting data about emotions, affective system design should be to 'support human users in understanding, interpreting and experiencing emotion in its full complexity and ambiguity' (Boehner, DePaula, et al., 2007, p.275). However, there are limitations in the interactional approach in terms of supporting the design process of an affect-enabling artefact. These limitations include the following: the outcomes from the existing approaches are more often screen-based applications, and do not concern physically-bodied artefacts, and thus do not address the material elements in the embodied feature of affect. Furthermore, these approaches do not take affect-enabling capacity as the explicit goal of their design.

There is therefore a lack of design knowledge about how to create physically-bodied interactive artefacts that enables affective experience.

Giving form to interactive artefacts brings new challenges, for it presents a hybrid materiality blending computational and physical materials (Vallgårda and Redström, 2007; Wiberg and Robles, 2010). This is different for designers both within interaction design who traditionally deal with digital materials, and material designers who traditionally deal with non-interactive materials. Addressing such a challenge calls for the material-centred interaction approach, which integrates expertise from both interaction design and material design practice (Vallgårda, 2014), such as fashion practice (Genç et al., 2018).

### 1.2 Personal journey

The entanglement of emotions and technologies has been a consistent theme of my work and research. By January 2015, I had completed my Master's degree project on physicalising data that represents affective cues and emotional wellbeing in body silhouettes, colours and prints to inform fashion design practice (Zheng, 2014). I later became part of the e-textile community in London - a loosely connected network of fashion and textile practitioners, artists and technologists who are interested in creating more expressive wearable and interactive interfaces. E-textiles are considered to be a new domain which combines crafts, engineering, and programming (Kafai et al., 2011). I started experimenting with embedding sensors or actuators into textiles, and interactive materials to make the wearable outcomes responsive and interactive. My knowledge of the sensual quality of textiles and their intimate relation with the body stimulated my imagination, and prompted me to explore the creation of wearable, interactive, physical artefacts that modulate human emotions. I envisioned that in the near future we would be surrounded by emotionally sentient materials like those in the 'psychotropic houses' depicted in J. G. Ballard's short story *The Thousand Dreams of Stellavista* (Ballard, 1962) (which of course also had its own elements of dystopia). To my disappointment, the most advanced interactive affective artefacts that were proposed in 2015 were overly functional, instead of being of an emotionally evocative nature. As a fashion practitioner I expected to have an affective encounter with these new technologically enabled artefacts. Although they were invested with the most advanced computational capability, I did not find they touched me on an affective level, and neither did they enable an emotional experience. I called this an 'affective gap' – artefacts intended for affective interaction either do not enable a felt experience of being 'emotionally touched' – the kind of spontaneous emotional response that we often experience with conventional non-interactive artefacts, such as feeling safe and comforted when touching a soft surface, or cuddling a soft toy (Harlow, 1958). Furthermore, the pursuit of the sensory, bodily and visceral qualities of an affective experience, which is at the core of my fashion practice, are often missing in existing interactive affective artefacts. This sharp difference between expectation and reality left me deeply unsatisfied and sparked my desire to create interactive artefacts that enable a felt experience of affect – which became the central inquiry when developing my research question.

### 1.3 Research question, aims and objectives

In identifying the gap in knowledge outlined above, my research addresses the question:

> How can we design artefacts using interactive materials that enable affective experience?

My exploration focused on one type of interactive material - silicone pneumatic soft robotic (SPSR) material. I approached this research question by navigating the form-giving process of design.

The word 'we' in the research question reflected that I identified myself as a practitioner within the space of affective interaction design. I also chose the word to indicate that my work is intended to be useful to researchers and practitioners alike.

The title of the thesis indicates that the aim of the design in this research is to achieve interactive artefacts that are 'affect-enabling'. The openness of 'affect' may cause confusion, in that interacting with any artefact enables a certain affect. Indeed, as presented in section 2.1.1 (p.14-15), my research recognises that being a neurophysiological barometer of an individual's relationship to its surroundings at a given point in time (Barrett, 2012), the core affect is always present (Russel and Barrett, 1999; Barrett et al., 2007). Yet, as highlighted in my main research question, instead of just any affect, 'affect-enabling' refers to enabling an experience of affective qualities. An experience, according to Dewey (1934) and McCarthy and Wright (2004), is marked by a sense of fulfilment. In the same way, the term 'affective touch' used in my thesis refers to the quality of affect in the experience of being touched.

To address this question, the following aims and objectives were identified.

*Aim 1*

Formulate a design framework that is grounded in affect theories, synthesising practices from the interactional approach, fashion practice, and material-centred interaction design, to guide my design practice towards creating an affect-enabling artefact.

*Aim 2:*

Guided by the design framework formulated in Aim 1, develop a body of work with an affect-enabling outcome.

Objectives:

1. Identify the most affect-enabling properties of the SPSR material.
2. Explore technical configurations of SPSR artefacts to exploit the material's affect-enabling properties.
3. Develop a final artefact that enables a felt experience of a certain type of affect and evaluate it through a recognised evaluation method.

*Aim 3:*

Critically reflect on the broader implications arising from the findings of my research within the space of affective interaction design.

Objectives:

1. Summarise how the design framework was used in my practice in this research.
2. Discuss the broader implications arising from the findings of my research for other affective interaction designers.

### 1.4 Design framework and methodological approach

In addressing my Research Aim 1, I formulated a design framework to guide my design process – an affect-, material-, interaction-led (in short, AMI-led) design framework (Figure 1.1). This framework is grounded in theories of affect - in particular, those of Barrett (2012) and Massumi (1995), who emphasised the emergent nature of affect that it only arises through interaction. It synthesises the practices from the interactional approach, fashion practice and material-centred interaction design. To address the limitations of the interactional approach, I brought in fashion practice - the form-giving process of how physically-bodied artefacts are developed via the combination of cognitive process and making (Gully, 2010) through the emergence of entangled affect and materiality. I also brought in a material-centred interaction approach (Wiberg, 2018; Vallgårda, 2014), which provides guidelines for working with interactive materials with blended materiality across digital and physical substrates. A detailed description of this design framework is presented in section 3.1

As my research was tasked to find a viable design pathway to create affect-enabling interactive artefacts, I followed a general approach of Research through Design, an approach that employs methods and processes from design practice as a method of inquiry when designing interactive systems and artefacts (Zimmerman et al., 2007; Gaver, 2012; Andersen et al., 2019).

The methods of studio making, co-exploration and assessment were employed to carry out my studies. As shown in Figure 1.1 below, they were selected to facilitate each building block in the AMI-led Design Framework.

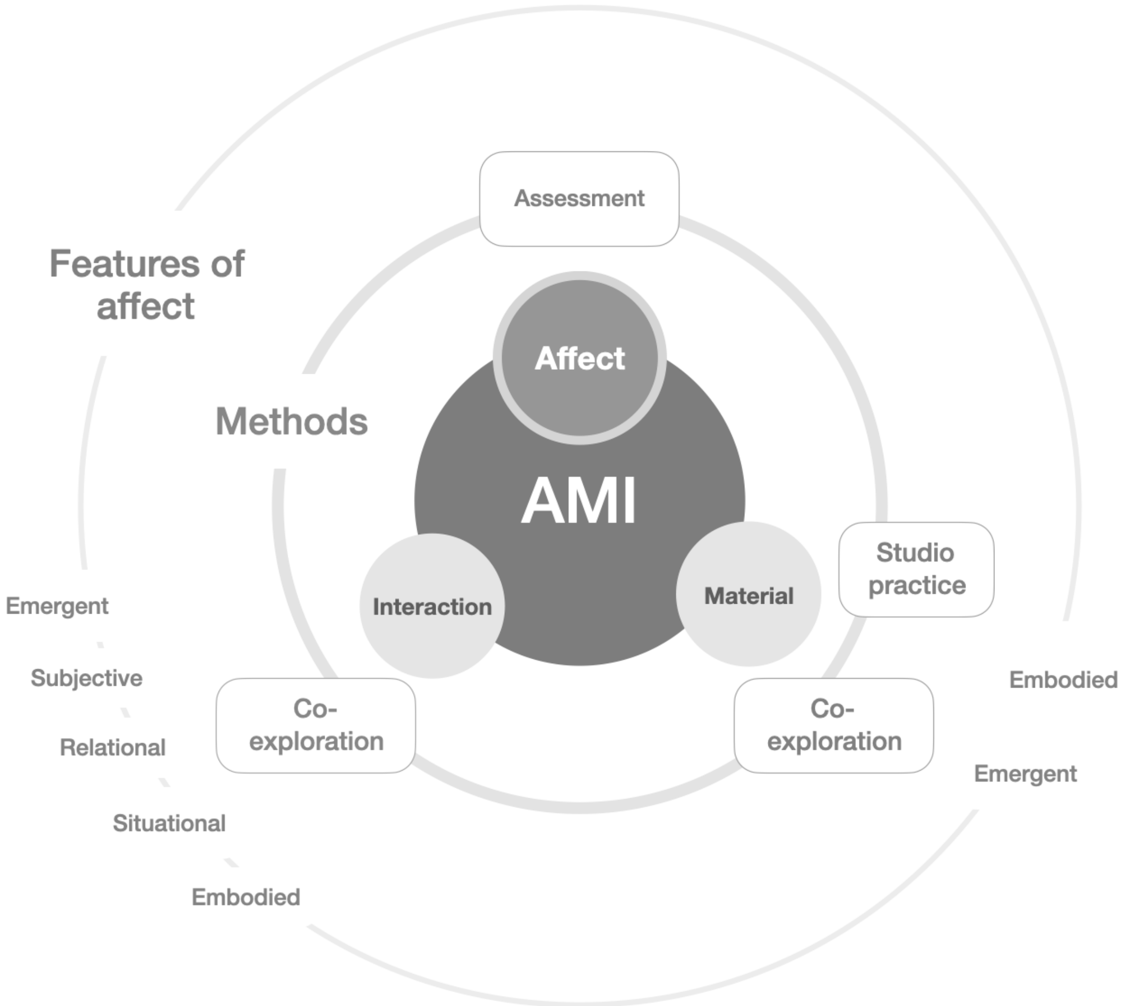


**Figure 1.1** An affect-, material- and interaction (AMI)-led design framework, and the methods used to facilitate the application of the framework in my practice

The AMI-led framework, which I have termed a design framework, evolved as my research developed. When the framework was formulated, it aligned more closely with the definition of a conceptual framework by Maxwell (2013), Ravitch and Riggan (2016), as a system of concepts that supported and guided my practice and choice of methods. At the end of my research, the framework was expanded to include the methods applied in my research, which can be seen as a methodological framework according to Wiberg (2013). In addition to being inclusive of the shifting nature of the framework, terming it a 'design framework' also reflects the practical elements of my research and the nature that it allows 'design-centred research planning and opportunity seeking' (Gaver, 2012, p.938, see also Forlizzi, 2008).

## 1.5 Scope, situation, and audience of this research

This research is concerned with how to give form to physically-bodied interactive artefacts that enable affect. It is situated primarily in the emerging space of affective interaction design. Designers and researchers within this space come from diverse disciplinary backgrounds, ranging from interaction design (e.g. Lottridge et al., 2011; Boehner et al., 2007), design (e.g. Gaver, 2009), and material design such as fashion and textile design (e.g. Genç et al., 2018). My research speaks to designers and researchers within this space whose practices involve physically-bodied artefacts, although practitioners and researchers with a material design background may find the language and process of this research more familiar.

## 1.6 Thesis structure

Design research by practice with the Research through Design approach, is acknowledged to be messy, with a degree of unpredictability and with unexpected issues or inspirations during the design process that influence the trajectory of the research exploration (Portugal et al., 2014; Durrant et al., 2017; Gaver et al., 2012). My design practice followed the AMI-led design framework, which promotes the enabling of the emergent findings of the properties of the material and its affective affordance to inform and inspire the direction of my subsequent focus. In writing up this thesis, I experienced a tension between reporting this non-linear trajectory within the expected normative format of PhD thesis (Gaver et al., 2012; Crouch and Pearce, 2012) and within the limited word count for a practice-based thesis. For example, the emergent findings on the sensorial quality of affective touch from the SPSR artefacts led me to conduct a further literature review in order to refine my subsequent focus and situate the novelty of my subsequent research. Within the thesis structure this exploration of the literature is reported in Chapter 2, together with the literature review that I conducted at the beginning of my research. In addition, in Appendix 16, I have included a personal reflection on my practice over the period of research.

Chapter 2 reviews all the relevant literature and context. It first establishes the theoretical grounding of affect. It introduces why soft robotics and the silicone pneumatic soft robotic (SPSR) material was chosen for this research and identifies the specific requirements for designing with the SPSR material. It surveys the existing practices in affective interaction design, fashion practice and material-centred interaction design, through which the gap in knowledge is identified and the main research question is formulated. Finally the chapter elaborates on the literature and the context that influenced the focus of my last phase of design exploration.

Chapter 3 specifies the methodological approach and ethics considerations of this research. This includes detail of the affect-, material-, and interaction-led, or AMI-led design framework, which was formulated in order to fulfil the task of Research Aim 1, and guided my design practice.

In addressing Research Aim 2 and in order to develop an artefact with an affect-enabling outcome, I conducted three phases of design exploration; namely, the initial exploration, exploration with a broad focus, and the exploration with a defined focus. Each of Chapters 4~6 is dedicated to one phase of the exploration.

Chapter 4 documents the initial exploration from April 2016 to January 2017. The exploration aimed to study the designability and identify the most affect-enabling properties of the SPSR material.

Chapter 5 describes the exploration with a broad focus, undertaken from April 2017 to April 2018. The exploration investigated the positive affective touch experience a silicone pneumatic soft robotic (SPSR) artefact could afford, and how it could be designed.

Chapter 6 documents the exploration with a defined focus, undertaken from June 2018 to December 2019. The exploration was about designing and evaluating a soft robotic device using SPSR material to deliver CT-optimal affective touch (a gentle stroking touch).

Chapter 7 reflects on the implications of the AMI-led design framework, which was to address research Aim 3. It also reflects on the ethics considerations of designing affective touch machines.

Chapter 8 is the concluding chapter. It considers how successfully the research addressed the research aims and objectives and the research question. It then presents the contributions to knowledge made by this PhD before outlining future work.

# Chapter 2 Literature and context review

This research is situated within the interdisciplinary space of affective interaction design, and is concerned with how to give form to physically-bodied interactive artefacts that enable affect.

This chapter therefore reviews all relevant literature and context of this research, where the first step was to review relevant theories of affect to develop a theoretical grounding for approaching affect that resonates with Barrett's theory of constructed emotions (2012, 2017b) and Massumi's theory of affect (1995). I then introduced the reasons for the selection of soft robotics and the silicone pneumatic soft robotic (SPSR) material for this research and identified the specific needs for designing with SPSR material.

I also surveyed current practices in the space of affective interaction design. I specify why my research identified with the interactional approach to affect (Boehner et al., 2007, Höök, 2009, Fritsch, 2009, 2018) and then further process the limitations in this approach, which are as follows: the outcomes are more often screen-based applications, and do not concern physically-bodied artefacts; the approach does not address the material elements in the form-giving process and does not explicitly foreground affect-enabling as the aim of design.

I introduced fashion practice and material-centred interaction design (Wiberg, 2018; Vallgårda, 2014) to address the limitations mentioned above. Fashion practice contributed as an affect-led practice, with know-how in working with emergent materiality and affective affordance towards the outcome of physically-bodied, affect-enabling artefacts. The material-centred interaction design approach provides a conceptual guide to bring cross-disciplinary expertise together to navigate the challenges brought by working with interactive materials.

Reviewing knowledge from the above domains helped to establish the scope of how I approached my research question, identify my aims and objectives and provided a foundation for me to formulate my design framework that would guide my practice.

I finally elaborate on the literature and context that influenced me to adopt a defined focus at the last phase of design exploration - simulating CT-optimal touch.

### 2.1 What is affect?

If the goal of the design is to enable a felt experience of affect, it is crucial to understand what affect is and how it occurs. In the next two sections I give an overview of relevant affect theories in science and humanities research. I then explain the theoretical grounding I adopted in my research.

#### 2.1.1 Affect theories in the sciences

The last few decades, from the 1990s onwards, have seen a renewed understanding of the importance of affect and emotion by the scientific community. How we feel is no longer considered a marginal subject; rather, it is acknowledged that it plays a vital role in human experience, decision-making, and development (e.g. Bechara et al., 1994; Damasio, 1994; LeDoux, 1996; Kahneman, 2011). However, scientists have not found a consensus on how emotions are created (Russell and Barrett, 1999). To illustrate this in depth, I review the historical, contemporary and emergent theories of affect below. I use both the terms 'emotion' and 'affect' as they are used in the respective theories. Then in section 2.1.3 I provide a review of the difference between these two terms and their relationship.

Modern research on the emotions can be traced back to the work of Charles Darwin, and specifically his 1872 publication *The Expression of the Emotions in Man and Animals* in (Darwin and Prodger, 1998). In this text, Darwin took an evolutionary approach to show that basic expressions of emotion are similar in animals and humans (Rolls, 2005, p.31). His view was later transformed into the theoretical foundation for the modern science of emotional expression (Barrett, 2011, p.400, and discussed in the following paragraphs). In the subsequent century the science of emotion progressed, and theories with different perspectives on the relationship between bodily changes and the perception of emotions were developed. One of the earliest formal theories of the emotions was developed by William James and Carl Lange independently in 1884 and 1885 (Cannon, 1927). The

James-Lange theory of emotion states that emotions are primarily caused by physiological changes (Coleman and Snarey, 2011). This view was challenged by Cannon, who argued that bodily changes cannot cause emotion, as they are too difficult and too slow to be felt, and that visceral changes also occur in non-emotional states. The Cannon-Bard theory viewed physiological arousal and emotional experience as occurring simultaneously yet independently. Later on, Schachter and Singer (1962) took this further to develop the 'two-factor theory' of emotion, stating that the experience of emotion and visceral changes happen at the same time. Their theory maintains that emotions are composed of two factors: physiological and cognitive. Neither of the two factors causes the other. Instead, the physiological arousal, or bodily change, is interpreted cognitively in context to produce an emotional label for the emotion to be experienced.

The relationship between our experiencing of emotions and our cognitive processing of them has remained a topic of research and debate to the present day. Darwin's intention was not to craft a theory of emotion but to make an argument for his theory of evolution against creationism, and indeed his finding that humans and other mammals, such as primate species, share common facial expressions for certain emotions contributed to his argument that we derive from a common origin. The idea that certain emotions (such as terror and rage) prompt distinctive patterns of bodily changes, and that such patterns are universal, has had a profound influence on classical theories of the construction of emotion (Barrett, 2011). In modern psychology, the popular explanation of how emotion is created is represented by two competing theories: appraisal theory and basic emotion theory. Appraisal theory states that emotion results from people's interpretation and evaluations of events, and it recognises and takes into account individual differences in emotional reactions to the same event (e.g. Arnold, 1960; Ellsworth, 2013; Frijda, 1986; Lazarus, 1991; Ortony et al., 1988; Roseman, 2013; Scherer, 2009). Basic emotion theory is the most popular and deeply rooted psychological theory of emotion, and mainly involves studying facial expressions (e.g. Ekman and Friesen, 1969; Ekman, 1992; Izard, 1971; Tomkins, 1962, Tomkins 1963). It takes a Darwinian view, arguing that the basic emotions manifested by facial behaviour are universal and discrete entities (e.g. Ekman, 1992). Although it is the most influential, such a view has been increasingly challenged within the contemporary debate (Crivelli and Fridlund, 2019; Russell and Barrett, 1999; Keltner et al., 2019; Barrett, 2006).

Russell and Barrett (1999) and Barrett (2006) have noted that the dominant scientific paradigm in the psychological study of emotion, such as that developed in basic emotion theory, is grounded in the assumption that emotions are discrete entities existing within us and can be triggered by the right stimuli or the right mental interpretation, and that they can be discovered and objectively measured by scientists. They (Russell and Barrett, 1999) have opposed this static understanding of what emotion is, and have argued that rather than being a static entity, emotions are an emergent phenomenon. When we feel angry it is not that anger exists within us, but we have had 'an experience of anger, or experience of someone else […] as angry'(Barrett, 2012, p.371). Emotions are 'mental events that result from the interplay of more basic psychological systems' (Barrett, 2012, p.359), which are constructed by the brain 'on the spot' (Barrett, 2017a, p.30): 'In every waking moment, your brain uses past experience, organized as concepts, to guide your actions and give your sensations meaning. When the concepts involved are emotion concepts, your brain constructs instances of emotion' (Barrett, 2017a, p.31).

In Barrett's theory, what constitutes the basic building block of our emotional life is not emotion, but core affect. Affect has many causes, and is always present (Russell and Barrett, 1999; Barrett et al., 2007; Barrett, 2012, 2014). Barrett and her colleagues developed the 'Conceptual Act' model (Barrett, 2012, 2014, 2017a), which they later termed the 'theory of constructed emotion' (Barrett, 2017a, 2017b). This model is constituted of the core affect system and the conceptual system. The core affect system comprises the variations of positive or negative states produced by the basic psychological and biological system. Core affect is a constant flow. 'In a sense, core affect is a neurophysiological barometer of the individual's relationship to an environment at a given point in time' (Barrett, 2012, p.364). Core affect can be described as either pleasant or unpleasant, with a certain degree of arousal. It is the internal code for, or representation of, information about the external world. The conceptual system is what people know about emotions. It is a 'storehouse of knowledge that is sculpted by prior experience' (Barrett, 2012, p.364). During the ebb and flow of core affect, when the conceptual system picks up something meaningful, an experience of emotion is felt. When people effortlessly and instantly experience anger or sadness and see these emotions in other people, it is because these concepts are already stored in the person themselves. So 'emotions are perceptions – they are mental contents […]. They are not modules in the brain, but they do, of course, correspond to brain states' (Barrett, 2012, p.362).

The conceptual system is highly individualised and context specific. Thus there is relational and situational content in an emotional experience (Barrett et al., 2007, p.380). Barrett believes, therefore, that there are no 'universal' basic emotions. Variation is the norm (Barrett, 2017a, p.32). What is 'universal' to all humans is the sense-making process.

Barrett's notion of affect is particularly adaptable to affective interaction design, as it unpacks the kind of experiential aspects of affect that have been upheld in design practice, especially in fashion practice (detailed in section 2.4). Its emphasis on the emergent nature of affect connects with both fashion practice (section 2.4.2.2) and interaction design, in particular, the interaction approach (section 2.3.2.4).

### 2.1.2 Affect theories in the humanities

Compared to the scientific approach, which attempts to understand how affect and emotion occur from a cognitive and biological perspective and studies their functions, the discussions of affect and emotions in the humanities and cultural studies are more concerned with human experience. For example, for Massumi (1995), affect and experience are 'like two sides of a coin' (p. 94). Affect 'cannot but be experienced' (p.94). '(T)he account of affect will have to […] directly address forms of experience, forms of life, on a qualitative register' (p.1).

The notion of affect originated in the work of Baruch Spinoza in the 17th century. Spinoza defined affect as an 'ability to affect and be affected' (Massumi and McKim, 2009, p.1). Deleuze and Guattari (2013) re-evaluated Spinoza's ideas and referred to affect as 'a force that produces a change of state or capabilities in a relation' (p.18). Massumi interpreted

Deleuze and Guattari's concept of affect as 'a prepersonal intensity corresponding to the passage from one experiential state of the body to another and implying an augmentation or diminution in that body's capacity to act' (Massumi, 2013, p.xv). The most recent resurgence of interest in affect and theories of affect in the humanities and cultural studies has been marked by two essays, one by Sedgwick and Frank (1995) and the other by Massumi (1995), as well as other subsequent works (Gregg and Seigworth, 2010, loc 106). Sedgwick and Frank endorsed Tomkins' psychobiological theory (1962) in their approach to affect, which postulated that a number of different affects are hard-wired in the brain, and this serves evolutionary purposes. Tomkins' theory is essentially a Darwinian, 'basic emotion' approach (Leys, 2011, pp.437–439). Massumi, on the other hand, espoused Spinozan-Deleuzian ideas to conceptualise affect as 'non-linguistic, bodily "intensity"' (ibid., p.442). These two understandings of affect, the first describing affect as an innate human biological response, the second defining it as an autonomous force, differentiate the two main positions within affect theory (Seigworth and Gregg, 2010, pp.5–6). However, Leys has suggested that, although appearing different, both of these two positions of the new affect theories emphasise the independence of affect from consciousness and meaning, which embraces the same anti-intentionalism paradigm in the science of affect represented by the works of Tomkins (1962) and Ekman (e.g. 1984; 1992), which renders affect and cognition as separate systems: this has been the dominant approach to affect in psychology and the affective neurosciences. Leys pointed out that such an anti-intentionalist paradigm has met with doubt within the scientific community, for example by Russell and Barrett (1999) and Barrett et al., (2007) who experimented with alternative paradigms, as also mentioned in the previous section. Leys (2011) asked whether there is the possibility of alternative accounts of affect that do not separate affect from cognition or meaning in the way discussed above; she nevertheless predicts that the 'engrossing phenomenon of an ongoing clash between competing ways of thinking about the emotions' may remain for some time (Leys, 2011, pp.471–472).

Clough (2008), in particular, has referred to the latest examination of affect in cultural and critical studies as the 'affective turn'. Such an 'affective turn' privileges movement, emergence and potentiality in relationship to the body (Clough, 2008, p.15), and Clough and Halley have extended the discussion to explore how such a turn to affect in critical theory has captured political, economic and cultural tendencies (Clough and Halley, 2007).

### 2.1.3 Relationship between affect and emotion

Although the theoretical discussion above is around the term 'affect', the word 'emotion' is more used in our everyday life. Science and humanities scholars have both made a distinction between affect and emotion.

For instance, Barrett (2012, 2017) distinguishes between affect and emotions. For Barrett, during the ebb and flow of core affect, emotions are the parts of affect that are recognised to be meaningful by a person's conceptual system, based on his or her past social and cultural experience.

Many theorists such as Spinoza, Bergson, James and Whitehead, and especially Deleuze and Guattari, Shouse and Massumi, have drawn a distinction between affect and emotion (Leys, 2011, p.144).

> […] emotions are social, […] and affects are pre-personal […] An affect is a nonconscious experience of intensity; it is a moment of unformed and unstructured potential […] Affect cannot be fully realised in language […] because affect is always prior to and/or outside consciousness […] Affect is the body's way of preparing itself for action in a given circumstance by adding a quantitative dimension of intensity to the quality of an experience. The body has a grammar of its own that cannot be fully captured in language.
>
> (Shouse, 2005, n.p.)

Massumi (1995, p.88) considers that it is crucial to theorise the distinction between affect and emotion, as they follow different logics and pertain to different orders. Affect is dynamic, and it is powerful, as potentially its emergence can effect change, while emotion is static, and is a partial capture of affect (White, 2008, p.183; Massumi, 1995, p.86). Emotion is a slice of affect, a linguistic fix which carries socially and culturally agreed concepts (Massumi, 1995, p.88). We all need affect to feel alive, to register vitality (ibid, p.97). However, because of this, affect is unqualified, and thus 'resistant to critique'.

While affect is unqualified intensity, emotions are 'qualified intensity' (Massumi, 1995, p.88). This qualification can be considered in personal, conscious, and social registers. A personal register refers to the fact that an emotion is 'intensity owned' and 'from that point onward defined as personal' while affect is 'not ownable or recognisable'(Massumi, 1995, p.88). An emotion is subjective (Massumi, 1995, p.88), while affect is 'disconnected from the subjective' (Leys, 2011, p.441). A conscious register refers to the fact that an emotion involves cognition, while affect is disconnected from cognition – 'a matter of autonomic responses that are held to occur below the threshold of conscious and cognition' (Leys, 2011, p.443). A social register refers to the fact that an emotion is described in language. Such language has consensual meanings within a culture, which is a 'socio-linguistic fixing of the quality of an experience' (Massumi, 1995, p.88). Clough (2008) considers that distinguishing affect from emotion can be helpful. Turning to affect 'without following the circuit from affect to subjectively felt emotional status' contributes to 'the forging of a new body' p.2).

Tienhoven (2018, p.14) believes that the concept of affect as pre-personal, pre-social and pre-conscious creates both opportunities and difficulty. The opportunities lie firstly in the fact that this notion indicates a universality of affect that is located outside any culture. This means it is the same everywhere in the world, a claim also made by scientists of basic emotion theory such as Tomkins (1962). An inclusive notion such as this reduces cultural biases. The opportunities secondly lie in the fact that viewing affect as an automatic force places affect neither within the human subject nor in the object: it emerges in the in-between and is deeply relational (van Tienhoven, 2018, p.14). This notion undermines the default assumption that only humans have affective agency and gives equal affective agency to non-human matter. The difficulty refers to the fact that rendering affect outside of human consciousness raises serious methodological issues, as this notion disables any attempt to describe or critique it.

#### 2.1.4 Affect in my doctoral research

My research has embraced the notion of affect from an experiential angle, one that addresses it as a qualitive register of an experience. It resonates strongly with Barrett's (2012, 2017b) theory of constructed emotion to consider affect as an event, an emergence that is highly subjective and contextual, instead of as a static discrete entity. It also joins Massumi (1995) in seeing affect as an intensity corresponding to the passage from one experiential state of the body to another. In this it also emphasises the participation of bodies – both the human body and the body of designed interactive artefacts.

##### 2.1.4.1 Core features of affect

Synthesising the theories of affect described above, I summarise the core features of affect that inform the grounding of my design approach. I took these features as a foundation to develop an epistemological response – the design framework to guide my design practice (section 3.1).

*Emergent*

The convergence of Barrett's and Massumi's theories produces the emergent nature of affect: that affect resides neither within humans nor in objects: it arises in the in-between, through interactions. It is an event, rather than a static entity. Emergence occurs when an entity is observed to have properties that its parts do not have on their own, properties which emerge only when the parts interact in a wider whole (O'Connor, 2020, n.p).

The emergent nature of affect has informed my practice in a significant way. First, due to its emergent nature, affect cannot be '*designed*', but can only be *enabled*. In the same way, a designer cannot dictate how people feel about an artefact. The designer can, however, facilitate the interactions between an artefact and people, to enable people make their own affective response toward the interactive artefacts, and leave space for the emergence of an affective relationship between individuals and an interactive artefact. Thus, the practice of my research has been dedicated to exploring how to design an '*affect-enabling'* interactive artefact. To design an artefact with affective affordance and an interaction-led approach is a response to this feature. Second, the emergent nature of affect directly connects with my fashion practice, which can be seen in the way which affect operates in the design process. The relevance of fashion practice to the features of affect is discussed in more detail in section 2.4.2.1 and section 2.4.2.2.

*Embodied*

Bodies are essential for affect to happen.

As affect is defined as an ability to affect and be affected (Massumi and McKim, 2009): for affect to happen the involvement of physical body and sensorial experience is crucial. Bodies are defined 'not by an outer skin-envelope or other surface boundary but by their potential to reciprocate or co-participate in the passages of affect' (Seigworth and Gress, 2010, p. 65). In the context of this research, this refers to the participation of the physical bodies of both the artefacts and the human individuals. It also relates to how my design practice attends to the material manifestation of an interactive artefact, which is a system that includes both physical material and digital material (Wiberg, 2018). This feature informed a material-led design approach (section 3.1.2) as well as an interaction-led approach (section 3.1.3) to facilitate the interaction between human bodies and the designed artefacts.

*Subjective*

This refers to the fact that an individual's affective response to an interactive artefact is dependent on subjective elements, such as 'habits, acquired skills, inclinations, desires, even willings' (Massumi and McKim, 2009, p.2). The theory of constructed emotion also suggests that a perceptual system that generates an affective response learns its content through individual life experience, which varies across individuals and cultures (Barrett, 2012, p.372). Designing and evaluating the interactive artefact should consider the facilitation of such individual subjectivity. The designer's subjectivity, in terms of skills and desires, also influences the becoming of the artefact, through the intuitive or intentional articulation of the materiality of the artefact. This feature informed an affect-led approach, which maintains the ability of each individual to formulate their own affective meaning, relation and context in relation to the material in exploration, or a designed artefact. Of course, this affective sense-making cannot be enabled without interaction, so this feature also informed an interaction-led approach.

*Relational*

The theory of constructed emotion characterises affect as a neurophysiological barometer of the individual's relationship to an environment at a given point in time (Russell and Barrett, 1999; Barrett, 2014, 2012). Massumi connects the autonomy of affect to the autonomy of relation. The passages of affect – forces and intensities – are relations (Seigworth and Gregg, 2010, p.1). To respond to this feature, the form-giving process should include not only the materiality that constitutes the body of the artefact, but also the body of the human, in order to enable affective relations to emerge through the interaction between the materiality of the artefact and the human body. Being relational also means that an affect-enabling artefact will have an influence on relations between and among humans who interact with this artefact. This feature informed the need to take social and ethical implications into the design considerations (e.g. critiques by Turkle, 2012; Arnold and Scheutz, 2017; Lacey and Caudwell, 2019, as well as section 7.2). This feature informed an interaction-led design approach (section 3.1.3).

*Situational*

With sensorial stimulations from the artefact, affect emerges from a relation to past memories – experiences which were formed within particular cultural and social situations (Boehner, DePaula, et al., 2007), in which the artefact is presented. 'The body doesn't just absorb pulses or discrete stimulations; it infolds contexts, it infolds volitions and cognitions that are nothing if not situated' (Massumi, 1995, pp. 90-91). A context-specific artefact can be more affect-enabling than an artefact that is intended for universal use. This feature informed an interaction-led design approach (section 3.1.3) to allow the use cases to emerge.

#### 2.1.4.2 Relationship between affect and emotion in my research

Synthesising section 2.1.3 on the relationship between affect and emotion articulated by Barrett and Massumi, my research also made a distinction between affect and emotions, in the respect that affect is inclusive of emotion. Affect is a constant flow while emotion is a momentary recognition of strong affect. However they are both important to this research. Affect includes both the recognisable and unrecognisable, the describable and indescribable, as well as that which totally escape the perception threshold, while emotions, although a slice of affect, carry important information about affect, are descriptions of recognisable affect in communicable language a linguistic fix which carries socially and culturally agreed concepts (Massumi, 1995, p.88). Such language was often used by my research participants when giving feedback on the affective affordance of a probing artefact or evaluating the affective quality of the final artefact.

A designed interactive artefact, when encountered by people, evokes both affect and emotions. Although affect and emotion can be discussed separately in theories of affect, in reality it is more often difficult to separate the two. What was important for my research was to be inclusive of both affect and emotion. The practice of this research operated on the level of affect, rather than merely on the level of emotions. There is little research on the kind of affect and emotions an artefact made from silicone pneumatic soft robotic material may evoke,[1] and these are thus largely unknown. To approach this unknown, my research had to begin by being open to all kinds of affective reactions to the artefacts. To refer only to emotions would have risked excluding the other moments of affect that are not clearly identified in this linguistic way. To explore the affective affordance of the SPSR material, and eventually the SPSR artefacts, it was important to collect information on both affect and emotion to allow the access of both describable and indescribable affect.

[1] More discussion on this in Section 2.2.3

## 2.2 Pneumatic soft robotic (SPSR) material

Coming from a background of fashion practice, finding the materials that embody the sentiment of the concept is a crucial first step in design. I felt unable to design unless I found a type of interactive material with a physicality that connects to, or embodies, the nature of affect. Among interactive materials, I was especially attracted to the potential of dynamic materials such as soft robotics that demonstrate changes in their physical form when stimulated. Compared to materials that can be made interactive through other modalities, such as visuality (e.g., LED lights) and sound, form-changing materials indicate a physical 'corporeality' that interacts with our own human bodies.

### 2.2.1 Soft robotics

A soft robot is an engineered mobile machine that is largely constructed from soft materials. These are an emerging class of 'elastically soft, versatile and biologically inspired machines', primarily made of 'easily deformable matter such as fluids, gels, and elastomers that match the elastic and rheological properties of biological tissue and organs' (Majidi, 2013, p.5). They function by capitalising on 'soft' designs at various levels: surface, movement mechanisms and modes of interaction. Compared with conventional robots, which are kinematic chains of rigid links that prioritise control, soft robots allow a redundant, or 'infinite' degree of freedom (DoF) in their movement (Trivedi et al., 2008, p.99). To date the exploration on soft robotic technologies has been dominated by technical robotic research, which focuses on functionality, efficiency and complexity of movement, as well as precision of motion control (Laschi et al., 2016). And the visions for future applications include smart skins, assistive devices, medical devices, biodegradable and environmental robots, and intelligent soft robots (Laschi et al., 2016, Rossiter, 2016).

### 2.2.2 Silicone pneumatic soft robotic (SPSR) material

In order to find a suitable soft robotic material for my research, I experimented with various form-changing interactive materials to make soft actuators. These included materials that enact shape-changing when they receive external stimuli: for example, shape memory alloy

(SMA) changes shape in different temperature ranges (Gök, Bilir and Gürcüm, 2015); electroactive polymer (EAP) morphs in size when stimulated by an electric field (Bar-Cohen and Zhang, 2008). These also included form-changing mechanisms that can be actuated and controlled via microcontroller, such as motor-driven actuation (Zheng, 2017), tendon-driven actuation (using wires to mimic muscles and tendons) (Rucker and III, 2011) and pneumatically driven soft robotic material (Ilievski *et al.*, 2011). Of these materials, I found the sensual properties of pneumatically driven soft robotics made from stretchy silicone surfaces to be the most affective. The actuation is via pressurised air that deforms the pliable surface to enact a change in form. The form-changing behaviour is manoeuvrable via digitally controlled valves, and by crafting the structure of the silicone. There are several key properties of this silicone pneumatic soft robotic (SPSR) material, that embody the features of affect. These are:

1) Materiality with potential affective affordance

   The surface material is made from silicone, which is also a material widely used in prosthetic makeup, the process of using prosthetic sculpting, moulding and casting to create cosmetic effects in films. A material such as this has a resemblance to skin. When a silicone pneumatic soft robotic artefact is actuated, it manifests visually smooth shape changing movement. Such movement and tactile properties have a certain quality of being organic, alive, or 'creature-like', a quality also recognised by Jørgensen (2017b). The ambiguity of being at the boundary between organic and mechanical stimulates engagement for design speculation (Gaver et al., 2013). Smooth, more naturalistic movements are more likable than mechanistic movements (ÁlvaroCastro-González et al., 2016). Softness is also an attribute that contributes to affective affordance (Winters, 2017, Isbister and Höök, 2009).

2) The great potential of diversified physical forms

   Due to its soft structures, soft robotics materials and technology have redundant degrees of freedom (Trivedi et al., 2008). The word 'redundant' well illustrates how it is viewed as problematic in conventional robotic engineering, which aims at control.

However, this characteristic of 'redundant degrees of freedom' offered great potential for the diversified physical forms that I could achieve.

On top of the affective potential, SPSR material offers practical advantages for designers to create artefacts that interact with the body.

3) Easier technical threshold

Compared to rigid robotics, soft robots are lower in cost and are technically easier to access (Majidi, 2013), especially for creative designers such as myself: I do not have a trained engineering background and have taught myself to work with technologies. It is thus much easier to learn the mechanisms required for the actuation and control in soft robotics to create dramatic shape-changing effects.

4) Wearability

Compared with other actuating mechanisms (e.g. hydraulic, using water or liquid for actuation), the pneumatic actuating mechanism has the best potential to be miniaturised to a wearable size, and does not create a hazardous situation when minor leakages occur.

5) Skin safety

As the surface material is made from silicone, which is also a material widely used in prosthetic make-up, I can specifically select silicone material that is certified as safe for skin contact (Copies of Skin Safe Certificate of this material used in my practice are provided in Appendix 15).

### 2.2.3 Soft robotics in the context of affective interaction design

Although silicone material is not novel, and has been widely used in many products, designing and casting actuators using silicone material in a soft robotic mechanism are an emerging area in affective interaction design. Only a small number of studies have started to explore SPSR material from perspectives that involve affect. When this research started, in September 2015, there was little literature or research exploring the affect-enabling properties of soft robotic materials, other than that by Park et al. (2011), who identified the 'human-like', pleasant quality of a tactile interface produced by a pneumatically driven soft interface, and Yao et al. (2013), who explored expressive interfaces via shape change. To that date no research was found that had focused on exploiting the affective affordance, the capability to introduce an affective response from the interactants (Hayashi et al., 2016, p.46; see also Clement and Waitt, 2018) of soft robotics material for the purpose of designing wearable artefacts to enable affect. The vast majority of work within technical robotic research (Jørgensen, 2017b) focused on bio-inspired systems for complex tasks (Schmitt et al., 2018).

However, since this doctoral research started, more researchers have started to identify the emotionally engaging properties of soft robotics. For example, Trimmer (2015) and Ohta et al. (2017) considered that soft robots are more emotionally appealing to people than industrial robots, due to their soft, organic forms. Usevitch and Stanley (2019) and Barone et al. (2019) recognised the more intuitive properties of tactile sensations enabled by soft pneumatic actuators as a form of giving haptic feedback. Humanities researchers Arnold and Scheutz (2017) have observed the strong affective influence that soft-bodied robots have on people during interaction. Creative practitioners explored soft robotics within a broader discussion on aesthetics and the expressive potential of soft robotic artefacts. Jørgensen explored the visual experience of soft robotic movement (Jørgensen, 2017a). Practising from artistic research, Jorgensen (2017b) emphasised the value of soft robotics as an aesthetic, cultural and ecological phenomenon and that soft robotic technology is able to conjure 'sensuous knowledge, cultural imaginaries and fascination' (Jørgensen, 2017b, p.153). Yao et al. (2013) explored expressive interfaces via shape change. Winters explored fluid-actuated soft silicone robots as a new mode of expressive surfaces within the context of textile research (Winters, 2017, pp.120–131). Both Jørgensen and Winters approached soft robotics from the viewpoint of materiality and the value of the process of making in generating embodied and situated knowledge. These practice-based works touched upon the affective aspect of the material within the scope of aesthetic exploration but did not specifically foreground their investigation of the affective affordance of soft robotics. My doctoral research developed alongside this emerging and growing body of work and contributed with an original investigation into the affective affordance of silicone pneumatic soft robotic (SPSR) material, exploring a viable design process toward creating affect-enabling artefacts using SPSR material.

#### 2.2.4 A material-led approach is needed for designing with the SPSR material

SPSR material is an interactive material, which is also referred to as computational composite (Vallgårda, 2014) with a hybridity of digital and physical material composites (more discussion in section 2.5). The material properties of interactive material often unfold only when design making is underway (Vallgårda, 2014), thus a guiding approach for creating affect-enabling interactive artefacts using such material would need to be a material-led one. A material-led interaction design approach could provide conceptual guidance on exploring design with such material (elaborated in section 2.5). To create an SPSR artefact, I needed to orchestrate the material properties and study the affective affordance at the same time, as both are emergent, and much of its affective affordance is unknown to design practitioners (as discussed in the section 2.2.3 above). For this I also needed an approach that could support me in navigating the double emergence of affect affordance and material properties. To address this need I brought in fashion practice, which I articulate in section 2.4.

## 2.3 The space of affective interaction design

### 2.3.1 History

Interaction design is considered a recent addition to the list of design disciplines that have emerged since the mid 1990s, and can be characterised loosely as the shaping of digital things for people's use (Löwgren, 2013, p.9). It is situated as a sub-discipline within the field of Human-Computer Interaction (hereafter referred to as HCI). HCI as an area of research and practice emerged in the early 1980s. Initially it was considered a specialist area in computer science embracing cognitive science and human factors engineering. It has now developed into an immense spectrum with numerous sub-communities, and could be broadly understood as the critical analysis of usability with the development of novel technology and applications (Carroll, 2013, pp.21–31).

Affective interaction design is still a developing field, within the young discipline of interaction design. Its history is traceable only back to the 1990s, when Picard coined the term 'Affective Computing' in 1995 to refer to 'computing that relates to, arises from, or influences emotions' (Picard, 1995, p.1), which opened a viable research agenda on emotion within HCI and interaction design (Picard, 1997). This coincided with the resurrection of the topic of affect across disciplines. For example, in neuroscience, it is recognised that emotion is part of the very mechanisms of rational thinking, perception and decision making (e.g. Bechara et al., 1994; Damasio, 1994), and also in the humanities and social sciences, as mentioned in section 2.1.2. In computer science and artificial intelligence (AI), due to the realisation that emotion is an integral part of intelligence, AI researchers started to integrate emotions into computer systems. Picard argued that 'if we want computers to be genuinely intelligent […] they will need the ability to recognise and express emotions, to have emotions, and to have what has come to be called "emotional intelligence"' (Picard, 1997, p.x).

Noticeably, 'affective interaction design' is not a fixed term, but loosely used by interaction design researchers to refer to work that 'is coloured by an emotional experience' (Lottridge et al., 2011, p.197), which include practices with varying focus, including:

- affective sensing, or the automatic recognition of affective states of the users e.g. (Reynolds and Picard, 2001; Guribye et al., 2016; Conati et al., 2005),
- building expressive behaviours into digital or physical interface, e.g. (Strong and Gaver, 1996)
- affective loop, which is the combination of the above two steps, referring to a system whose behaviour continuously adapts to the recognised affective status of the user e.g. (Höök, 2009; Bruns Alonso et al., 2013)
- practice interchangeable with Emotional Design (Gkouskos and Chen, 2012). Emotional Design refers to the effort to promote positive emotions (Norman, 2007),

or pleasure in users by means of the design properties of products and services (Triberti et al., 2017).

My research is concerned with physically-bodied artefacts capable of enabling affect. Thus it can also be seen as the building of expressive behaviours into a physical interface, using the particular material of soft robotics.

### 2.3.2 Affective interaction design approaches

Within the space of affective interaction design, four main strands of design approaches have formed: emotional design, affective computing, the interactional approach, and technology as experience. Below I discuss these four main approaches in the themes of their theoretical grounding, aim and subject of design.

#### 2.3.2.1 Emotional Design

Grounded in scientific finding on the relation of affective and cognition systems, Norman developed the theory of Emotional Design (Norman, 2002, 2007), which has had significant influence within the interaction design community (Fritsch, 2009, p.2). In *Emotional Design*, Norman argues that '[a]ttractive things work better'(Norman, 2007, p.17), suggesting that beauty is a central concern of design and should be addressed during the design process. He identifies three levels on which design affects the user: the visceral, the behavioural and the reflective. Visceral design is inspired by natural phenomena that attract us: for instance, appearance, colour, taste, smell and sound serve the evolutionary and co-evolutionary process in plants, animals and humans. Visceral design focuses on bringing out the physical features of a product that have immediate emotional impact. Behavioural design concerns the performance of a product when it is in use. Reflective design is about the message, culture and meaning of a product, or of its use. This often dominates a user's overall impression of a product and influences the relationship between the user and the product (Norman, 2007, p. 62-87). Thus, it is important for a design to strike a balance among the different levels of design, to promote positive emotions (Gkouskos and Chen, 2012), or pleasure in users (Green and Jordan, 2002). For this articulation Norman is considered to be 'an evangelist of emotional design' (Jeon, 2017, p.12). His work is significant in that it established that the material composition of a designed artefact enables different affective experiences, and that an affect-enabling artefact has the agency to drive user acceptance, enable a pleasant user experience, and enhance bonding with, and thus the longevity of, the product in use. However, he did not provide any specific methodological approach for applying Emotional Design during the process of creating affect-enabling design (Gkouskos and Chen, 2012, p.5058).

#### 2.3.2.2 Technology as Experience

Technology as Experience researchers advocate that emotion is part of our embodied experience of being in the world. However they believe that singling out emotion from the overall interaction leaves us disoriented (Höök, 2013, pp.654–655). Referencing theories of experience such as that of Dewey (1934), they consider the process of emotion as an aspect of overall aesthetic experiences to address in the design process (Gaver, 2009; McCarthy and Wright, 2004; Norman, 2007; Hassenzahl, 2008), and oppose the study of emotion separately from the overall experience. My research, by default, resonates with this approach to render emotion an essential element of an experience (e.g. (Gaver, 2009), as in a sense this is what designers have always worked with (Dewey, 1934; Höök, 2013). However, diverging from Technology as Experience researchers, for my research it was important to study and demonstrate how an affectively engaging artefact could be created. This is not to isolate emotion out of the holistic experience it is integral with, but to allow focused investigation into a viable design process so that the field can then link it back to the complex social and subjective elements of an experience.

#### 2.3.2.3 Affective Computing

The dominant paradigm in affective interaction design is still an Affective Computing approach (Boehner et al., 2007, Jung, 2017). It has been pointed out that this paradigm views emotional expression as signals that reveal processes and states that are otherwise hidden (Boehner, DePaula, et al., 2007; Jung, 2017; Ekman and Scherer, 1984; Barrett, 2006), a notion rooted in the 'basic emotions' theories of affect (Tompkins, 1963). In the

Affective Computing approach, the aim of the design is the success of the algorithm, and the subject of design is computational models of affect sensing and responsive behaviours. Boehner et al.(2007) summarised that Affective Computing is an information-processing approach to capturing, modelling, augmenting and supporting human activity (Boehner, DePaula, et al., 2007). Although instrumental in the development of machines that are more and more capable of learning people's affective status, this has met with criticism for being overly goal-oriented and inadequate in supporting rich and complex human experience (Boehner, DePaula, et al., 2007; Höök, 2013; Fritsch, 2009, 2018).

#### 2.3.2.4 The interactional approach

The beginning of the 2000s saw the work of early advocates for alternative approaches to that of Affective Computing, such as the work from Fagerberg et al.(2004), Sengers (2002), Gaver et al.(2004), McCarthy and Wright (2004) and Sundström et al. (2005). Drawing from and further developing this work, interaction designers and researchers including Boehner, Gaver, Dourish, Höök and Fritsch (Boehner et al., 2005; Sengers et al., 2002; Boehner, DePaula, et al., 2007; DePaula and Dourish, 2005; Gaver, 2009; Höök, 2008, 2009; Fritsch, 2009, 2018) critiqued the limitations of an informational approach through Affective Computing, and developed the interactional approach to affect, as a counter reaction to Picard's cognitivist models of emotion. The interactional approach is not intended to replace, but to extend, the HCI agenda of affective interaction research (Boehner et al., 2005, p.59). This strand of work draws upon phenomenology and sees emotion as a valued complexity, constructed in the course of interaction – between people and between people and machines. Within the interactional approach, different researchers have their own gravitations, which I discuss below.

Boehner et al. (2007) drew on phenomenological sociology, including empirical work by Schutz (1943), Garfinkel (1967), Dor (2001) and McCarthy and Wright's (2004) that consider theories of emotion as part of socially grounded sense-making, and called for attention to be paid to 'social, cultural, and interactional accounts of emotion' (Boehner et al., 2007, p.280). Their work sees 'emotion as interaction: dynamic, culturally mediated and socially constructed and experienced' (Boehner et al., 2007, p. 275). They argue that rather than sensing and transmitting emotions, the goal of affective system design should be to 'support human users in understanding, interpreting and experiencing emotion in its full complexity and ambiguity' (Boehner et al., 2007, p. 275).

Höök (2009) considers that addressing the socio-cultural aspects of emotion is still not enough to design affective interaction (p.3585). Drawing on theoretical discussions on embodiment within interaction design such as that by Dourish (2004) and Fällman (2003), she suggested involving corporeal elements in interaction to create strong affective experience. She proposed an 'affective loop experience' (Höök, 2009, p.3585), in which emotions are seen as processes, that are co-constructed and co-interpreted with the participation of bodily experience, and that the system can influence, and be influenced by, human users corporeally.

Most recently, Fritsch took Massumi's (Massumi, 1995, 2002; Massumi and McKim, 2009, also see section 2.1.2) concept of affect as a theoretical foundation to propose the concept of affective engagement as a resource for interaction design. This concept views affect as a 'processual, relational and dynamic account of the concept in terms of events and becoming' (Fritsch, 2009, p.4). According to Fritsch, designing for affective engagement incorporates an understanding that the affective experience cannot be fully orchestrated. Thus, the design focus should instead be on process and evolution. Designing for affective engagement supports interaction design, in which the 'goal of the design process transcends ideals of effective, task-oriented design' (Fritsch, 2009, p.8); instead it can 'actively provide conditions of emergence and contexts for rich affective experiences' (Fritsch, 2009, p.8). For Fritsch, the interactional approach to affect not only influences the affective experience of the individual, but also can effect change in future-oriented societal formation (Fritsch, 2018).

All the above practices within the interactional approach view affect as having an *emergent* nature, and suggest that it only happens during interaction between humans and the designed system. This is rooted in the same field of understanding of affect as in my research, resonating with Barrett (2012, 2017b) and Massumi (1995). Their approaches address the *subjective* feature of affect by giving users the freedom to make their own open-ended interpretation of affect. In addition, the 'emotion as interaction' approach (Boehner et al., 2007) addresses in particular the situational and relational features of affect. The 'affect loop experience' approach (Höök, 2009) particularly addresses the *embodied* features of affect by intentionally involving bodily experience in the loop. In this sense, users can make sense of the information about themselves generated through the system in their own subjectivity, which carries their cultural and social influences. My practice resonates with this interactional approach to affective interaction design – the interaction-led approach in my design framework (section 3.1.3) can be seen as taking on the key advocate of this approach. Thus my research can be seen as joining this body of work to extend this approach to address the form-giving process to a physically-bodied interactive artefact using interactive materials.

The current interactional approach, however does not provide guidance for designing physically-bodied artefacts that aimed to be affect-enabling. I specify their limitations below.

The first limitation lies in the lack of physically-bodied artefacts in the scope of practice of these approaches. In the examples given by Boehner et al., (2007) and Höök (2009), sensory data is fed to the user in abstracted forms and the user is able to interpret this information about affect on their own subjective terms and discover their own patterns, rather than the system making an interpretation and telling the user what the system interprets their affective status as, which happens more often in the Affective Computing (Picard 1995) approach. The focus of these examples was on the affective information processing model of the system, rather than interactive artefacts that have physical bodies, and the application was oriented towards screen-based or mobile-based interactions. In the example given by Fritsch (2009), although the design outcome involved physical material as signage, the emphasis was on the system and interactive behaviours. As physically-bodied artefacts are outside the scope of these practices, the layer of materiality of the embodied feature of affect is thus not addressed.

The second limitation lies in the fact that affect-enabling ability was not explicitly mentioned as a goal of the interactive approaches above. Their work provided digital information about users' affect back to the users to enable their subjective sense-making process. The design investigations did not focus on how to articulate the material features to enhance the affect-enabling capability of the artefacts. The lack of research in interaction design on practical techniques and methods to support design that aims at an affect-enabling outcome has also been identified by Hayashi and Baranauskas (2013).

The third limitation lies in the fact that there is a lack of practice-focused design frameworks to guide the design and form-giving process to the material elements of the artefacts. In the examples given by Boehner et al. (2007) and Fritsch (2009), interactive systems were introduced to human interactants to explore and make sense of through interaction, *after* the completion of design. In my doctoral research, my practice was concerned with working with a novel type of material (SPSR material) to find ways to achieve an affect-enabling artefact. It was about the conceptualisation and form-giving process of physically-bodied artefacts. At the same time, my practice also needed to acquire knowledge about the affective affordance of the SPSR material during the design process. The interactional approach of Boehner et al. (2007) and Fritsch (2009) do not provide insight into the process of the formation of interactive artefacts. Höök (2009) introduced an extra step *during* the design process of the interactive system. When designing a system called FriendSense, 'a system for sensor-based synchronous communication with a whole group of friends' (Höök, 2009, p. 3587), the design team first used a technology probe, which is a simple but functional technical system 'designed to uncover and learn from real life practices and experiences' (Höök, 2009, p. 3587), to give to potential users to use in their everyday environment. Design lessons learnt through this process informed the forms and the features of the interactive system and interface. Using a probing process is informative, and I adopted a similar approach when formulating the design framework of this research (the interaction-led approach within the AMI-led framework, used in Studies 2 and 3). However, the subject of their design is mainly an interactive system. Designing an interactive system and giving form to a physically-bodied artefact are different processes, and draw on very different design knowledge (Vallgårda, 2014). Hayashi and Baranauskas (2011) and Hayashi

(2013) developed principles to incorporate the consideration of the affectability of the system and the product during the design process. However, the subject of their design mainly concerned digital artefacts such as software and computers (Hayashi and Baranauskas, 2011, p. 15). Although I have drawn insights from their approach such as involving users as design partners to co-explore the affective affordance of the material, their approach does not apply directly to my practice.

In the early stages of my PhD, I specifically explored incorporating the materiality of interactive artefacts on an equal footing with the participation of the human body and the interaction between them (Zheng, 2017). I proposed that design can facilitate a playful encounter between affective technologies – its materiality and physical human bodies, in order to enable new affective relations to emerge through this process of open-ended performative interactions. This can be seen as resonating with the interactional approach with the contribution of introducing materiality into the practice. This concept fed into the formulation of the design framework in this research (specified in section 3.1).

## 2.4 Fashion practice

### 2.4.1 Definition

In this research, I use the term fashion practice, to differentiate it from the more widely used term 'fashion design' in two ways. First, in this research I refer to the creative process of fashion design, rather than a practice with a functional and commercial focus in the apparel industry. The practice of fashion designers such as Hussein Chalayan (Şölen Kipöz and Güner, 2011, p.329), Boudicca (Brody, 2012), and Iris Van Herpen (Au, 2012)) who explore the creative, intellectual space and stress innovation over practicality or market value, adopting conceptually related and interdisciplinary methodologies in their production, is considered to be 'conceptual fashion design' (Au, 2012, p.20). Fashion practice in my research thus refers to such type of conceptual fashion design.

Secondly fashion practice in my research extends the conventional understanding of fashion design by removing the boundaries of taking fabric as material, and clothing as outcome.

The fashion design process is most often referred to as the invention and construction of garments in the design studio with the manipulation of fabric (e.g. Lindqvist, 2015, Dieffenbacher, 2020, Toledo, 2012, Sorger and Udale, 2005). Interactive materials, represented by SPSR material, do not fit into this conventional understanding of the fashion design process. This is because its material properties, design potential, sensory and affective affordance needs to be explored, before it is able to be directly adopted into garment construction, without which the process of fashion garment design cannot take place. For some fashion designers, this can be considered as a limitation of such material, and they are thus reluctant to engage with interactive materials (Pugh, 2021). However, with their temporal forms and interactive gestalt (Vallgårda, 2014), which non-interactive fabrics do not provide, interactive materials provoke profound possibilities for interacting with and augmenting the body.

Fashion theory encompasses contributions by design historians, psychologists, sociologists, anthropologists and cultural theorists, each with its own methodological and conceptual particularities (Holroyd, 2013. However, as also observed by Chun (2020) and Finn (2014), 'research on fashion tends to stay on the social and symbolic level rather than incorporating the actual practice of fashion designers' (Chun, 2020, p.99). The fashion design process as a cognitive process and the capacities of mind-body-environment coordination in the emergence and uncertainty (Gully, 2010), although much less researched, can be helpful in addressing the challenges brought by working with emergent interactive materials beyond fabric and clothing.

Removing the boundaries of fabric as material and clothing as an outcome, it gives space for imagining artefacts made from the interactive material to be in any form that can be affectively related to the body. This process takes place in the conception stage of what emergent technology could become, and thus it is *a process one step ahead of when a traditional sense of fashion design can happen*.

In addition to the cognitive process, another essential activity of fashion practice is making, where the designer is considered as maker and the maker as designer (Gully, 2010, p.40).

Fashion practice, in this thesis, is understood as an essentially cognitive process looping with making activities. In relation to my research question, this thus refers to the form-giving process of how physically bodied artefacts are developed via the combination of a cognitive process and making, through the emergence of entangled affect and materiality.

### 2.4.2 In what capacity can fashion practice help?

Integrating fashion practice with my research can help address the three limitations within the interactional approach, as identified in section 2.3.2.4, for it is an affect-led practice, and it has the know-how to work with emergent materiality and affective affordance towards the outcome of physically-bodied, affect-enabling artefacts. Figure 2.1 illustrates what I synthesised as how the process of fashion practice relates to features of affect and the emergent interactive materiality - that is, the emergence of affect and materiality is involved in each of the processes, and such emergence of affect and materiality is often deliberately prompted. Fashion practice responds particularly strongly to the embodied, subjective, emergent and relational features of affect. I detail in the sections below.

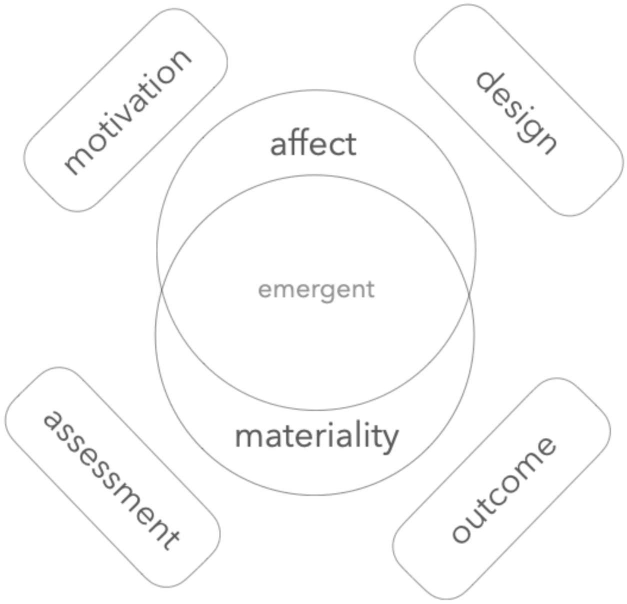


**Figure 2.1** Entangled emergence of affect and materiality is in every step of fashion practice

#### 2.4.2.1 An affect-led practice with affect-enabling being the goal

Van Tienhoven proposed to 'see the fashion object as a phenomenon that is inherently affect-producing' (van Tienhoven, 2018, p. 19). She called this the 'affective power of fashion' (van Tienhoven, 2018, p. 10) and suggested that such power has transformative potential. Although there is a scarcity of literature dedicated to affect in the fashion design process (van Tienhoven, 2018, p.3), fashion design activity is infused with affect at every step of its design activities (Toledo, 2012) - affect was part of the motivation, guiding the design process, toward the goal of affect-enabling (Figure 2.1).

Isabel Toledo was a practicing fashion designer who published textual works about her own motivation and practice. Toledo's work is widely acknowledged and which included Michelle Obama's dress for the Obama presidential inauguration ceremony in 2009. She described the overarching approach to her design work as 'dressing emotion' (Toledo, 2012, pp.71, 110). The motivation for her work was the expression of thought or emotion. For example, she said: '[m]y take on a design line came from the need to graphically describe a feeling.' (Toledo, 2012, p.152). 'I wanted to capture the abstraction and free-form emotion of jazz in cloth.' (ibid., p. 153).

The aim of designing the fashion artefact, or fashion object, is to evoke emotions in the wearer or the viewer, and 'touches humans by attending to the unconscious, irrational, and emotional processes' (Van Tienhoven, 2018, p.2).

> As a designer, I like to think that I am clothing a woman's mind and mood as well as her body. Creating clothes that spoke to so many different kinds of women, in their various life roles and moods, had always been one of my key goals as a designer. (Toledo, 2012, p.239)

> 'The interaction between body and cloth creates an emotion, which can affect the mood of the person wearing that garment.' (Toledo, 2012, p.25)

And whether a fashion artefact is successful or not is dependent on whether it is affect-enabling. For example, Toledo (2012) considered that the fashion artefact could be successfully tuned in to the wearer's ever-changing emotions (p.174; 239). Traditionally, this 'affect-enabling' is measured by the extent to which how much the new designs are worn by wearers. Only by being worn does the wheel of fashion move forward. In contrast, fashion artefacts, if they fail to tune in to affect in the wearer, will become obsolescent. For example, Toledo (2012) considered the reason that American sportswear was losing popularity by the 1980s was because 'it had lost its emotional connection to women' (p. 194).

This affect-led conceptualisation and design process was incorporated in the affect-led approach in my design framework (see section 3.1.1).

#### 2.4.2.2 A practice that works in, and fosters, emergence

The way fashion practice operates resonates strongly with how affect operates, in the sense that they both operate in an in-betweenness, in which they depart from the constant flow of normality, moving toward a changed experiential status. Such in-betweenness, is also where some of the most pioneering conceptual fashion designers operate – such as Hussein Chalayan (Şölen Kipöz and Güner, 2011) and Boudicca (Brody, 2012). For example, Evans recognised that for Chalayan, it is ‘precisely the homelessness of the cultures of new media and technology’ that the designer goes exploring (Evans, 2005).

Both affect and fashion practice function as a force towards potential and they both make their impact through the body by way of visceral sensory stimulation.

> Ideas emerge as to pathways that may be taken, and this exploration gives glimpses of what might lie ahead. The fashion designer will latch onto and try different configurations and multiple versions of this emerging something in order to take it to a higher level of resolution. (Gully, 2010, p.43)

Fashion practitioners operate on that which is emergent, and they prompt emergent materiality and forms during the design process. ‘In the fashion industry, designers are continually looking for the “next”’ (Dieffenbacher, 2013, p.7). When one form is settled, fashion designers will look for new emerging ideas; sometimes they pursue these by deliberately destabilising, disrupting or challenging the existing stability, creating chaos. In fashion practice, a designer often pursues unfamiliar materials, subverts familiar materials or juxtaposes materials to prompt emergence. Fashion practice operates through this flow of emergence and evokes the process of becoming. It captures the ephemeral and prompts the temporal, and, through these layers of ephemeral and temporal forms, relations and materiality emerge, and during the design process one idea is built on the previous one to push into new territory. ‘[The] [d]esigner grapples with their imagination in order to bring the idea into reality, into a recognisable form […] In the context of fashion design, what is inexplicable becomes tangible within the design process itself and in the final expression of clothing’ (Dieffenbacher, 2013, p.14). This approach to emergent materiality towards an affect-enabling tangible outcome offers the support I was particularly looking for in order to design with novel SPSR material. The prompting of emergence is a design method unique to fashion. Through the emergent materiality that is prompted, new design opportunities can be identified and pursued. This approach and methods are also what was lacking in the interactional approach. This emergence-prompting approach was integrated in the interaction-led approach (detailed in section 3.1.3) in my proposed design framework together with the probing techniques in co-exploration sessions (detailed in section 3.3.2).

#### 2.4.2.3 A material-led practice characterised by making, with a physically-bodied artefact as outcome

Toledo (2012) explained that she had an emotional, or 'soulful connection' to fabric - the medium of her design (p. 71). For example, she said:

> I understand clothes from an abstract place that is not necessarily visual, but deep and emotional. (Toledo, 2012, p.25)

> Using lace as a component in my designs continues to intrigue me, always inspiring me to investigate its emotional properties. (Toledo, 2012, pp.205–206)

Design itself is considered to be 'the collected experience of the material culture, and the collected body of experience, skill and understanding embodied in the arts of planning, inventing, making and doing' (by Bruce Archer and colleagues cited by Cross 1982). Making is an essential fashion method, throughout the process of conceiving, experimenting and constructing (Gully, 2010). Gully advocated that in fashion design we need to consider the designer as maker and the maker as designer (2010, p.40). Making as a method and a form of inquiry has been incorporated into the material-led approach (detailed in section 3.1.2) in my proposed design framework and adopted in the method of studio practice (detailed in section 3.3.1).

The outcome of fashion design has been characterised by three-dimensional, physically-bodied artefacts designed for the human form (Black, 2021). This embodies a fashion epistemology (Pecorari, 2016) as an 'object-centred, materially-founded account of knowledge production' (Rheinberger, 2005). Within the context of my research, this addresses the gap in which 'emotion became part of a lost corporeality' exposed in the Affective Computing approach (Ryan, 2014, p.100), which is likewise a limitation of the interactional approach.

### *2.4.3* Fashion practice in interaction design

Fashion design has mostly been explored within interaction design and HCI within the context of wearable interfaces – material objects worn on the body, from a variety of aspects. These include developing novel interactive materials that could be used by fashion designers (Berzowska, 2005), software for wearable devices (Juhlin, 2015), and integrating expressive, soft interactive interface into clothing (Tomico et al., 2013, 2017). Some work focus on employing fashion design to improve the visual appearance of the enclosing surface of digital devices (Jung and Stolterman, 2010), while other projects explore pedagogical methods to help fashion designers investigate the expressive potential of interactive materials through making (Genç et al., 2018). The E-textile Summercamp's Swatchbook Exchange[2] is a platform for sharing physical work samples in the field of electronic textiles, with work emphasising physicality and quality workmanship. Still, there is lack of an explicit discussion on integrating fashion practice into affective interaction design, for its epistemological and methodological contribution. My research initiated such a link by bringing aspects of the conceptual fashion design practice to address challenges that are hard to tackle with non-material approaches within affective interaction design.

### 2.4.4 Limitation of fashion practice

In terms of its material aspect, fashion design expertise has traditionally worked with non-interactive materials. As interactive material design is an emergent front that often relies on the hybridity between designers and collaboration from engineers, material and computer scientists (Genç et al., 2018; Vallgårda, 2014), fashion designers need to acquire theoretical and practical knowledge to develop know-how in operating digitally and mechanically actuated dynamic material (Genç et al., 2018). In this regard, a material-centred interaction

[2] The E-Textile Summercamp is a week-long event which brings together expert practioners from the fields of eTextiles and Soft Circuitry (Source https://etextile-summercamp.org/)

approach (Vallgårda, 2014; Wiberg, 2018) offers guidance, which I will detail in the next section.

## 2.5 Material-centred interaction design

A physically-bodied artefact, being interactive, while it provides opportunities for novel experiences, presents new challenges for designers, for it presents a hybrid materiality blending physical (tangible) and computational (intangible) materials (Vallgårda and Redström, 2007; Wiberg and Robles, 2010). This is different for designers both within HCI who traditionally deal with digital materials, and material designers who traditionally deal with non-interactive materials.

In fact, there has been a growing interest in the exploration of the dimension of materiality within the field of interaction design over the last 15 years (e.g. Wiberg, 2014; Giaccardi and Karana, 2015; Wiberg et al., 2012); it has even been described as a "material-turn" (Robles and Wiberg, 2010). The explorative approach varies drawing on a diversity of knowledge established from other research fields such as material culture studies (Ingold, 2012; Woodward, 2007), craft (e.g. Buechley and Perner-Wilson, 2012), and designerly approaches (Cross, 2001) including Research through Design (RtD) (Durrant et al., 2017; Gaver, 2012). Among these, I find work by Wiberg (Wiberg and Robles, 2010, Wiberg et al., 2012, Wiberg 2014, 2018) and Vallgårda (2014, Vallgårda et al., 2015, Wiberg et al., 2012) most applicable to this research, as they have developed a more refined theoretical framework to guide the design process, working with the type of hybrid materiality that concerns this research.

In a material-centred interaction design approach, designers working in this space 'make no metaphysical or ontological distinction between physical and digital materials […]' (Wiberg, 2018, p. 61). Vallgårda identifies three form elements that need to be addressed: physical form, temporal form and interaction gestalt (Vallgårda, 2014, p.577). The element of physical form refers to the three-dimensional shape of the artefact, including the material, colour, scale, density etc. The temporal form is the pattern of the status changes triggered by computational elements or the algorithm. The interaction gestalt is the performance of movements that users will do in relation to the artefact. In this sense, interaction design for physically-bodied artefacts is essentially a form giving practice (Vallgårda, 2014). There is a complex web of interdependencies among the three form elements. Juggling these elements, interaction design is considered to be a relational practice of designing across a multitude of substrates and configuring multiple materials to work in concert (Wiberg, 2018, p.48, 105). Such a relational practice also refers to the sensitivity to both the desired experience and the material properties that can enable such experience during the material configurations (Wiberg, 2018, p.64).

The material-centred interaction design approach advocates that designerly perspective can be applied to form new expressions and experiences (Wiberg et al., 2013). Bringing practices from material design disciplines into interaction design can help approach the materiality for experiential qualities and to strike a balance of all three forms to create a coherent entity. For example, it is suggested that interaction design should borrow practices from design and craft to develop sensitivity to material properties (Wiberg, 2018), as, although physical form and the interactional gestalt may be new to interaction design, they are more or less established approaches within design practices at large (Vallgårda, 2014). Introducing fashion practice into designing interactive materials can be seen as my response to the call from this approach.

Bringing in the material-centred interaction design approach provides a complement to the limitations of the interactional approach and fashion practice.

Although the relational approach in material-centred interaction design coincides with the relational feature of affect (section 2.1.4.1), my review in section 2.3.2 showed that there is a lack of literature that connects affective interaction design with the material centred interaction design. Similarly, within the literature on material-centred interaction design, there has not been a focus on designing for the purpose of affective interaction. My research thus contributes by initiating a link between the two domains of research.

## 2.6 Synthesised discussion

In the previous sections, from studying the theories of affect I have established the theoretical grounding of affect in my research (section 2.1.4). I have identified the key features of affect: it is emergent, subjective, embodied, relational and situational. A design process aimed at enabling affect should strive to respond to all these features of affect.

From analysing the material in use – SPSR material (detailed in section 2.2 - as a type of interactive material (detailed in section 2.5), I have identified the specific design needs for an approach that could support me in navigating the double emergence of affect affordance and material properties.

Existing practices from the interactional approach to affective interaction design consider affect to be emergent and addresses the subjective, situational, relational features of affect. However, I showed that the outcomes are more often screen-based applications, that do not concern physically-bodied artefacts and thus do not address the material elements in the embodied feature of affect: they do not address the form-giving process of the material elements in the artefact. Furthermore, these approaches do not explicitly take affect-enabling as the aim of design. There is a lack of design knowledge to aid the form-giving process with the aim of creating physically-bodied, affect-enabling interactive artefacts. To address these limitations, I proposed to first bring in fashion practice, as it is an affect-led practice, with expertise on working through emergent materiality and affective affordance towards the outcome of physically-bodied, affect-enabling artefacts. The limitation of fashion design practice lies in the fact that its expertise has been traditionally focused on dealing with non-interactive materials such as fabric, and there is a lack of know-how in operating interactive materials (Vallgårda, 2014). For this I proposed to bring in a material-centred interaction approach (Wiberg, 2018; Vallgårda, 2014), which provides guidelines for working with interactive materials with blended materiality across digital and physical substrates. Figure 2.2 is a graphical mapping of the above summary. The figure maps out the strengths and limitations of the three practices in relation to the features of affect, as well as the identified design needs for creating affect-enabling interactive artefacts.


**Figure 2.2** Mapping of the strength and limitation of relevant practices in relation to the specific need of this research

Identifying the gap of knowledge helped me to refine my research question (specified in section 1.3) and set out the scope of my practice. That is, to approach the designing of interactive artefacts that enable affective experience, through navigating the form-giving process of design, working specifically with SPSR materteral.

I was also able to identify the steps needed to address my research question, which took the form of the aims and objectives of my research. These aims and objectives have been set out in Chapter 1 (section 1.3).

The review of theories of affect and the analysis of the three relevant practices provided a foundation for me to formulate the design framework to guide my design practice. I will detail this design framework in the next chapter (section 3.1).

## 2.7 Affective touch with soft robotics

The focus on designing an affect-enabling artefact for affective touch experience using SPSR material is the scope of the second phase of my practice (exploration with a broad focus) and the third and final phase of practice (exploration with a defined focus). This focus was not planned beforehand but emerged during my design process. This reflects the fact that my design practice accommodated the emergent nature of both affect and the novel interactive material in use. The trajectory of the design was influenced by the emerging material affordance and affective preference of the designer and research co-explorers. It has emerged from my practice in the initial exploration that tactile modality was the most affect-enabling yet less researched property of SPSR material, and the most preferred modality to focus on.  One finding from the exploration with a broad focus was that the artefact made from SPSR material enable both innate affect and affect with a social nature (section 5.3.2.2). This finding led me to consult the literature on affective touch and on man-made artefacts to generate affective touch. In this section I elaborate on the literature and context that influenced me towards the formulation of the defined focus for the final phase of design exploration (Chapter 6).

### 2.7.1 Touch from a physically-bodied artefact can be affect-enabling

Affective touch from non-human matter can enable affect.

Historically, Harlow (1958) famously referred the contact comfort provided by a terry cloth as an important basic variable for love (Harlow, 1958, p.677). His team introduced baby monkeys to two artificial mother surrogates, both with an identical shape, one covered with a soft cloth and the other made from wire mesh. Both artificial mother surrogates could generate warmth. Milk was provided by the 'wire' mother but not the 'cloth' mother.  The result showed that the infant monkeys spent the majority of their day with the 'cloth mother' (Figure 2.3) and only around an hour a day with the 'wire' mother. In Harlow's (1958) words: 'We were not surprised to discover that contact comfort was an important basic affectional or love variable, but we did not expect it to overshadow so completely the variable of nursing' (ibid., p. 677). He also placed infant monkeys in contact with fear-producing stimuli and an unfamiliar environment and observed that the infant monkeys used the cloth mother as 'a source of security, a base of operations' (Ibid., p. 679). The design of Harlow's experiment had met with criticism on ethical grounds (e.g. Gluck, 1997; King, 2015) in relation to the treatment of infant monkeys. However, his intention was to advocate frequent and intimate body contact between the infant and the caregiver (Harlow, 1958, p.677), which contrasted with the prevailing norm at that time in the United States (see also John Bowlby, 1957) recommended that parents should have less bodily contact with their children.

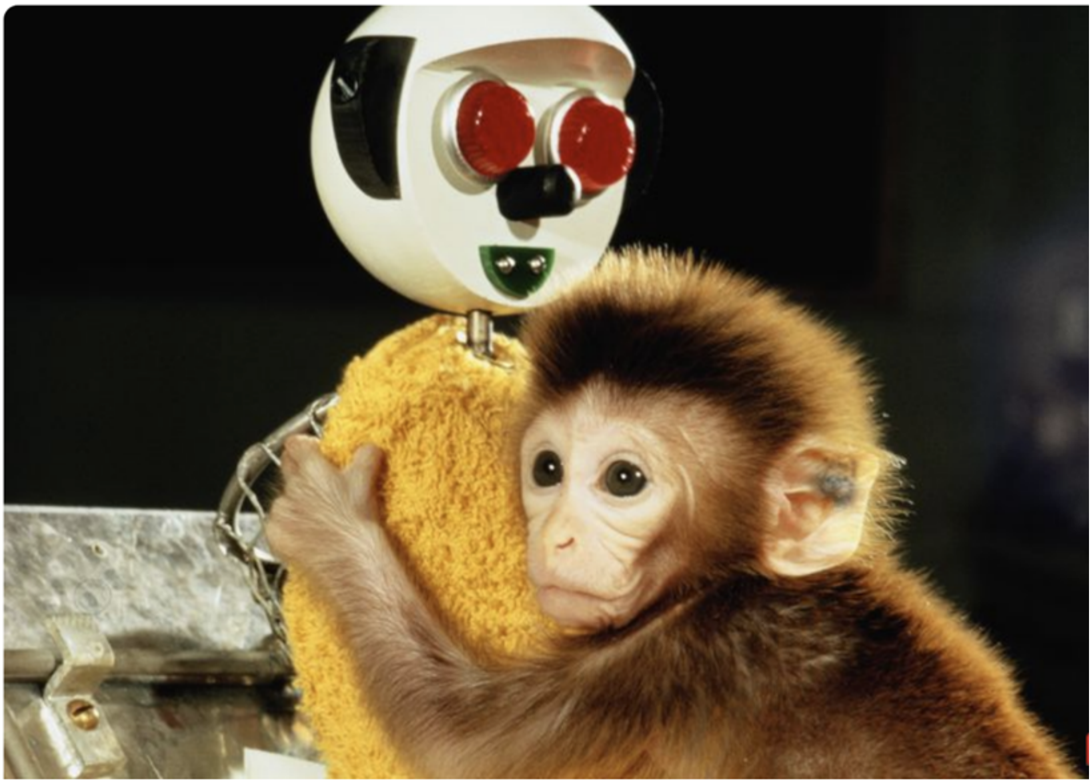

**Figure 2.3** H. Harlow (1958) The nature of love. *American Psychologist*. 13 (12), 673–685. image credit Martin Rogers/Getty Images

Modern neuroscience also observes that there are two types of touch we encounter: affective touch, the touch we use to feel, and discriminative touch (non-affective touch), the touch we use to sense. Affective touch connects to a primal, innate process while the meaning of discriminative touch involves learning process (McGlone et al., 2014).

For a long time, science viewed touch as generally most useful for sensing, such as perceiving three-dimensional objects, senses of position and movement of the body (Mountcastle, 2005). This type of touch is known as discriminative touch. Discriminative touch is a rapid, first-touch system, that allows the input tactile signal to be transmitted and centrally processed rapidly in the brain, quickly triggering motor action, which is very important for survival. This system is processed in the somatosensory cortex and represents an analytical process that is dependent on previous tactile experiences (Liljencrantz and Olausson, 2014; McGlone et al., 2014), and shows no relationship with perceived pleasantness (Löken et al., 2009). More recent research has discovered the neuromechanism which makes us find gentle stroking pleasant - affective touch. Affective touch is a slow, second-touch system, mediated by C-tactile afferents (CT afferents), which respond to much slower, gentle movement across skin with hairs, at close to skin temperature. This system is important for the development and function of the brain. CT afferents project via brain regions that are correlated with reward, emotion-related processing (Olausson et al., 2002; Björnsdotter et al., 2010; Craig, 2009; Gordon et al.). The activation of CT afferents elicits pleasant sensations and has affective regulatory and therapeutic functions. More specifically, gentle, caressing touch with the physical traits of a velocity of 1-10cm/s (Löken et al., 2009), an indentation force between 3-0.25mN (McGlone et al., 2007), an applied force of around 0.22-0.5N (Ackerley, Carlsson, et al., 2014; Manzotti et al., 2019; McGlone et al., 2007; Pawling et al., 2017; Trotter et al., 2016; Vallbo et al., 1999), and at approximately skin temperature (Ackerley, Backlund Wasling, et al., 2014) most optimally excites the CT afferents, and is thus called CT-optimal touch.

Tactile sensations that evoke innate affect can be associated with the visceral level in Noman's model of emotion (2002) (section 2.3.2.1) and can also be connected with Massumi's notion that one feature of affect does not involve cognitive processing or meaning-making through social and cultural activities, but through bodily thinking, or 'visceral perception' (Massumi, 2002, pp.60–61).

There were three aspects of the significance of Harlow's study and the science of CT-optimal touch for my research on designing material artefacts for affective touch interaction. The first significant indication was that they demonstrated that positive feelings towards contact comfort, such as the kind provided by the soft, 'cloth' mother and the CT-optimal touch are considered to be an innate rather than a learnt experience (McGlone et al., 2014). Such innate processes are shared across humans, and are pre-social and pre-cultural, as seen in the infant monkeys that had been raised in cages alone with no social contact. Moreover, the brains of two-month-old infants respond in the same way as adults towards C-optimal touch and non-affective touch (Jönsson et al., 2018), even though they only learn to associate affective meaning in other forms of non-CT optimal social touch much later. The 'learnt affective touch', or social touch (Huisman, 2017), refers to the type or aspect of touch whose affective meaning is only established through social interaction, personal memory and cultural influence. This resonates with the finding from my Study 4 (detailed in section 5.3.2.2).

The second significant indication was that they demonstrated that non-human matter, when satisfying certain physical attributes, can enable an innate affective experience, and can afford psychological benefit in humans. In fact, Harlow even concluded that 'Love for the real mother and love for the surrogate mother appear to be very similar' (Harlow, 1958, p. 684). In the CT-optimal touch experiments, the touch stimulation was performed not by a human hand but by an artificial agent: a soft brush operated by a human experimenter, or by a robotic hand (Figure 8.2). CT-optimal touch performed by a soft brush has been shown to have positive potential in alleviating stress (Triscoli et al., 2017) (Figure 2.4), reducing feelings of social exclusion (von Mohr et al., 2017) and enhancing emotional bonding between children and care-givers (Jönsson et al., 2018). The case of CT-optimal touch provided inspiration for the direction of my exploration with a defined focus.

The third significance was that the attributes of CT-optimal touch on velocity, temperature and pressure provided knowledge on parameters of an affective touch that I could use directly in my practice.

The findings above have provided information and inspirations for me to hypothesise that to simulate CT-optimal touch as a gentle stroking to enable a positive innate affect can be the unique affective affordance that the materiality of SPSR material offers, and this became the defined focus of the last phase of my practice.

**Figure 2.4** Device for simulating stroking (Triscoli et al., 2017)

### 2.7.2 Simulating CT-optimal affective touch using SPSR material

In HCI and interaction design, designing aspects of machine touch and human-machine touch interaction is referred to as haptics design (Eid and Osman, 2016, p. 27; Eid, Orozco and El Saddik, 2007, p.26). Designing for affective touch experience is still an emergent topic front, and most often carried out within an Affective Computing approach. For example, affective haptics is referred to as 'the acquisition of human emotions through the human touch sensory system, the processing of emotion-related haptic data to detect affect, and the display of emotional reactions via haptic interfaces'(Eid and Osman, 2016, p27), and does not include participants' emotional reaction to haptic stimuli (Eid and Osman, 2016). Rather than affective touch, most practice employs sensations that are essentially discriminative touch, that rely on instructing or 'training' users to associate affective meaning with a particular stimulation (Huisman, 2017). The kind of affect that is socially constructed and culturally mediated, is what has been addressed by the interactional approach (section 2.3.2.4). However the interactional approach has not been concerned with the innate affect that can be evoked by the materiality constituting an interactive artefact, nor did this approach investigate the two different types of affect that are at stake when designing interactive affective artefacts. Thus, the differentiation I made between innate affect and affect with a social nature in this research (see also discussion of Study 4 in section 5.3.2.2) and eventually creating an artefact intended to attend to innate affect in Study 5 (Chapter 6) contributes to the space of affective interaction design.

Designing a device or artefact that generates active touch stimulation (rather than just sensing) for affective touch experience is an emergent topic marked by only a handful of work. It is however, a topic participated by cross-disciplinary researchers and practitioners including interaction designers, robotics researchers and fashion practitioners. Across these fields, I have identified 32 studies[3] (a list of these is presented in Appendix 9) which are directly involved with wearable actuator design to deliver affective touch stimulation. Of these, only three wearable projects used pneumatic actuators (Teh et al., 2008; SENSOREE, 2018; Hu et al., 2018). There is a scarcity of work that directly addresses the design area of creating the experience of being affectively touched using pneumatic actuators.

In terms of the type of actuator, a majority of the studies engage with a symbolic approach, employing a vibratory motor as the actuator to represent a touch (Knoop and Rossiter, 2015, p.1134; Eid and Osman, 2016, p.27; Choi and Kuchenbecker, 2013). It has been found that instead of prompting pleasant feelings, high-frequency vibrations can induce negative sensations (Kaaresoja and Linjama, 2005) and feel less natural (Rossiter et al., 2017). Alternative actuators that may generate more pleasant touch sensations have been explored, such as air (Obrist et al., 2015; Hashimoto and Kajimoto, 2008), Shape Memory Alloy (SMA) (Gupta et al., 2017), friction (Bianchi et al., 2016), heat (*The HugShirt*, 2014), pneumatic actuators (Hu et al., 2018; Park et al., 2011; Zheng, 2018), and soft robotic actuators (Rossiter et al., 2017). Several researchers found that soft pneumatic actuators (SPSR material) have the potential to produce a more realistic touch sensation, with better affective qualities (Löffler et al., 2019; Pohl et al., 2017; Delazio et al., 2018; Park et al., 2011; and my own work during this research - Zheng, 2018). I could not find existing work that exploits all three attributes of CT-optimal affective touch. It was motivating for my research

[3] These works were identified before I started Study 5, which was around summer 2018.

to find that simulating CT-optimal affective touch with the SPSR material would generate original knowledge that will be useful for the community.

In summary, the realisation that simulating CT-optimal touch as a gentle stroking to enable a positive innate affect may be the unique affective affordance that the materiality of the SPSR material offers, the technical possibility of the artefact created in my practice, and the lack of existing work in the field that aims to exploit all three attributes of CT-optimal affective touch, had motivated me to focus on creating and evaluating an SPSR artefact that simulates CT-optimal affective touch.

# Chapter 3 Methodological approach

In this chapter, to fulfil the task of Research Aim 1, I formulated an affect-, material- and interaction (AMI)-led design framework to guide my design practice. This design framework is a hybrid one that combines the interactional approach, fashion practice and the material-centred interaction design. I detail each of the building blocks in this design framework. In terms of methods, the practice of this research followed a Research through Design approach, which is a fundamental concept for approaching an enquiry through the practice of design. I then describe the specific methods employed in each study. Finally, I address the research ethics considerations.

## 3.1 The AMI-led design framework

To approach the main research question, and to fulfil Aim 1 of my research, I first set out to formulate a design framework – a system of concepts that supports and guide my design practice (Maxwell, 2013, p.39).

Such a system of concepts is grounded in theories of affect and a synthesis of practices from the interactional approach, fashion practice and material-centred interaction design, as reviewed in Chapter 2, and illustrated in Figure 2.2.

As illustrated in Figure 3.1, my design framework was grounded in theories of affect (identified in section 2.1) combined with the three practices discussed above. In this affect-, material-, and interaction-led – or AMI-led – design framework, my use of '-led' reflects the way in which emergent findings during my practice inform the research sub-questions and design responses. This is a response to the emergent feature of affect and the SPSR material. My practice contributes to theory-building, rather than following from it. Each of the affect-, material- and interaction-led approaches is a response to certain features of affect. Meanwhile, they also combine conceptual and methodological elements from the interactional approach, fashion practice and material-centred interaction design, reviewed in Chapter 2. For convenience, I reiterate here the definitions of these three practices within the context of my research:

- Interaction approach, refers to the practice that sees emotion as interaction (Boehner, DePaula, et al., 2007a, p.280). In this approach, rather than sensing and transmitting data about emotions, the affective system design is to 'support human users in understanding, interpreting and experiencing emotion in its full complexity and ambiguity' (Boehner, DePaula, et al., 2007a, p.275).

- Fashion practice here refers to the form-giving process of how physically bodied artefacts are developed via the combination of a cognitive process and making (Gully, 2010), through the emergence of entangled affect and materiality.

- The material-centred interaction design approach refers to a practice that treats digital and physical material equality when designing with computational material, and that brings sensitivity from craft and design to aid the form-giving process of designing computational artefacts (Wiberg, 2018; Vallgårda, 2014).

The three building blocks are entangled rather than being clear-cut. With the guidance of this AMI-led design framework, I embarked on three phases of design explorations to develop a body of work with an affect-enabling outcome, working with SPSR material – which is the task of Research Aim 2. How this framework was applied in each practice phase of exploration is explained in each of the corresponding chapters (Chapter 4, 5 and 6). When an affect-enabling SPSR artefact was achieved, assessed by a recognised evaluation method (in my case a lab-based scientific study), it marked strong support for the effectiveness of the design framework within the specific context of this research. The research then moved on to address Research Aim 3 to critically discuss the wider implications of this framework. To do this, I reflected on the application of this framework in my practice. I then explored the wider applicability and implications of the framework through interviewing four expert practitioners in affective interaction design and one experienced practitioner in fashion and interaction design. These discussions are presented in Chapter 7 (section 7.1).

In the following text I elaborate on each of the three building blocks of AMI – led design framework. I detail how each approach responds to the features of affect and the specific design needs (as shown in Figure 3.1), which practice the conceptual elements of this building block originates from, and any other aspects that are particular to this research.

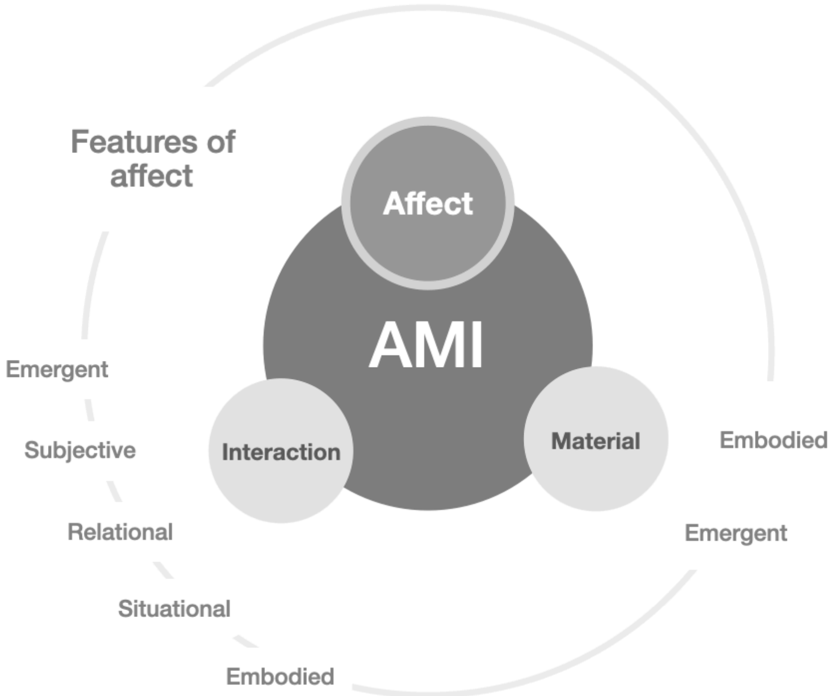


**Figure 3.1** Illustration of the AMI-led (affect-, material-, interaction-led) design framework. Each approach responds to one or several key features of affect.

### *3.1.1* Being affect-led

The affect-led approach was adopted to ensure that the purpose of the design remains to enable an affective experience. This was to avoid designing an affective artefact that focuses overly on functionality and usability. It responds to the subjective feature of affect, taking the subjective affective judgement of both the designer (myself) and the participants into account. It includes three aspects.

First, as in fashion practice, it recognises the indispensable role of the designer's subjectivity that influences the decision-making in the orientation of the process, in my case this was choosing which material, which modality and which context to focus on (Au, 2012).

I established affection towards the materials and prototypes through the studio making method. For example, the choice of SPSR material was largely because I, as the designer, through studio practice with the material, found that it has great potential affective affordance, which prompted a strong desire to work with this material. Of course, such judgement was also influenced by my observation of how people seemed to connect affectively with this material during interactive activities in the preliminary studies. The same elements had also played a role for the design decision to focus on touch modality. This is different from an 'emotion as interaction' approach (Boehner et al., 2007) and the 'affective loop experience' (Höök, 2009) approach, which takes only the affective subjectivity of the users into account.

Second, it was led by the affective response from my research participants, or co-explorers, in my research. Co-exploration method (details of this method are explained in section 3.3.2) was used to facilitate the affective response from co-explorers, by engaging them in exploring the affective affordance of the artefacts made from SPSR material.

Thirdly, an affect-led approach indicates an element of assessing affect. This is discussed in detail in section 3.3.3.

### 3.1.2 Being material-led

The material–led approach draws on both fashion practice and the material-centred interaction design approach (Wiberg, 2018; Vallgårda, 2014). This approach responds to affect as both embodied and emergent. It emphasises the importance of two layers of physical attributes of the interactive affective artefacts. One layer emphasises the appropriation of the physical components: this was mostly carried out by me during studio practice. The other layer emphasises the affect-enabling materiality that emerged during interaction in co-exploration.

As discussed in previous chapter (Section 2.4.2.3), material is central to fashion practice. This material-led approach applies a fashion practitioner's uncompromising demand and sensitivity towards the affective quality of the material being used in a design, the unfolding materiality during practice, and the affective quality of the experience that the final artefact enables. The materiality of interactive materials such as the SPSR material includes both passive properties (such as texture, tactility, and visuality) and dynamic properties, including temporal form and interactive gestalt, as noted by Vallgårda (2014), when it moves or interacts. Material-centred interaction design practice, provided conceptual support in emphasising that there should be no conceptual difference between the computational and non-computational substrates in the SPSR material (Wiberg, 2018). Thus, during the design practice the affective sensitivity from fashion practice should be applied equally to all the physical, digital, electronic, mechanical attributes substrates that contributes to affective affordance.

The material-led approach applies in the studio practice method, for it generates insight from the designer into how the materiality and its affective affordance unfold during interaction with the material. It also applies in the co-exploration method, as it generates insight from the co-explorers on how the materiality and its affective affordance unfold when they interact with the probing artefacts.

Being material-led allowed the development of the research and practice to be informed and inspired by the affect-enabling properties of SPSR material that emerged through studio making and co-exploration.

### 3.1.3 Being interaction-led

This approach accommodates all the features of affect. First the emergent feature of affect calls for an interaction-led approach. This approach resonates with the interactional approach to affective interaction design (Boehner et al., 2007, Höök, 2009, Fritsch, 2009, 2018) to consider affect as an emergent event that only arises during interactions. However, it differs from most interactional approach practices, where the human interactants were introduced to interact with the system only *after* the design had been completed: my own interaction-led approach instead introduced research participants to the material and probing artefacts *during* the design exploration, *as part of* the form-giving process.

Secondly, designers need to have a knowledge of material and its affective affordance – either previously acquired by themselves or provided to them by others (Au, 2012). As identified in Section 2.2.3, due to the novelty of SPSR material there is a lack of knowledge on its material properties and affective affordance for designers to draw from. Thus, directly interacting with the material through studio practice and facilitating the interactions between the material in exploration and co-explorers, was an essential way to enable the emergence of the knowledge about which properties of the SPSR artefacts are most enabling, what kinds of affect they enable and in what situations they could be used.

My previous research on devising playful interactions between humans, technology and materiality to generate knowledge about our emotional selves and human-technology relationships also fed into this approach (Zheng, 2017). Apart from gathering information and knowledge, this process of mutual mediation also serves as a form-giving process. Potentially meaningful forms of SPSR artefacts, relations and interactive gestalt emerge as part of the process.

The co-exploration method was used to facilitate the interaction-led approach, which is detailed in the following section.

## 3.2 Research through design

As my research is tasked with finding a viable design pathway to create affect-enabling interactive artefacts, I followed a Research through Design approach, referring to 'practice-based inquiry that generates transferrable knowledge'(Durrant et al., 2017, p.3). As a fundamental concept for approaching inquiry through the practice of design (Frayling, 1993), it is practised in doctoral research in both design (for example, Congdon, 2020) and fashion (Holroyd, 2013). It has also grown to be a recognised approach in interaction design, referring to an approach that employs methods and processes from design practice as a legitimate method of inquiry when designing interactive systems and artefacts (Zimmerman et al., 2007; Gaver, 2012; Andersen et al., 2019). In my research I first outlined a design framework to guide the design process, and I then employed methods that originated from fashion practice, design and interaction design to carry out my inquiry into a viable pathway to create affect-enabling artefacts.

## 3.3 Methods

The methods employed by each study could only be decided when the research sub-questions of the specific study were established. The focus of subsequent exploration depended upon the information and inspiration gathered from the previous exploration. This characteristic reflects a common feature of a practice-based design research - that the specific methods at different stage can vary as the design practice unfolds (e.g. Vaughan, 2017; Congdon, 2020). This characteristic was determined by the nature of the topic of my research, that I was tasked with finding a way through a jungle with no available map or design guidelines. This characteristic was also influenced by the theoretical grounding and design framework of this research, that promotes the following of the emergent nature of affect and letting the properties of the material and its affective affordance inform and inspire the direction of the subsequent focus.

Studio making, co-exploration and assessment were the three main methods employed in various studies of my practice. These methods drew elements mainly from the three practices: fashion practice, the interactional approach and the material-centred interaction design. They were selected to facilitate the application of the AMI-led design framework: the studio making and co-exploration methods were to facilitate the material-led approach; the co-exploration method was also intended to facilitate the interaction-led approach, and the assessment method was to facilitate the affect-led approach. I elaborate on each method below.

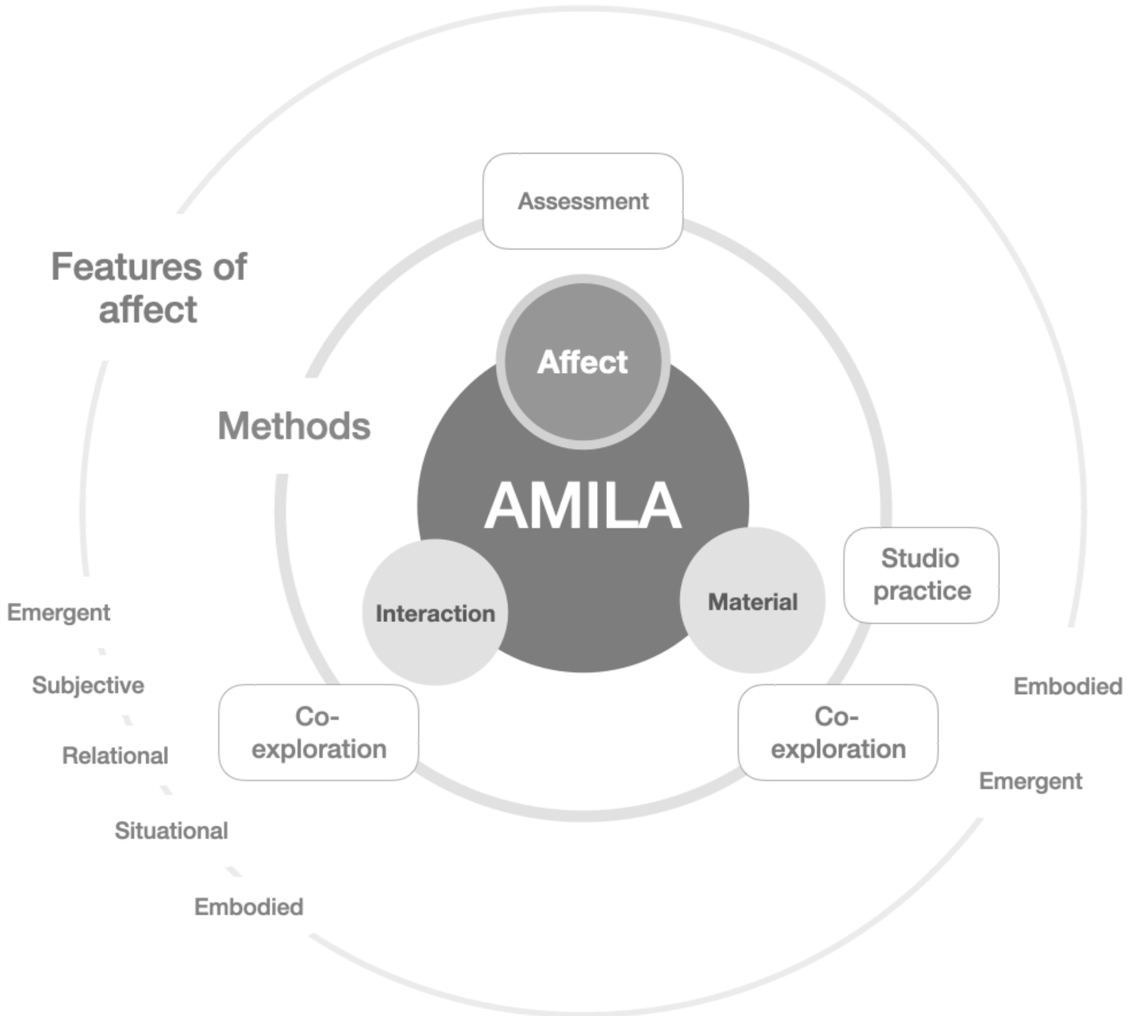


**Figure 3.2** Methods employed in the research in relation to implementing the building blocks of the AMI-led design framework.

### 3.3.1 Studio practice

Studio practice here refers to the activity of making, which comes from my fashion practice. It refers to me as a practitioner working in the studio to conduct experimental making activities and articulate the form-giving with SPSR materials. The studio is the 'natural' working environment where a fashion designer or a creative designer conceptualises, explores and experiments with materials and concepts (Edmonds et al., 2005, p.457; Gully, 2010). As a design research activity, making contributes to knowledge production (Löwgren, 2016, p.28); in my case the emergent knowledge of the properties and affective affordance of the SPSR material, and the know-how to construct affect-enabling artefacts using this material.

I used studio practice during the initial exploration in Study 1 to study the designability and establish my own understanding of the affective affordance. I used this method then to create the necessary toolkits and develop probing artefacts to facilitate the co-exploration in Studies 2 & 3. After this I used studio making to develop the research artefact for affective touch during the exploration with a broad focus in Study 4 and finally the artefact simulating CT-optimal touch in exploration with a defined focus in Study 5.

The fact that interactive materials such as SPSR material are a combination of analogue, digital and mechanical elements meant that it required an expanded skill set to configurate a desirable outcome. I was faced with the decision of whether to acquire new skills myself or to collaborate with engineering expertise. I decided to acquire the new skills that are essential for manipulating the materiality of SPSR material (which included 3D mould design in software, silicone casting, air chamber design, and reinforcement design) for the purpose of accessing primary tacit knowledge of the designability and affective affordance of SPSR material, and to seek technical support on configuring the mechatronic components, for time efficiency. However, using my basic mechatronic skills from my previous e-textile projects, and familiarising myself with the technical aspects relevant to SPSR material, I was able to participate in co-configuration of the digital components. Such participation enabled me to gain tacit knowledge about articulating the temporal form of this material.

In this method, I acted as the designer and the maker. I conducted experimental making directly with the material. I planned the angle of exploration: for example, the technical steps and the affective elements of making, and reflected on whether they project positive potential toward the research aims. When it came to making design decisions about the direction in which to continue the making, based on information, inspiration and constraint, I acted both as designer maker and design researcher.

‘Making is required for explorative design of non-idiomatic interaction’ (Löwgren, 2016, p.28). To navigate the often interdependent trinity of forms (physical form, temporal form and interactive gestalt) (Vallgårda, 2014), interactive designers have to start somewhere: thus hands-on experimental making is the necessary first step for designers to make sense of the material (Vallgårda, 2014). The strengths of this method thus include its provision of access to the possibilities of physical forms and temporal forms of unfamiliar interactive materials that cannot be facilitated by a scientific method (Löwgren, 2016; Cross, 2001). Similarly, Archer observed that: ‘[t]here are circumstances where the best or only way to shed light on a proposition, a principle, a material, a process or a function is to attempt to construct something, or to enact something, calculated to explore, embody or test it.’ (Archer, 1995, p.11). I was faced with such circumstance: encountering the unfamiliar SPSR material, and lacking existing knowledge on the materiality and affective affordance. To an extent, making was the only way for me to start the practice, thus it is a vital method to answer my research question regarding how to create an affect-enabling artefact.

The limitation of the making method lies in the fact that the material outcomes were bounded by the limitations of my skillsets and knowledge base. The design choices were influenced by my subjective affective preference. Thus the material outcome of making process carried out by a different designer with the same material and follow the same design framework would vary from mine. With my acquisition of new skills in 3D modelling, casting and coding, the limitation lay in the fact that it could be time consuming, and the material outcome was limited to the level of skill that I could develop within the time constraints of the research.

### 3.3.2 Co-exploration

To implement the interaction-led approach, the co-exploration method was adopted to facilitate the interaction between the artefacts and participants. It also facilitated the material-centred approach. Co-exploration is not an established term, but I used it to emphasise the exploratory nature of the participatory sessions in my research, in the form of workshops. This method adopted elements from participatory design methods (Sanders, 2002; Heidingsfelder et al., 2016) and the 'material probe' method from material-centred interaction design researchers Jung and Stolterman (2010). The elements from participatory design are embedded in the method of probing, as probes are also considered as part of the participatory design practice (Jarke and Maaß, 2018). Jung and Stolterman propose 'material probe' as a novel approach to explore conceptual dimensions of materiality such as affective and aesthetic qualities. Specifically, they aim to understand how people perceive material qualities of artefacts and to discuss how designers could incorporate non-functional user desires related to material qualities in the design of digital artefacts (Jung and Stolterman, 2010, p.154). In Jung and Stolterman's study, participants were invited to talk about their experience of physical artefacts based on their memories, play with material samples and speculate on their material preferences, and to envisage desirable digital products in the future with their favourable material qualities. Resonating with their approach, in the co-exploration workshops in my research, there were three categories of activity:

1) Participants talked about a personal artefact that has emotional value to them. This activity served as both an icebreaker, and a sensitisation process for participants to tune into the topic of the workshop.
2) Participants played with the probing artefacts made from SPSR materials and share their thoughts on its affective affordance via questionnaires. The physical SPSR artefacts were intended to enable participants to access the full sensory experience of this material.
3) Participants envisioned a desirable, personal affective artefact and create a mock-up using the SPSR and other physical materials provided. This was to empower the participants and catalyse their vision for desirable future product made from SPSR material.

There were four sessions of co-exploration workshops during my practice (during Studies 1-4). Each workshop used between one and three of the above activities. Details of the activities are documented in sections describing each individual workshop respectively.

In co-exploration sessions, my role was mainly as a moderator, facilitating these activities. At the beginning of the sessions, introducing the project and artefacts, I acted as the designer and researcher who communicates the design intention and the research question to be explored. More details of my role in each aspect of the co-exploration sessions is specified in Studies 1- 4 (see sections 4.2.1.5 for Study 1, section 4.3.1.1 for Study 2, section 5.2.1.1 for Study 3 and section 5.3.1.2 for Study 4).

I termed these activities 'co-exploration' to indicate that the participants and the designer explore the affective affordance and design space of the interactive material together. In this collaborative activity, the probing method facilitated the conversation between myself as designer and researcher and the research participants as co-explorers.

Unlike the design probes used in classic cultural probes (Gaver et al., 1999) and user studies (e.g. Häkkilä et al., 2015), in which the specific use case and targeted user group are already determined before the study, co-exploration sessions were used in the explorative stage of my research (Study 1-4), when my practice dealt with the conceptualisation and form-giving process of an artefact without knowing the specific use-case. The probes were intended to elicit feedback on affective affordance, catalyse personal visions of potential use cases and establish materiality preference (Jung and Stolterman, 2011, P. 154),

As Cash et al (2022) pointed out, in early-stage explorations, design researchers examine often messy design situations, using a variety of approaches and perspectives, thus the data collection and analysis can serve only the limited factors affecting the concept under study (p.6). The purpose of my research at this stage was a limited one - narrowing the research space to a manageable set of options, and refining the selected path toward the solution (Lindberg et al., 2016), in my case, for Research Aim2. This included two aspects. The first aspect was related to the conceptual elements - to generate information about and inspiration from the key affective affordance of the SPSR material, concepts of forms and possible use cases, for me as the practitioner to identify design opportunities. On top of this, the feedback from participants acted also as a form of assessing the affective affordance of different material expressions of SPSR material. The second aspect was related to the technical elements – to narrow them down to a manageable set of technical parameters to focus on, in order to produce a complete final artefact. My design decisions for subsequent explorations were made upon balancing the above conceptual and technical elements. The findings during this stage were not intended to be generalisable to a wider population. Thus the only inclusion criteria was that the participants should be people who were interested in the topics and activities of the workshop, and who wanted to volunteer to join the co-exploration sessions. Although bias of self-selection (Heckman, 2010) may not be avoided, the literature shows that recruiting participants who volunteer is a common practice for studies of this kind, especially in the case of exploring emergent technology (e.g. Jung and Stolterman, 2010; Cash et al., 2022).

In terms of numbers of participants, the existing literature on using probe methods in participatory sessions showed that a range of 8 to 15 participants in total is a common group size for effective facilitation (e.g. Jung and Stolterman, 2010; Visser et al., 2005).

The strength of this method included the following:

- It engaged with participants around topics such as feelings, ideas and aspirations toward a novel materiality that traditional HCI methods have frequently left unexplored (Boehner, Vertesi, et al., 2007).

- It offered a playful, hands-on experience for participants to access a novel technology. The format is more engaging and empowering for participants than traditional format that does not involve hands-on experience (Boehner, Vertesi, et al., 2007).

- The co-explorers' participation enabled the collective production of knowledge (Jarke and Maaß, 2018), and their feedback and ideas informed and inspired my design process (Visser et al., 2005).

- A material probe has the advantage of providing a direct channel to understand people's sensitivity to materiality for future digital artefacts in general (Jung and

Stolterman, 2010). This method also produces material outcomes that embody affective response and material configurations that can directly inform design. In my case, I took it further. The material probe used in my research was made directly from the material in question - SPSR material. This provided participants with direct contact, to access the full sensory experience of this material, so that their feedback could directly feed into the design concept development, and their feedback had more fidelity than experience with indirect contact, such as images, video and other metaphorical representations.

- I used questionnaires as a tool for documenting feedback from each participant. This method has several advantages. For participants, a questionnaire is less intrusive than video recording. The literature shows that in probing sessions, the challenges encountered in a group discussion format include that one or a few participants sometimes dominate the topics discussed and affect the willingness of other participants to freely express their views (O.Nyumba et al., 2018), and the homogenising effect, in which individual responses tend to be masked by the overall consensus (Acocella, 2012). The individual questionnaire mitigates this risk by allowing equal time and freedom for each participant to reflect and express their ideas. In addition, compared with group discussion, this format offers a higher degree of privacy in relation to topics of emotion and touch, which to some participants are topics of sensitivity and intimacy. Participants had the freedom to talk with other participants either in pairs or in a small group if they wished.

The limitations of the method can include the following:

- In probe methods, the participants' responses to probe questions tend to have a fragmentary and anecdotal nature (Boehner, Vertesi, et al., 2007).
- Self-reporting questionnaires only capture written forms of information, and do not capture richer information such as body gestures and facial expression, as in video recording.
- Participants did not take part in the data analysis and interpretation. The interpretation and analysis of the data in the probe method, following a design

research approach in creative practice, is impossible to produce without, and to some extent relies on designer's (my own) subjectivity and personal interest. Thus the decisions to narrow down to a particular mode of interaction (touch) and the defined focus on CT-optimal affective touch should not be understood as the only way of exploiting the SPSR material for affective interaction design. A process led by a different designer might well have led to a completely different focus, even if they followed the same design framework and methods.

- The sampling was not intended to be generalisable to a wider population. The affective preferences of the participants cannot therefore be taken to represent wider population preferences. Its purpose was above all to enable me, with my co-explorers, to narrow down the range of possibilities that could be explored on a scale that was manageable within the PhD.

### 3.3.3 Assessment

There is a wide range of assessment methods adopted in interaction design and psychology, including self-reporting (Weidman et al., 2017), physiological and neurophysiological sensing (Calvo and D'Mello, 2010), multi-modal analysis (Sakr et al., 2016) and ethnography (Bareither, 2019). There is no one-size-fits-all assessment method for affect (Calvo and D'Mello, 2010). In design, there are methods for prompting affective response through more intuitive activities such as material and making (June and Stolterman, 2011, Wallace et al., 2013). In fashion practice, there is not normally a formal procedure of assessing affect or emotions. As described in section 2.4.2.1, during the design process designers take an intuitive approach in assessing the affective affordance of materials, or the assessment is made among the design team (Au, 2012). The final outcome is judged based on the acceptance of, and response from the wearers or audiences (van Tienhoven, 2018).

In my research, there were two different requirements for assessing affective response. The first of these was during the design exploration phase that led to the conceptualisation of the artefact. Collecting my own and research participants' (co-explorers') affective responses to the probing artefacts helped to inform the affective affordance and forms of the SPSR material. In Study 1, due to the explorative nature of this stage, I relied on my designer's intuition and my subjective affective preference to comment on the affective affordance of SPSR material, which is documented in section 4.2.2. In the second part of Study 1, and Studies 2, 3 & 4, I used the method of co-exploration to engage participation. Self-reporting questionnaires were used to capture the information on participants' affective responses toward the probing artefacts. Material outcomes in terms of the configuration of the actuation from the participants and the speculative artefacts made by the participants together with my field notes also captured the non-textual information on the affective response from the participants. The advantages and limitations of co-exploration and self-reporting questionnaires have been discussed above, in section 3.3.2. The details of the questions in each questionnaire are specified in the 'Process' section of each study.

The second requirement in assessing the affective responses was the evaluation of the final artefact, in order to fulfil Research Aim 2. In this evaluation, a scientific method was chosen. Qualitative data on the subjective rating of the pleasantness and intensity, neurophysiological responses, and qualitative comments were collected. As at this later stage of research, I was able to define and isolate key factors to be tested linking to a wider population: the quantitative method (supplemented by qualitative comments) was appropriate and could identify wider implications (Cash et al., 2022, p.7). The protocol design, sample size calculation, stimulation design, and data analysis were conducted according to the required rigour of an experimental study and are detailed in section 6.4.1 . The rationale of the evaluation method is specified in section 6.4 (page 131-132), and the limitations of this method are discussed in section 6.4.3 (final paragraph). The evaluation of the final artefact was conducted through collaboration with KatLab at University College London (UCL), and brain-computer interface researchers (See footnote 10 and 12). Details of the evaluation are provided in section 6.4.

## 3.4 Ethics considerations

I completed the training in research ethics required by the Royal College of Art (RCA). I consulted the RCA Research Ethics Policy prior to each study to refamiliarise myself with relevant processes. When planning and carrying out the studies, I have followed the Royal College of Art processes and protocols regarding research ethics. I specify several ethical considerations that are particular to this research below.

First, all the co-exploration studies and the evaluation in Study 5 involved human participants. Ethics approval was sought prior to each study. All the participants provided their informed consent prior to participating in the sessions. Studies 1 – 4 were conducted between October 2016 and November 2017. One workshop in Study 2 (during the STATE Festival 2016, 'STATE of Emotion', in Berlin) was managed by the STATE of Emotion festival organising committee; I adhered to their ethics policy, as well as the RCA policy, and consent from participants was managed by the organising committee. The participant consent forms for Studies 1 and 3-5 were approved by RCA Research Ethics Committee. Study 5 was conducted from Oct to Dec 2019, when the Research Ethics Policy required an additional form for ethics approval by the RCA Research Ethics Committee. All the participant consent forms and the ethics approval form are made available for the thesis examination committee.

Second, the nature of the topic has meant due consideration of the ethical ramifications of affect, emotion and touch. It was made clear to participants that they did not have to reveal any personal details or details of any emotions that they felt, and that they could choose not to participate or excuse themselves from participation at any time. In Chapter 7 (section 7.2), I reflected on the wider ethical ramifications of designing machine delivered affective touch informed by the practice of this research, as well as the most recent literature on this aspect, and suggested the incorporation of discussion on sensitivity and ethics into any future AMI-led conceptual framework.

Thirdly, all participants were expected to interact with, or wear, the artefact for each study. I ensured that the artefacts used for the interaction were made safe and followed the risk assessment and ethics process. The parts of the artefacts that were in direct contact with the skin were made from either textile used for normal clothing, or certified skin-safe silicone material (Smooth-on Ecoflex™ 00-30, 00-35 Fast[4]). Some artefacts were actuated by electrical micro-controllers and circuits. These electronic parts were not in direct contact with the skin. As such electronics rely on low power, they thus pose no risk of physical harm to participants.

[4] Copies of Skin Safety Certification of Ecoflex™ 00-30 and 00-35 Fast are provided in Appendix 15. They can also be downloaded from on the manufacture's website: https://www.smooth-on.com/products/ecoflex-00-30/, and Ecoflex™ 00-35 Fast can be found at https://www.smooth-on.com/products/ecoflex-00-35/

# Chapter 4 Initial exploration: the affective affordance of SPSR material

To address Research Aim 2: developing an artefact with an affective-enabling outcome guided by the AMI-led design framework, I carried out three phases of practice exploration. This chapter describes the first of the three practice phases - initial exploration from April 2016 to January 2017. The exploration aimed to study the designability of SPSR material and identify its most affect-enabling properties. Two studies, Study 1 and Study 2, are included in this phase. Studio practice and co-exploration methods were used. The process, outcomes and discussion are described and discussed in each study. The outcome of this phase of practice informed my decision to exploit the tactile modality of the SPSR material and focus on the designing for a positive affective touch experience for the next phase of practice.

## 4.1 Research sub-questions and methods

The exploration focused on two research sub-questions:

1) how to make SPSR artefacts, and
2) what the affective affordances of the SPSR material are.

It constituted two studies. In Study 1, I conducted material discovery activity through studio practice and co-exploration. In Study 2, I co-explored the affective affordance of SPSR artefacts with two groups of participants. Feedback was collected in the form of my subjective evaluation as the designer, as well as co-explorers' responses to a questionnaire. The aim of the processes conducted in this study was to identify the most prominent affect-enabling properties of SPSR material and the associate context of use, in order to inform a more narrowly focused modality for my subsequent practice to explore.

This phase of practice followed the affect-, material- and interaction-led (AMI-led) design framework. In Study 1 my experimental making was led by the material as well as my affective intuition[5] toward the material. The workshops in Study 2 were led by the interaction between the SPSR artefacts and the participants. The participants' experimental making using SPSR materials took a material-led approach. Both making and interaction were led by the participants' affective preferences.

## 4.2 Study 1. Material discovery

### 4.2.1 Process

Although I had preliminary experience of making soft actuators with SPSR material, its materiality was still relatively unfamiliar to me. First, I needed to educate myself about the designability of this material. That is, to learn about the making process of this material, and what variations of forms I could manipulate, and to formulate my initial ideas about the affective experiences they could afford.

#### 4.2.1.1 Material discovery with studio practice 1: taking the basic steps in making silicone pneumatic soft robotics

At the time I started the exploration, there were limited resources for learning about how to make soft robots. I followed tutorials by Fino-Radin (2013) to make my first soft robotic gripper (Figure 4.1, right), and tutorials by Panagiotis et al. (2016) to make my first fibre-reinforced tentacle actuator (Figure 4.1, left). During this process I acquired new skills, including 3D modelling and silicone casting.

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[5] Such sensitivity of affective intuition is also enabled by my background in fashion practice, as mentioned in Section 1.2.

**Figure 4.1** Fibre-reinforced tentacle actuator (left), 4-leg soft gripper (right)

I summarise the principal steps in creating inflatable (pneumatic) silicone soft robotic artefacts below, as shown in Figure 4.2.

Step 1: Moulding the design in 3D modelling software (here I used Rhinoceros Version 5.0), as shown in Figure 4.2 (a).

Step 2: Printing the mould with a 3D printer as shown in Figure 4.2 (b). Before 2018, for the most of my moulds, I used an Ultimaker 2 Extended 3D printer, and since 2018 I have used a Flashforge Creator Pro 3D printer. For the moulds that needed a finer resolution such as those used to create the fibre-reinforced structures (Figure 4.1left and Figure 4.6), I used the 3D printing service at Rapidform RCA where an Object ™ 90 nozzle Polymerjet was employed.

Step 3: Casting liquid silicone into the mould and waiting until the material has cured, as shown in Figure 4.2 (c). I have tried silicone rubber with various degrees of softness, including Ecoflex™ 00-30, 00-35Fast, 00-50, Dragon Skin 10™ (Smooth-on Inc, Pennsylvania, United States), and Transil 20 (Mouldlife, Suffolk, UK).

Step 4: Pumping air into the air chamber. The pumping device can be either a manual squeeze bulb or a mechanical air pump. Instead of air, liquid, such as water or coloured fluid (Morin et al., 2012), can also be used to actuate the shape change. However, for this research, I focused on pneumatically driven soft actuators.

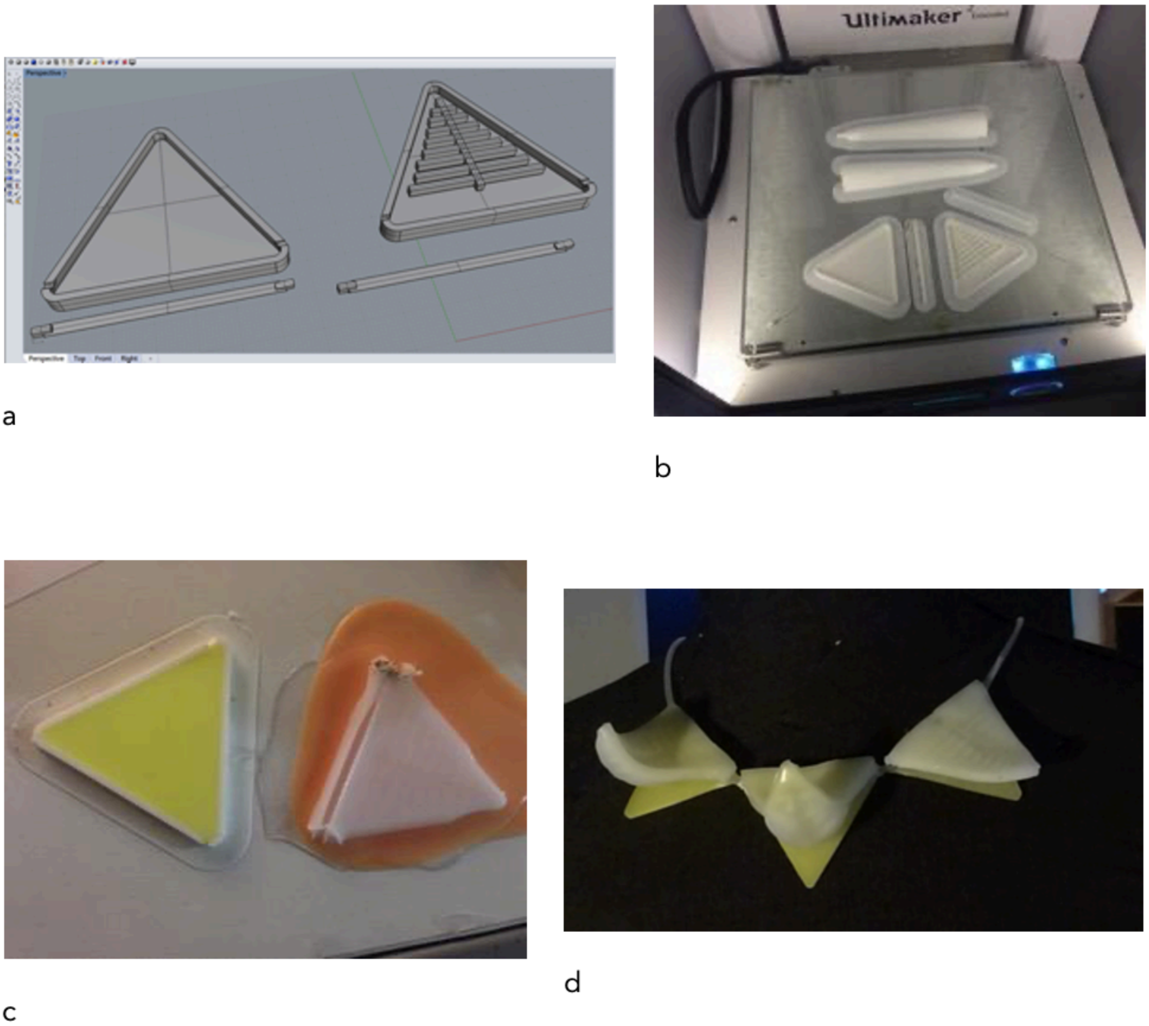


**Figure 4.2** The making process of an inflatable robotic artefact (a) Creating a 3D model in Rhinoceros. (b) 3D-printing the mould; (c) Casting silicone into the mould (d) The finished artefact, whose movement is actuated by pumping air or liquid into the channel

For a more complex actuator such as the one in Figure 4.1 (left) and Figure 4.6, non-stretchable materials are embedded into the Ecoflex™ 00-30 silicone rubber as a structure for reinforcement. Here the reinforcement was non-elastic thread applied in a spiral after Step 3. The angle of the spiral determines the angle of the curling movement. After the threading, a thin coating of silicone was applied to seal the threading inside.

Designing different forms of movement can be achieved by various means. One option is to alter the internal air channel by restricting and enabling different areas of expansion. This approach involves enabling and restricting the expansion of the silicone material. When actuated, the enabled area expands while the restricted area does not. This contrast causes a variation in dynamic forms. The artefacts shown in Figure 4.1(right), Figure 4.2 (d), Figure 4.4 and Figure 4.5 were designed and realised using this technique. Figure 4.3 is achieved via applying different thickness on the same surface. Yao et al. (2013) carried out an interesting investigation into this shape-changing effect based on restricting and freeing expansion in different, varying areas. This can also be done via embedded structures. Martinez et al. (2012) explored embedding origami structures to create specific movements with soft actuators. These artefacts can be used to actuate bigger structures, such as feathers or textiles. Neidlinger et al. (2017) explored such structures to create shape-morphing parts on garments.

#### 4.2.1.2 Material discovery with studio practice 2: exploring variations of forms

After familiarising myself with the process of making an SPSR artefact, I then appropriated different aspects of making procedures to create dynamic artefacts of my own design. Some examples follow. By altering the shape of the mould I created forms other than a gripper, such as a leaf shape (Figure 4.4) and a triangle form (Figure 4.5). I made the surface layer of a three-legged silicone gripper with uneven thickness. When inflated, the thinner patches of the surface ballooned out more than the thicker patches (Figure 4.3). Based on the fibre-reinforced tentacle actuator, I altered the angle of the threading of the middle layer to create curling at a different angle. I also altered the shape to created pointed tentacles (Figure 4.6).

**Figure 4.3** Soft actuator with uneven surface tension

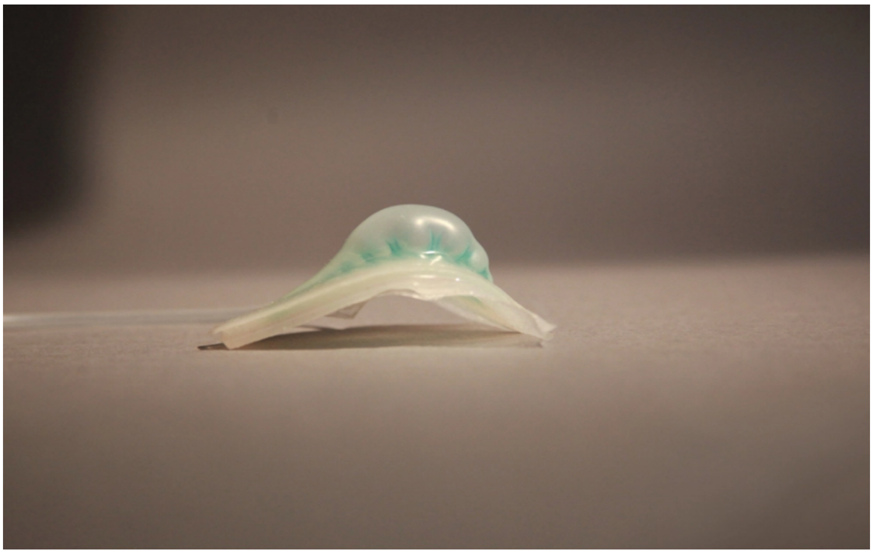

**Figure 4.4** Soft actuator in leaf form

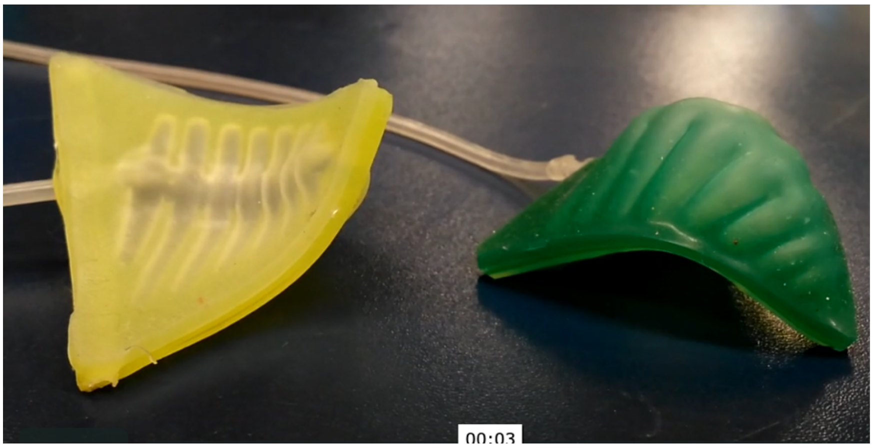


**Figure 4.5** Soft actuator in triangle form and bright, opaque colours

**Figure 4.6** Fibre-reinforced pointed soft actuator in tentacle form

#### 4.2.1.3 Material discovery in studio practice 3: Exploring variations in texture

Figure 4.7 shows the exploration of textural variations. I combined silicone with other materials, including feathers (Figure 4.7, left), fur (Figure 4.7, middle), and textile (Figure 4.7, right). I also tried alternative methods to actuate the movement - for example, liquids of various thicknesses and temperatures – in order to identify the variety of tactile sensations that these enabled.

The added materials offered an equally surprising element when animated. In this sense the soft actuator was the moving mechanism, while visual and tactile sensations were delivered by the surface agent, namely feathers, fur, textiles, etc. The shared properties of these materials are their predictability and familiarity, as sensorially they recall the experience of stroking pets or touching domestic textiles. In these examples, the novelty and intensity of sensation when using silicone alone as a surface was mitigated by the familiarity of the surface material.

For the exploration of texture, instead of inflating the chambers with air I also experimented with injecting liquid of different thicknesses. This created a variation in tactile texture of different levels of softness.

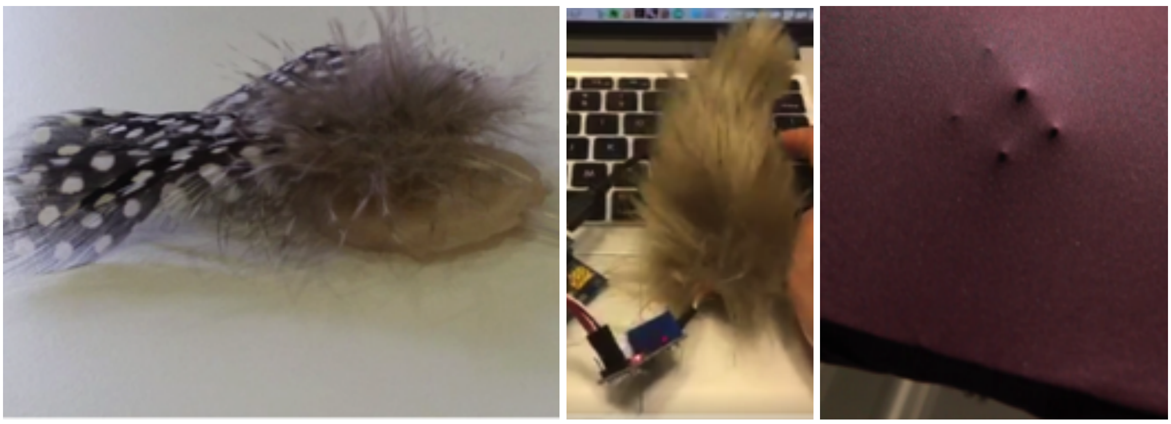

**Figure 4.7** Exploration of textures

#### 4.2.1.4 Material discovery in studio practice 4: experimenting with touch modality

Figure 4.8 and Figure 4.9 show experimentation with 'being touched' by the SPSR artefacts. I explored the concept of touch-sensitive SPSR artefacts. The artefact in Figure 4.9 is a fibre-reinforced actuator that 'curled' when actuated. A conductive thread was embedded as a 'capacitive' sensor to detect the pressure it felt when being touched. When gently touched, its body shook, and when greater force was applied, such as when it was squeezed, the artefact curled around the interactant's hand (Figure 4.9, right).

**Figure 4.8** Exploring being 'touched' by an SPSR gripper

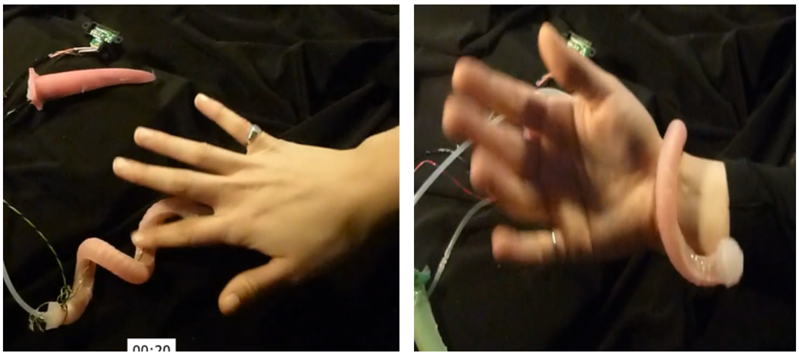

**Figure 4.9** Touch-sensitive SPSR artefact

#### 4.2.1.5 Material discovery with co-exploration

After I had familiarised myself with the design and making of the SPSR artefacts, and formed an initial impression of their affective affordances, I invited designers and artists to co-explore the material properties, through which I could collect information on the affective affordance of different aspects of the SPSR material. This was carried out through a workshop at the Royal College of Art during the 2016 AcrossRCA programme. AcrossRCA is a term used by the institution to refer to one week every year where Master's students from different art and design programmes in the College take part in themed projects together. I chose to co-explore with artists and designers because they all have their own making-based practice, which means that they are likely to be more explorative and observant in relation to the elements of materiality (Wiberg, 2018). These are also professions that rely on intuition and imagination, so these practitioners' imagination for this material would be less limited by existing social norms and common expectations, and they would be open to richer inspirations for design. The workshop was titled 'Sentimental Soft Robotics'. 15 artists and designers from 13 different MA programmes participated in this workshop. The recruitment was managed by the AcrossRCA project coordinator.

This co-exploration mainly focused on materiality on different scales (e.g. a hand-held-size, a wearable size, and a larger than body size, using alternative materials that included latex and plastic sheeting, which was provided by me), surface textures (mixing the material with different materials of the participants' personal choice, such as textiles, plastics, found small chips of materials, etc), and colours. A snapshot of these activities is shown in Figure 4.10. I developed a toolkit – a 'personalisable air supply' device (Figure 4.11), which was a hacked blood pressure measuring device. Participants could set the inflation time they wanted by pressing the button for a certain length of time, e.g. 10 seconds. The device remembered this duration and would inflate at regular intervals to actuate the SPSR artefact designed by the participants. In this way, participants did not need to know about coding and could focus on imagining and prototyping their artefact with more familiar materials.

My role in this session included the following. I introduced myself to the group and facilitated participants introducing themselves to each other. I made a brief presentation on what SPSR material is and outlined the idea of affective interaction design. I then presented the materials, tools and toolkit and explained how they can be used. During participants free exploration using the materials provided, I checked in with each individual or group to give assistance in using the material or tools, taking care that I did not modify their ideas but only assisted them. Finally, I moderated when the individual or groups presented their outcome to the rest of the group.


**Figure 4.10** Sentimental Soft Robotics workshop, Royal College of Art, 2016

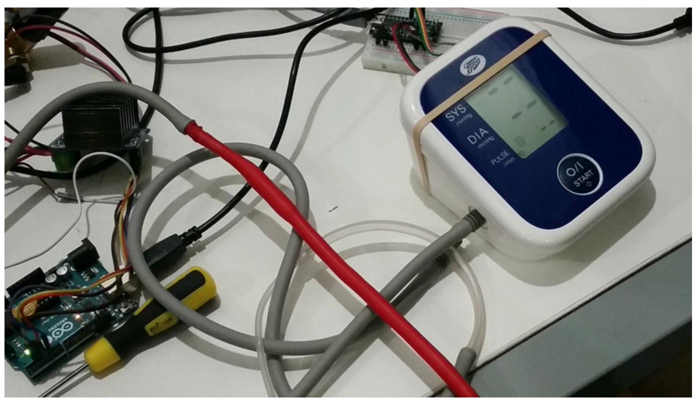


**Figure 4.11** 'Personalisable air supply' toolkit

### 4.2.2 Outcome and discussion

I discuss the affective affordance of SPSR material that I identified through material discoveries.

When combined with other sensual materials such as feathers, fur and textile, the added materials offer an equally surprising element when animated. In this sense the soft actuator is the moving mechanism, while visual and tactile sensations are delivered by the surface agent, namely feathers, fur, textiles, etc. The shared properties of these materials are their predictability and familiarity, as they are familiar materials, and the sensorial experience of them is already established in our memory. For example, they remind us of the experience of stroking pets or touching domestic textiles. In these examples, the novelty and intensity of sensation when using silicone alone as a surface is reduced by the familiarity of the surface material.

When it is actuated with liquids of different thicknesses and temperatures, there is increased novelty. However, the actuation depends on a hydraulic pump, which often comes in a larger size than a pneumatic pump. The potential leakage of liquid made it less wearer-friendly and more technically demanding than pneumatic actuation systems. So for this research, I decided to use a pneumatic actuation system for the design of a small, wearable artefact.

Latex rubber, especially the thinnest kind, also has an attractive tactile quality when inflated. Its lighter weight makes it a more practical material than silicone to make medium-sized artefacts. However, the affective engagement it offers is not as intense as that offered by silicone. One reason for this might be because the inflated latex bears a resemblance to a balloon. With such familiarity the novelty of the sensory stimuli is reduced.

In terms of scale, silicone at a bodily, hand-held size is the most engaging in terms of scale and material. When used on small-scale artefacts such as hand-held objects, the sensation of touch by the hand is pleasant and makes one want to touch the artefact more. Some co-explorers attributed vulnerability to hand-held sized actuators. When used on objects on a bigger scale, however, the weight of silicone became impractical for air to actuate and there was an increased response of fear or threat.

In terms of movement, movements that seem natural, with a degree of unpredictability, are more engaging than movements that follow one rhythm and are predictable.

In terms of the mode of interaction, direct physical tactility generated stronger relationship projections. I found the tactile quality of the SPSR artefacts very appealing: when the soft gripper 'grabbed' my hand, it felt like a touch from a finger. The surface texture of soft silicone shares certain features of the skin. It is soft, smooth, and can quickly sync to skin temperature when it is touched.

In summary, when soft silicone material is used as direct surface material, its hand-held size and tactility are the most affect-enabling properties. I took artefacts with these properties into the next study.

### 4.3 Study 2. Co-exploration of the affective affordances of SPSR artefacts

In order to learn more about the affective affordance of the SPSR artefacts, I introduced a selection of the SPSR artefacts to two groups of co-explorers in face-to-face physical sessions. Informed by the previous study, the selected artefacts were of hand-held size, with soft silicone material as direct surface material. I collected their feedback through a self-reporting questionnaire.

The process, results from the questionnaire and preliminary discussion were reported in a presentation during the AISB 2019 Symposium on Movement that Shapes Behaviour (MTSB'19) in April 2019. The presentation was later published in the symposium proceedings (Zheng and Walker, 2019[6]). Here I provide a summary of this study.

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[6] The authors' contributions are as follows: I conceived the study, conducted data collection and analysis, drafted and edited the manuscript. Dr. Kevin Walker provided supervision and feedback on data analysis.

### 4.3.1 Process

#### 4.3.1.1 Co-explorers

The first group of co-explorers was formed of the same fifteen artists and designers who had participated in the 'Sentimental Soft Robotics' workshop at the Royal College of Art during the AcrossRCA programme. They were selected for the reason explained in section 4.2.1.5. The second group of co-explorers were nine participants from a workshop I hosted at the STATE Festival in Berlin. The workshop was titled: 'Extimacy! Wear your Heart on your Sleeve? Why not the Sofa and the Curtains?' The co-explorers were adult visitors to the festival. I chose the festival visitors as co-exploration participants first because these visitors were from a broader background than just artists and designers (as in Study 1), and second because, with the festival's title 'STATE OF EMOTION – The Sentimental Machine', the STATE Festival 2016 dealt with scientific and technological breakthroughs at the interface between emotional research and artificial intelligence as well as their social implications and possible future developments, and at the event visitors would be enthusiastic about sharing their thoughts and comments on the SPSR material. The recruitment was managed by the festival's organising committee.

From the above two groups of co-explorers, 24 participants returned the questionnaire. The ages of participants ranged from 18 to 49; half of the participants were between 18 and 29 and the other half between 30 and 49; fifteen designated themselves as female, seven as male, and two did not indicate their gender. This reflected that the affective response from more female than male participants were received. As the co-explorers were volunteers who were attracted to the themes and descriptions of these two workshops, these participants could have had more positive attitudes toward new technologies, which could have influenced their affective judgement about the SPSR artefacts. Another group of participants who were not enthusiastic about technology and design might have had a different response towards the SPSR artefacts.

My role in these sessions included the following. I introduced myself and my research to the participants. I facilitated the introduction of participants to each other. I introduced the tasks and administered the questionnaires.  To reduce the impact of my presence on the participants' feedback, the artefacts were presented on a table, so that the participants could initiate the contact without my mediation.

#### 4.3.1.2 Research artefacts

Four probing artefacts were presented to participants to interact with (Figure 4.12). These were selected from the artefacts I had made in the studio by that time, which are representative of the basic kinetic features of soft robotic actuators: expansion, contraction and bending (Laschi, Mazzolai and Cianchetti, 2016). These artefacts could be controlled manually by participants via a hand-squeeze bulb. Participants could freely touch and manipulate the artefacts in their hands or position them on their bodies. Participants were also encouraged to interact with each other using the artefacts.

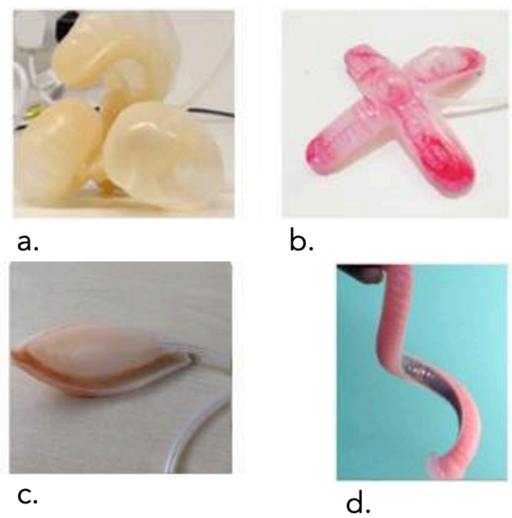

**Figure 4.12** Artefacts used for gaining feedback

Artefact a: a three-legged asymmetric soft robot in a pale, half-translucent skin shade. The image shows the artefact when it was inflated manually: each of the three legs took a different amount of air, forming a body which seemed more organic.

Artefact b: a ‘gripper’ (Shintake et al., 2018; Ilievski et al., 2011), a four-legged symmetrical soft robot, in a mixture of scarlet and translucent colours. When inflated, its four legs each took an equal amount of air.

Artefact c: a ‘leaf’-like shape, pale, half translucent skin shade, gentle inflation created a very subtle bending movement.

Artefact d: a tube-like robot, coloured warm pink. When inflated, it created a curling movement.

#### 4.3.1.3 The self-report questionnaire

The questionnaire (shown in Appendix 3) asked five questions:

1) How does the artefact make you feel?
2) With what property do you associate the feeling(s)?
3) Why does it (the artefact) evoke such a feeling?
4) Would you say it is a positive or a negative feeling?
5) How strongly does the artefact affect your feeling, 1 being no impact at all, 10 being most impactful?

As pointed out in Chapter 2 (section 2.1.4.2), descriptions of both emotions and affect were valuable for this research. The design of the questionnaire aimed to capture affective responses toward the SPSR artefact in words that describe emotion (as in question 1), in valence and arousal (as in question 4 and 5), and open-ended descriptive words (as in question 3), in relation to the elements of the material properties of the SPSR artefacts (as in question 2). In Question 1, 24 ‘emotion labels’ were taken from Plutchik’s (1980, Mondal and Gokhale, 2020) ‘Wheel of Emotions’. Participants could choose one or several labels to describe their subjective feelings about the artefact. If none of the labels applied, participants could choose ‘other’ and write their own emotion labels. Question 4 and 5 were adapted from the valence and arousal circumplex model (Russell and Barrett, 1999, Posner et al., 2005), which describes affect in valence and intensity.

The artefacts were placed on a table, and participants walked around and picked up any objects they wanted to interact with. The artefacts could be actuated by manually operating a hand-squeeze bulb.

#### 4.3.1.4 Procedure

Participants first familiarised themselves with the selected artefacts, they then selected one of the artefacts to interact with and completed the questionnaire.

### 4.3.2 Outcome and discussion

Table 4.1 shows the summary of participants' responses to the questionnaire questions, and Figure 4.13 shows the word cloud of responses to Question 1.

| | ***Question*** | ***Response*** |
|---|---|---|
| 1 | How does the artefact make you feel? | Figure 4.18 |
| 2 | With what property do you associate the feeling(s)? | 100% movement<br>75% surface texture<br>50% touch<br>17% other<br>8% sound |
| 3 | Why does it (the artefact) evoke such a feeling? | I identified six themes from the responses:<br>a. aliveness<br>b. novelty/uncanniness<br>c. tactile sensations<br>d. unpredictability<br>e. activeness<br>f. intentionality |
| 4 | Would you say it is a positive or a negative feeling? | 79.1% positive<br>8.3% neutral<br>4.2% mixed<br>4.2& negative<br>4.2% other |
| 5 | How strongly does the artefact affect your feeling? 1 being no impact at all, 10 being most impactful. | Mean value 6.58 |

**Table 4.1** Summary of responses to the questionnaire in Study 2 (adapted from Zheng and Walker, 2019, p.16)


**Figure 4.13** Word cloud of responses to Question 1. (Zheng and Walker, 2019, p. 16)

Most of the participants (79.1%) attributed positive emotions to the artefacts. Participants gave a mean value of 6.58 (out of 10) to rate how strongly they considered the artefact affected their feeling, indicating that the artefacts were affectively impactful. The emotion labels mentioned most frequently were 'joy', 'surprise', and 'interest' (Figure 4.13). Among the elements listed, movement and tactile stimuli were rated most highly in relation to their contribution to the association with an emotional response. This resonated with the findings from the material discovery in Study 1 (section 4.2.2). From participants' description of what they thought contributed to the evocation of emotional responses, I coded the textual answers from co-explorers with a simple thematic analysis (Braun and Clarke, 2006). I attributed six features of the soft robotic artefacts: aliveness, novelty, tactile sensation, unpredictability, activeness, and intentionality[7]. Interestingly, there was a juxtaposition of

[7] Detailed description of the six themes can be found in the paper Zheng, C. Y. & Walker, K. (2019) 'Soft grippers not only grasp fruits: from affective to psychotropic HRI', in Proceedings of the AISB 2019 Symposium on Movement that Shapes Behaviour (MTSB'19). April 2019 Falmouth University, UK: . pp. 15–18. [online]. Available from: http://aisb2019.falmouthgamesacademy.com/wp-content/uploads/2019/07/MTSB19_Proceedings_Reduced.pdf.

both positive and negative valence toward the same artefact: for example one co-explorer described the affective response to the artefact as *serenity, joy, sadness* and *terror* at the same time, and another chose the words *interest, joy, empathy* and *disgust* at the same time toward the same artefact.

### 4.4 Direction for subsequent exploration

Overall, my findings indicated that the modality of movement and tactility emerged as the most enabling features for affective intensity. Compared with movement, creating synthetic touch using SPSR material is an area which has been much less researched (section 2.7). Personally, I became more affectively enthusiastic about the topic of creating affective touch using SPSR material. Based on both the information from the affective responses to the SPSR artefacts and my own affective preference, my decision that emerged from this initial exploration of practice was to focus on positive affective touch as the chosen modality for small-sized, wearable artefacts, for the next stage of practice.

# Chapter 5 Exploration with a broad focus: SPSR material for affective touch

This chapter describes the second of the three practice phases, the exploration with a broad focus, from April 2017 to April 2018. The exploration investigated the most distinctive positive affective touch experience a silicone pneumatic soft robotic (SPSR) artefact could afford, and how to design tactile artefacts from SPSR material. It consisted of Studies 3 and 4. Following the AMI-led design framework, in Study 3 I conducted co-exploration in the form of a participatory workshop. The findings of Study 3 supported the affective potential of the SPSR artefact, informed the initial template (Version 0) of the Variables Map for Designing Affective Touch Artefacts using SPSR Material, and informed the subsequent direction of creating a modularised and personalisable research artefact. In Study 4 I designed and assessed a modularised and personalisable SPSR artefact for affective touch experience - AffectNode. Studio practice, co-exploration and assessment methods were used. The outcome supported the affectiveness of AffectNode and generated Version 1 and Version 2 of the Variables Map for Designing Affective Touch Artefacts Using SPSR Material.

## 5.1 Research sub-questions and methods

Informed and inspired by the findings from the previous phase of initial exploration, this phase focused on exploring designing SPSR tactile artefacts to enable positive affect. It addressed the following research sub-questions:

1) What positive affective touch experience does an SPSR artefact afford, and among these what is the most distinctive affective touch experience?
2) How can an SPSR artefact be designed to enable a positive affective touch experience?

It constituted two studies: Study 3, a workshop on creating a touching/hugging machine with soft robotics (Hugging Machine), and, Study 4, AffectNode – a modularised and personalisable artefact for affective touch design (AffectNode).

This phase of practice followed the Affect-, Material- and Interaction-led (AMI-led) design framework. In Study 3, co-exploration in the format of workshop was an implementation of the interaction-led approach. The participants' experimental making using SPSR material took a material-led approach. Both making and interaction were led by the participants' affective preference. In Study 4, I first carried out experimental making in studio practice, which was led by the material. The co-exploration implemented the interaction-led approach to facilitate the interaction between SPSR artefacts and co-explorers in order to enable the emergence of an affective preference for a future affective touch artefact. An assessment of the affective quality of the designed artefacts was an implementation of the affect-led approach.

## 5.2 Study 3. Workshop: Creating a touching/hugging machine with soft robotics

I used the method of a co-exploration workshop. The aim was to generate information and inspiration that would help to identify the kind of affective touch experience the SPSR material could best afford, as well as the mode of interaction and the form of such an artefact. The title of the workshop was 'Creating a Touch/Hugging Machine with Soft Robotics' (The 'Hugging Machine' workshop). The workshop was proposed to, and accepted by, the 13th Athens Digital Art Festival (ADAF), 18-21 May 2017. The festival invited 'artists to "transcend" digital culture and exchange opinions under the theme 'PostFuture'.[8] This theme fitted the wider context that the workshop intended to explore. The workshop was conducted on 20 May 2017.

[8]Quoted from the ADAF festival website: https://2017.adaf.gr/festival/, accessed 2 May 2019

### 5.2.1 Process

#### 5.2.1.1 Co-explorers

The workshop was set to accommodate between six and twelve participants. I considered that this number allowed a diversity of personal views, and between three and six groups could be formed to work on the creative project. This is also a size of group that enabled me to comfortably facilitate the workshop with the help of an assistant, enabling me to give each individual attention for their engagement and I was also able to assist with the making activity. The recruitment was handled by the ADAF Workshop & Talks Curator.[9] Ten participants, seven designating themselves as women and three as men, participated. Two participants were not present for the activity in Part 3 and Part 4; however, they illustrated their ideas and submitted their design for this activity. Demographic information was not collected but was observed. All participants were young adults and they introduced themselves as European students or professionals. Like the possible recruitment bias identified in the previous study (section 4.3.1.1), it was possible that participants attending the ADAF festival and who were attracted to the theme of the workshop would have a more positive attitude towards the SPSR artefacts, than participants who do not normally attend such events.

My role in this session included the following. I introduced myself to the participants. I moderated during the warm-up activity, where participants introduced themselves to each other. I briefed on the background of the workshop and introduced the tasks and materials for individual prototyping. During the prototyping activity, I talked with each group briefly to ask what their idea was and what the use case of their intended artefact would be. I assisted whenever they encountered any difficulties on using the materials to realise their prototype. I moderated the 'show & tell' session and group discussion. A workshop

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[9] The description of the workshop can also be found on the ADAF website: https://2017.adaf.gr/events/creating-a-touchhugging-machine-with-soft-robotics-workshop/

assistant helped with administering consent forms and questionnaires and creating documentation.

#### 5.2.1.2 The SPSR artefacts

The workshop was intended to offer a free space to allow people to generate their own subjective associations with the SPSR artefacts, and thus inspire their imagination about possible affective relations. Thus, instead of offering refined artefacts with pre-determined names and prescribed ways of interacting, the selected artefacts were made with vague properties, which open to interpretation by the participants. As shown in Figure 5.1, the probing artefacts used in this workshop included: a three-legged soft robot, four-legged soft robot both with automated actuation, a four-legged soft robot with a hand squeeze actuation, a 'curled one' with a hand-squeeze actuation and finally the 'Wiggling tail' with automated actuation. The forms of the three-legged, four-legged and the 'curled one' artefacts were the same as those used in Study 2 except that the first two had automated actuation in this workshop. The 'Wiggling tail' was a newly made artefact by myself and it represented a different actuating mechanism. I wanted to see if this mechanism could afford a positive affective response from the co-explorers.

**Figure 5.1** Probing artefacts used in the 'Hugging Machine' workshop. From left to right: three-legged robot, four-legged robot, four-legged with a hand squeeze, the 'curled one', and the 'wiggling tail'

#### 5.2.1.3 Questionnaires for capturing feedback

In Activity 1, on Questionnaire 1 (provided in Appendix 5), participants were asked the questions below and to respond to with their subjective opinions:

1) *What emotion(s) does it evoke for you?*
2) *Why?*
3) *What memories or experiences does it remind you of?*
4) *How do you feel about it?*
5) *How do you want it to interact with you?*
6) *Please identify and label the touch*.

With Question 1) and 2) I hoped to collect words relating to emotions. I asked Question 3) because often the physical elements in an experience, for example a remembered object, are informative or inspirational for conceiving the form of an SPSR artefact for affective touch experience. Question 4) allowed participants to describe affects that were still vague. Question 5) was to gather information on what might be a desirable mode of interaction for the SPSR artefact might be. Finally, Question 6) was for the participants to give a name to the touch they felt while interacting with the SPSR artefacts.

In Activity 2, Questionnaire 2 (provided in Appendix 6) was for participants to document information about the 'touching machine' they had made. The questions included:

1) *What is the experience?*
2) *How would you name this tactile experience?*
3) *Why is it important?*

#### 5.2.1.4 Material for making

Materials were provided for making a personal affective touch machine, as shown in Figure 5.2.

Participants could make use of any of the SPSR artefact in their projects. If they wanted to create forms that were different from the available SPSR artefacts, a variety of pliable materials were offered, e.g. balloons and latex. Participants could cut the latex into any specific shape of pneumatic actuator, and seal with the latex glue to make it inflatable. The 'personalised air pump' kit (Figure 4.11) enabled participants to create timed inflating behaviour. Additional air pumps and manual inflation squeeze bulb were provided. Miniature figures were provided to help imagine the relationship of the object to the body.

***Inflatable materials***
SPSR artefacts
The 'Personalised air pump' kit
Latex and glue
Balloons and manual balloon pump
Tubing
Additional air pump
Squeeze bulb for manual inflation

***For securing material together:***
Safety pin
Stapler and staples
Glue gun
Various sticky tapes
Strings
Velcro

***For cutting***
Craft scissors

***Relational material***
Miniature figures

***Other wearable material***
Textile of various textures
Wool and yarn
Feathers
Metal wires
Other craft accessories

**Figure 5.2** Material provided for co-exploration during the 'Hugging Machine' workshop

#### 5.2.1.5 Procedure

The workshop process is described in Table 5.1. Prior to the workshop, for the purpose of sensitisation (Visser et al., 2005), participants were asked (via email) to think of a personal object that evoked an emotional touch experience for them to bring to the workshop. This could be either the actual physical object itself or a picture of it, although a physical object was preferred.

| Time | Action | Data capture tool |
|---|---|---|
| 10min | Warm-up | |
| 10min | Brief introduction to the workshop and SPSR material | |
| 20min | Activity 1. Feeling the SPSR artefacts | Questionnaire 1 |
| 60min (with a break) | Activity 2. Prototyping a hugging/touching machine | Questionnaire 2 |
| 30min | Show & tell and group discussion | |

**Table 5.1** Schedule for the workshop Creating a Touch/Hugging Machine with Soft Robotics, 20 May 2017

During the warm-up, participants introduced themselves. They described a personal object that evoked an emotional touch experience for them. I then gave a brief introduction to the workshop and the SPSR artefacts. In Activity 1, participants were presented with the five SPSR material artefacts (Figure 5.1). Participants interacted with each of the artefacts freely, and they could also discuss the artefact with other participants. Each participant interviewed another participant on how they felt about each SPSR artefact and wrote their answer in the Questionnaire 1 (Appendix 5 and 7). This was to facilitate the dynamic flow among the participants so that they felt more comfortable working in a group. Following this, Activity 2 was a session independent of Activity 1. In this session, participants worked alone or together to imagine and prototype an interactive personal artefact for affective touch experience, using the materials provided (Figure 5.2). Participants documented their ideas and designs for their imagined objects in Questionnaire 2 (Appendix 6). In the final session participants showed and explained their objects to the rest of the group and the group discussed these concepts.

### 5.2.2 Outcome and discussion

#### 5.2.2.1 Affective response towards the SPSR artefacts

For the data from Questionnaire 1, I first put all the participants' responses about each artefact together (shown in Appendix 7). Observing this data, I felt that responses to questions 1), 2), 3), 4), 6) were words relating to emotions, affect, and the type of touch that participants used to describe the experience elicited by the SPSR artefacts. I decided to analyse the frequency of these words. I generated a list of words and their frequencies for each of the five artefacts, grouping the words into 'positive', 'negative', and 'neutral' valence. The lists for every artefact are shown in Figures 5.3~5.7. As mentioned earlier in the methodology chapter (p.65 final paragraph to p.66 first paragraph), these graphs (including Figure 5.8) are considered forms of visualisation of participants' feedback. They serve the purpose of informing and inspiring my design decisions to narrow down the research scope in terms of both conceptual and technical elements, rather than claiming to knowledge generalisable to population.

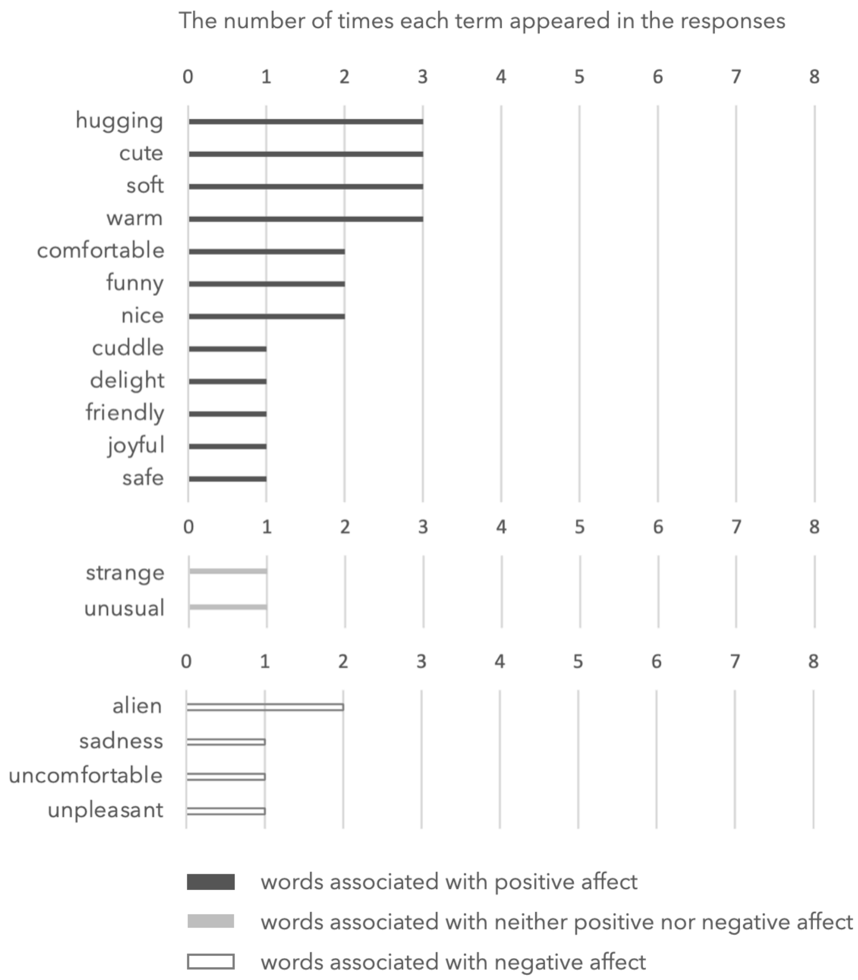


**Figure 5.3** Words used by co-explorers to describe the SPSR artefact: three-legged robot

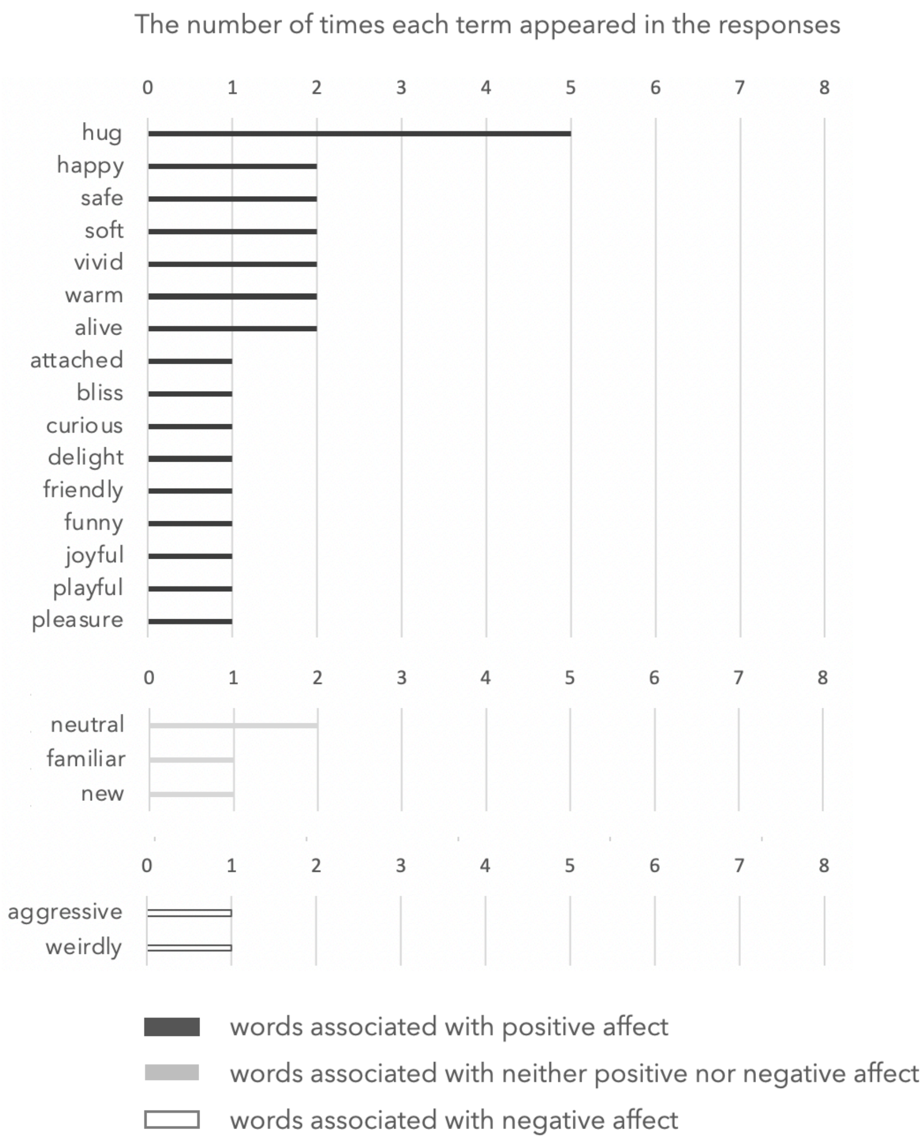


**Figure 5.4** Words used by co-explorers to describe the SPSR artefact: four-legged robot

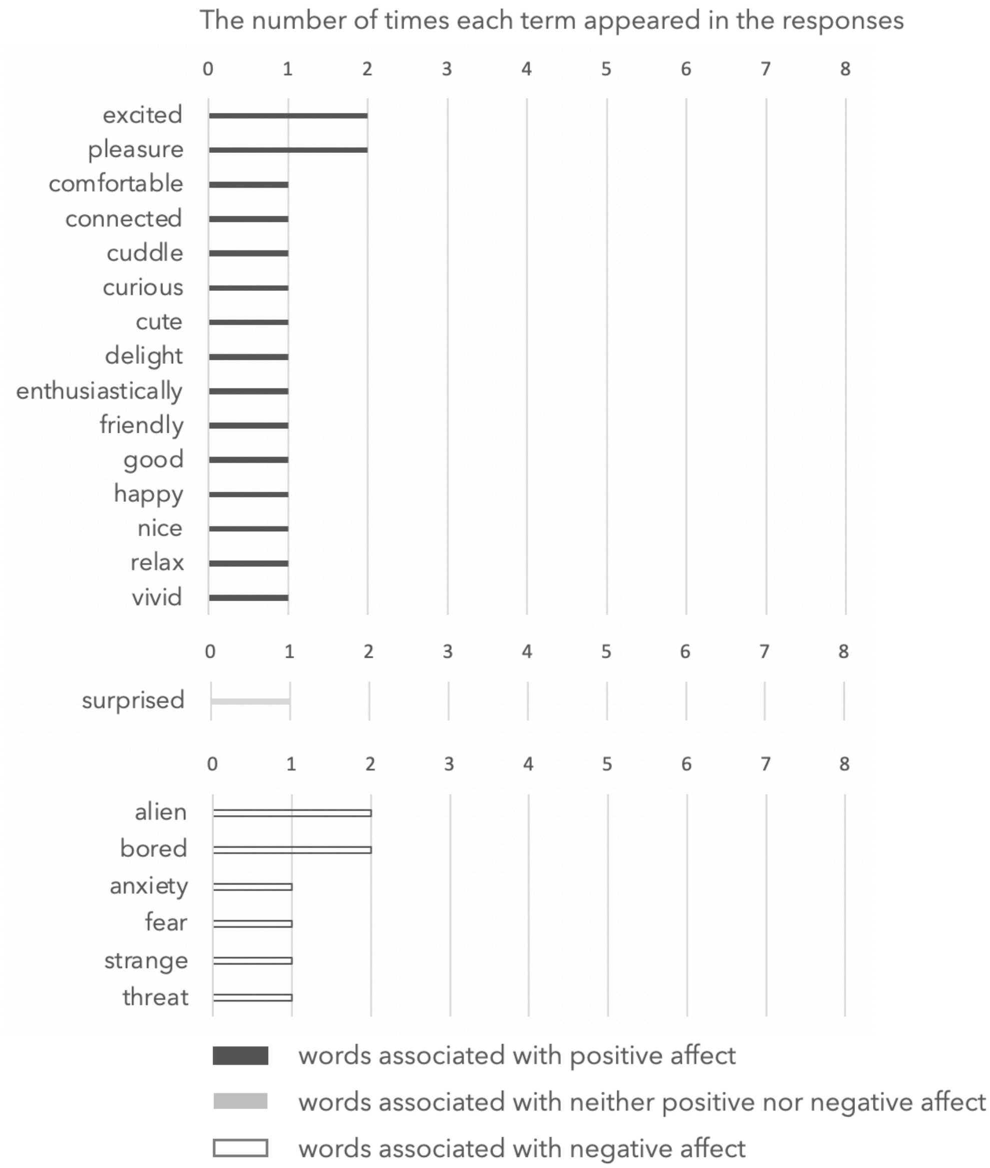


**Figure 5.5** Words used by co-explorers to describe the SPSR artefact: four-legged robot with hand squeeze

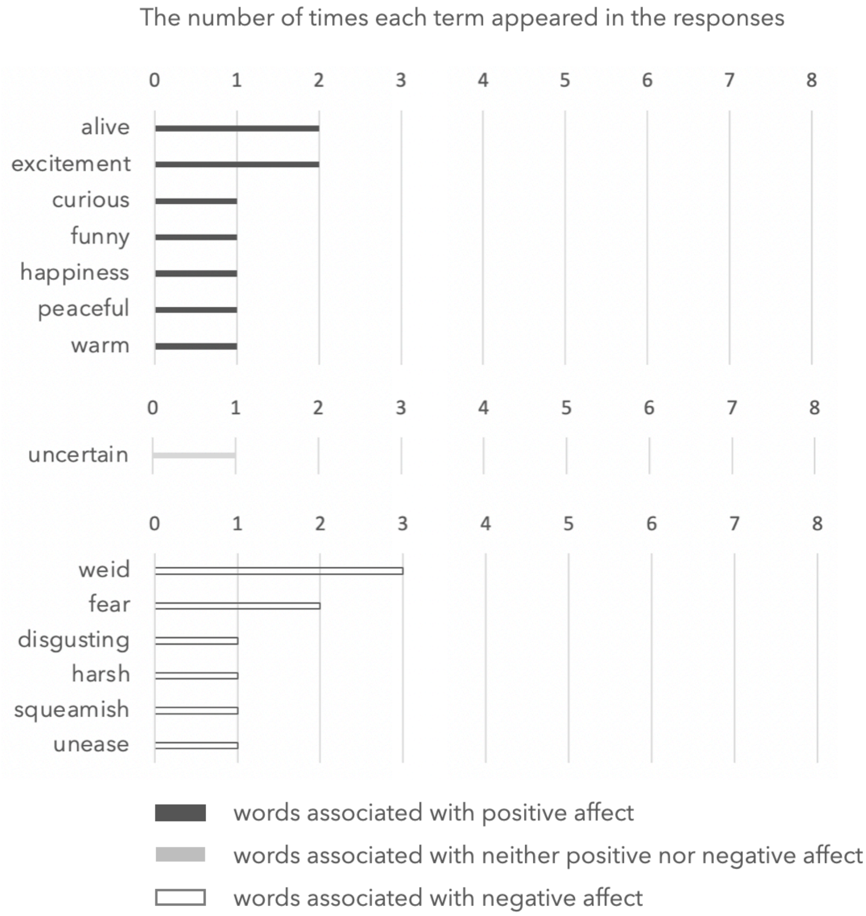


**Figure 5.6** Words used by co-explorers to describe the SPSR artefact: Wiggling tail

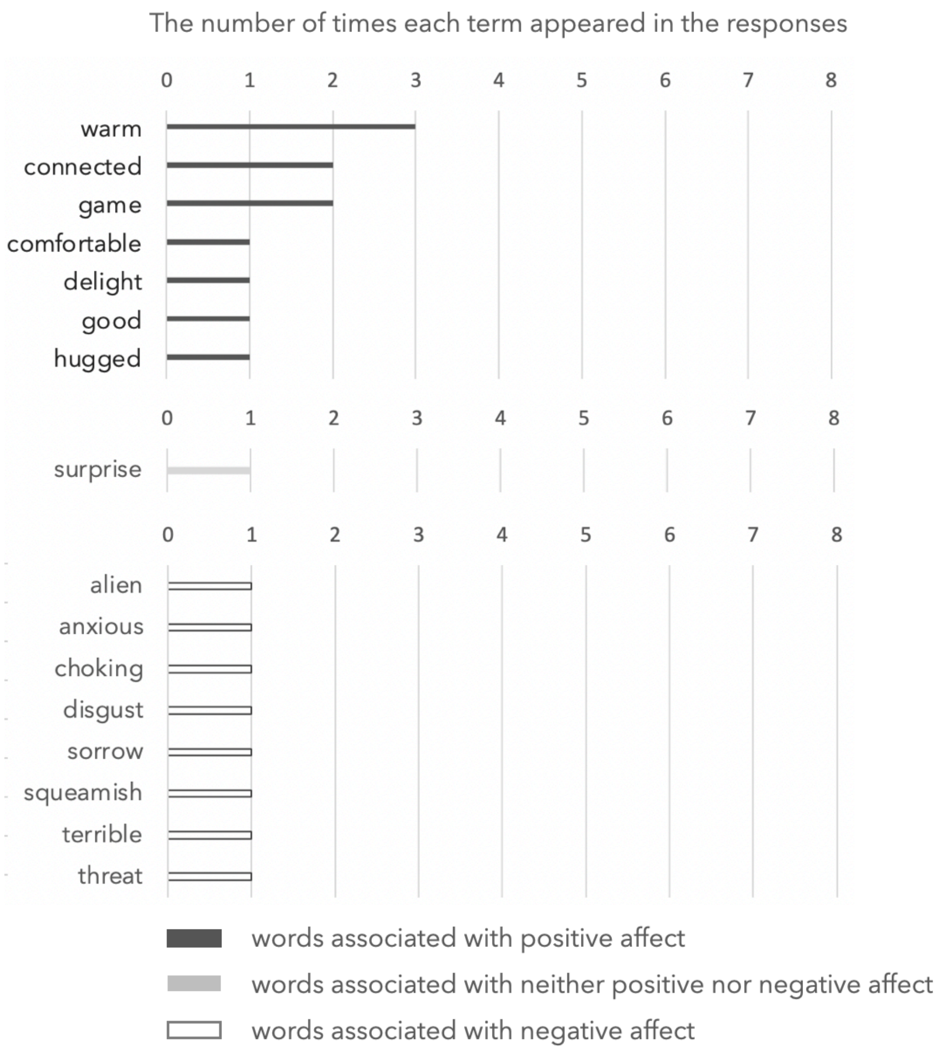


**Figure 5.7** Words used by co-explorers to describe the SPSR artefact: Curled one

I then correlated all 10 participants' responses to Question 5) 'How do you want it to interact with you?' to each artefact together, to form a small qualitative data set.

From these two sets of information, it showed that the 'wiggling tail' and the 'curled one' elicited a much higher proportion of negative affective responses, such as 'fear' and 'disgust', and most participants did not want an affective touch interaction with these objects. For example, in response to Question 5) regarding the 'wiggling tail' artefact, participants wrote that they wanted to:

> *' [remain] staring at it from a distance…'*

*'leave it'*.

And regarding the 'curled one' artefact, they wanted to:

*'touch it but not hug it',*

*'throw it',*

*'throw it to other people….'*

*'I don't want it to interact with me'*.

In comparison, the lists of word frequency and participants' responses to Question 5) for the other three artefacts were clearly associated with much more positive affect.

The negative affective response toward the 'wiggling tail' and the 'curled one' artefacts could have been due to their actuation mechanism. For example, the co-explorer who wanted to 'throw' the 'curled one' artefact described it as like a 'snake'. This can be related to the shape of the tentacle being a long tube: when actuated, it curled its body and wrapped around the co-explorer's hand, creating an association with a snake. Both the 'wiggling tail' and the 'curled one' artefacts shared a similar form which is a tentacle-like shape. The actuation mechanism was also similar in both, relying on force from inside to bend the tentacle from one side to another, although they differed in how the force was generated (a metal rod attached to a DC motor in the 'wiggling tail' artefact and pneumatic force in the 'curled one' artefact). Clearly, the tentacle form and its associated actuation mechanism in their current form did not contribute to enabling positive affect.

Although these two artefacts could well be a source of inspiration for designing for other types of affect associated with 'threat' or 'fear', they did not serve my research question at this stage, which was focused on the tactile properties that contribute to enabling positive affect. Thus I decided to discontinue working with the tentacle form and its associated actuation method in this project. I thus went on to continue analysing the other three artefacts. My evaluation process at this point had achieved what I needed: it allowed me to focus on some forms of artefact rather than others. To make predictions about how wider populations might respond to such artefacts, I would have needed more rigorous selection of participants and experimental protocols (such as I used later – see section 6.4). My purpose here was merely to eliminate some types of artefact in order to prioritise others within the timescale of the PhD.

I aggregated the words describing all the other three artefacts together and generated a list of words and their frequency, grouping them into 'positive', 'negative', and 'neutral' (Figure 5.8).

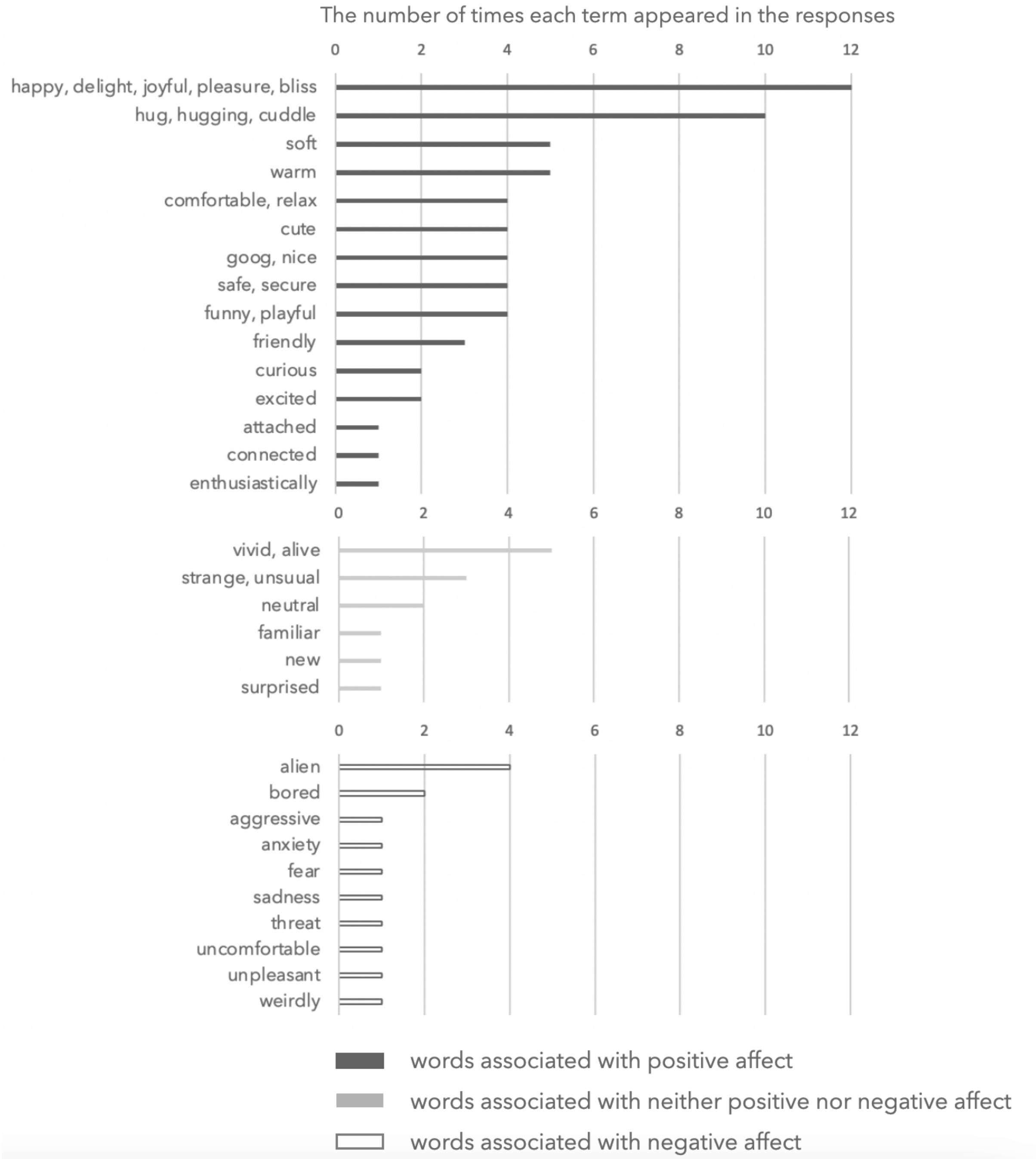


**Figure 5.8** Analysis of words used by co-explorers to describe the SPSR artefacts in terms of affect: three-legged robot, four-legged robot, and four-legged robot with a hand squeeze

In these results, both the variety of vocabulary and frequency of words indicating positive affect overwhelmingly outnumbered those indicating negative affect. There was a very rich vocabulary describing the experience of being touched by an SPSR artefact. There were also feature-describing words comparing the touch of an SPSR artefact to that of a baby, mother, pet, animal, insect, octopus, elf etc. There was a degree of novelty associated with the touch sensation from the SPSR artefacts, indicated by the words 'strange', 'unusual', 'new' and 'surprise'. The most frequently associated experiences were 'hugging' and 'cuddling', and the quality of the experience was described mostly as 'cute', 'warm', 'alien', 'comfortable', 'delightful', 'friendly', 'safe', 'happy', 'nice', 'vivid', and 'funny'.

#### 5.2.2.2 Prototypes for affective touch experience made by participants

For activity 2, five prototypes of personal objects for affective touch were created (three group projects and two individual projects). These prototypes are described below and shown in Figure 5.9 ~ Figure 5.13.

*Distant Whisper* (Figure 5.9) was a jewellery-like piece worn around the ear, enabling the ear to feel the transformation of the activity of talking/whispering/breathing into pulsating movement by the soft robotic artefact.

**Figure 5.9** Participant co-exploration project: *Distant Whisper*

*Social Breath/Chewing (*Figure 5.10) was a 'soft robotic chewing gum' intended to enable the experiencing of another person's chewing force. It was intended to offer stress relief and tactile communication, for communicating with and feeling the presence of friends and sharing experiences.

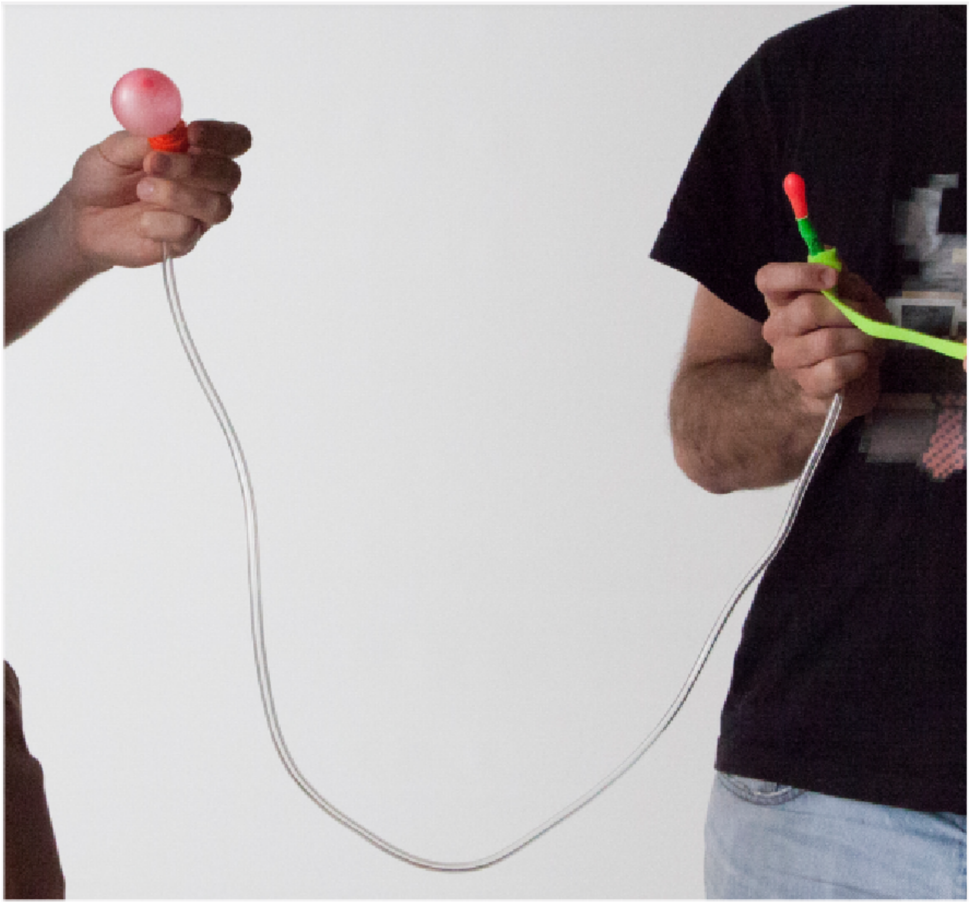

**Figure 5.10** Participant co-exploration project: *Social Breath/chewing*

*Inflatable 'Tickle'* was a 'neck belt' (Figure 5.11) with feathers. The participants who created this prototype explained that this was intended to produce an experience that is 'scary at first and then amazing', and to 'create happiness and smiles by tickling'.

**Figure 5.11** Participant co-exploration project: *Inflatable 'Tickle'*

Figure 5.12 shows a smart pillow that hugs, which was intended to calm the users when they experience a nightmare, and wake them up from it.

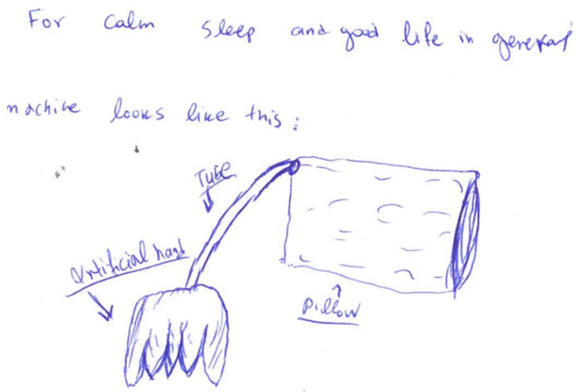


**Figure 5.12** Participant co-exploration project: *Smart Pillow*

*Wearable Hug/stroke* (Figure 5.13) was a mobile inflatable structure that was intended to fit any part of the body: the movement was designed be connected to the heartbeat or manually activated. This prototype was intended to help change people's feelings and make them feel more comfortable.

**Figure 5.13** Participant co-exploration project Wearable Hug*/stroke*

In the group discussion on the artefacts and scenarios created, participants started to discuss not only a 'one-to-one' situation but also the 'one-to-many' or 'many-to-many' modes of interaction, meaning that multiple parties could exchange physical contacts remotely or virtually. Speculations on what be beneficial applications might be and what could go wrong were initiated in the last few minutes of the workshop. However, none of the participants had a clear scenario in which to articulate the speculation in a more specific context.

#### 5.2.2.3 Discussion

All the participants' artefacts had the purpose of evoking positive emotions. The scenarios generated from the artefacts made by the participants included providing care (the *Wearable Hug/stroke* or the *Smart Pillow*), communicating emotional support (*Distant whisper*), mitigating emotions at times of stress (*Wearable Hug/stroke*), enjoying a fun and pleasant experience (*Inflatable 'tickle'*) and maintaining social bonds (*Social Breath/chewing*). These provided information for the first research sub-question of this phase of exploration (section 5.1) on the positive affective touch experience an SPSR artefact could afford.

In relation to the second research sub-question of this phase of exploration on *how an SPSR artefact can be designed to enable positive affective touch experience*, these outcomes informed a variety of design variables for creating affective touch experience using SPSR material. I mapped these elements out in Figure 5.14, to form an initial set (Version 0) of variables that are important when designing affective touch artefacts using SPSR material. I elaborate on the variables below.

In participants' personal projects, the parts of the body that participants chose for the artefacts to interact with included the mouth, ear, neck, belly, hand, arm, and head. Stimulating different parts of the body was associated with different meanings of touch, and it also affected the form of the artefact.

Technical factors that influenced or were influenced by the form of the artefacts included the application of force (a gentle touch, or a very tight squeeze), surface texture, the size of the artefacts and the touch patterns (e.g. among the personal objects made, the touch patterns mentioned included 'poking', 'grabbing', 'squeezing' and 'tickling').

Listening to and discussing with participants about their projects, it became apparent that questions about when the object might be used, with whom, and how the touch was triggered, were all important elements impacting the meaning of affective touch.

In term of the form element, the three-legged and four-legged soft robotic artefacts enabled overwhelmingly positive affect and the touch stimulation was most often compared with 'hugging' and 'cuddling'. Their actuating mechanism, which includes simple expansion to press against skin and a grabbing motion, could be adopted in future artefact design.

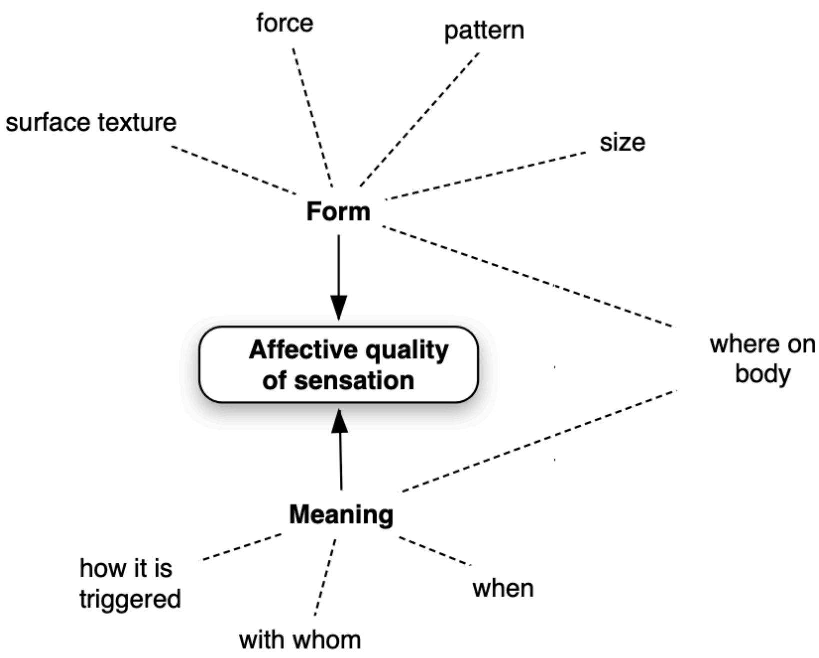


**Figure 5.14** Variables Map for Designing Affective Touch Artefacts Using SPSR Material - Version 0

The group discussion on the 'one-to-many' or 'many-to-many' modes of interaction, indicated that these scales of the remote exchange of physical contact are a completely new phenomenon, and there is no existing cultural reference to ground the imagination in relation to possible scenarios. This raised the issue of the potential ethical implications that should be considered when applying the interactive artefacts in a real-world context at a later stage. I reflect on the considerations of ethics in designing affective touch machine in section 7.2.

#### 5.2.2.4 Direction of subsequent exploration

As the research sought to understand the nature of positive affect, the curling mechanism and the tentacle form that were embodied in the two artefacts I identify as 'wiggling tail' and the 'curled one', which contributed to negative affect, were eliminated from the study at this stage. My practice instead focused on tactile mechanisms that enable positive affect.

To be able to design an SPSR artefact require the defining of almost all the variables. One major challenge of designing computational composites is the interdependencies of the form elements (Vallgårda, 2014, p.579). This means that change in one variable will result in the adjustment of all other variables. For example, placing the artefact on the wrist, and on the belly, require two sets of different definitions of all other variables: the surface texture, size of the body-contacting actuator, force and patterns that are perceived to be pleasant, when and how it is triggered, and with whom it interacts. Given the multiplicity of the variables, and their interdependence, it was sensible to reduce complexity on the form factor - starting from defining the most simplified form, in order to explore the knowledge of all other variables, through interacting with co-explorers. However, one simplest, fixed form can reduce the opportunities for designing. I realised that a good way to overcome this limitation was to make such a form modularised, enabling the same form to be multiplied and arranged in different ways, which offered the opportunity to create variable artefacts from the same form.

## 5.3 Study 4. AffectNode – a modularised and personalisable artefact for affective touch design

Building on the learnings from the previous study, this study thus undertook the task of choosing one form and developing a simplified, modularised initial artefact that allow the participants to personalise the rest of the parameters – namely the position it was worn on the body, when to use it, with whom it interacts, and how it should be triggered. It focused on the sensation of pleasant touch.

I conducted studio practice to make the artefact, called AffectNode. I then conducted one-to-one co-exploration with the artefact with six participants on the personalisation aspect of the artefact. Following this I assessed the affect affordance of one particular tactile stimulation generated from this artefact, on three body positions with 20 participants. Part of this study was presented at a workshop entitled 'Reshaping Touch Communication: an Interdisciplinary Research Agenda', during the ACM CHI Conference on Human Factors in

Computing Systems in Montreal, Canada, on 21 April 2018 (Zheng, 2018)[10]. I summarise the study below.

### 5.3.1 Process

#### 5.3.1.1 Designing the AffectNode artefact

I made a modularised, simplified form of soft actuator, called AffectNode (Figure 5.15 ~ Figure 5.16). AffectNode consisted of a wrist-worn inflatable silicone pad and a control board. The silicone pad expands when inflated and contracts when deflated. The surface material is EcoFlex™ 00-30, which produces a skin-like texture. The control board consisted of an Arduino microcontroller, circuits, electric pumps (as used in a blood pressure monitor) and exhaust valve, and a pair of buttons (Figure 5.17 ~ Figure 5.18).

**Figure 5.15** The modular, inflatable Node

**Figure 5.16** The inflatable artefact worn at different preferred positions of participants' hands (Zheng, 2018)

[10] The paper is archived on the workshop website, and can be downloaded from: https://intouchchi.wordpress.com/.

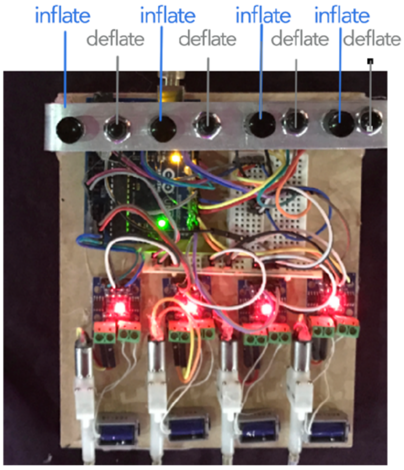


**Figure 5.17** The control board of AffectNode (Only one of the four channels is used in this experiment)

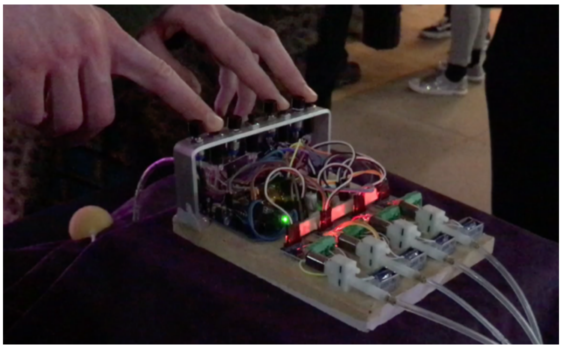

**Figure 5.18** Participants actuating AffectNode and AffectNodes2 remotely

The applied force and the touch patterns could be personalised by operating the buttons from the control board. I added this set of fixed and personalisable variables into the previous version of the Variables Map for Designing Affective Touch Artefacts Using the SPSR material to form an evolved version (Version 1) (Figure 5.19). The buttons were arranged as inflation and deflation controls. These two buttons can articulate four statuses: the 'inflate' status, when the inflate button was pressed continuously; the 'maintain inflated status', when the inflate button was released after being pressed, but no release button was pressed, the 'deflate' status, when the deflate button was pressed, and the 'maintain deflated status' when the deflate button is released after being pressed, but no inflate button was pressed. The touch patterns were recorded via a software programme developed in house[11], and could be played back through the AffectNode artefact.

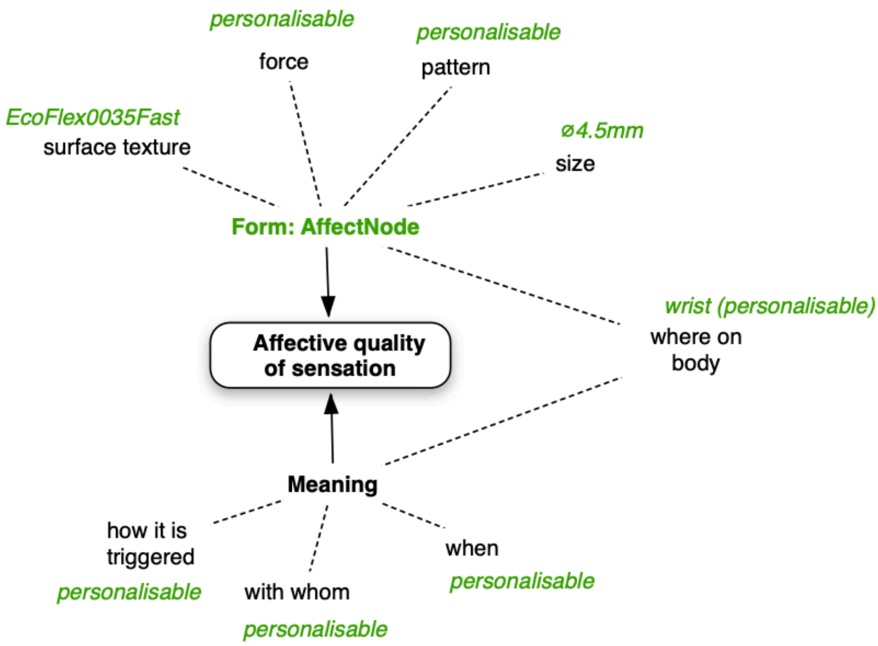


**Figure 5.19** Variables Map for Designing Affective Touch Artefacts Using SPSR material – Version 1 (The text in green colour shows the specifics of variable adopted for the AffectNode artefact)

AffectNode used only the expanding and contracting mechanism, which is one of the most basic movements of SPSR material (assessed in the previous study with the three-legged and four-legged soft robotic artefact). An AffectNode unit can be multiplied and arranged into different combinations of forms and touch patterns. For example, I made AffectNodes2 which was an artefact with an array of four such modular nodes, and the inflation and deflation of the node could be controlled separately to produce variable touch behaviours, including poking, tapping, stroking and squeezing (Figures 5.20 and 5.18).

[11] The software programme was developed in collaboration with Adrian Godwin.

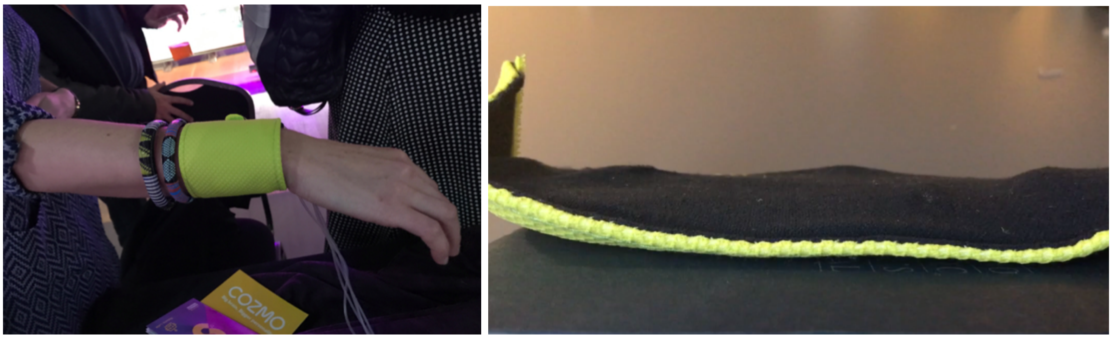


**Figure 5.20** The AffectNodes2 artefact

#### 5.3.1.2 Co-explorers

In the first part of the study, I worked with six co-explorers individually in a face-to-face setting. I used a small number of participants because AffectNode was an initial artefact with the concept of a modularised and personalisable unit. I needed to get a quick sense of whether this was the right direction towards a mature affect-enabling SPSR artefact. If it turned out to be the right direction, I would move to the next step; if not, I would need to readjust the artefact concept. This was also to gather information about which design variable(s) were most important in order to move to the next step of the practice. The co-explorers were members of London Hackspace, where I often conduct my making and mechatronic work. Two of the co-explorers were known to me and the other four co-explorers were unknown to me prior to this study. They were aged between 22 and 54, three women and three men, all from UK and European cultural backgrounds. The recruitment could have created bias, as that the members of the hackspace are generally passionate about new technology, which may have influenced their response to be more positive than those who are not members of a hackspace.

In the second part of the study, the administrator of School of Communication and School of Design within the Royal College of Art circulated the recruitment email among postgraduate students. 20 participants, including postgraduate students and visitors to the college degree show took part in giving their feedback. They were aged between 23 and 71 (mean age: 29.5). 17 defined themselves as female and 3 as male. Thus the outcome may infer more about the preferences of the female gender than that of the male gender.

My role in this study included the following. In a one-to-one setting, I introduced myself to each participant. I explained the tasks and presented the artefacts. I assisted each of the participants operating the artefact in the first part of the study and administered the stimuli in the second part of the study. I administered the questionnaire and made notes on participants' verbal feedback.

#### 5.3.1.3 Procedure

In the first part of the study, each of the six co-explorers first familiarised themselves with the operation of the button to 'design' their choice of touch sensation by articulating the inflation and deflation of the pad. I asked participants if there was any particular pressure and rhythm that felt pleasant. If the answer was yes, I helped them record this touch pattern through the software. I then asked participants when they would like to replay this tactile message and with whom they would like to interact. In this concept, the personalised behaviour pattern of the actuator could be collected, and also the corresponding context the participants refer to could also be identified.

In the second part of the study, I took the learning from the first part of the study, to test the AffectNode with a narrower set of parameters that I hypothesised would enable positive affective response from a majority of the participants. I devised one tactile pattern and invited each participant to give feedback on the pleasantness of this tactile pattern applied on three body positions, using an adaptation of Betella and Verschure's AffectiveSlider (2016) (Figure 5.21). The design of the tactile pattern incorporated learning from the first part of the study, that a repeated pulsating such as a heart-rate-like pattern, is considered by most participant as pleasant (see section 5.3.2 below). However, the technical constraints prevented me from creating tactile beats as fast as an average human heart rate which is 60-100bpm (NHS UK, 2018); it was only possible to produce a rate of lower than 30bpm. After trying various pulsating rate, I applied my own affective judgement to select a pulsating rate that I perceived the most pleasant: pulsating at 20bpm with a pattern of 1000ms for 'inflate' status, 800ms for 'maintain inflated' status, 800ms for 'deflate' status and 1200ms for 'maintain deflated' status, as this rate felt like calm breathing. Consulting the literature, I found that this was coincident with the breathing rate of dogs, which is15-30 breaths per minute (VCA Animal Hospital, n.d.). Research has shown that shape-changing artefacts applying tactile stimulations at this rate against human skin can be perceived as relaxing (Yohanan and MacLean, 2011). This 'breathing' tactile pattern thus was used in the assessment. Each participant experienced the same tactile stimulation twice for each body location. After each stimulation, they gave their rating of the pleasantness on the AffectiveSlider. The three body positions were first on the inner side of the wrist, then on the outer side of the wrist, and finally on a preferred (personalised) position. According to the findings from the previous part of the study (section 5.3.2.1 below), the force that felt pleasant at different body positions can vary greatly; thus I only offered participants the opportunity to personalise the position within the small area around the wrist, arm, or hand. Participants can only choose a preferred position after they experienced both the inner and the outer side of the wrist. The sequence of the inner and outer side positions was not randomised, thus it was possible to enable a 'sequence' effect (Acheson, 2010).

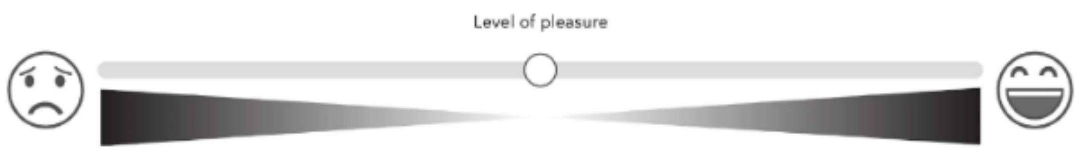


**Figure 5.21** Adaptation of the Affective Slider (Betella and Verschure, 2016), ranging from 0-1, divided by 100 increments, the left extremity is a score 0 being the most unpleasant feeling, and the right extremity is score 1, indicating the most pleasant.

### 5.3.2 Outcome and discussion

#### 5.3.2.1 Outcome

In the first part of the study, within 10 minutes of interacting with AffectNode, each participant successfully identified at least one touch pattern that felt pleasant. I recorded their personalised version of this pleasant touch pattern, visualised in Figure 5.22. This data was anonymised at the time of collection and cannot be traced back to the individual participants.

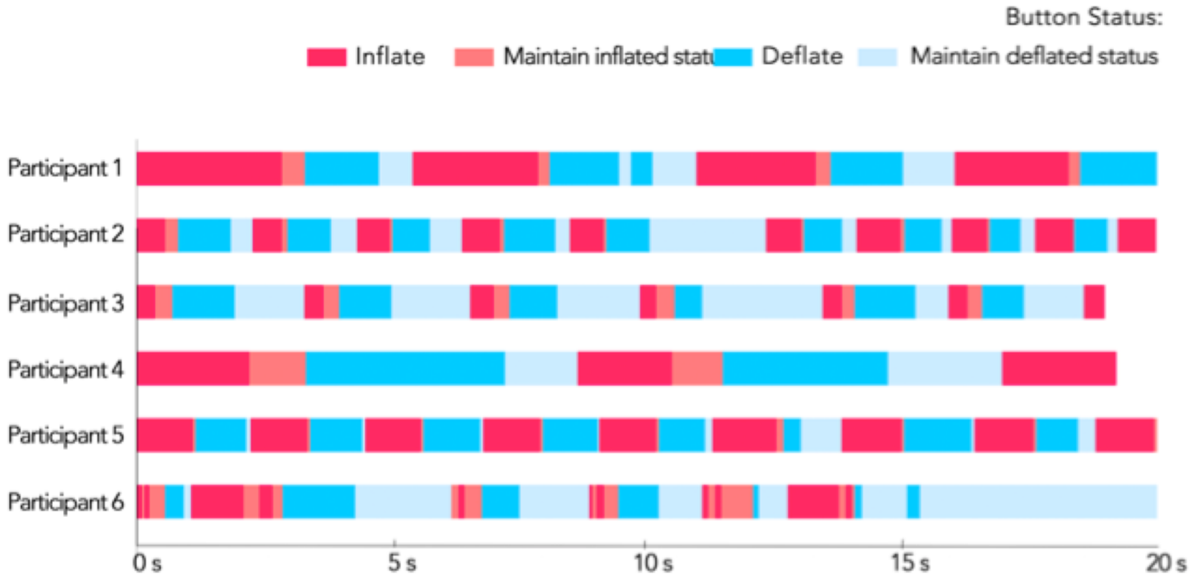


**Figure 5.22** Personalised touch patterns from participants (Zheng, 2018)

The force level that participant found pleasant differed significantly: e.g., when the pad was a quarter-, half- and fully inflated, and when it was excessively inflated. Half the participants related a pleasant sensation to the rhythm of a calm breathing rate. In terms of touch patterns, five out of six participants preferred a repeated pattern, while one participant favoured an irregular pattern. It turned out that different body positions have very different touch differentiation thresholds. For example, one participant configured a pleasant force setting when putting the artefact around his wrist. He then put the artefact around his neck and found it needed a much lower force to feel pleasant.

Responses were highly individual when we discussed when to use the touch patterns, which included 'before going to sleep', 'during meditation', 'when feeling stressed' and 'when feeling relaxed', and 'at any time'. Equally, the highly individualised responses to the question of whom the participants would like to interact with ranged from the participant him/herself to family and friends and partners. While two participants said that what made the interaction meaningful was the feeling of being connected with another person, three mentioned that they would prefer to interact with the artefact themselves in moments of stress.

For the second part of the study, Table 5.2 shows the pleasantness ratings of the 'breathing' tactile stimulation from the AffectNode artefact. The values include the individual and group mean values of each body position and across three positions.

| Participant | Position 1 (Average of 2 ratings) | Position 2 (Average of 2 ratings) | Position 3 (Average of 2 ratings) | Preferred position | Individual mean rating |
|---|---|---|---|---|---|
| 1 | 0.58 | 0.62 | 0.63 | A | 0.61 |
| 2 | 0.64 | 0.68 | 0.66 | B | 0.66 |
| 3 | 0.6 | 0.39 | 0.57 | B | 0.52 |
| 4 | 0.67 | 0.79 | 0.38 | A | 0.61 |
| 5 | 0.96 | 0.63 | 0.86 | A | 0.82 |
| 6 | 0.75 | 0.85 | 0.78 | C | 0.79 |
| 7 | 0.78 | 0.17 | 0.76 | A | 0.57 |
| 8 | 0.62 | 0.78 | 0.89 | A | 0.76 |
| 9 | 0.78 | 0.88 | 0.89 | B | 0.85 |
| 10 | 0.29 | 0.56 | 0.63 | D | 0.49 |
| 11 | 0.79 | 0.6 | 0.82 | C | 0.74 |
| 12 | 0.76 | 0.77 | 0.87 | A | 0.80 |
| 13 | 0.86 | 0.69 | 0.82 | E | 0.79 |
| 14 | 0.56 | 0.6 | 0.81 | E | 0.66 |
| 15 | 0.34 | 0.49 | 0.74 | E | 0.52 |
| 16 | 0.83 | 0.65 | 0.84 | A | 0.77 |
| 17 | 0.29 | 0.62 | 0.69 | F | 0.53 |
| 18 | 0.61 | 0.61 | 0.85 | G | 0.69 |
| 19 | 0.73 | 0.5 | 0.67 | A | 0.63 |
| 20 | 0.5 | 0.6 | 0.6 | B | 0.57 |
| **GROUP MEAN** | **0.65** | **0.62** | **0.74** | | **0.67** |

**Table 5.2** Individual and group mean pleasantness ratings of the stimulations from the AffectNode artefact (Position A: inner wrist; Position B: outer wrist; Position C: side wrist; Position D: outer forearm; Position E: palm; Position F: inner upper arm; Position G: inner forearm

Averaging the ratings of three positions given by each participant, except for one individual mean rating that was slightly below a rating of 0.5 which was on the unpleasant side of the scale, the individual mean ratings given by all the other 19 participants were above 0.5 which were on the 'pleasant' side of the scale. Participants gave six preferred body positions around the hand, wrist and arm, as shown in Table 5.2.

#### 5.3.2.2 Discussion

First, in the first part of the study all the participants successfully identified, within a 10-minute interaction with AffectNode, at least one set of haptic patterns that evoked pleasant feelings. In the second part of the study, 19 out of 20 participants found the haptic stimulations pleasant. This result supported the potential of this material to produce affective touch with positive valence and demonstrated a manageable set of design parameters. The group mean value of the preferred position is higher than the two default positions, although the positions varied greatly. I interpreted this as that giving a choice of personalisation can contribute to the affect-enabling capacity of an interactive artefact.

Secondly, the feedback informed the direction of improvement in terms of the technical configuration of some of the variables for the temporal form, namely to reduce the flow rate, and the noise. Most participants expressed the view that the sensation would feel more pleasant if the pad was inflated and deflated more slowly, and they felt rather negative towards the noise from the pump and valve operating. The inflation and deflation speed here referred to the slow rising and slow decreasing of the pad, so that it exhibited behaviour similar to contacting human skin with slowly increasing force. In this artefact this could be achieved by reducing the flow rate: that is, the amount of air passing through the tubing in a given time. Noise was produced by the air-supplying pump and the valve opening and closing. Apparently, these sounds contributed negatively to the pleasantness of the touch experience. I incorporated this learning into revising the 'Variables Map for Designing Affective Touch Sensation Using SPSR Material' to produce Version 2 of this model (Figure 5.23). The orange highlighted parameters are novel learnings from this study. Subsequent work was needed to address these two factors in order to improve the affective quality of the touch sensation enabled by the SPSR artefact.

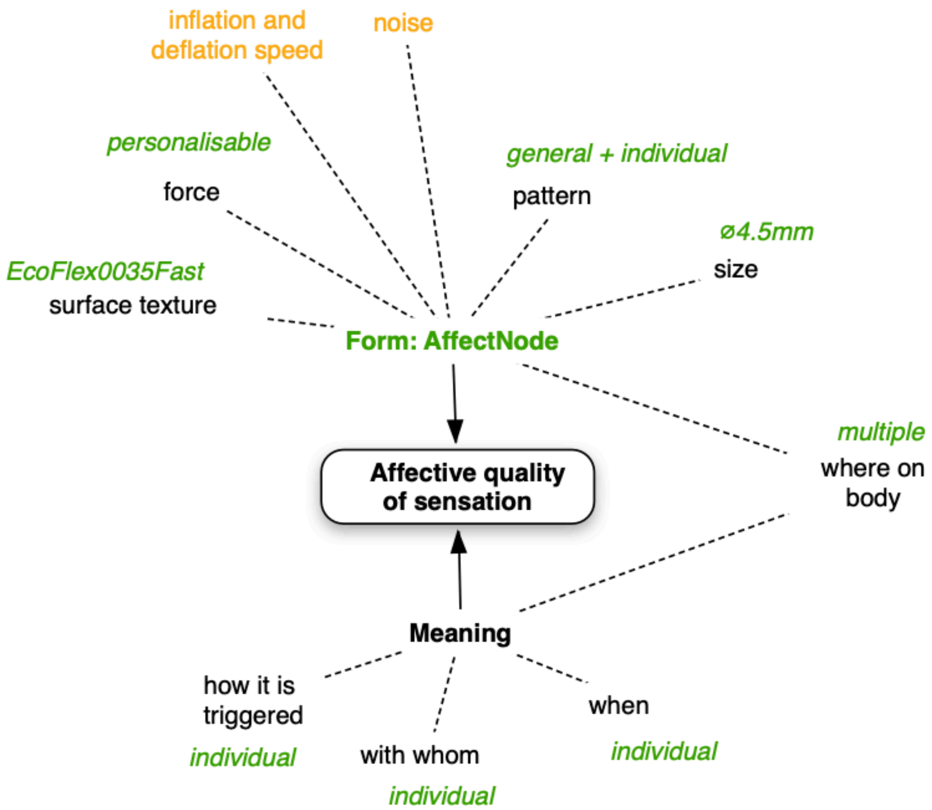


**Figure 5.23** Variables Map for Designing Affective Touch Artefacts Using SPSR Material – Version 2 (The orange highlighted variables are added as learnt from Study 5)

Thirdly, the feedback brought my attention to distinguishing between innate affect and learned affect, and that being able to enable the innate affect can be the most distinctive affective touch experience that SPSR material affords.

In the first part of the study, half the participants found pulsating and repetitive patterns, such as a heartbeat, pleasant. In particular, all but one participant considered the repetitive pulsating tactile pattern in the second part of the study pleasant. I recalled that in Study 3, the 'Hugging machine' workshop, participants described the characteristics of touch sensations from the SPSR material as 'comfortable', 'soft', 'safe' and 'warm', and associated touch from the SPSR artefacts to a baby's touch, or a mother's touch (See section 5.2.2). On the other hand, there was a highly diverse pattern in the social elements – e.g. when to use it and who to interact with – that affected individuals perceiving a touch sensation as pleasant.

The above distinction made me aware that there can be two types of positive touch sensations: one type evokes a kind of primal, innate affect, such as that of a heartbeat, and this preference was shared among the participants of different ages and backgrounds. Another type is related to the social elements, and involves interpretation through the lens of social, cultural and personal memory, and is highly diverse.

This awareness prompted me to consult the relevant literature, which was presented in section 2.7. I summarise the brief points as below.

- My awareness of the difference between innate and social aspects of affective touch resonated with the literature in the field of modern neuroscience on affective touch and discriminative touch (McGlone et al., 2014). Affective touch connects to a primal, innate process while the meaning of discriminative touch involves a learning process (McGlone et al., 2014). Discriminative touch can also be associated with as social touch (Huisman, 2017). CT-optimal touch, or a gentle stroking touch satisfying a set of attributes of velocity, temperature and pressure is considered to be most enabling of pleasant sensation (second paragraph, section 2.7.1).
- In the field of interaction design, there is a lack of research on creating the experience of being affectively touched using pneumatic soft actuators, and there has been no research with the aim of exploiting all three attributes of CT-optimal affective touch. Section 2.7.2 included a detailed review on this gap. Thus, exploring innate affect contributes to the space of affective interaction design.

Fourth, it is important to clarify that, although the innate affect and social affect can refer to different types of touch, they can also refer to the innate aspect of affect and social aspect of affect of the same touch. For example, in my Variable Map for Designing Affective Touch Artefacts Using SPSR Material – Version 2 (Figure 5.23), the design variables of temperature, velocity and applied force of the SPSR artefact are related to and determined by the innate aspect of affect while the variables 'how it is triggered', 'with whom', 'when' are social factors of touch, that are related to and determined by the social aspect of affect. There is no doubt that when deploying the SPSR artefact in a real-world application, we need both the sensorial and social quality for a machine-produced touch stimulation to afford a holistic experience. However in the design exploration stage, they could be explored separately to allow the extraction of knowledge about each aspect more precisely and effectively (Lim et al., 2008, p.7:3).

Fifth, the attributes of CT-optimal touch that relate to velocity, temperature and pressure provided knowledge about parameters of an affective-enabling touch stimulation that I was able to use in configuring the SPSR artefact. And technically, based on the knowledge I had gained so far from designing and making artefacts with SPSR material, it was highly possible that these parameters of CT-optimal touch could be achieved through refining AffectNodes2.

## 5.4 Direction for subsequent exploration

Given the constraints of time and resources, I chose to focus on working on the sensorial qualities that enable innate affective touch. In particular, I decided that the defined focus for the next, and final, phase of exploration was to design an artefact using all three parameters of CT-optimal affective touch - velocity, temperature and pressure. There were a number of reasons for this decision: the outcome of my studies had shown that the SPSR material has strong potential to enable innate positive affect; I now had useful knowledge about parameters of CT-optimal touch and the technical feasibility of configuring the SPSR artefact to achieve these; there is much less research on designing material qualities to enable innate affective experience than on the social aspects of experience (as indicated above and detailed in section 2.7.2) thus the learning from this practice would address a gap in knowledge.

# Chapter 6 Exploration with a defined focus: designing and evaluating a soft robotic CT-optimal Affective Touch (S-CAT) device

This chapter describes the exploration carried out with a defined focus on designing a soft robotic device that exploits the velocity, temperature and pressure of a CT-optimal affective touch – S-CAT device. I report on Study 5 – the making and evaluation of the S-CAT device. I made the S-CAT device through studio practice. I detail the experimental process to enable the S-CAT device to achieve various stroking velocities, applied force and temperature within the range of CT-optimal touch. The evaluation of the device was a lab-based experimental study and I conducted it through collaboration. With 22 participants, we compared subjective ratings of pleasantness and intensity, neurophysiological responses, and qualitative comments about touch stimulation at CT-optimal and non-CT-optimal speeds, performed by the S-CAT device (robot touch), skin-to-skin touch (human touch) and a widely used affective touch stimulator (brush touch). The results suggested that the affective touch stimulation delivered by the S-CAT device provides comparable pleasantness to that elicited by brush stroking, and that slow velocities can lead to stronger feelings of subjective pleasantness than fast velocities, as in skin-to-skin touch and brush stroking. With this outcome I achieved my Research Aim 2. Learning from this process was incorporated into the Version 3 and Version 4 of the Variables Map for Designing Affective Touch Artefacts Using SPSR material (for CT-optimal touch).

### 6.1 Research sub-questions and methods

This phase focused on designing CT-optimal touch with SPSR material. It was led by two research sub-questions:

1) How can an SPSR artefact be designed to deliver CT-optimal touch?
2) How affective is it?

The first question was explored through studio practice of making in which the artefact, an S-CAT device, was designed and constructed. The second question was addressed through assessment, by the method of lab-based experimental study through collaboration with KatLab at University College London (UCL), which is one of the leading research labs in the UK for the neuroscience and psychology on affective touch. Thus the affect- and material-led approach from my design framework were implemented.

## 6.2 Configuration of CT-optimal affective touch behaviour, and the development of the S-CAT device

### 6.2.1 Design parameters

The S-CAT prototype aims to achieve the following specific parameters of CT-optimal affective touch (the parameters were mentioned in section 2.7.1 which I repeat here for convenience):

- at a velocity of 1-10cm/s (Ackerley, Carlsson, et al., 2014; Löken et al., 2009; Mountcastle, 2005)

- with an applied force of around 0.22-0.5N (Ackerley, Carlsson, et al., 2014; Manzotti et al., 2019; McGlone et al., 2007; Pawling et al., 2017; Trotter et al., 2016; Vallbo et al., 1999)

- at approximately skin temperature (Ackerley, Backlund, Wasling, et al., 2014)

CT-optimal touch is a stroking touch in which the touch stimulator makes a sweeping or tracing movement across the skin. I continued to use the concept of the AffectNodes2 prototype (Figure 5.20), which is an array of cells inflated in sequence: when actuated in a linear sequence, a rippling effect is produced. Incorporating the above design parameters, I developed Version 3 of the Variables Map for Designing Affective Touch Artefacts Using SPSR Material (for CT-optimal touch), shown in Figure 6.1. The variables coloured in orange were identified for this study to produce the most favourable set of combinations to produce a caress-like stroking touch that satisfies the key attributes of CT-optimal touch noted above, in addition to response to the learning from the previous study, namely noise reduction and reducing the flow rate.

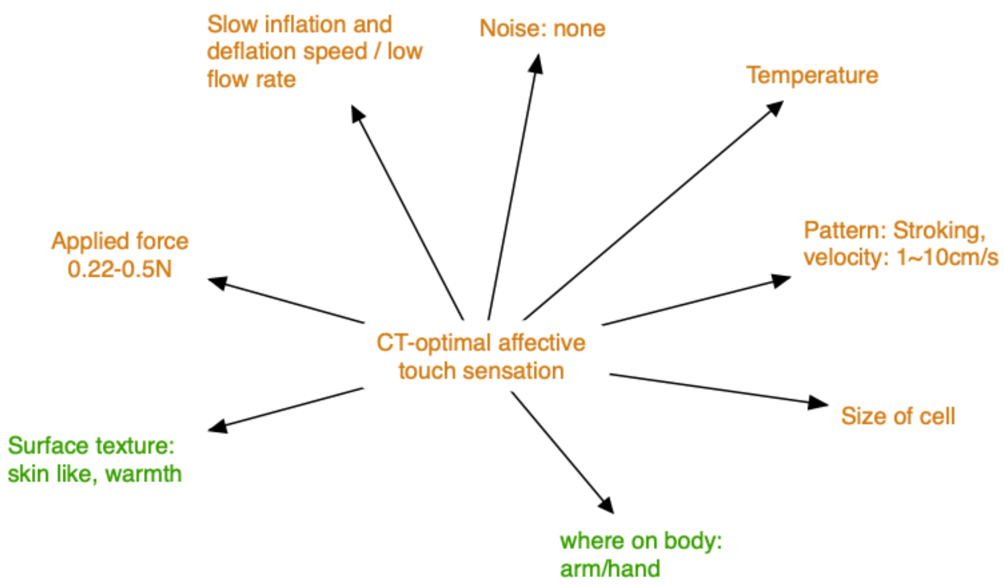


**Figure 6.1** Variables Map for Designing Affective Touch Artefacts Using SPSR Material – Version 3. This map excludes the social aspect of affective touch and focuses on the innate aspect of affective touch (for CT-optimal touch)

The S-CAT artefact consisted of the actuator, the hardware set made up of an air supply (e.g. a pump), air regulation (e.g. valves), microcontrollers (e.g. an Arduino board), and the codes to control the system. I describe the design of the touch behaviour below.

### 6.2.2 Dimension

As the studies on CT-optimal touch were undertaken by stimulating the outer side of the arm (e.g. von Mohr et al., 2017), this artefact took the form of an armband. The width of each cell is 10mm. Cells narrower than this size were extremely hard to inflate, as the surface was too tense, and their sensation on the skin felt more rigid than soft. The width of the actuator, which is also the length of each cell (Figure 6.3) was set at 70mm, is the dimension of the area of contact with the skin when a stroking gesture was performed (Figure 6.2).

**Figure 6.2** Performing stroking on mannequin arm to determine dimension of actuator

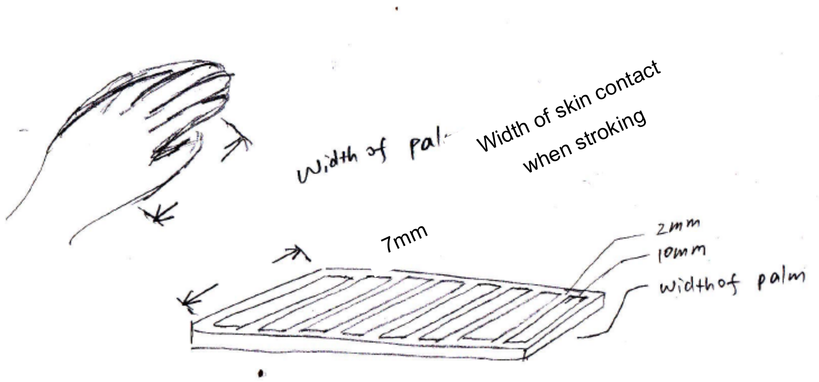


**Figure 6.3** The dimensions of the actuator of the S-CAT device for hand stroking

### 6.2.3 Velocity of stroking

Figure 6.5 is an illustration of the actuator when it is not actuated and when it is actuated in motion. There is an overlap between the inflation of adjacent cells, as in the lower image in Figure 6.5. [redacted]

[redacted]

The stroking velocity is the speed with which the sensation of affective touch moves across the body of a user. The stroking velocity is the rate of propagation of the cells being inflated and thus pressing upon the body, one point after another. The stroking velocity (v) can be calculated by using the distance between the centres of two adjacent cells (d) divided by the time lag between the inflation of two adjacent cells:

$$T_1: v=d/T1$$

$T_1$ can be set via codes that control the opening time of the valve connected to the cell.

For example, in Figure 6.3, the width of each cell is 10mm, and the wall between two adjacent cells is 2mm thick: thus the distance between the centres of two adjacent cells (v) is 12mm. With a time lag between the inflation of two adjacent cells $T_1$ being 200ms, the velocity of stroking would be: 12mm / 200ms = 6cm/s, as shown in the coding to control inflation and deflation behaviour (here $T_1$ is referred to as 'travel delay').

### 6.2.4 Perceived continuity of stroking

This is a new variable, found to be of key relevance to creating a stroking touch using the rippling effect of an array of actuators. The smaller the gap between the centres of two contact adjacent cell (d), the more it felt a continuous stroke. In AffectNodes2, the two adjacent cells are still too wide, making the gaps between them clearly perceptible. To improve this, I minimised the spacing between two adjacent cells to 2mm, as shown in Figure 6.3. This was the narrowest that can be enabled by silicone material (Ecoflex™ 00-35 FAST). This is also the smallest thickness that can be achieved from the mould manufactured by my 3D printer (Flashforge Creator Pro). In other words, I was working at the limits of both the material and the technology accessible to me.

The overlap time reduces the interactant's impression that the cells are being individually operated and enhances the sensation of a continuous stroking motion. It is not possible to eliminate the gap between two separate ripples using this rippling method, no matter how close the adjacent cell is (v) and how short the interval between the actuation of the adjacent cell ($T_1$). However, according to research, minimal interruption in the continuity of touch can be made up by human perception (Geldard & Sherrick 1972, Seizova-Cajic & Taylor, 2014).

Manipulating the temporal form (Vallgårda, 2014) also contributed to improve perceived continuity. This included experimenting with different combinations of inflation time, holding time, deflation time, travel delay time ($T_1$) through codes, the flow rate control which influences the inflation time and felt pressure, as well as the different surface silicone materials with a variety of tensions (including Ecoflex™ 00-30, 00-35 FAST, 00-50, Mouldlife Transil 20). The best continuity is with the coding combination shown in Figure 6.7, which is at a velocity of 6cm/s, using Ecoflex™ 00-35 FAST as a surface material. For velocity slower than 6cm/s, the perceived continuity began to be compromised.

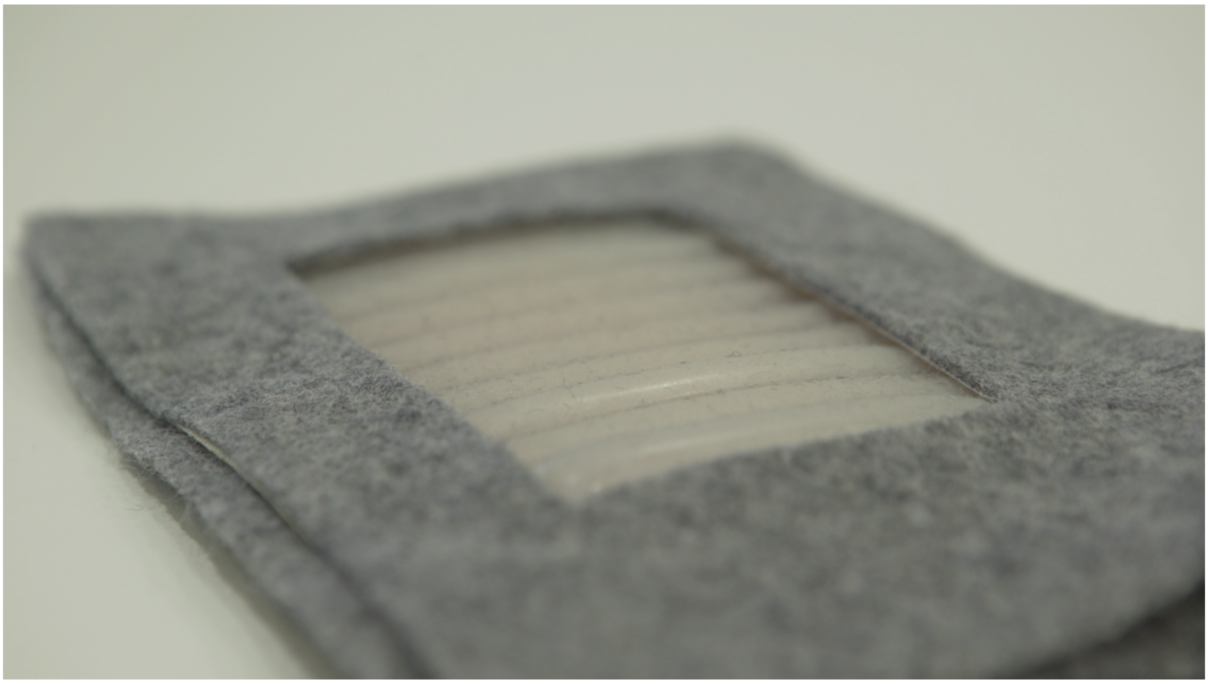

**Figure 6.4** The skin-contacting side of the S-CAT device (actuator embedded in textile)

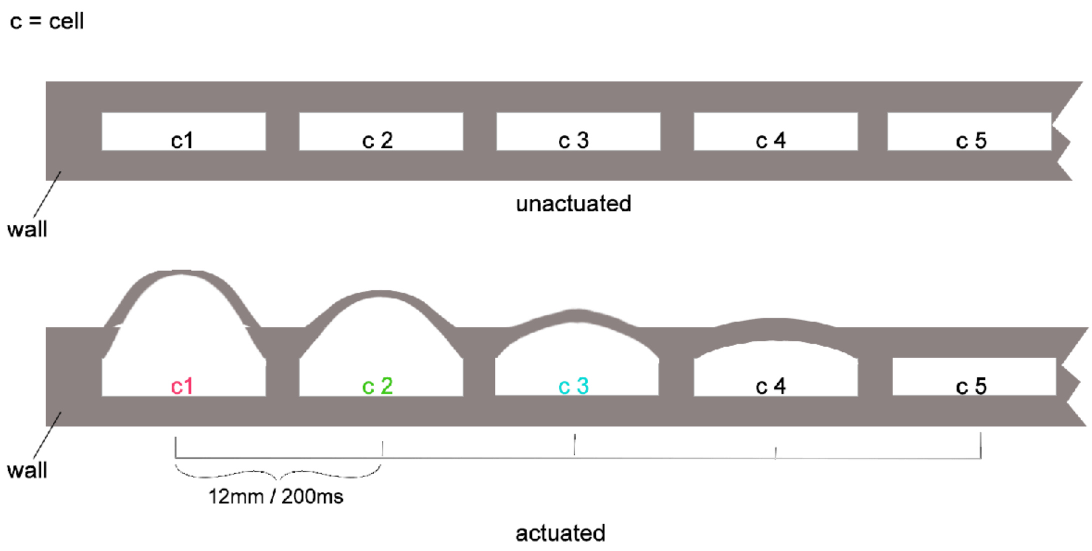


**Figure 6.5** The inflation design of the actuator in the S-CAT device to achieve CT-optimal affective touch velocity and continuity of touch (profile of actuator)

[redacted]

[redacted]

[redacted]

### 6.2.5 Noise

The reduction or elimination of noise can be achieved by either choosing an air supply and valves with a low noise level, or by containing the noise-generating equipment with noise-reducing material such as a foam box. I looked into options for air supply with a reduced noise level, which included a number of possibilities. Piezoelectric pumps, especially the miniature ones, generate no noise, and resonate at frequency levels that are outside the human hearing range. However the no-noise pumps are not powerful enough to supply air into the armband but are much smaller actuators. Building an air reservoir, e.g. by pressurising air into a pressure bottle, and releasing it on demand, does not generate noise. An off-the-shelf peristaltic pump is powerful enough for the actuators but makes much less noise. Balancing the cost and time, I found the most viable was a Schego Optimal membrane pump, using existing valves, and with a noise-concealing layer made from wool fabric and foam.

### 6.2.6 Flow rates

Clamps were used to manually restrict the flow rate to find the most favourable rate.

### 6.2.7 Force

Force can be regulated by adjusting the combination of flow rate, inflation, holding and deflation time. It is worth mentioning that I found that the AffectNodes2 actuator also generated an applied force of 0.4N, which is within the range of CT-optimal affective touch. This may have contributed to evoking a pleasant response in the co-explorers.

### 6.2.8 Temperature

A temperature-regulating layer can be built using conductive wire and textile. However for time efficiency I used an external warmer (water box) to raise the temperature.

### 6.2.9 Personalisability

Notably, the S-CAT is more than a CT-optimal affective touch simulator: the caressing speed is adjustable between 6cm/s ~ 36cm/s, making it a caressing machine that can be personalised.

## 6.3 The S-CAT device for evaluation

The S-CAT device is a proof-of-concept prototype for a completely soft, wearable affective touch stimulator that is easily configurable. It consists of a soft armband (Figure 6.8) and a control box (not shown in image). The pneumatic mini-pumps, the electronic micro-controllers and the power are contained in a 'control box' external to the band, connected only via air tubing to the band. The dimension of the control box is 15x15x25cm, which is much smaller than a lab device, making it viable as a home or desktop device. In terms of configurability, the S-CAT device can generate a stroking speed within the CT-optimal velocity; also, the caressing speed is adjustable between 6cm/s ~ 36cm/s. The applied force on the skin is 0.48N, and once warmed up to a temperature of between 36-38°C by a warm water box it maintains this temperature for a duration of about 4 minutes. Schego optimal (Nr.850, 220-240V/50Hz – 5w) was chosen. An acoustic isolation box was built to conceal the remaining noise.  As shown in Figure 6.9, the dimension of the actuator array was 5.5 cm wide and 9cm long. When actuated, the skin-contacting area was close to the planned skin-stimulating area of 4cm wide and 9cm long. This was to facilitate the skin area being stimulated that had been identified through prior research (e.g. Crucianelli et al., 2013; Krahé et al., 2016; von Mohr et al., 2017).

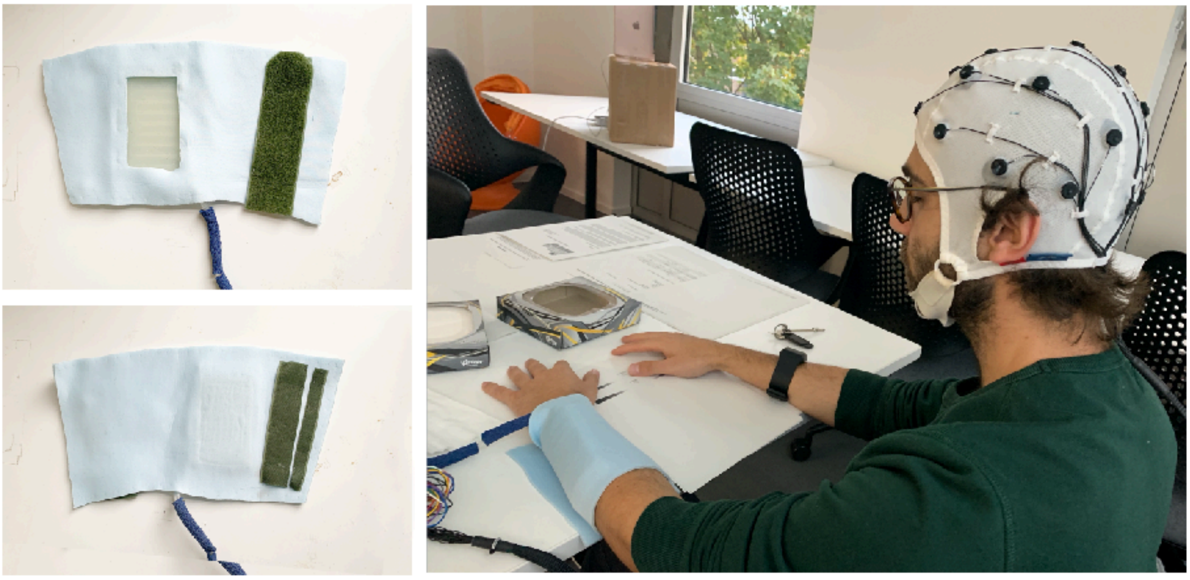

**Figure 6.8** S-CAT band. The image on top left shows the side that contacts the skin. The image on the right shows how it is worn on the arm during stimulation sessions

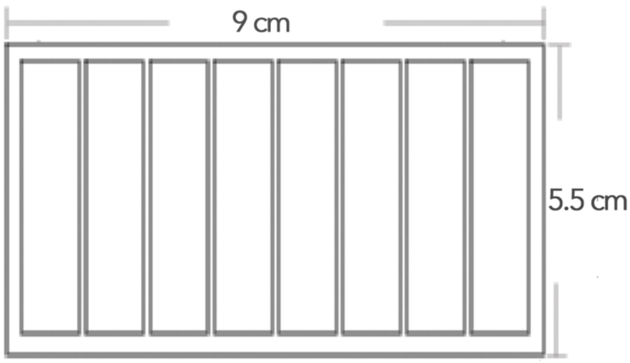


**Figure 6.9** Dimensions of the actuator design in the S-CAT device

### 6.4 Evaluation of the S-CAT device

In order to address Research Aim2, and especially objective 3 within this Aim, I assessed the affect-enabling capability of the S-CAT device with a recognised evaluation method. In neuroscience studies, the most widely used protocol for evaluating CT-optimal affective touch uses soft brushes as stimulators involved collecting subjective rating of pleasantness and activation on two velocities: slow speed within the range of CT-optimal velocity, and fast speed outside the range of CT-optimal velocity, for example Krahé et al. (2018), von Mohr et al. (2017, 2018). A handful of studies have begun to examine the response of brain waves (electroencephalography, or EEG signals) to the stimulation of affective touch. For example, a mother's affective touch stimulation to the infant (Maulsby, 1971), soft fabric stroking of the skin (Singh et al., 2014), and a soft brush applying CT-optimal velocity touch on the forearm (von Mohr et al., 2018).

As my device was inspired by the affect-enabling capability of CT-optimal touch delivered by a soft brush, it was apparent that one effective way to evaluate the validity of this device was to compare touch delivered by the S-CAT device with touch delivered by a soft brush, to test whether they elicited a comparable psychological effect, by replicating the above mentioned, well-established experiment protocol mentioned above. I was also curious to ascertain how participants compare the S-CAT stimulation with human hand stimulation: as in the previous Studies, 3 and 4, subjective feedback had frequently mentioned the resemblance to human touch. Thus, my evaluation sought to compare affective touch (CT optimal velocity) and non-affective touch (non-CT optimal velocity) stimuli applied by a soft brush, a human hand and the S-CAT device. As the literature suggested that using more than one methods to collect data adds convergent validity (Bethel and Murphy, 2010, p.357), neurophysiological response (EEG) to supplement the subjective ratings was also collected, as well as qualitative comments from participants to supplement and further the understanding of the above quantitative data mentioned above. The reason to include qualitative comments was also that my research upheld the subjective aspects of affect.

Due to the fact that to design and conduct such an evaluation requires expertise in planning a scientifically rigorous protocol, and also in statistics for analysing and interpreting data from both the subjective rating and brain signals, I sought collaboration with Dr. Mariana von Mohr, Professor Katerina Fotopoulou, Ker-Jiun Wang, and Dr. Maitreyee Wairagkar[12] [13] [14].

[12] I invited Dr. Mariana von Mohr, the co-author of the only study using EEG to evaluate CT-optimal affective touch applied by soft brush (von Mohr et al., 2018), to collaborate on the protocol design and analysis of subjective ratings data. The protocol design of this study was adapted from von Mohr et al's study (2018) to facilitate the comparison of the results. Data analysis of EEG data was in collaboration with Ker-Jiun Wang and Dr. Maitreyee Wairagkar, both of whom are experienced in analysing EEG data. The data analysis and interpretation were supervised by Professor Katerina Fotopoulou, head of KatLab at University College London, a leading expert in the UK on CT-optimal affective touch research.

Ker-Jiun Wang was PhD student at University of Pittsburgh whose research focus on bioengineering, adaptive control of wearable robotic system through biophysiological sensing, including using EEG sensors. He has obtained his doctoral degree in 2020. Dr. Wairagkar is a postdoc researcher in artificial intelligence, social robotics, brain-computer interface, and assistive technology at Imperial College London.

[13] My collaborators and I have published a 1 page work-in-progress paper on this study for the 2021 IEEE World Haptics Conference (WHC) (Zheng et al., 2021) on this study. We have also co-authored a full manuscript which is unpublished, reporting on this study. Sections 6.4.1 to 6.4.4 in my thesis are based on the report of this study.

[14] The contribution of each collaborator for the study report is as follows. I conceived and co-designed the experimental protocol, led the data collection, performed data analysis on qualitative comments and partial analysis of the data on subjective ratings and drafted the report. Dr. Von Mohr advised on the experimental protocol and helped to analyse data on subjective ratings and STQ ratings, as well as edit the relevant sections in the write-up. Dr. Wang Ker-Jiun processed the raw EEG data and had written the EEG data processing section. Dr. Wairagkar performed the analysis of EEG data and wrote the results and analysis of EEG data. Professor Fotopoulou provided an initial consultation on the feasibility of the study and supervised on the data analysis and interpretation, as well as final report writing. I would also like to acknowledge help from two MA students from

Due to the nature of the evaluation as an experimental study which involves statistical analysis (Lazar et al., 2010), the tone of the reporting in this section may be different from that of the reporting of design practice in the previous chapters. The rationale for choosing this method is explained at the beginning of this section, and also in section 3.3.3: I have made an effort to use a narrative that is more accessible to the lay person than the classic reporting style in scientific literature, while retaining the necessary terms and language.

To investigate whether the S-CAT device is capable of eliciting comparable psychological effects to human and brush touch, our hypothesis was constructed as follows:

1. Our participants would give on average higher pleasantness ratings in response to slow vs fast touch in all three stimulus types and lower intensity ratings in response to slow vs fast touch in all three stimulus types, with no differences between the type of stimulation (human, robot, brush), or in interaction with velocity.
2. We expected decreasing EEG band power, particularly in the theta and beta frequencies in temporal and parietal areas, when comparing touch against rest and affective, CT-optimal touch against non-CT-optimal touch in all types of stimulation separately (human, robot, brush) based on previous study (von Mohr et al., 2018), with no differences between the type of stimulation (human, robot, brush), or in interaction with velocity.
3. We expected no adverse or unexpected effects such as fear or disgust towards the soft robotics device.

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Information Experience Design at the Royal College of Art: Erik Lintunen and James Roadnight. Lintunen helped with designing some of the tools for data collection, namely the visual guide, and timestamp for logging robot touch, as well as several sessions of the data collection, and Roadnight co-facilitated several sessions of the data collection.

### 6.4.1 Methods

#### 6.4.1.1 Participants

22 adults (13 classing themselves as female, 8 as male, 1 preferring not to say, age mean 29.5, age SD 9.6) participated in the study. This sample size was determined based on power calculations using GPower 3.1 (Faul et al., 2009) based on a previous study on EEG power and CT vs non-CT optimal touch using a brush (von Mohr, Crowley et al., 2018) with an effect size of $\eta^2_{partial=}$ .18.

#### 6.4.1.2 Stimulation design

We employed a 2 (tactile speed: slow vs fast) x 3 (stimulation type: human skin, brush, robot) within-subjects design; hence there were six experimental conditions: human slow (HS), human fast (HF), brush slow (BS), brush fast (BF), robot slow (RS) and robot fast (RF). A slow tactile stimulation speed of 6cm/s was chosen because this is within the optimal range for targeting CT afferents (Löken et al., 2009) and it is also the slowest speed of continuous touch that the S-CAT device can perform. A fast tactile stimulation speed of 36cm/s was chosen, as this is the non-CT-optimal speed.

The order of the experimental conditions was randomised across participants. Each experimental condition consisted of eight blocks: each block had 12 seconds of tactile stimulation followed by 6 seconds of rest (see Figure 6.10). The tactile strokes were applied back and forth in the stimulation area, with a break of 0.5s between each stroke. The break between each stroke was intended to minimise habituation (McGlone et al., 2012).

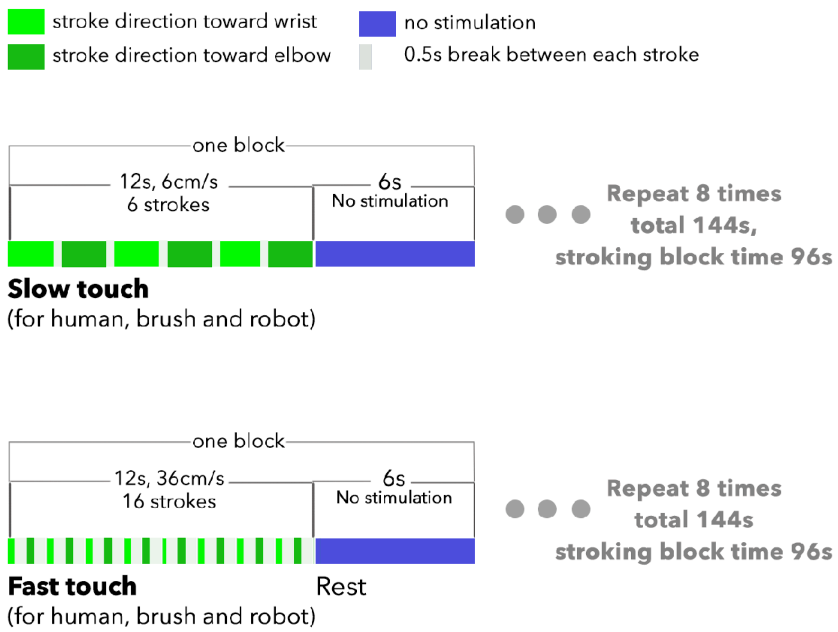


**Figure 6.10** Design of slow (CT-optimal speed) touch and fast (non-CT-optimal speed) touch stimulation sessions

#### 6.4.1.3 Stimulators

1) *Robot / the S-CAT device (as specified in section 6.3)*
2) *Human Skin*

   A female experimenter (myself) kept four fingers together and used the area between the middle phalanx and proximal phalanx of her left hand as a skin contacting area. This is because applying human touch using this area had shown consistency in covering the 4cm-wide marked stimulation area on the arm, and compared with using the palm, the force applied using this gesture appeared to be more controllable and produced the most consistent force (see also Gentsch et al., 2015). As with the robot stimulator, the experimenter placed her hand on top of a box with warm water with temperature controlled at 36.5 -38°C to keep the consistency of a body temperature level.

3) *Brush.*

   As in previous studies (e.g. Crucianelli et al., 2013; Krahé et al., 2016; von Mohr et al., 2017), we used a soft brush (No.7 natural hair blusher brush, The Boots

Company) held by the same experimenter who had delivered the skin-to-skin touch in the above condition.

#### 6.4.1.4 Measures

For the behavioural data, we used the AffectiveSlider (Betella and Verschure, 2016) (Figure 6.11) for participants to give their subjective rating of the level of pleasantness and the level of activation (intensity of arousal) following tactile stimulation after each experimental condition. We explained to the participants that 'the pleasure scale refers to the level of pleasantness that you feel about the sensation, extreme left being most unpleasant and extreme right position being extremely pleasant', and 'the scale of activation refers to how activating or intense that you feel about the sensation is: the extreme left position means the least activating and the extreme right position means extremely activating'. The scale ranged from 0, 'not at all',' to 1 'extremely"'.

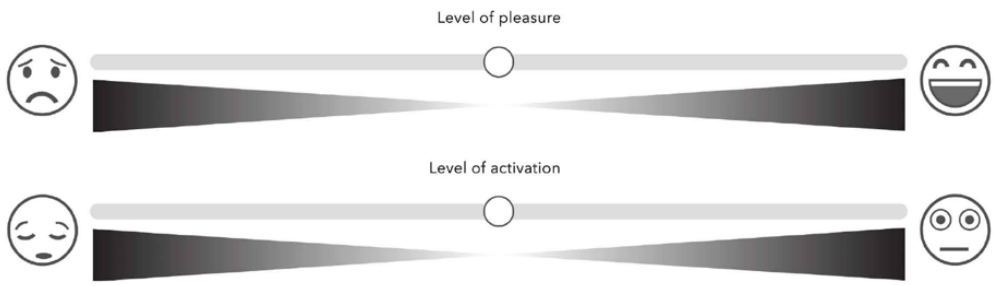


**Figure 6.11** Adaptation of Affective Slider (Betella and Verschure, 2016), divided by 100 points

To collect qualitative comments from participants, immediately after each touch stimulation session we asked a single open question, 'How did that make you feel?' to allow participants to freely describe verbally their subjective feelings.

Affective touch is a form of social touch: people's pre-existing attitude toward social touch may influence their perception of affective touch (Krahé et al., 2018; Wilhelm et al., 2001). For this reason we also collected information on individual preference for touch using a Social Touch Questionnaire (STQ) (Wilhelm et al., 2001). The STQ (Appendix 11) is a self-reporting measure that assesses participants' attitudes toward social touch. It has been employed in previous studies on CT-optimal touch (Bennett et al., 2014). Scores range from 0-80; higher scores indicate an aversion to giving, receiving and witnessing social touch. We aimed to explore whether there are individual differences in how people respond to touch from the S-CAT device, particularly based on their preferences regarding touch.

For collecting EEG data, we used an EEG Electrode Cap Kit from OpenBCI (OpenBCI, New York, United States), with the application of wet electrodes (Ag/AgCl coated). We recorded EEG signals using OpenBCI Cyton + Daisy biosensing board (16-Channels, 24-bit data resolution, 125 Hz sampling rate). The performance of the OpenBCI EEG capturing system has also been tested in existing studies (e.g.Lakhan et al., 2019). The placement of electrodes is as shown in Figure 6.12.

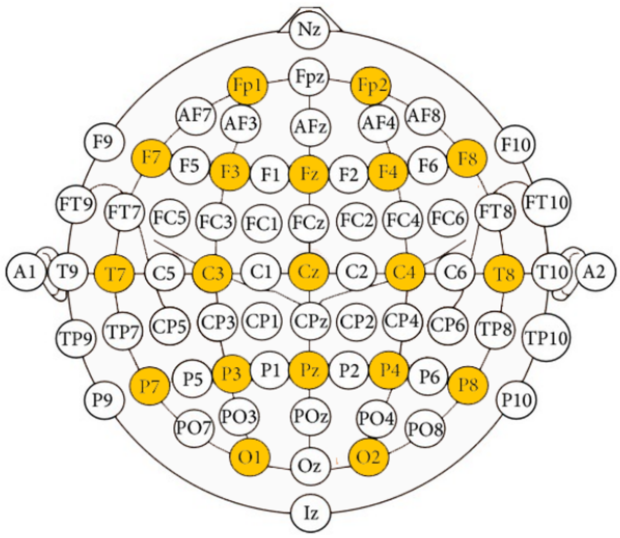


**Figure 6.12** Placement of 16 electrodes (highlighted in yellow, the three electrodes in the centre included ground, zero, and one unused electrode)

EEG data from 22 participants was collected. During data inspection, data from 11 participants was of a satisfactory quality. We rejected data from 11 participants with low-quality EEG signals due to prominent body artefacts, low signal to noise ratio, inconsistent time-frequency electrode response, and problematic channels due to potentially unstable electrode/wire connections with either human skin or the electric board. The raw EEG data was pre-processed with a band-pass filter at 0.5 ~ 50Hz, to eliminate DC offset drifts and the high frequency and power line noise. The EEG time-series data was then segmented using the sliding window (1 sec, 125 samples), and Fast Fourier Transformation (FFT) technique, to obtain the power spectrum of the signal to be analysed in the frequency domain. We extracted the average peak values of the power of each frequency band – Delta (0.5-4 Hz), Theta (4-8 Hz), Alpha (8-13 Hz), Beta (13-30 Hz) and Gamma (30-80 Hz), as the features to be analysed. These features were further smoothed out by an averaging filter (with 2-second sliding window) over time to remove eye movement, blinking, facial expressions and other body artefacts. The entire EEG data processing and analysis was conducted in MATLAB R2018a (The MathWorks Inc., Natick, USA) and used our custom scripts, as well as the EEGLAB toolbox (Delorme & Makeig, 2004).

#### 6.4.1.5 Procedure

The study was held in a designated, quiet room, with plain white walls. There was one female researcher (myself) and one male researcher present at the room during every testing session.

I marked the stimulation area on the hairy side of the left forearm of each participant, with a water-removable marker pen, where all the touch stimuli would be applied.

Prior to the experimental tactile conditions, each participant was asked to close their eyes and relax for 5 minutes (300 seconds). EEG data about this resting status was collected as a baseline.

After receiving training from experienced researchers in the team, I applied all the touch stimuli for all the participants throughout the study. An on-screen visual guide during each touch condition helped me to maintain consistency in the velocity of brushing and hand touching (as in von Mohr et al., 2018; Voos et al., 2013).

Participants were asked to close their eyes during each of the tactile conditions. I checked during the stimulation and ensured that they had all closed their eyes throughout. After each condition, participants were asked to open their eyes, and to rate the perceived pleasure and activation/arousal using the AffectiveSlider, and verbally respond to the question: 'How did the stimulus just now make you feel?'

Participants were asked to close their eyes as a reset for 40-60 seconds before the next stimulus to avoid continuing the effect from previous stimuli and to help them return to neutral/calm status. The entire experimental session for each participant lasted approximately 40 minutes.

#### 6.4.1.6 Plan of data analysis

An aggregation of data from subjective ratings, Social Touch Questionnaire (STQ) and qualitative comments is provided in Appendix 12 and 14.

For subjective ratings of pleasantness and arousal, we first examined descriptive statistics followed by inferential statistics. Specifically, we conducted repeated measures ANOVAs specifying stimulation type (human, brush, robot) and speed (slow, fast) separately on pleasantness and activation / arousal ratings. Effect size is presented as partial eta-squared ($\eta^2_{partial}$), where .01 represents a small effect size, .06 represents a medium effect size, and .14 represents a large effect size (Cohen, 1988). Greenhouse-Geisser corrections were used when sphericity assumptions were violated. In addition to our main behavioural analyses of pleasantness, we conducted planned contrasts (two separate t tests; using Bonferroni adjusted alpha levels of 0.025 per test) on pleasantness rating for slow robot touch against slow brush touch and separately against slow human touch, as these were the critical comparisons regarding the device's potential for eliciting pleasantness ratings comparable to those from human-to-human CT-optimal touch. In addition, based on our expectation about the potential of the robotic device to lead to comparable pleasantness effects to human or brush touch, non-significant ($p>.025$) findings in these planned contrasts were followed up using Bayesian statistics (Carey et al., 2021), which present the ratio of the likelihood of the alternative hypothesis relative to the likelihood of the null hypothesis. A Bayes Factor (BF) >3 indicates evidence for the alternative hypothesis, whereas a BF<0.3 indicates evidence for the null hypothesis. A BF between 0.3 and 3 indicates an inconclusive result which is not in favour of either hypothesis. This is possible for both parametric and non-parametric hypothesis testing (van Doorn et al., 2020).

To observe the effects of different types of stimuli (fast and slow strokes applied by hand, brush and robot) and a resting condition on band power of different frequencies in different brain regions, we first examined descriptive statistics by tabularising mean and standard deviation of band powers of all 11 participants. We then used separate non-parametric Friedman tests to compare changes in theta and beta frequency bands in parietal and temporal regions independently between all the six different types of tactile stimulation and rest. We used resting state EEG as a baseline where no tactile stimulus was presented. The significance threshold was set to p=0.05. For cases where p-value from the Friedman test indicated statistical significance, pairwise comparison was done for each of the stimulus conditions using Dunn-Bonferroni post hoc tests specifically to compare six touch stimuli against the resting condition. Next, we compared slow touch against fast touch in all three types of stimulation separately, using Wilcoxon Signed Ranks Test to observe the difference between CT-optimal and CT-sub optimal touch. Finally, to compare three modes of touch stimuli, we compared band powers of slow human, slow brush and slow robot touch using separate Friedman tests in theta and beta bands in temporal and parietal regions.

For qualitative comments, the answers were recorded and transcribed. Simple thematic analysis (Braun and Clarke, 2006) by myself was applied to generate relevant themes.

### 6.4.2 Results

#### 6.4.2.1 Subjective ratings of pleasantness and arousal

The analyses of pleasantness ratings showed that the main effect of speed, $F(2,21)=9.06$, $p=.007$, $\eta^2_{partial=}.30$, was statistically significant. Averaging across stimulation type, slow touch (M= .71, SD=.15) was reported as more pleasant than fast touch (M= .60, SD=.13). The main effect of stimulation type was non-significant, $F(2,42)=.12$, $p=.887$, $\eta^2_{partial=}.01$, and stimulation type did not interact with speed, $F(2,42)=.93$, $p=.402$, $\eta^2_{partial=}.04$. Thus, participants perceived slow touch as more pleasant than fast touch, irrespective of stimulation type ( i.e., robot, brush or human touch). See Figure 6.13, left panel.

Similarly, analyses of activation / arousal ratings showed that the main effect of speed, *F*(2,21)=6.27, *p*=.021, $\eta^2_{partial=}$.23, was statistically significant, with fast touch (M= .71, SD=.15) perceived as more arousing /intense than slow touch (M= .60, SD=.13). The main effect of stimulation type was non-significant, *F* (2,42)=.17, *p*=.820, $\eta^2_{partial=}$.01, and stimulation type did not interact with speed, *F*(2,42)=1.70, *p*=.194, $\eta^2_{partial=}$.08. Thus, as expected and in contrast to perceived pleasantness, people perceive fast touch as more arousing or intense than slow touch, irrespective of stimulation type (i.e., robot, brush or human touch). See Figure 6.13, right panel.

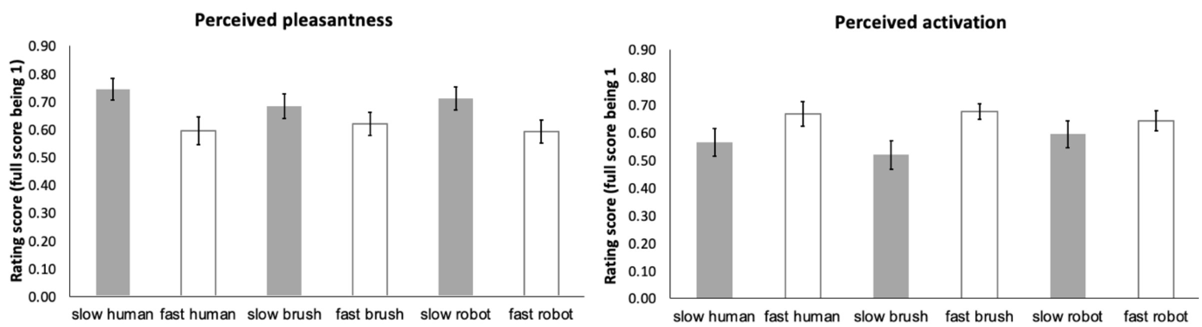


**Figure 6.13** Subjective mean rating of pleasantness rating (left) and activation rating (right). Error bars denote standard error of the mean.

There was no significant difference in our planned contrast between the pleasantness rating of Robot slow (M=.71, SD=.20) vs. Brush slow touch (*M*=.68,*SD*=.21; t(42) = 0.53, p = .604) ). We then conducted Bayesian analysis, testing the null hypothesis against the alternative hypothesis that robot touch may lead to less pleasantness feelings than those elicited by brush touch. We obtained a result of $BF_{10}$=0.157 (error ~8.162e-4), which indicates moderate evidence in favour of the null hypothesis best explaining our data. Similarly, there was no significant difference in our planned contrast between the pleasantness rating of Robot slow (M=.71, SD=.20) vs. Human slow touch (*M*=.75, *SD*=.18; t(42) = -.83, p = .416 . We then conducted Bayesian analysis, testing the null hypothesis against the alternative hypothesis that robot touch may lead to less pleasantness feelings than those elicited by human touch. We obtained a result of $BF_{10}$=0.475 (error%~0.024), which suggests the evidence is inconclusive.

#### 6.4.2.2 Relationship between STQ, pleasantness and activation

We anticipated a lower differentiation between CT-optimal and non-CT-optimal touch in people with generally more negative attitudes to social touch, irrespective of stimulation method. However the results from the Social Touch Questionnaire were insignificant. Across stimulation type, the more the participant's preference for social touch, the more they can discriminate between the pleasantness of slow and fast touch (r= -.416, p=.054), and the activation between fast and slow touch (r= -.453, p=.034). Thus we did not find the total STQ score to be a significant predictor of the pleasantness ratings or of the activation ratings.

#### 6.4.2.3 Changes in EEG band power due to different stimuli

Descriptive results are summarised in Table 6.1, including the average band power of five frequency bands (delta, theta, alpha, beta and gamma) in all the brain regions (prefrontal, frontal, central, parietal, temporal and occipital) during resting state and six types of tactile stimulus (fast and slow touch by brush, human and robot).

| | | Pre-frontal | Frontal | Central | Parietal | Temporal | Occipital |
|---|---|---|---|---|---|---|---|
| Delta | Resting | 156.04 (5.84) | 153.12 (9.20) | 152.47 (12.03) | 155.18 (8.03) | 159.56 (12.70) | 151.72 (9.36) |
| | HS | 156.52 (4.55) | 153.54 (11.45) | 153.82 (11.97) | 164.31 (7.57) | 163.49 (14.84) | 159.38 (5.48) |
| | BS | 160.16 (4.62) | 161.52 (13.33) | 160.50 (13.86) | 174.30 (8.65) | 175.31 (17.08) | 175.36 (7.47) |
| | RS | 155.84 (4.42) | 154.59 (11.57) | 152.11 (10.67) | 164.94 (6.14) | 163.87 (13.09) | 160.81 (6.94) |
| | HF | 158.81 (4.42) | 157.87 (10.69) | 155.66 (12.60) | 165.63 (7.71) | 167.03 (14.25) | 165.37 (6.54) |
| | BF | 155.82 (4.76) | 159.64 (14.19) | 157.52 (15.15) | 176.07 (9.07) | 173.94 (20.20) | 171.08 (7.65) |
| | RF | 156.07 (4.92) | 153.41 (9.75) | 153.69 (10.56) | 161.40 (6.47) | 162.33 (12.10) | 159.46 (6.08) |
| Theta | Resting | 98.69 (6.44) | 100.35 (8.40) | 97.40 (12.19) | 104.35 (10.51) | 105.26 (14.03) | 101.21 (10.30) |
| | HS | 98.50 (4.18) | 101.46 (9.13) | 98.45 (11.60) | 112.29 (10.16) | 109.02 (15.07) | 108.25 (6.98) |
| | BS | 101.22 (3.94) | 107.91 (12.73) | 103.79 (15.07) | 122.09 (10.09) | 122.12 (18.27) | 120.54 (10.37) |
| | RS | 98.29 (4.42) | 102.02 (10.12) | 96.78 (11.91) | 113.21 (8.62) | 111.84 (12.62) | 108.59 (7.66) |
| | HF | 100.45 (4.26) | 104.53 (10.59) | 100.20 (12.69) | 113.51 (9.75) | 113.63 (14.55) | 113.83 (8.31) |
| | BF | 98.74 (4.71) | 108.02 (15.64) | 104.49 (17.37) | 126.02 (11.06) | 122.50 (22.05) | 120.71 (10.78) |
| | RF | 99.31 (4.17) | 100.90 (7.97) | 97.50 (11.34) | 109.19 (8.83) | 107.40 (11.88) | 104.78 (7.62) |
| Alpha | Resting | 98.42 (6.29) | 100.76 (8.22) | 96.71 (10.17) | 104.50 (9.65) | 104.55 (13.19) | 101.48 (10.03) |
| | HS | 97.47 (3.62) | 100.82 (7.92) | 96.67 (9.57) | 110.64 (8.90) | 106.82 (12.67) | 108.09 (6.25) |
| | BS | 99.55 (3.59) | 106.11 (11.10) | 101.35 (12.68) | 118.68 (8.73) | 118.36 (16.15) | 116.06 (10.17) |
| | RS | 96.66 (4.44) | 100.79 (9.03) | 94.70 (9.68) | 111.02 (8.31) | 109.57 (11.01) | 107.45 (7.36) |
| | HF | 97.77 (3.97) | 102.14 (9.54) | 97.08 (10.18) | 109.97 (8.26) | 109.69 (11.95) | 111.08 (7.37) |
| | BF | 93.96 (4.23) | 102.64 (13.72) | 98.45 (14.92) | 119.21 (8.88) | 116.05 (18.88) | 113.02 (9.96) |
| | RF | 97.73 (4.44) | 100.16 (9.03) | 95.72 (9.68) | 108.07 (8.31) | 105.39 (11.01) | 102.95 (7.36) |
| Beta | Resting | 89.40 (6.14) | 93.95 (9.72) | 90.07 (11.45) | 99.65 (11.27) | 99.64 (15.89) | 99.45 (10.62) |
| | HS | 88.33 (2.84) | 92.76 (8.45) | 89.49 (9.93) | 103.96 (9.74) | 100.75 (14.16) | 105.10 (6.19) |
| | BS | 88.91 (2.84) | 96.61 (11.62) | 93.00 (13.28) | 111.18 (9.09) | 110.84 (17.55) | 110.19 (10.42) |
| | RS | 86.55 (3.60) | 92.63 (9.62) | 87.53 (10.73) | 104.60 (8.39) | 103.98 (12.35) | 103.79 (6.72) |
| | HF | 87.65 (3.50) | 92.87 (10.13) | 88.78 (10.95) | 102.97 (8.79) | 103.34 (13.13) | 106.91 (7.11) |
| | BF | 83.52 (3.57) | 93.00 (13.87) | 89.25 (14.62) | 109.70 (8.79) | 107.27 (19.38) | 104.67 (9.91) |
| | RF | 88.31 (3.59) | 92.25 (7.67) | 88.52 (9.90) | 102.28 (8.42) | 99.72 (11.28) | 99.34 (6.26) |
| Gamma | Resting | 88.30 (6.73) | 95.37 (12.49) | 89.87 (13.68) | 103.18 (13.38) | 102.19 (19.28) | 106.38 (11.34) |
| | HS | 88.08 (2.69) | 93.20 (10.58) | 88.60 (10.63) | 105.76 (10.27) | 103.32 (16.55) | 111.45 (6.65) |
| | BS | 85.51 (2.19) | 94.32 (12.56) | 90.09 (14.53) | 111.04 (10.13) | 109.65 (19.00) | 113.41 (9.93) |
| | RS | 83.64 (3.02) | 92.28 (11.07) | 85.99 (12.57) | 106.83 (9.42) | 106.03 (14.83) | 110.35 (7.04) |
| | HF | 86.69 (3.46) | 92.36 (11.78) | 87.43 (12.37) | 106.05 (9.58) | 105.84 (15.74) | 113.55 (7.57) |
| | BF | 79.53 (3.30) | 89.23 (12.56) | 84.51 (14.53) | 106.04 (10.08) | 103.44 (19.98) | 104.27 (10.04) |
| | RF | 85.45 (3.04) | 91.09 (9.20) | 86.34 (10.73) | 104.15 (8.87) | 101.98 (14.10) | 105.31 (7.04) |

**Table 6.1** Mean of band power in five different frequency bands in different brain regions for all types of stimuli (HF=human hand fast speed, HS=human hand slow speed, BF=brush fast speed, BS=brush slow speed, RF=robot fast speed, RS=robot slow speed)

A previous study (von Mohr, Crowley et al., 2018) suggested an attenuation in the theta band power specific to the CT-optimal affective touch compared with the non-CT-optimal non-affective touch and resting state, particularly in the parietal and temporal regions. Here, a similar pattern was also observed in the beta band in the parietal region. Hence, in this study we compare the effect of three different CT and non-CT touch stimuli on the theta and beta band power in the parietal and temporal regions.

First, we compared the band power of all stimuli with the resting state in the theta and beta frequency bands in the temporal and parietal regions independently, using separate Friedman tests, as shown in Table 6.2, first row. We obtained significant differences in theta band power in the temporal ($p$=0.001, $\chi 2$= 23.26) and parietal ($p$=0.007, $\chi 2$= 17.88) regions and beta band power in the temporal region ($p$=0.024, $\chi 2$= 14.61) with different touch stimuli.

To investigate further, upon pairwise comparisons with Bonferroni correction, we observed that the band power of non-CT-optimal fast brush touch was significantly different from the resting state in theta in both the temporal ($p$ = 0.005) and parietal ($p$ = 0.047) regions. No other (affective and non-affective) touch stimuli showed significant difference from resting state.

Secondly, to assess differences in CT-optimal affective touch and non-CT-optimal non-affective touch for each stimulus, we compared band powers in pairwise human slow and human fast touch, brush slow and brush fast touch, and robot slow and robot fast touch conditions independently using Wilcoxon Signed Ranks Test for theta and beta frequencies in the temporal and parietal regions, as shown in Table 2, second row. We observed no statistical difference between CT-optimal affective and non-CT-optimal non-affective touch in EEG band powers, unlike the previous study.

| | Statistical Test | Theta - Temporal | Theta - Parietal | Beta - Temporal | Beta - Parietal |
|---|---|---|---|---|---|
| 1. | Friedman's test Rest-BF-BS-RF-RS-HF-HS | $p$ = **0.001** $\chi^2$(6 df) = 23.26 | $p$ = **0.007** $\chi^2$(6 df) = 17.88 | $p$ = **0.024** $\chi^2$(6 df) = 14.61 | $p$ = 0.092 $\chi^2$(6 df) = 10.87 |
| | Significant pairs from pairwise comparisons ($p$ adjusted with Bonferroni correction) | Rest-BF $p$ = **0.005** | Rest - BF $p$ = **0.047** | - | - |
| 2. | Wilcoxon Signed Ranks Test to compare affective (slow) vs non-affective (fast) touch | | | | |
| | HS-HF | $p$ = 0.091 $Z$ = -1.689 | $p$ = 0.373 $Z$ = -0.889 | $p$ = 0.286 $Z$ = -1.067 | $p$ = 0.790 $Z$ = -0.267 |
| | BS-BF | $p$ = 0.062 $Z$ = -1.867 | $p$ = 0.075 $Z$ = -1.778 | $p$ = 0.110 $Z$ = -1.6 | $p$ = 0.328 $Z$ = -0.978 |
| | RS-RF | $p$ = 0.155 $Z$ = -1.423 | $p$ = 0.328 $Z$ = -0.978 | $p$ = 0.213 $Z$ = -1.245 | $p$ = 0.328 $Z$ = -0.978 |
| 3. | Friedman's test to compare different stimuli for affective (slow) touch HS-BS-RS | $p$ = 0.78 $\chi^2$(6 df) = 5.091 | $p$ = 0.234 $\chi^2$(6 df) = 2.9 | $p$ = 0.078 $\chi^2$(6 df) = 5.091 | $p$ = 0.086 $\chi^2$(6 df) = 4.909 |

**Table 6.2** Statistical results from analysing EEG data. * Values in bold are statistically significant (HF=human hand fast speed, HS=human hand slow speed, BF=brush fast speed, BS=brush slow speed, RF=robot fast speed, RS=robot slow speed)

Finally, to assess whether there were any differences in the band powers of different touch stimuli, we compared CT-optimal affective human, brush and robot touch using a separate Friedman test for each theta and beta band in the temporal and parietal regions, as shown in Table 6.2, third row. We observed no statistically significant differences between affective touch from three types of stimuli, which shows promise for soft robotics as a mode of providing affective touch.

To summarise, in contrast to our hypothesis, we did not observe a decrease in theta and beta band powers between CT-optimal touch and resting state, and CT-optimal affective touch and non-CT-optimal touch, although as expected, there were no significant differences in the EEG band power of different types of stimulation (human, robot, brush).

#### 6.4.2.4 Qualitative comments

Qualitative comments from all 22 participants were used in the analysis. In general, participants reported that slow touch feels more comfortable or pleasant, while fast touch feels more stimulating and less relaxing, irrespective of stimulation type (human hand, brush or robot). This is consistent with the results from subjective ratings of pleasantness and activation.

There were no major adverse emotions associated with slow robotic touch; instead, positive affective words seemed to dominate the qualitative comments. All three types of stimulation received comparable overwhelmingly positive comments referring to pleasantness. For example, there are 12 references for positive and pleasant comments compared with only 1-2 references for negative comments for each stimulation type. Words such as 'calming', 'relaxing' were used to describe all three stimulation types. Figure 6.14 shows the word cloud describing feelings about human, brush and robot slow touch.


**Figure 6.14** Word cloud of qualitative comments on human (left), brush (middle), and robot (right) slow touch

Participants assigned metaphors. Slow brush touch is often associated with the kind of comfort felt when being with furry pets, e.g. a cat or a dog. Slow brush touch was sometimes commented as 'ticklish' and is frequently commented on as more activating or even unpleasant, with the brushing direction from hand to elbow observed as more activating or even unpleasant, as it brushed against the direction of the hair growth. Some participants thus seemed to prefer robot touch over brush touch for this reason. Slow robot touch was frequently commented as similar to having a massage.

Some participants described the mechanism of what makes these touches feel pleasant, e.g. warmth, repetitiveness, however irregularity also contributes to touch feeling human-like. Warmth was frequently commented on as a contributing feature to the pleasant feeling., and caring qualities were projected onto it such as “feeling safe”, “human-like”, “cuddling”.

All three types of stimulation received comments on accustomisation. The intensity of sensation was found to decrease over time. For slow robot touch, although a session of familiarisation had been run prior to the testing session, some participants still commented on the novelty of the sensation. However, as the stimulation was repeated during the session, and familiarity increased, the novelty decreased, and the sensation was perceived as more pleasant. Some participants first differentiated a small gap between each tap from the pneumatic actuator, as time went by they felt more of a continuous stroking, which reflects a kind of tactile continuity perception (Geldard and Sherrick, 1972; Seizova-Cajic and Taylor, 2014). Several participants mentioned that the sound of human touch (the friction of skin) is also a comforting feeling.

### 6.4.3 Discussion

Both subjective ratings and qualitative comments revealed that, in line with our hypothesis, CT-optimal touch was perceived as more pleasant on average, while fast, non-CT-optimal touch was perceived as more stimulating on average, both irrespective of stimulation type (human hand, brush or robot). There was no main effect of stimulation mode, nor interaction between stimulation mode and velocity, in either measure. There was no significant difference between the pleasantness ratings of slow touch delivered by the S-CAT device and brush, nor between the S-CAT device and human hand. Bayesian analysis showed inconclusive result comparing slow touch delivered by the S-CAT device and the human touch, however, it suggested that there is no difference in the pleasantness rating between slow touch delivered by the S-CAT device and brush. Qualitative comments suggested a similar level of positivity toward slow touch from robot, a brush, and a human hand. These results suggested that affective touch delivered by the S-CAT device provides comparable pleasantness to that elicited by brush stroking. In the EEG responses, there were no significant differences in the EEG band power of different types of stimulation, suggesting that slow robot touch, as delivered by our wearable device, can produce comparable pleasantness to that of slow brush and slow human touch, although these EEG effects should be treated with caution as we were not able to confirm previous findings of velocity modulation even within modalities. Indeed, contrary to part of our hypothesis, we did not observe a decrease in theta and beta band powers between CT-optimal affective touch and resting state, and CT-optimal affective touch and non-affective, non-CT-optimal touch. This could be due to our small sample size and limited number of EEG trials sample, or it may relate to the fact that CT-optimal touch may not be associated with a clear pattern of EEG effects, as suggested by the conflicting results of previous studies (see first paragraph of section 6.4).

Nevertheless, the confirmation on the subjective effects of slow (vs fast) robotic touch is an encouragement for future work to improve the S-CAT device, while its neurophysiological effects may be best captured in future studies by other functional neuroimaging techniques such as magnetic resonance imaging. Moreover, based on our participants' qualitative comments, as well as some technical considerations, future work includes achieving a higher fidelity to human touch, developing built-in temperature control, and improving wearability and configurability. In terms of a higher fidelity to human touch, the continuity and force variations of the touch behaviours can be ameliorated. Several mechanical properties were observed to be associated with improving the caring quality of the sensation: these include comments that repetitiveness and warmth contribute to the feeling of safety, relaxation and care, while variation in movement contributes to the perception of being less machine-like and more like human touch. Based this information, I refined the Variables Map for Designing Affective Touch Using SPSR Material, specifically for simulating CT-optimal affective touch as shown in Figure 6.15, adding three variables were added informed from above discussion (text in orange boxes). In terms of wearability, work can be done to miniaturise the control box and power supply to make these a wearable size and integrate them into the touch interface. In terms of configurability, efforts can be made to allow users to adjust the stroking speed, pressure of touch and the rhythm or touch patterns via a graphical interface such as a phone app.

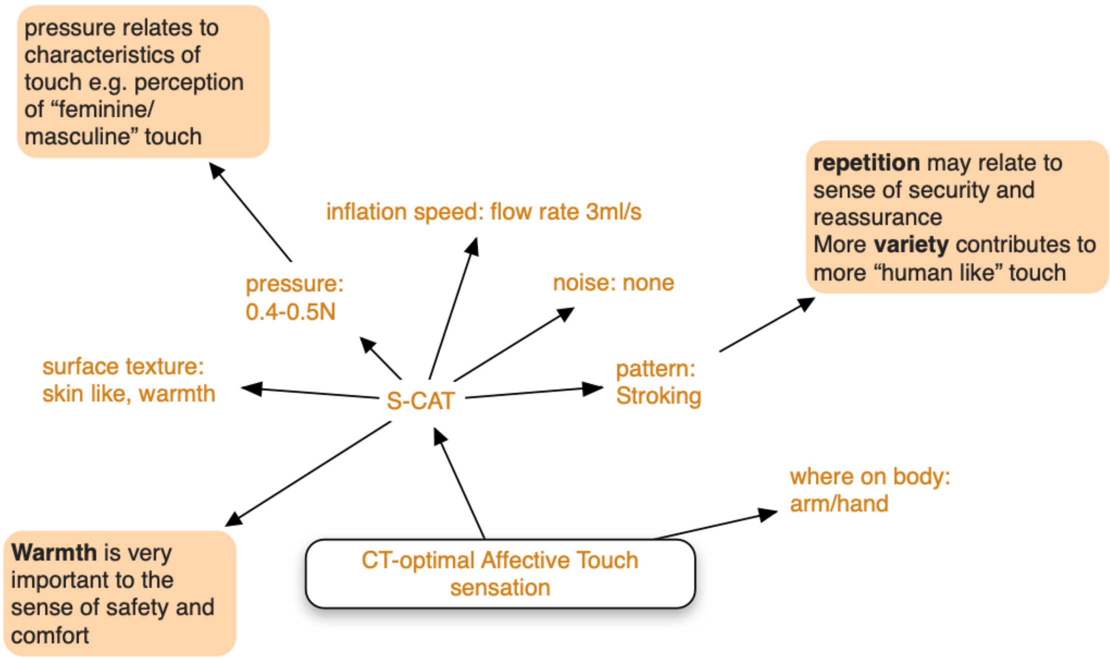


**Figure 6.15** Variables Map for Designing Affective Touch Artefacts Using SPSR Material – Version 4 with the focus on innate aspect of affective touch (for CT-optimal touch)

The qualitative comments gave interesting additional information. Slow human touch was perceived with most consistently to be pleasant, comfortable and relaxing, although two participants reported an aversion to human touch, and one participant attributed this touch aversion to the experience of social touch with a negative affective valence in her childhood. This observation may be linked to findings from studies on social anxiety contributing to aversion toward affective touch and supportive social touch (Kashdan et al., 2017; Krahé et al., 2018; Lapp and Croy, 2020; Wilhelm et al., 2001), and should be explored in future studies. However, although two participants considered human touch to be psychologically uncomfortable, they found both slow and fast robot touch more acceptable than human and brush touch. Wilhelm et al.(2001) also pointed out that although people with high social anxiety rate human touch very differently from those without, they did not differ on ‘an item not directly referring to social touch’ e.g. on the question ‘I like petting animals’(p. 189). We postulate that for individuals who are prevented from benefiting from social and affective touch due to touch aversion, an affective touch performed by a wearable S-CAT device may be a helpful alternative. In addition, future studies could explore whether in certain situations, such as clinical settings, where there are subtle boundaries between professional touch, comforting touch and inappropriate touch (Bruhn, 1978), an S-CAT device to comfort patients in distress may be helpful to reduce the complexity of social connotations. The concept of an S-CAT device can also enable remote affective touch on occasions when these touches are inaccessible, for example in intensive care, in tele-care, in treatment that requires patients to be in isolation such as in radiotherapy (Goldsworthy et al., 2020), or during quarantine amid a pandemic such as Covid-19. These applications support the usefulness of further exploration for this novel design space of simulated CT-optimal affective touch.

The limitations of the study also include the fact that only two velocities were tested and the effects of the experimenter’s gender were not examined, nor was the sexual orientation of our participants. The study further relied on subjective, rather than behavioural, measures, and hence social desirability biases cannot be excluded. Finally, this was a lab-based study and thus robotic touch will eventually need to be evaluated in everyday life.

#### 6.4.4 Conclusion

In this study we compared subjective ratings of pleasantness and intensity, neurophysiological responses, and qualitative comments about touch stimulation at CT-optimal and non-CT-optimal speeds, performed by an S-CAT device (robot touch), skin-to-skin touch (human touch) and a widely used affective touch stimulator (brush touch). The results suggested that the newly developed S-CAT device can deliver touch at different velocities, and slow velocities can lead to stronger feelings of tactile subjective pleasantness than fast velocities, as in skin-to-skin touch and brush stroking. The results also suggested that affective touch delivered by the S-CAT device provides comparable pleasantness to that elicited by brush stroking. The study detected no meaningful differences in neurophysiological responses, but the combination of quantitative and qualitative behavioural results from our sample warrants further investigation into the potential benefits of the S-CAT device as a device for the exchange of remote, affective touch. Future work could include the validation of the psychological benefit of touch stimulation from this device with a larger sample size, as well as refining the device to achieve a higher fidelity to human touch, and to improve wearability and personalisability.

# Chapter 7 Discussion

In addressing Research Aim 3, in this chapter I reflect on the broader implications of the knowledge generated from my research. In particular, I discuss the implications arising from the AMI-led design framework and the associated methods I used. I also reflect on the ethics considerations in designing an affective touch machine

## 7.1 The AMI-led design framework

### 7.1.1 The AMI-led design framework in my research

The AMI-led design framework was applied in all three phases of my practice. Table 7.1, maps out what affect, material, and interaction refers to in each phase of my exploration.

| AMI-led conceptual framework building blocks | Initial exploration | | Exploration with a broad focus | | Exploration with a defined focus |
|---|---|---|---|---|---|
| | **Study 1** | **Study 2** | **Study 3** | **Study 4** | **Study 5** |
| **Affect** | Any | Any | Positive affect | Pleasantness | Pleasantness |
| **Material** | SPSR material | Various actuating mechanism | Various actuating mechanism | AffectNode (the expanding and contrasting actuation mechanism) | S-CAT artefact (multiple AffectNodes rippling across skin) |
| | All modalities | All modalities | Touch modality | Touch from AffectNode applied around wrist | CT-optimal touch applied on hairy side of left forearm |
| **Interaction** | Myself interacting with material | Co-explorers interacting with probing artefacts | Co-explorers interacting with probing artefacts | Co-explorers interacting with AffectNode | n/a |
| | Co-explorers interact with probing artefacts | | Making personal artefacts | Making personalised touch patterns | |

**Table 7.1** Specifying affect, material and interaction in every study during the three phases of explorations in my practice

There are several characteristics of my practice that may have influenced how I applied the AMI-led design framework:

- I started this journey as a fashion practitioner as well as an e-textile practitioner. This meant that I am familiar with material practice with a sensitivity to the affective qualities, and at the same time, although without engineering training, I am familiar with how coding and mechatronics work. I chose to acquire new skills to configure digital materials, and I was open to collaborating with other disciplines. Another design practitioner with a different background may address the skillsets required for the design process differently.

- As a creative design practitioner, I benefited from using this framework in that it allowed me to explore possible areas of design space before narrowing down to a defined focus. In this process it gives agency to me as a designer, and also to my co-explorers, to influence the direction of the focus. This progressive narrowing-down of the scope of affect and material properties for investigation can be observed from Table 7.1.

- The framework could be applied to explore both the sensory (innate affect) and the social aspects of affect. My practice had only unpacked the sensory or innate aspect of affect enabled by the SPSR artefacts. Future work could include applying this framework for exploring the social aspect of affective touch design.

- The methods of studio practice, co-exploration and assessment that I explored through my practice, have been instrumental in supporting me in implementing my design framework and achieving the aims and objectives of my research. Within the context of my research, they have become an integral part of the design framework. Thus when discussing the implementations of the AMI-led design framework with experts and experienced practioners in the field (see the following section), I have expanded the AMI-led design framework to include these methods (Figure 7.1).

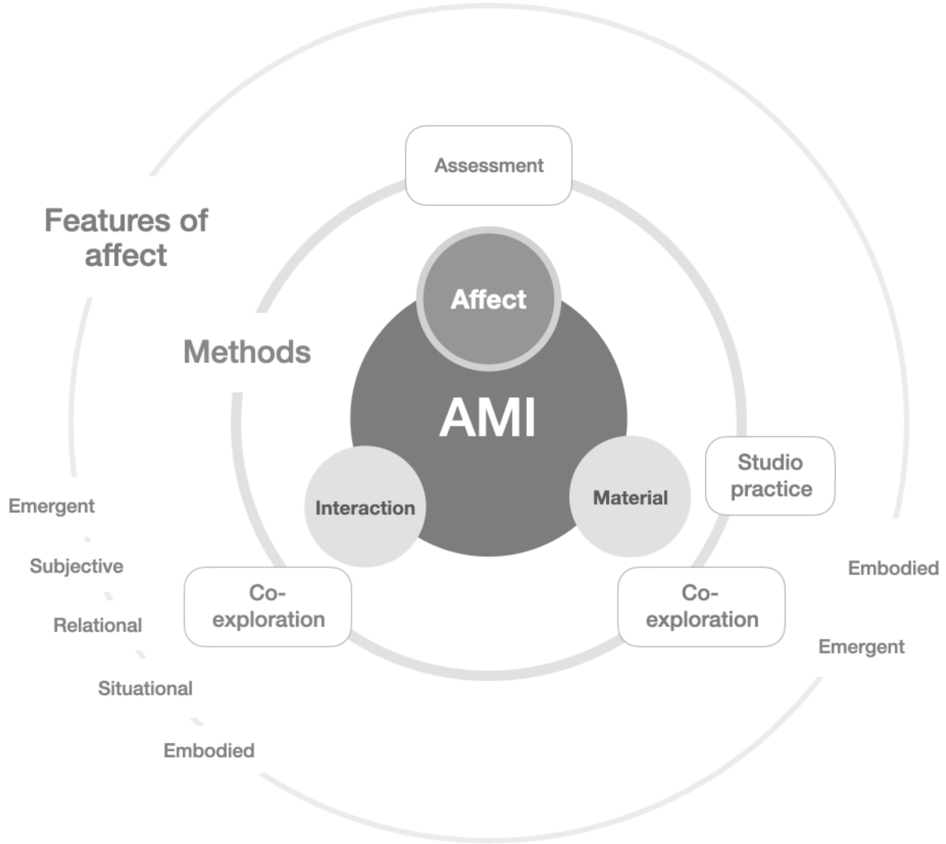


**Figure 7.1** The expanded affect-, material- and interaction (AMI)-led design framework, which includes the methods used to facilitate the application of the framework in my practice (same as Figure 1.1, shown here again to reflect its development)

### 7.1.2 Reflecting on the broader implications of the AMI-led framework through expert interviews

In order to explore the implications of this design framework in the space of affective interaction design (hereafter referred to as 'this space' in this chapter), and how the knowledge from it could be drawn on by other designers within this space, I conducted interviews with selected experts and an experienced practitioner, as the literature shows that incorporating feedback from experts and experienced practitioners is a common method for deriving design knowledge (Sas et al., 2014; Zimmerman et al., 2007; Mueller and Isbister, 2014), and an efficient method of gathering data for exploratory purposes (Bogner et al., 2009, p.2). In order to gather rich insights, I selected interviewees within the space of affective interaction design, whose practices stem from varied backgrounds, including: design engineering and craft (Tsaknaki), bioresponsive design for emotional well-being (Neidlinger), interaction design grounded in Massumi's affect theory (Massumi, 1995, 2002, Massumi and McKim, 2009), and fashion practice (Garrett, Freire)[15]. Table 7.2 shows the backgrounds of each interviewee in detail.

The semi-structured interviews were conducted over videoconferencing (Zoom) and lasted approximately one hour. I first introduced the expanded AMI-led design framework, including its theoretical underpinning, and how it was applied in my research through the three methods I used (Figure 7.1). The participants' commentary centred around the broader implications of this expanded framework, including how the framework and methods could potentially be applied by other designers within the space. I recorded the interview sessions. I analysed the interview transcriptions using NVIVO12 software. These resulted in the themes presented below.

[15] In order to maintain the relevance of the commentary to the research aim, I selected interviewees whose practices are closely related to the elements of the AMI-led design framework, and on top of this my selection criteria also included:

- A majority of the interviewees should be practitioners in creating physically bodied artefacts relatable to affective experience
- At least one expert from the interactional approach practice
- At least one interviewee from fashion practice

| Name | Category | Background |
|---|---|---|
| Kristin Neidlinger | Expert | Neidlinger founded and has been involved since 2010 with SENSOREE Therapeutic Biomedia: a wearable technology company promoting emotional wellbeing through externalising affect. She is also a PhD candidate at the University of Twente.[16] |
| Jonas Fritsch | Expert | Fritsch is Associate Professor of Interaction Design at the IT University of Copenhagen in the Department of Digital Design, where he heads the Section on Design Research and the Affective Interaction & Relations (AIR) Lab[17]. He has theorised affective interaction design through affect philosophy, in particular the work of Brian Massumi (Fritsch, 2009, 2018) |
| Vasiliki Tsaknaki | Expert | Tsaknaki is an interaction designer, engineer and crafter, and assistant Professor, in the Digital Design Department at the IT University of Copenhagen. Her research combines designing with the body, materials experiences, data, computational crafts and soma design methods. The interactive artefacts that she develops and studies have a strong focus on the touch and feel of interaction (e.g. (Tsaknaki et al., 2021, 2015, 2015). [18] |
| Rachael Garrett | Experienced practitioner | Garrett has a background in fashion design and has worked in the industry in the UK. Her work on digital fabrication for fashion has been exhibited at several Irish fashion events including Mercedes Benz Fashion Week Cork, the European Technology Summit Gala showcasing 3D Printing in Fashion, and the Irish Fashion Innovation Awards.<br><br>She was also educated in interaction design and currently she is a PhD candidate at the Royal Institute of Technology in Stockholm (KTH). Her research includes exploring research through fashion design and its meaningful role in HCI.[19] |
| Rachel Freire | Expert | Freire is a London based artist and designer working in fashion, costume and garment technology. Her conceptual fashion label was shown during London Fashion Week in 2009. She is textile designer for mi.mu gloves, a wearable gestural interface which enables people to compose and play music with their hands.[20] |

**Table 7.2** Backgrounds of experts and experienced practitioner interviewed

[16] Source: https://www.sensoree.com/about/

[17] Source: https://pure.itu.dk/portal/en/persons/jonas-fritsch(d37cba38-dff2-4c27-a515-226cfadfd849).html

[18] Also from source: http://vasilikitsaknaki.com/about

[19] Source: https://www.kth.se/profile/rachaelg

[20] Source: http://www.rachelfreire.com/about

#### 7.1.2.1 How the framework could potentially be applied by designers within the space

All the participants stated that they recognised and supported the theoretical grounding and the three building blocks of the framework. They also affirmed the appropriateness of the combination of the three general methods, namely studio practice, co-exploration and assessment. However, it was pointed out that there can be a variety of nuanced specific methods under each of the three general methods. Individual designers would choose the specific methods within these general methods based on their specific project.

Two participants considered this framework useful for designers with backgrounds in both HCI and design, and one participant considered the framework to be useful also for robotic engineers within this space, while three participants considered that designers with a material and making practice background (including fashion practice) will be more familiar with the elements of this framework, and thus find it easier to tune in with the concepts used in this framework.

Each participant reflected on how they would apply this framework in their own practice. From these suggestions, I synthesised several ways that the knowledge of the expanded framework may be applied within the space, which I specify below.

*1) For a generative design process*

The framework can be applied as a generative method to enable the emergence of ideas, forms and relations for artefact design, in the same way as how I applied it in my practice. For example, Fritsch said: 'I think this one would be very usable in terms of guiding the kinds of design or development processes that we see in our lab.' (Fritsch, 2022b)

Expert and experienced practitioners, who are familiar with the elements emphasised by this framework, and who have already established a system of working, may want to adapt the framework to focus on one element that embodies the focus of their practice. For example, Fritsch emphasised the 'relational' aspect (Fritsch, 2022b), while Neidlinger (2022) and Tsaknaki (2022) emphasised the element of 'the body'.

*2) For reflective purposes*

The framework may be used as a set of analytical lenses to make sense of one's practice. For example, Fritsch said: 'I would immediately start mapping my existing practices and methods into the different kinds of brackets [of this framework]. … It opens up a space for us to try to map our existing practice onto this framework. That's a good thing from an expert side of things.' (Fritsch, 2022b)

*3) For cross-disciplinary communication*

Freire (2022) pointed out that very often a project on creating interactive artefacts involves collaboration between collaborators from the fields of art, design, HCI, and even science. What she found challenging is that each of these disciplines have their own language on the objectives and process of design, which creates barriers for communication. She envisions that the AMI-led design framework – the affect, material, and interaction led building blocks, and the methods of making, co-exploration and assessment provides a foundation of language. Cross-disciplinary collaborators could log their thoughts and ideas under these categories and compare notes. In this way the framework provides a structure and a set of shared language to facilitate communication.

*4) For educational purposes*

It was mentioned that this framework may be used as educational material, for example in interaction design courses where students work with physical materials and prototypes. In this use case, the framework would need to provide more details of how its underpinning helps the students achieve their goals, better visual presentation of a step-by-step guidance for students to implement the different elements within the framework in their actions.

Practitioners from different disciplinary backgrounds may gravitate differently in terms of the three building blocks. For example, fashion practitioners may gravitate more towards the material-led approach and shift to connect with interaction-led approach, while an HCI practitioner may start from the interaction-led approach and move towards connecting to the material-led approach. The triangulation of the three building blocks provides a stable structure. When focusing on one of the blocks it reminds a designer to always relate to the other building blocks, ensuring a balanced relationship between the three building blocks.

In any case, taking my practice for an example (table 7.1), each design practitioner would need to define what they mean by affect in relation to their individual practices and projects. For example, for Neidlinger, affect refers to an emotional bond with the artefact and entails an emotional durability or therapeutic effect (Neidlinger, 2022); for Garrett, affect would refer to strong sensorial impact (Garrett, 2022); and for Fritsch, it entails the desirable qualities of an experience (Fritsch, 2022b). The affective dimension can also be specified differently in different types of projects, for example, it may refer to the level of relaxation in a healthcare product (Hall et al., 2022), or sensory and somatic qualities in an urban space design project (Fritsch, 2022a).

#### 7.1.2.2 Broader implications of this framework

All the interviewees agreed with the notion that the space of affective interaction design is still setting its agenda and combining material design and affect is still a nascent field, thus the AMI-led framework makes a timely contribution by incorporating both domains. Although the interaction-led and material-led approach are familiar to the participants, it was pointed out that the novelty of this framework lies in that it brings 'affect-enabling' to the fore as the goal of designing physical artefacts, and it crosses the boundaries of affect theories, material practice and interaction design by bringing them together, as vital elements for designing an affective interactive artefact. The framework emphasises the relational elements between the three and helps designers to balance these elements. As technologies are moving closer to our bodies and even onto/into our bodies, to study how these artefacts can impact us affectively is of great importance. This framework captures knowledge that has the potential to facilitate such design research.

It has been appreciated that the expanded framework provides a solid theoretical grounding, while the building blocks and methods give ample space for adaptation, expansion and specification from different design practitioners and design teams, , in comparison to frameworks with highly specified elements e.g. (Frederiksen and Støy, 2019). 'It is open enough so that you can fill in [...] your own experiences and methods [...], but it also provides enough direction to kind of guide explorations and investigations' (Fritsch, 2022b). Fritsch (2022b) envisioned using the framework as a tool to construct a library-like collection of affective interaction design practices and methods (Knudsen and Stage, 2015; Fritsch, 2022a).

There are some implications that are specific to fashion practice, where this framework can serve as an analytical tool to unpack how to meaningfully engage with affective interaction design. As Garrett suggested, an issue emerges when bringing fashion into interaction, that reflects a kind of techno-fetishism: 'a wondrous engagement with new technology just because it's new technology' (Hertz, 2015, p.25). The attention of such projects is focused excessively on the technological aspects. Interestingly, she sees that this framework embodies some key facets of fashion practice:

> What I like about this framework is that it can go deeper, and it can go into level of why fashion itself is interesting - this triangulation of affect, interaction and material, because if you take the technology out, fashion is still this triangulation of affect, interaction (and) material. (Garrett, 2022)

She envisioned that this framework may be used to study what makes fashion fashion, through the lens of affect, material and interaction. In such an exploration we can unpack the unique knowledge and qualities of outcomes produced through a fashion process, or 'research through fashion', that can be meaningfully engaged to advance the space of affective interaction design.

As fashion practice is an integral part of the theoretical grounding and methods of this extended framework, this framework also provides knowledge for fashion practitioners. In the current landscape of fashion practice, this framework will be primarily of interest to fashion practitioners who already work with interactive materials, and those who identify themselves as practicing in the space of affective interaction design. These include those working in academia, or running a conceptual design practice, such as Freire (2021) or both such as Winters (2017); fashion designers turned interaction designers such as Skach (2021), Garrett (Karpashevich et al., 2022), and Saito (Petreca et al., 2019)). Many of these practitioners are active in the international e-textile community. These also include fashion practitioners who are interested in starting to work with interactive materials and fashion practice educators who intend to introduce interactive materials to students (Genç et al., 2018). Although fashion practice in the commercially driven context is beyond the scope of this thesis, the relevance of this framework to this context can be meaningful future work to be explored. As interactive and digital materials begin to be incorporated into fabrics for fashion practitioners (Genç et al., 2018), we can be confident that the audience for this research will be expanding in the near future.

#### 7.1.2.3 Points to reflect on

The experts and the experienced practitioner also voiced several points to be reflected upon regarding this framework, which could form tasks for future work.

- Consider emphasising the 'body' element as an extra layer, especially for designing on-the-body artefacts.
- Further articulate the methods layer, for there is a plethora of practices within assessment methods (which I have explained in section 3.3.3) and co-exploration (such as different types of participatory design and co-creation). Developing a mapping of existing practices and methods within the domain addressed by the framework could be a starting point.
- Further develop the relational and social dimensions of affective interaction design, especially the ways that fashion practice can engage with it. As my research only explored in detail the innate aspects of affect (see sections 5.3.2.2 and Study 5), the social aspects of affective experience with the artefact have not yet been sufficiently unpacked. Hyper sociality and cultural relevance are key features of fashion thinking (Pajaczkowska, 2016, pp.90–91), and can lead the advancement of the social and cultural dimensions of technology interacting with the body (Ryan, 2014). Future

work could further unpack and identify how fashion practice can play a critical part in driving the exploration of the social, cultural and relational dimensions of affective experience design.

## 7.2 Reflections on considerations of ethics in designing affective touch machine

Ethical design for an affective touch machine should seek opportunities to contribute to the wellbeing of individuals, families and the community and avoid harm to individuals, communities and the environment (Israel and Hay, 2006, p. 2; also see Peach, 1995). In Chapter 6 (section 6.4.3) I identified several design opportunities for the S-CAT device to deliver supportive touch to individuals. These potential opportunities for doing good also bring with them complex ethical concerns. Design often comes with a large degree of serendipity and some unexpected circumstances (Storni 2012). It is already known to HCI researchers that, with participatory approach, engaging participants in activities with novel interactive technologies in sensitive contexts, ethical challenges beyond the scope of formal approaches to ethics often emerge during studies (Waycott et al., 2017). Designing technologies that affectively touch humans is one such case. Conducting this doctoral research has expanded my awareness of different nuances of ethical considerations both for designing and for researching touch technologies. In the following text I discuss the awareness and the questions generated in relation to the most recent literature. Most of the literature was not available when I started my research, so this discussion is intended to evolve ethical practice of future design studies.

### 7.2.1 The ethics of mimicking human touch

The touch delivered by an S-CAT device has attributes that resemble those of human affective touch. Some of the qualitative comments by participants associated the S-CAT touch with human touch (section 6.4.2.4). From a sensory cognition perspective, it is worth asking whether, the more a machine-delivered touch feels like a real human touch, the more positive affect it enables. Research on the appearance of robots has shown that robots that look almost like real humans evoke discomfort in humans, the so-called 'uncanny valley' effect (Mori et al., 2012). Recent research indicates that this 'uncanny valley' issue may also apply to robot touch (D'Alonzo et al., 2019). Are there other touch sensations from SPSR material that do not feel like human touch, but are affect-enabling in a beneficial way? This is a question that can prompt material designers to carry out future exploration.

A machine touch that mimics human touch inevitably invites more affective bonding, either intended or unintended, which brings us to the ethical considerations of unintended bonding with a machine. The SPSR artefacts are made from silicone and air. The material is innocent of any intention to encourage bonding or attachment, nor is this my intention as the designer. However, we humans, as mammals, are capable of developing affective attachments to objects, our tools, and robots (Scheutz, 2011), and soft-bodied robots have an even stronger conduit for bonding (Arnold and Scheutz, 2017). Harlow's experiment with monkeys and soft cloth 'mothers' revealed that objects facilitating tactile comfort could enable attachment (Harlow, 1958). Is this kind of attachment always doing good or is there a risk of harm? How can we investigate? How should we as designers intervene to avoid harmful implications? There are obviously more questions than answers in this emergent domain. Knowledge of these questions will help to inform ethical design. From a material perspective, investigations could be conducted on what aspects of the attributes of the artefact or material heighten or dampen affective attributions (Arnold, 2017). The AMI-led design framework can be used to facilitate these investigations.

Arnold has suggested that before we can study fully the relational consequences the artefact brings about, design intervention should be applied to prevent a robotic touch that mimics living organisms (not just human beings but also, for example, tenderness from pets). One such design intervention might be the introduction of disfluency (Arnold, 2017). However, my observation from the studies was that it can be difficult to speculate on the relational consequence without the presence of the physical artefact interacting with people in a situated context (for research purposes instead of for commercial adoption). For example, in Study 3, it was only after presenting the newly created artefact Social Breath/chewing (Figure 5.10) and its imagined context of use, that participants began to speculate about ethical concerns regarding the possibility of sending touch to and receiving touch from multiple people. However, they found it difficult to speculate on what can go wrong and what will be considered ethical hazards, as little cultural and social reference exists for these issues. This is also related to the fact that, according to affect theory, affective relations only emerge during physical interaction. The S-CAT device, being a high fidelity simulation of human touch, can be used in a situated context for the purpose of investigating the ethical implications. Once we are equipped with more knowledge about this aspect, design recommendations can be made in collaboration with researchers with social and ethical expertise. Reflecting on ethical judgement as it unfolds is a characteristic of co-designing novel technologies and, as Light and Akama (2019) observe, '(c)ollaborative research on the spot is often the only way to find out how to be ethical in that situation' (p. 244). They further argue that ethics are produced through 'doing ethics' or rather making situated judgements that feed back into a larger understanding of what ethical conduct means for a society and for the research community.

### 7.2.2 The ethics of an interactive system around the collecting, storing and distributing data on affective touch

Although designing an interactive system is beyond the scope of this research, the S-CAT device, like any interactive artefact, only functions within an interactive system. Despite the benefits of providing a physical channel to connect people over the obstacle of geographical distance, machine touch raises questions of trust in terms of the reliability, security and safety of the machines and systems (Friedman et al., 2008). The archiving and distribution of touch that is enabled through the connected device brings issues of consent, privacy, agency, control, and ownership (Jewitt et al., 2020). These ethical challenges are shared across designing emerging, interactive and connected touch technologies, which has been researched (Waycott et al., 2016), and I would like to direct readers to the work of Parisi (2008); Jewitt et al. (2020), and Paterson (2007).

### 7.2.3 The ethics of researching touch

One principal learning in relation to the consideration of ethics from my studies in this research is the multiple layers of sensitivity in researching touch, especially with a participatory approach. I invited the research participants to conduct touch-based co-exploration activities, including sharing personal stories and objects of touch and prototyping personal objects of affective touch using SPSR material. Although I did not observe that participants expressed discomfort during this process, I have developed several additional ethical considerations for potential tensions for future research into touch. I detail as follows.

First, there could have been a tension between the expectation to share original thoughts and the feeling of being exposed. When showing the research artefacts to my colleagues at the RCA and my friends, and when exhibiting these artefacts during two work-in-progress shows at the RCA (January 2017, and January 2018), among the informal feedback I have received, there have been comments associating the touch deriving from the SPSR material to the kind of touch experienced in intimate contexts. However, such association never appeared among the comments from participants in my formal studies. It may be possible that participants withheld their thoughts relating to more sensitive contexts in front of other participants or the researcher. In my Studies 2 - 4, although the questionnaire format gives privacy to participants when they document their thoughts, it is not anonymised for the researcher. In Study 3, during the 'Show and Tell' activity the participants were expected to share their artefacts and their thoughts with the group. It is possible that some participants still felt exposed in doing this. In Studies 4 and 5, the setting was a one-to-one format, where the participant gave their feedback in the presence of the researchers. This removed the tension of having to share in front of a group of people, but the presence of the researcher and being identifiable might still have created tension. In future studies, it might be useful to explore the applicability of data collection methods that ensure anonymity at all stages; that is, the participant's identity cannot be associated with the feedback he or she gives, even to the researcher who collects the data, or moderates the workshops. Taking a broader perspective, Kettley asks '(h)ow 'free' are people to present themselves as they wish?' (Kettley, 2021, p.38), and attributes this to the dynamic relationship between the participant and researcher.

Secondly, participants have dramatically different sensitivities towards the activities of talking about the experience of touch and being touched by unfamiliar robotic artefacts. It is possible that highly sensitive participants encountered unexpected tension during the activities, while much less sensitive participants enjoyed the opportunity to share personal experience and individual creativity. This awareness was formalised during Study 5, when the Social Touch Questionnaire (STQ) was introduced. According to Wilhelm et al., (2001), a participant with a total score of over 32 is considered to have a high level of social anxiety and a score of 20 is considered to indicate a low level of social anxiety. A number of participants in Study 5 had scores over 32 (ranging from 36~53). High social anxiety can be accompanied by a heightened aversion to social touch (Wilhelm et al., 2001), which indicates that it is more likely to cause a feeling of discomfort in these participants during activities involving being touched and talking about the experience of touch. Simply excluding this kind of participants to prevent potential distress is not a solution, as these individuals are also stakeholders in the development of such touch technology and their opinion and imagination are invaluable in co-shaping the becoming of touch technologies. For example, one participant, with a STQ score of 43, expressed that she dislikes human touch due to her experience of uncomfortable touch in childhood. However, she found the soft robotic touch more acceptable. In contrast, some participants expressed that they consider it a positive experience to be able to share their experiences and express their thoughts on touch. How to facilitate a fulfilling experience for these participants to share and contribute, while at the same time facilitating an environment in which the highly anxious participants feel safe and comfortable is a useful question to consider going forward.

Thirdly, like participants, researchers also have different sensitivities towards the experience of facilitating the activity of talking about affective touch experience and imagination. Researchers may encounter unforeseen discomfort themselves. The potential distress that might be experienced by highly socially anxious participants can also cause stress for the moderating researcher. Thus, ethical consideration should also take the protection of researchers into account. Jewitt et al. (2020) propose that informed consent should also be sought from members of the research team.

In terms of the theoretical underpinning of research ethics, a highly relevant strand of literature has developed a relational framing, which extends the ethics consideration beyond the standard deontological guidelines (e.g. informed consent) to a care-based approach. This care-based approach to ethics is also characterised by micro-ethical considerations. I detail this literature as follows. Contrasting with the general approach of deciding on the overall ethical approach beforehand, the focus of micro-ethics is instead on 'what happens in every interaction' (Komesaroff, 1995). It can be seen to include concerns about the internal relations among participants and between participants and the researcher, and the micro-ethical judgement of situations that emerge during the design research process (Spiel et al., 2018, Kettley 2017, 2021). Among these, Kettley (2017, 2021) formulated a holistic framework, the Person-Centred Approach (PCA) which draws on therapeutic practice and that of the caring professions (Rogers, 1961) for design-led research involving participants. The PCA is a framework for empathy and valuing, central to which is respect for the autonomy of the individual. There are several good practices advocated by the care-based micro-ethics approach that are highly relevant to the questions raised from the reflections I have expressed above. In terms of consent, Jewitt et al. (2020) suggest introducing different levels of consent, gauged by the sensitivity of each touch activity. Micro-ethics researchers have taken this further to suggest that informed consent should be checked at regular intervals and should be open to dialogue, with the possibility of making adjustments for individuals in response to their concerns or preferences (Kettley et al., 2017, p.11). Structured de-briefing held as soon as possible after participatory sessions (Kettley et al., 2017, Spiel et al., 2018) can 'support the team's shared development of the research themes, supporting individuals for whom difficult personal issues are brought to the surface and providing insight into the growth of the research team as a context for the growth of the participants' [p.12].

This emerging design space can only be advanced through interdisciplinary negotiation through active participation in exploring and shaping the ethical grounds of designing machine touch. The above considerations should be incorporated into future AMI-led design framework for designing affective touch. Researchers designing for modalities other than touch can choose the relevant elements to apply.

# Chapter 8 Conclusion

In this chapter I first report how my research achieved its aims, and how I answered my research question. Following this, I articulate the original contribution to knowledge before sharing thoughts on future work.

## 8.1 Achieving the aims and answering the research question

In this section, I discuss how I have achieved all three aims, and thus addressed my main research question. The aims and objectives were specified in the introductory chapter (section1.3). I include them here again for convenience.

*Aim 1*

Formulate a design framework that is grounded in affect theories, synthesising practices from the interactional approach, fashion practice, and material-centred interaction design, to guide my design practice towards creating an affect-enabling artefact.

*Aim 2:*

Guided by the design framework formulated in Aim 1, develop a body of work with an affect-enabling outcome.

*Aim 3:*

Critically reflect on the broader implications arising from the findings of my research within the space of affective interaction design.

My research achieved Aim 1 by formulating the AMI-led design framework.

Through three phases of exploration by practice, applying the AMI-led design framework, I have developed the final S-CAT device that was evidenced to enable pleasantness. In this

Aim 2 was achieved. Through this process, my practice generated knowledge on the affective affordance of SPSR material as well as the technical configurations of the SPSR artefacts for affective touch, and I provided documentation of these sets of knowledge. Aim 3 was achieved through reflecting on the broader implications arising from the AMI-led design framework and its associated methods. The implications of the design knowledge arisen from each study has been discussed in each corresponding chapter.

My research asked:

> How can we design artefacts using interactive materials that enable affective experience?

Taking the steps guided by my research aims and objectives, I addressed my research question by demonstrating one pathway to achieve an affect-enabling final artefact, using one type of novel interactive material – SPSR material, supported by the AMI-led design framework and three main methods of studio practice, co-exploration and assessment. The findings from trials during this research, and the framework that I developed, are of broader significance than this one pathway.

## 8.2 Original contribution to knowledge

This research makes an original contribution primarily to the practice of designing interactive affective artefacts, in both theory and practice.

It addresses a particular gap in the space of affective interaction design, that there was a lack of knowledge relevant to the needs of designers about how to navigate the design process to create physically-bodied interactive artefacts that are intended to offer an affective experience.

The affect-, material-, and interaction-led (AMI-led) design framework for guiding such form-giving process is a contribution to both theory and practice. The framework was developed through a rigorous process: it was formulated through a literature review of relevant theories and practice. It was tested through my empirical design process following this design framework, the process of which was documented. The wider applicability of the knowledge from the framework was critically reviewed by a group of experts in the field. Such a design framework for design can be considered a theoretical output from a Research through Design approach (Gaver, 2012, p.938).

The framework synthesises knowledge from the interactional approach (Boehner, DePaula, et al., 2007; Höök, 2009; Fritsch, 2009, 2018), fashion practice (Gully, 2010; Pajaczkowska, 2016) and material-centred interaction design (Wiberg, 2018; Vallgårda, 2014). The affect-, material-, and interaction-led approaches as building blocks and the methods combining studio making, co-exploration and assessment can be used by other designers within the space for a generative design process, as analytical lenses to make sense of their practices, as a tool for communication and as an educational tool. While providing a solid theoretical grounding for the conceptual building blocks, the framework remains open to give space for adaptation, expansion and specification by different design practitioners and design teams.

The S-CAT artefact is the first to use a silicone pneumatic actuator to simulate C-optimal affective touch in all three of its main characteristics. In a controlled experimental study, it was demonstrated that this SPSR artefact elicited pleasantness, and can enable psychological effect similar to manually applied touch (human hand and soft brush). Its success in delivering C-optimal affective touch provides opportunities for future applications such as healthcare (e.g. Goldsworthy et al., 2020). This contribution is endorsed by two grants I have been awarded. The first one was from Research England's MedTech SuperConnector programme from June 2018 and to April 2019 (MedTech SuperConnector, 2018) to support the application of the S-CAT artefacts in a healthcare and clinical context. The second was from Cancer Research UK to support adapting this device to improve cancer patients' comfort during stressful procedures such as radiotherapy (SOFTLI project)[21]. For the second grant, together with my collaborators we

[21] The project is entitled: SOFTLI - Improving care through Soft Robotic Tactile Intervention – Towards a smarter compassionate experience in cancer treatment, which was funded by Cancer Research UK (CRUK) Convergence Science

have produced publications on part of the project (Hall et al., 2022; Gimson et al., 2022). Furthermore, the S-CAT device has been chosen by a neuropsychology lab at University College London headed by Prof. Aikaterini Fotopoulou for their study to examine the effects of this device in order to explore opportunities in the development of robotic and digital systems to convey social support in the context of social media communications (Saramandi et. al, 2022).

My practice generated original knowledge for designing affective touch. It produced information on the affective affordance of SPSR material and artefacts. It produced evolving versions of the 'Variables Map for Designing Affective Touch Artefacts using SPSR Material', which contains relevant elements that impact the affective affordance of the SPSR artefact and provided detailed accounts of the technical configuration of these variables.

The detailed documentation of the design process, as well as the decision-making process provided an empirical account of in-situ design practice, which is open to critique and development by the community.

And finally, this research placed fashion practice within affective interaction design. Fashion practice contributed to the epistemology and methods of the design framework. The role of a material designer within interaction design is most often considered as merely to 'create attractive packaging for a finished black box of technology' (Winters, 2017, p.29): this research is a challenge to this norm by demonstrating that fashion practice can play an active role in addressing a gap in the theory and practice of interaction design and in shaping the future of affective touch technology.

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Centre at The Institute of Cancer Research, London, and Imperial College London (A26234). The project proposes to customise the soft robotic tactile artefact that I have developed for application in radiotherapy and MRI environment to improve patient comfort. I collaborated with working with Prof. Alison McGregor from Imperial College London and Dr. Helen McNair from the Institute of Cancer Research. The project duration is from July 2019 – June 2020 (extended to Mar 2021 due to Covid-19).

## 8.3 Limitations of this research

This research was mostly focused on the felt sensorial quality of the artefact, concentrating on the innate aspect of affect. The social aspects of affective touch have not been unpacked. The social aspects of machine-generated affective touch are equally important in a holistic experience and would need to be investigated if this touch is to be applied in a real life context.

The findings regarding co-explorers' affective response to the SPSR artefacts in Studies 1-4 cannot be generalised to represent preference at a population level, due to the small sample size. The sample size was dictated by the exploratory nature and the practical needs of the design studies. From Study 5, by contrast, with its larger sample and rigorous methods, conclusions may reasonably be drawn about wider populations.

How to apply the findings from my research in practices with specific disciplinary backgrounds would require additional investigation.

To conduct my literature review, I used the RCA Library Search platform, which includes a portal to ProQuest, ACM Digital Library, IEEE Xplore Digital Library, Google Scholar and Google search engines, with relevant key words. I expanded the search by following relevant references from the literature reviewed. In order to adhere to the scope of the thesis, from the initial large body of literature resulting from these search activities, work that directly addresses the scope of my thesis is included, which I specify as follows: For fashion practice (section 2.4) work that directly addresses the affective dimension of the form-giving process of fashion practice was included in the discussion, while work that does not directly address this scope, including fashion theory that addresses the cultural and social dimensions of fashion artefacts, is excluded. Fashion theory in these respects constitutes an important dimension of fashion scholarship. It is worthy of future work to contextualise fashion practice defined in my research in relation to broader fashion theory. For the section on affective touch with soft robotics (section 2.7), work on wearable artefact design that actively touches humans is included, while research on the experience of humans initiating the touch of other static material is excluded. Due to the reciprocity of touch (Leder and Krucoff, 2008), the experience of touching and being touched can be closely intertwined, and designing the affective qualities of touch from technology can benefit from exploring the experience of touching; thus, it can be meaningful for future work to relate to the literature of the experience of touching.

## 8.4 Future work

During the journey of this research, the focus of my practice was mostly on the selected modality of touch and the context of affective touch with a positive valence, and later specifically on simulating CT-optimal touch, which is a gentle stroking touch. This has informed several areas of emerging topics that could be further explored. These are:

1) To investigate how the AMI-led design framework can be applied by designers within the space of affective interaction design, and those who come from different disciplinary backgrounds, e.g. fashion design and HCI. This also includes experimenting with using the AMI-led design framework to investigate the social and ethical dimensions of affective interaction design, in collaboration with researchers from social science disciplines.

2) To explore the application of the S-CAT device within a healthcare context. This would be a continuation of the work on the SOFTLI project mentioned in page 168-169 (and Footnote 19). Together with health professionals I am currently seeking follow-up funding to support the further development and evaluation of this device, which include the following. Refine the S-CAT device, in order to produce haptic sensation that has a closer relationship to human touch, through configuring mechanical, digital and physical materiality. For this I would be interested in collaborating with therapeutic touch practitioners to study the attributes of therapeutic touch. Investigate social aspects and ethical implications of applying this device in real-life scenario, and I would like to conduct this through collaboration with researchers from relevant disciplines and stakeholders.

3) To explore tactile language from soft robotic materials that evokes affect beyond pleasantness. In this research, I have focused on the properties of SPSR material that affords affective touch with positive valence. Findings from the initial exploration stage indicated that there is a wide range of affective affordance that this material enables, in visual, movement and tactile modality terms. Future work could explore design opportunities in these diverse channels.

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# Appendix

Other research data can be provided upon request of the examiners, for the protection of participants' privacy.

***Appendix 1. List of publications, conference presentations and exhibitions relevant to this research***

**Published literature**

**C. Y. Zheng,** K. Wang, M. Wairagkar, M. von Mohr, E. Lintunen, K. Fotopoulou, Comparing soft robotic affective touch to human and brush affective touch, in proceedings of the 2021 World Haptic Conference, Montreal, July 2021, p.352. (The full paper of this study is being prepared to be submitted to the journal *Experimental Brain Research)*

Goldsworthy, S., **Zheng, Y. C.,** McNair, H., McGregor, A. (2020) 'The Potential for Haptic Touch Technology to Supplement Human Empathetic Touch During Radiotherapy'. *Journal of Medical Imaging and Radiation Sciences*. [Online] 51 (4, Supplement), S39–S43.

Wang, K.-J. & **Zheng, C. Y.** (2019) 'Toward a Wearable Affective Robot That Detects Human Emotions from Brain Signals by Using Deep Multi-Spectrogram Convolutional Neural Networks (Deep MS-CNN)', in *28th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN), 2019* [Online], October 2019, pp. 1–8.

**Zheng, C. Y.** & Walker, K. (2019) 'Soft Grippers Not Only Grasp Fruits: From Affective to Psychotropic HRI', in *Proceedings of the AISB 2019 Symposium on Movement that Shapes Behaviour (MTSB'19)*. [online]. April 2019, Falmouth University, UK: pp. 15–18.

**Zheng, C. Y.** (2018) 'Affective Touch with Soft Robotic Actuators – A Design Toolkit for Personalised Affective Communication', in *Workshop: Reshaping Touch Communication: An Interdisciplinary Research Agenda, ACM CHI Conference on Human Factors in Computing Systems*. 21 April 2018, Montreal.

**Zheng, C. Y.** (2017) 'Machinising Humans and Humanising Machines: Emotional Relationships Mediated by Technology and Material Experience', in Susan

Broadhurst & Sara Price (eds.) *Digital Bodies*. Palgrave Studies in Performance and Technology. [Online]. Palgrave Macmillan, London. pp. 111–127.

**Conference presentations**

Zheng, C. Y. (2020) 'Bringing Fashion Design Approaches Into Creating Affective Touch Interfaces: Toward a Sensorial and Experiential Quality-Oriented Design Framework. In: Workshop: Designing Digital Touch: Social and Sensory Aspects and Challenges, EuroHaptics2020. September 6, 2020, Leiden, Netherlands. Available from: https://designtouch2020.wordpress.com/workshop-programme/.

Zheng, C. Y., (2018) 'Sentimental Machines: Affective Experience Enabled by Soft Robotic Interfaces'. Invited presentation at Robot Art Forum, at the International Conference Robotics and Automation (ICRA), May 2018, Brisbane.

Zheng, C. Y. et al. (2016) 'Being Relational: Entering the World of Sensory and Embodied Communication Design'. Workshop at Design + Research + Society: Future-Focused Thinking, 2016 Design Research Society 50th Anniversary Conference (DRS16). 27-30 June 2016, Brighton, UK. Available from: https://www.drs2016.org/workshops (Accessed 3 April 2021).

**Exhibitions**

*Robotic Jewellery,* at 'Robot Late', Manchester Science Festival, Oct 2017 (by invitation).

*Emotive Soft Robotics*, at 'Communicating the Intangible', London Design Festival, 17-24 Sep, RCA.

*Tangible Emotions*, Work-in-Progress Show, RCA, London, Jan 2016.

***Appendix 2. Part of Study 1 and Study 2: Participant consent form for workshop: The sentimental soft robotics during AcrossRCA week, 2016***

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For further information:
Caroline Yan Zheng
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Project Title:
The Sentimental Soft Robotics at AcrossRCA week 2016

Workshop Date:
31 Oct – 4 Nov 2016

Workshop Information

**Summery of project**

Soft robotics, bio-inspired robotics and programmable materials offer a complete new page for designing interactivity. While robotic engineering focus on their potential on functionality, this AcrossRCA project explores especially the emotive properties of soft and bio-inspired robotics, namely their tactile, sensual qualities as a material as well as their liveliness, animal like, performativity when in dynamic forms. We ask what agency this disruptive material has on human feelings and what are the potential relations of human living with soft robotic objects.

The cross-disciplinary project introduces work-in-progress soft-robotics toolkits developed by both soft robotic labs and the project-leading team for artist and designers from different programs at RCA to have hands-on experience and prototype projects. Collectively we will explore above questions by making prototypes and present prototypes to catalyse social conversations.

The project includes a visit to soft robotics lab in London. An electronic engineering specialist will be supporting group projects. Toolkits and essential materials are provided.

For detailed day-by-day program please see attachment.

Consent Form

I confirm I have read the information on the *The Sentimental Soft Robotics* workshop and all queries have been answered to my satisfaction.

I understand that my participation in is voluntary and that I am free to withdraw from activities in part two is without penalty, and do not have to give any reason for withdrawing.

I understand that all information gathered during the workshop will be stored securely.

I consent to:

- Taking part in *The Sentimental Soft Robotics* workshop

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- Take part in giving feedback to research questionnaires in on-line or written form
- The workshop being audio recorded
- The workshop being video recorded
- Still photographs being taken during the workshop
- I agree to recordings being used for research purposes (as described)
- I agree to the use of anonymised quotes in publications/exhibitions

☐
Please tick here if you do NOT want video or audio used in the public domain

Participant Name : ..............................................................................................................................
(Please print)

Signature............................................................... Date: ..........................................................................

Thank you for your interest and participation.

Researchers Names : Caroline Yan Zheng

Signatures ................................................ ................................................ ................................................

Date: .........................................................

*This project follows the guidelines laid out by the Research Ethics Code of the Royal College of Art.*

## *Appendix 3. Study 2: Questionnaire used*

How does it make you feel?

- Which object you are interacting with? (1-4)

1 2 3 4

- How does the artefact make you feel?

| | | |
|---|---|---|
| o interest | o anticipation | o vigilance |
| o serenity | o joy | o ecstasy |
| o acceptance | o trust | o admiration |
| o apprehension | o fear | o terror |
| o distraction | o surprise | o amazement |
| o pensiveness | o sadness | o grief |
| o boredom | o disgust | o loathing |
| o annoyance | o anger | o rage |
| o other (please specify) | | |

- Due to what property do you associate the feeling? (please circle)
  - o Surface texture
  - o Movement
  - o Touch
  - o Sound
  - o Other (please specify)________
- Why it evoke your such feeling?
- Would you say it is a positive or negative feeling?
- How strong the artefact affects your feeling? 1 being no impact at all, 10 being very impactful._____
- Are you __Female, __ male,
- Which age group are you from (please circle): 15-17, 18-25, 26-29, 30-39, 40-49, 50-59, 60+
- Which country are you from? ________

***Appendix 4. Study 3: Participant consent form for workshop: Creating a touch/hugging machine with soft robotics during Athens Digital Arts Festival***

The workshop archive can be found on this link: https://2017.adaf.gr/events/creating-a-touchhugging-machine-with-soft-robotics-workshop/



Royal College of Art
RESEARCHRCA

For further information:
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Workshop Title:
**Creating a touch/hugging machine with soft robotics**

During: Athens Digital Arts Festival

Workshop Date: 20 May 2017

Workshop Information

**Summery of project**
One possibility in the post digital and post human age is the recreation of human physical experience with the integrity of digital and materiality. Digital tools such as affective computing are capable of sensing and analysing human emotional cues. Materials such as soft robotics are capable of producing aesthetic serendipities. A combination of the two might offer the potential of recreating the physical contact of emotional experiences that traditionally exclusive to human such as touch and hug. This workshop invites participants to explore this potential together. However emotional experience is highly dependent on personal experience, social & cultural context, and the emotional relations could not be designed by designers but only formed with sustained.

Interaction between the individuals and the artefacts. That is why in the workshop, we will share our memories, interaction patterns and use these to 'design' a personal touch/hug machine, and try them out to see if they make us produce the same oxytocin in us than human touches!

The workshop wishes to attract participants who are interested in below workshop activities.

The workshop starts by each of us sharing our personal experience on how a certain type of touch (e.g. hug, squeeze, stroke, tap, brush, nudge…) has brought us the feeling of comfort or companionship. You are welcome to bring an image or real object that related to this experience.

We will then discuss what type of touch these soft robotic artefacts have the potential to create.

Very excitingly, we use the mechatronic toolkit & materials provided with your imagination to create a touching/hugging machine for the festival audiences to experience!

Royal College of Art
RESEARCHRCA

**Consent Form**

I confirm I have read the information on the *Creating a touch/hugging machine with soft robotics* workshop and all queries have been answered to my satisfaction.

I understand that my participation in is voluntary and that I am free to withdraw from the workshop is without penalty, and do not have to give any reason for withdrawing.

I understand that all information gathered during the workshop will be stored securely. and

I consent to:

- Taking part in *Creating a touch/hugging machine with soft robotics* workshop
- Take part in giving feedback to research questionnaires in on-line or written form
- The workshop being audio recorded
- The workshop being video recorded
- Still photographs being taken during the workshop
- I agree to recordings being used for research purposes (as described)
- I agree to the use of anonymised quotes in publications/exhibitions

☐ Please tick here if you do NOT want video or audio used in the public domain

Participant Name
:………………………………………………………………………………………
(Please print)

Signature……………………………………………………..

Date: ……………………………………………………………………

Thank you for your interest and participation.

Researchers Name(s): Caroline Yan Zheng

Signatures ………………………………………… ……………………………………………
Date: …………………………………………………

*This project follows the guidelines laid out by the Research Ethics Code of the Royal College of Art.*

## *Appendix 5. Study 3: Questionnaire 1 for workshop: Creating a touch/hugging machine with soft robotics during Athens Digital Arts Festival*

Workshop Title:
**Creating a touch/hugging machine with soft robotics**
During: Athens Digital Arts Festival
Workshop Date: 20 May 2017
Workshop host: Caroline Yan Zheng (MPhil Candidate)
yan.zheng@network.rca.ac.uk

| | | What emotion(s) does it evoke of you? Why? | What memories or experiences does it remind of you? | How do you feel about it? | How do you want it to interact with you? | Please label the touch |
|---|---|---|---|---|---|---|
| 1 | soft robot 1 three legs | | | | | |
| 2 | soft robot 2 4 legs | | | | | |
| 3 | Soft robot with hand squeeze | | | | | |
| | | | | | | |
| 4 | curled one | | | | | |
| 5 | wiggling tails | | | | | |
| 6 | remote experience | | | | | |
| 7 | shared breath | | | | | |

Is there any difference between machine inflating and manual inflating, especially another person inflating?

______________________________________________

Your name: _______ , name of your interviewee: ___________

***Appendix 6. Study 3: Questionnaire 2 for workshop: Creating a touch/hugging machine with soft robotics during Athens Digital Arts Festival***

Workshop Title:
**Creating a touch/hugging machine with soft robotics**
During: Athens Digital Arts Festival
Workshop Date: 20 May 2017
Workshop host: Caroline Yan Zheng
(MPhil Candidate)
yan.zheng@network.rca.ac.uk

**Name of touching machine builders:**

**What is the experience?**

**How would you name this tactile experience?**

**Why it is important?**

***Appendix 7. Feedback for questionnaire 1 for workshop: Creating a touch/hugging machine with soft robotics during Athens Digital Arts Festival***

Data organised by Caroline Yan Zheng

28 Dec 2018

The table below shows an aggregation of all the participants' responses to Questions 1-5. Each row shows comments from one participant. Spelling has been corrected during transferring of the response. Unreadable words were marked as '[…]'.

| | Question | 1.What emotion(s) does it evoke of you? Why? | 2.What memories or experiences does it remind of you? | 3.How do you feel about it? | 4.How do you want it to interact with you? | 5. Please label the touch |
|---|---|---|---|---|---|---|
| 1 | soft robot 1 three legs | strange | an alien in the movies | funny | are half in my palm and the other half outside | soft |
| | | warmth | mother hugging me | warmth | don't stop | soft |
| | | safe | someone hugging me | warm | touching it | flexible |
| | | sadness | starfish/[…] chromosomes | emotional, it seems like becoming alive, while having a […] time doing so (this covers the cell below it) | licking it | balloon like, almost bursting |
| | | delight | alien aesthetic | I would like to have them touch me in everyday life (participant grouped this and the below cell to | When in doing something | something between a sex toy |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | share the same comment) | | |
| | | joyful, I felt some [...] liking me | pets or cute animals | nice and cute, cuddly | i wanted to grab me more firmly | hug |
| | | uncomfortable because it's an unusual thing to touch | jellyfish | not pleased | I would like more surface of my hand to be covered | squeeze |
| | | It felt like a handshake - meeting someone | friendly | funny | a reaction to your finger touch [...] | |
| | | | grabbing/pressuring my hand by fingers | nice... and comfortable | i would like it to have more legs | comfy and secure! |
| | | vulnerability | holding an octopus | it's cute | I want it to get more inflated | soft |
| 2 | soft robot 2 4 legs | pleasure | a starfish | feel a familiar feeling | on/off in my finger | softness |
| | | safe | mother hugging me | warmth | don't stop | soft |
| | | warm | the sense of hug | safe, close | hugging me | flexible |
| | | bliss | | emotional, it seems like becoming alive, while having a [...] time doing so | watch it | new, weirdly |
| | | delight | alien aesthetics | I would like to have them touch me in everyday life (participant grouped this and the above cell to | else, like studying or waiting for the bus | a toy |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | share the same comment) | | |
| | | neutral, did not had pressure of hug | chromosome | neutral | more firm | Osculate |
| | | more happy than the first one | starfish | more lively(vivid) | I would like it to have a variety of movement | hug |
| | | friendly | like a handshake ([…] to 3 legs) | funny | a reaction to your finger touch […] | |
| | | happy | it reminds me of starfish | curious and joyful/playful | to start walking | vivid! |
| | | being attacked | spider | looks cute but its aggressive deep inside | i want it to wrap around my hand | hugging |
| 3 | Soft robot with hand squeeze | anxiety | An […] | strange, threat | i use it when i am stressed | fear |
| | | heavy but comfortable | nurses taking your pulse | left blank | squeeze it under stress | balloon |
| | | relax | when i inflate my bike | good | keep like that | squeeze it |
| | | hotness | heartbeat pump | responsibility | hug by the neck | friendly |
| | | delight | alien aesthetics | enthusiastically | play with it with others | by alien lite |
| | | surprised, I felt more vivid then other | insect or elf? | nice, connected | i want the object to take initiative | cuddle |
| | | pleasant, because I was | insect/worm | happy, excited | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | able to control it | | | | |
| | | curiosity | breath of […] | having […][…][…] the .. was ..? the movement | the likes it like… | very exciting |
| | | | fake plastic spiders for pranks? - but cuter | bored | to melt | unnatural, artificial |
| | | pleasure | holding a baby | bored | I want to squeeze it more easily | passive |
| 4 | curled one | disgust | a huge warm in video games/Cronnenbergs film | threat | i don't want (it) to interact with me | alien - like |
| | | choking | worms(warms) | something very close to me | touch it but no hug | too warm |
| | | squeamish | snake | terrible in a good way | throw | tight |
| | | sorrow, anxious | a game in the street | want to get to know it better | throw it to other people to […]? | cocoon |
| | | delight | bracelet | want to take it with me | wear it | |
| | | surprise | creature wrapping the hand (like an octopus) | intimate | exciting if it was […] and press it against the ear | human like |
| | | a connection, an emotion | a snake | comfortable, hugged | more than one, doing the same action | connected |
| | | hunger | caterpillar | I want to eat it | I want it to get lighter | oily |
| 5 | wiggling tail | | fingers | unease | staring it from a | harsh |

| | | | | | |
|---|---|---|---|---|---|
| | fear | | | distance doing his thing | |
| | not so exciting | diet systems | sophisticated | leave it | common |
| | weird | warm | squeamish | tap it | flexible |
| | weird memories of touching animals, happiness & excitement, uncertain | heartbeat | I like it seems alive and peaceful | Keep it in my pocket | pet |
| | | weird creature | | it could be a weird new kind of “plant” in the house | |
| | fear | tongue or tail | curious | nothing more | alive |
| | sleazy | headless sardines | funny but disgusting | I want it to more differently | like a rubber from school |

***Appendix 8. Participant consent form for Study 4 feedback on AffectNode – a modularised affective touch unit for personalisable sensations***

Royal College of Art

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For further information:

Caroline Yan Zheng
(PhD Candidate)
yan.zheng@network.rca.ac.uk

**Project Title**:
Evaluating: AffectNode: Personalise Affective Tactile Language with Wearable Soft Pneumatic Accessories
Date:
4 Nov 2017

Information

In this experiment, we will facilitate participants in below activities:

- Wear the AffectNode artifact around the wrist;
- Evaluate whether the AffectNode artifact and interactive system have relaxing factor;
- Evaluate and identify a personalized tactile pattern that help relax;
- Participate in a 15min semi-structured interview after the personalization session;

Consent Form

I confirm I have read the information on the *Evaluating AffectNode* and all queries have been answered to my satisfaction.

I understand that my participation is voluntary and that I am free to withdraw without penalty, and do not have to give any reason for withdrawing.

I understand that all information gathered during the workshop will be stored securely.

I consent to:

- Taking part in the *Evaluating AffectNode*
- The session being audio recorded
- The workshop being video recorded
- Still photographs being taken during the workshop
- I agree to recordings being used for research purposes (as described)
- I agree to the use of anonymised quotes in publications/exhibitions

Please tick here if you do NOT want video or audio used in the public domain. ______

Participant Name :..............................................................................................................................
(Please print)

Signature............................................................Date..........................................

Thank you for your interest and participation.

Researchers Names : Caroline Yan Zheng,
Signatures ............................................... Date: .........................................................

*This project follows the guidelines laid out by the Research Ethics Code of the Royal College of Art.*

## *Appendix 9. Existing works on actuator design for affective touch*

W: Wearable

AT: Affective touch – the paper mentions "affective touch"

CAT: C-optimal affective touch

Work from soft robotics publications is highlighted in yellow box

Works from techno-fashion is highlighted in blue box

| | Prototype | Intention | Type of touch | Body position | actuation | modality | W | AT | CAT |
|---|---|---|---|---|---|---|---|---|---|
| **From human computer interaction (HCI) field** | | | | | | | | | |
| 1 | Poultry jacket? (Teh et al., 2006) | Care for pet – provide affection and interact | symbolic | upper body (poultry) | vibration | T | √ poultry jacket | X | X |
| 2 | TapTap (Bonanni et al., 2006) | Convey affection and nurture for use in emotional therapy | symbolic | personalisable body position | vibration | T | √ Scarf | X | X |
| 3 | Virtual interpersonal touch device (Bailenson et al., 2007) | Express emotions in virtual environment | symbolic | hand | force feedback joystick | H | X | X | X |
| 4 | Huggy pajama (Teh et al., 2008) | Remote communication of emotion | hug | chest, abdomen | Pneumatic temperature | T | √ jacket | X | X |
| 5 | HugMe (Eid et al., 2008) | Emotion communication in remote and virtual communication | symbolic | Upper arm | vibration | H,V, | √ jacket | X | X |
| 6 | fingertip friction stimulator (Salminen et al., 2008) | Evaluating sensation | symbolic | finger | friction-based horizontally rotating fingertip stimulator | H | X | X | X |
| 7 | An air generating speaker device (Hashimoto and Kajimoto, 2008) | To display 'emotional' not 'literal' information | symbolic | hand | air pressure generated by vibrating speaker. | H | X Hand-held | X | X |
| 8 | iFeel-IM! | Enhance emotionally | Hug, shiver, | chest (both | vibration, force by | T, Text | √ | X | X |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | (Tsetserukou et al., 2009) | immersive experience of real-time messaging.<br><br>Detect emotion from text to trigger haptic stimulation | heart rate pulse | front and back) | rotating motor+belt | | Belts around chest | | |
| 9 | Immersion jacket<br>(Lemmens et al., 2009) | Enhance immersive experience | Symbolic, editable | upper body, both front,back, both arms | vibration | T, V, A | √<br>jacket | X | X |
| 10 | haptic stimuli from screen<br>(Salminen et al., 2009) | Evaluating sensation | symbolic | finger | vibration | H, V | X<br>Screen devices | X | X |
| 11 | Remote social touch device<br>(Wang et al., 2010) | evaluate perceptibility only | Holding, squeezing | upper arm | friction, servo motor rotating and pull armband textile ti simulate a squeeze | T,A,Txt. | √<br>Arm band | X | X |
| 12 | VibroGlove<br>(Krishna et al., 2010) | Communicating emotions: sensory subsitution | symbolic | hand | vibration | H | √<br>glove | X | X |
| 13 | Poke<br>(Park et al., 2011) | Communicating emotions | Poke, shake, pat | cheek, hand | pneumatic | H, V, A | X<br>mobile phone attached | √ | X |
| 14 | EmoJacket<br>(Arafsha et al., 2012) | haptic actuators to improve user's immersion in gaming and movie watching. Involve user in the design through survey | vibration, warmth, heartbeat simulation, shivering | neck, chest, arms | vibration, heat | T | √<br>jacket | X | X |
| 15 | Kissenger<br>(Zhang et al., 2016) | Communicating emotions | kiss | lips | vibration | T,V,A | X | X | X |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 16 | VibeRate (Giannoulis and Sas, 2013) | Tool for creativity | symbolic | arm | vibration | T | √ Arm band | X | X |
| 17 | TaSST (Huisman et al., 2013) | Communicating emotion | symbolic | lower arm | vibration | T | √ Arm band | √ | X |
| 18 | Emotion-Air (Tsalamlal et al., 2013) | Evaluating affective properties of sensation | symbolic | hand | air jet | H | X | X | X |
| 19 | SWARM (Williams et al., 2015) | Modulating emotional status: sensory substitution | symbolic | neck | vibration | H, V, A | √ scarf | X | X |
| 20 | Personnalisable mid-air ? (Obrist et al., 2015) | Communicating emotions (meaning generating) | symbolic | hand and fingers | mid-air (AltraHaptics) | H, V | X | X | X |
| 21 | Good Vibes? (Kelling et al., 2016) | Stress alleviation | symbolic | upper arm | vibration | T | √ sleeve | X | X |
| 22 | (Bianchi et al., 2016) | Regulating emotional status | Caress with different velocities | wrist | force & friction by rotating motor + textile | T | √ | X | X |
| 23 | Affective Tele-Touch system (Cabibihan and Chauhan, 2017) | Regulating emotion during stressful movie. | Grasp Tickling ? | arm | vibration, warmth | T, V | √ Arm band | X | X |
| 24 | Flex-N-Feel (Singhal et al., 2017) | Facilitate sense of touch during remote virtual communication | Stroke, caress | hand | vibration | T,V,A | √ gloves | X | X |
| 25 | | A study to examine whether an the feel of the haptic sensation modify a user's emotional state. | Symbolic | hand | PHANToM force feedback device | T,V | X | X | X |
| 26 | Aegis (Korres et al., 2018) | Make interactive experience more pleasant Aegis: A biofeedback adaptive alarm | symbolic | wrist | vibration | T | √ Wrist band | X | X |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | system using vibrotactile feedback | | | | | | | |
| **From soft robotics field** | | | | | | | | | |
| 27 | Artificial muscle-driven laterotactile stimulators (Rossiter et al.) | For assistive and rehabilitation device | Stroke, tickling | Arm or lower leg | Soft actuation (artificial muscle-driven laterotactile stimulations) with low power EAP | T | V | V | X |
| | | | | | | | | | |
| 28 | Texture Units (TU) (Hu et al., 2018) | For robot to display emotions to users | Gooseb ump, spike | hand | pneumatic | T, V | X | X | X |
| **From fashion practice field** | | | | | | | | | |
| 29 | The HugShirt (*The HugShirt*, 2014) | Communicating emotions | hug | upper body, arm | Heat | H | √ shirt | X | X |
| 30 | AWElectric (Neidlinger et al., 2017) | Express and communicating emotions | Gooseb umps | spine? arms | vibration | H, V, A? | √ dress | X | X |
| 31 | Flexo (SENSOREE, 2018)? | Provide care: a remote physiotherapist with personalized healing touch | acupun cture | | pneumatic | H | √ dress | X | X |
| 32 | Fundawear | | | | | | | | |

### *Appendix 10. Study 5: Participant consent form for study 5 evaluation of the S-CAT device*



**Participant Project Information & Consent Form**

For further information: Caroline Yan Zheng (yan.zheng@network.rca.ac.uk)

*01.08.2019*

Dear Potential Participant,

*I am* Caroline *Zheng a PhD student* at the Royal College of Art. As part of my studies, I am conducting a research project entitled: Comparing brain waves towards different touch stimuli. You are invited to take part in this research project. This project tries to understand how the body respond to different tactile stimuli and how people subjectively feel about these different stimuli, using the method of wearable sensing and simple questionnaire.

If you consent to participate, you will be invited to spend around 1 hour with the researchers for the evaluation. The main activities are summarised as below:

Preparation: 10min, which include signing consent form, positioning the sensors and briefing the activities. The wearable sensors include a set of EEG sensors placed on the head and ear lobes, a wrist watch (that contains GSR sensor) and a heart rate variability sensor. All the sensors are off the shelf established product that pose minimal risk to the wearer.

Evaluation: You will be asked to close your eyes while experience between 5-7 different tactile stimuli. After each tactile stimuli, you will be asked to give feedback through rating simply questionnaire or verbally. Some tactile stimuli will require you to wear a wearable robotic interface to be able to experience the tactile sensation. The wearable robotic interface will be shown to you at the beginning of the study.

**Documentation:**
The sessions will be audio and video recorded.

Note:

1. The artefacts that in direct contact with the participants are made from textiles for normal clothing. Underneath this cover is a silicone material made from skin-safe rubber material. In some artefacts the rubber material is in direct contact of the skin. These robotic artefacts are actuated by micro-controllers and circuits. These electronic parts are not in direct contact with the skin.

2. Participation is entirely voluntary. You can withdraw at any time up to the point of publication and there will be no disadvantage if you decide not to complete the study. All information collected will be



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t +44 (0)20 7590 4126 f +44 (0)20 7590 4542 research@rca.ac.uk www.rca.ac.uk/research

confidential. All information gathered will be stored securely.

(a) At no time will any individual be identified in any reports resulting from this study.

(b) Images, quotes or video clips, which may allow you to be identified will only be used with your express permission.

3. The EEG sensor contacting your hair contains liquid conductive gel, which will make certain points of your hair wet. While some people wouldn't bother afterwards, other people may want to wash their hair. We will have cleaning tissues provided.

If you have any concerns or would like to know the outcome of this project, please contact me, Caroline Yan Zheng at the below address.

**Consent form participant:**

I *(please print)* ……………………………. have read the information above and all queries have been answered to my satisfaction. I agree to voluntarily participate in this research and give my consent freely. I understand that I can withdraw my participation from the project up to the point of publication, without penalty, and do not have to give any reason for withdrawing.

I understand that all information gathered will be stored securely, and my opinions will be accurately represented. Any data in which I can be clearly identified will be used in the public domain only with my consent.

Participant Signature…………………………………………………………….

Researcher Signature…………………………………………………………

Date: ……………………………………………………………

**Complaints Procedure:**

This project follows the guidelines laid out by the Royal College of Art Research Ethics Policy.

If you have any questions, please speak with the researcher. If you have any concerns or a complaint about the manner in which this research is conducted, please contact the RCA Research Ethics Committee by emailing ethics@rca.ac.uk or by sending a letter addressed to:

The Research Ethics Committee
Royal College of Art
Kensington Gore
London
SW7 2EU

**Thank you for your interest.**

## *Appendix 11. Study 5: Social touch questionnaire (SQT) used for study on evaluation of the S-CAT device*

S-CATS Study Sep-Nov 2019
contact: yan.zheng@network.rca.ac.uk

**Social Touch Questionnaire ***
Participant No. __________
Date: __________________

| | | not at all<br>0 | slightly<br>1 | moderately<br>2 | very<br>3 | extremely<br>4 |
|---|---|---|---|---|---|---|
| 1 | I generally like when people express their affection towards me in a physical way (R) | | | | | |
| 2 | I feel uncomfortable when someone I don't know very well hugs me | | | | | |
| 3 | I get nervous when an acquaintance keeps holding my hand after a handshake | | | | | |
| 4 | generally seek physical contact with others (R) | | | | | |
| 5 | I feel embarrassed if I have to touch someone in order to get their attention | | | | | |
| 6 | I consider myself to be a 'touchy-feely' person (R) | | | | | |
| 7 | It annoys me when someone touches me unexpectedly | | | | | |
| 8 | I'd feel uncomfortable if a professor touched me on the shoulder in public | | | | | |
| 9 | I'd be happy to give a neck/shoulder massage to a friend if they are feeling stressed (R) | | | | | |
| 10 | I feel uncomfortable if I make physical contact with a stranger on the bus or subway | | | | | |
| 11 | I like being caressed in intimate situations ( R) | | | | | |
| 12 | As a child, I was often cuddled by family members (e.g. parents, siblings) ( R) | | | | | |
| 13 | I would rather avoid shaking hands with strangers | | | | | |
| 14 | I greet my close friends with a kiss, cheek-to-cheek ( R) | | | | | |
| 15 | I feel comfortable touching people I do not know very well (R) | | | | | |
| 16 | I feel disgusted when I see public displays of intimate affection | | | | | |
| 17 | It would make me feel anxious if someone I had just met touched me on the wrist | | | | | |
| 18 | If I had the means, I would get weekly professional massages (R ) | | | | | |
| 19 | I hate being tickled | | | | | |
| 20 | I like petting animals | | | | | |

*Wilhelm, F. H. et al. (2001) Social anxiety and response to touch: incongruence between self-evaluative and physiological reactions. *Biological Psychology*. [Online] 58 (3), 181–202.

## *Appendix 12. Study 5: Demographic information sheet used for study on evaluation of the S-CAT device*

1. What is your age ____ ☐ prefer not to say

2. How do you currently describe your gender identity?

☐ Male
☐ Female
☐ Other
Please specify ___
☐ Prefer not to say

3. Which of these best describes your ethic group?

| White | Mixed | Asian or Asian British | Chinese/other |
|---|---|---|---|
| ☐ White British | ☐ White and Black Caribbean | ☐ Indian | ☐ Chinese |
| ☐ White Irish | ☐ White and Black African | ☐ Pakistani | ☐ Other ______ |
| ☐ Any other White background | ☐ White and Asian | ☐ Bangladeshi | |
| | ☐ Any other Mixed background | ☐ Any other Asian background | |
| | | | |
| ☐ Prefer not to say | | | |

***Appendix 13. Study 5: Recruitment flyers used for study on evaluation of the S-CAT device***


## Are you interested in EEG and touch?

**We are looking for participants for an interesting study - last chance!**

Thank you for all the interested folks who participated in October. Our October sessions have been overbooked so really apologise for those who could not participate. Our preliminary results are encouraging, so we are opening more slots before the end of the term, which are also the final slots.

As part of a PhD research, the project is entitled: Comparing brain waves towards different touch stimuli. You are invited to take part in this research project. This project tries to understand how the body respond to different tactile stimuli and how people subjectively feel about these different stimuli, using electroencephalogram (EEG) and wearable sensing, and simple questionnaires. Each session takes around 45-60min. We are hosting the final sessions on below dates. There are altogether 18 slots available. As a token of appreciation for your precious time, we will send your individual brain wave visualisation once we have finished processing all the data. All data will be anonymised to protect your privacy. The study procedure has been approved by RCA Ethics Committee and complies with the UK Data Protection Act (2018)

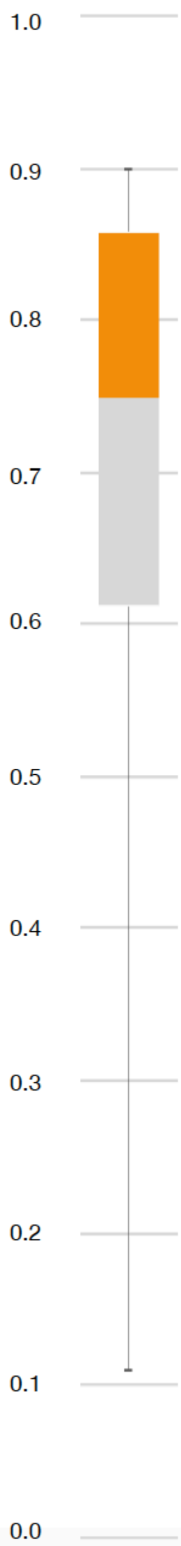
The dates are:
30th Nov Saturday full day (White City)
5th Dec Thursday 2 – 8pm (White City)
9th Dec Monday full day (White City)

Please email yan.zheng@network.rca.ac.uk to reserve a slot. We will send a detailed description of the process as well as consent form.

Participants do not have to only form RCA, so please also help spread the word to others.

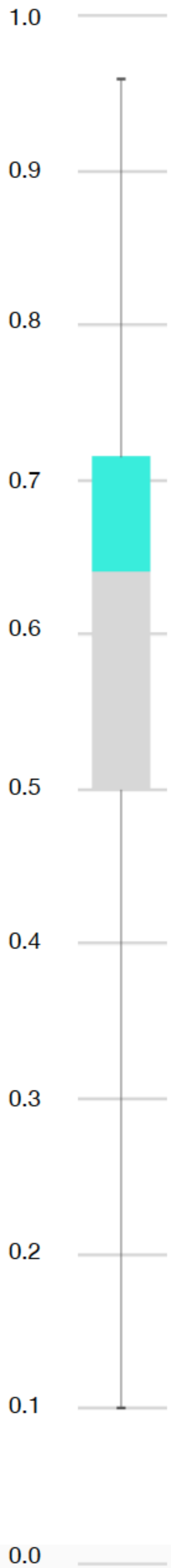
### *Appendix 14. Results from subjective ratings, qualitative comments and Social touch questionnaire (SQT) from study on evaluation of the S-CAT device*

## SLOW ROBOT VERBAL FEEDBACK



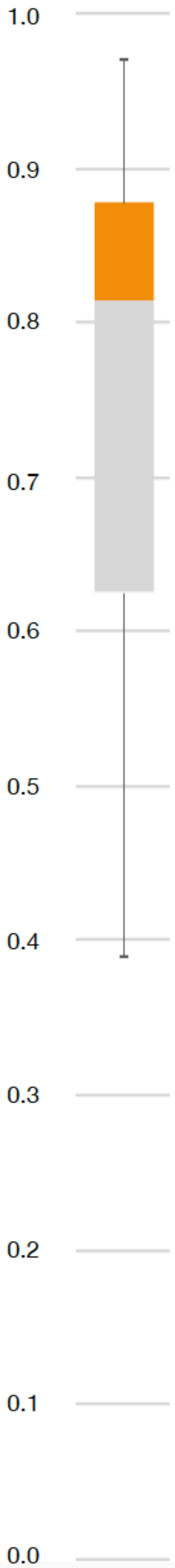

| Rating | Verbal comment (Researcher notes) | STQ |
|---|---|---|
| 0.90 | I like this one. I like it wrap around the whole arm. It's smooth. It's like fun blood pressure machine, but more fun. | 39 |
| 0.90 | rocking motion and again the hair is not involved. Pleasant but prefer the one before (Robot Fast touch). But I prefer these than the brush. | 20 |
| 0.89 | the first touch is a bit weird. The rythem is more complex than the previous one (fast robot). Felt like massage. Gradually the feeling decay. | 51 |
| 0.89 | II liked the other one (fast robot) better. The sense of safety is the same. I felt the progression (the progression of the progressing cell pressuring on to the skin) at the start, when it goes on it (it reduced). At the last one I felt smooth and don't feel the break any more. | 20 |
| 0.87 | really relaxing. Feels like some cuddling. Maybe cause the repetitive movement | 28 |
| 0.86 | couldn't compare to anything, kind of calming. The first one's trying to compare but couldn't. Compare to caring touch, like a stroke. Care come from the time, the repetition. | 26 |
| 0.85 | that was very nice. I enjoyed that. More feeling of something pressing than touching me. | 40 |
| 0.85 | its actually quite nice. Very light, neutral, more like a massage. If felt quite nice but very light, I wouldn't mind more pressure. | 30 |
| 0.85 | at first a litle weird. It reminds me a familiar touch. It reminds me of inbetween sensation, e.g. inbetween sheet..hand.. Moving in a bed, with acompany of someone else. Accidental touch (unreadable notes) | 14 |
| 0.78 | very soothing, cause it moves too smoothly, cause the haptic of it, it's just different, it's really pleasant. It's nice. It's like a wave, really smooth, or too smooth. Weird, (further asked to explain), cause it's unfamiliar, almost too smooth, like a wave. can't associate to anything familiar, like i'm in a massage chair, but never had it on my arm. | 38 |
| 0.77 | feels more comfortable and acceptable than the familiarisation session. Now it doesn't feel like animal but water wave. | 49 |
| 0.73 | feeling like blood pressure taken. Also feeling like being under water, like water fluctuating onto the skin. | 43 |
| 0.70 | quie nice. But a bit less calming comparing with the brush. Compare with human slow touch they are at the same level of enjoyment, but human touch is more relaxing. | 21 |
| 0.69 | First few moment I felt like an external creature. Later on feel more comfortable. Afterwards, I forgot I am wearing it. When it started, the warm temperature make you feel comfortable and safe. | 26 |
| 0.68 | felt more like massage | 40 |
| 0.62 | felt much more organic, like some variation in the intensity, which made it felt organic. Felt like it's longer, cause maybe slower. Slower pace is more comfortable. Felt more comforting, felt like human. the feeling of variability made it not like machine but human touch. it was less stimulating than brush, more in the reassuring territory. a bit more pressure to the muscular level.(this participant was then given the dial button to adjust the pressure level and she managed to identified a most pleasant level of pressure. | 24 |
| 0.61 | This is the weirdest one. Multi direction. Felt alien and unfamiliar. | 29 |
| 0.60 | very subtle. The touch waves as opposed ..? Slightly pleasurable, not extremely. Like a light massage. | 29 |
| 0.60 | I was visualising the feeling. Couldn't tell positive or negative. There was this void making, didn't feel like it is a thing. Couldn't figure the object felt like, like an abscent of, probably thinking of being hydraulic, felt liquid | 27 |
| 0.47 | slightly uncomfortable, but wasn't uncomfortable, maybe cause unfamiliar. Slightly annoying. | 36 |
| 0.41 | intensified a bit more. Felt the same. | 47 |
| 0.11 | I don't like it. It makes me nervous. The touch feels sticky and wet, very unpleasant, because it's not like a normal touch. | 53 |

## FAST ROBOT VERBAL FEEDBACK



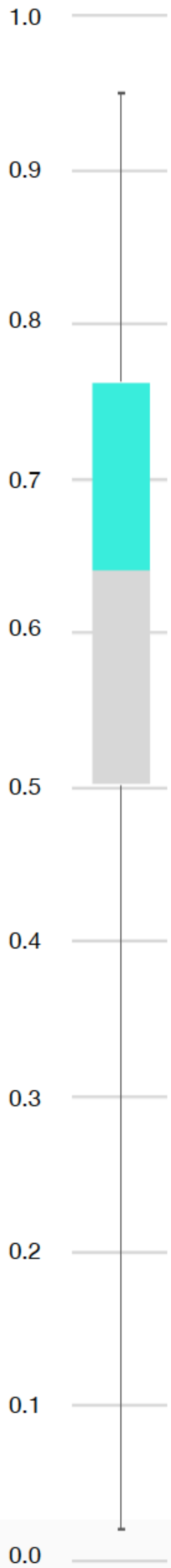

| Rating | Verbal comment (Researcher notes) | STQ |
|---|---|---|
| 0.96 | Loved it. As no hair, so the hair on my arm not stimulated. Felt like heart beat. Like when you are lying with somebody and feeling their heartbeat, blood pumping. | 20 |
| 0.81 | I felt the sensation of progression. I like it. I had the feeling of safety. (asked to explain further on safety) something is getting bigger, but not as big as dangerous. | 20 |
| 0.79 | little bit calm, cause similar to massage. Slower than heart beat | 47 |
| 0.78 | feel like ordinary touch, like someone touch me by his finger. Generally positive. Definitely not uncomfortable | 51 |
| 0.77 | previous one (Slow Robot touch) was more enjoyable. This one felt more mechanical. The Slow Robot touch felt more natural. The sound of this one is mechanical. The presses were shorter. | 40 |
| 0.72 | neutral. More sensitive at first, less sensitive later | 36 |
| 0.70 | funky, interesting, cause it's not normal. | 39 |
| 0.68 | unfamiliar. The sequence and the stimulation felt unfamiliar. | 29 |
| 0.66 | more neutral, less pleasurable, but not unpleasurable. Doesn't make me feel anything | 30 |
| 0.66 | I already know what to expect. The first movement it's kike an external thing trying to get in my body. Then it's like part of my body. In the end it felt like my vessel is beating, rather than the external. Maybe the movement press the vessel so it felt like that. | 26 |
| 0.66 | ticklish | 40 |
| 0.62 | Quite a smooth movement. Very nice. It was a bit short so not very relaxing, but not unpleasant. | 21 |
| 0.61 | I wasn't really thinking. Not make me feel anything | 28 |
| 0.52 | slightly pleasant. What was intersting is I become very aware of what I was wearing - the whole cuff. As there are more contactng points, some feeling is transferred all around the cloth. | 24 |
| 0.50 | not uncomfortable. Like pinching, not relaxing. Like an alarm clock, ntification or sth.. To keep alert. It's active. It's not unpleasant, cause the touch is quite soft. It's the interval, rhythm (that make it less pleasant). | 38 |
| 0.50 | not much feeling, cause it goes straight back & forward. Compare with MS, this one is more like machine, cause machine has ...alive things don't know (indicating MS feels alive) it familarise easier. | 49 |
| 0.50 | the sound like heart beat. The touch felt impratial | 29 |
| 0.42 | it's okay. The first time was unpredictable, later I got used to it. | 53 |
| 0.38 | I don't really like this one. Feels like electrick shock, like impulse. Not as comforting as the previous one (MS). | 43 |
| 0.36 | slightly less pleasant . Doesn't felt stroke, more like contraction. Repetitive. | 27 |
| 0.34 | hectic. not continuously, more like tapping | 26 |
| 0.10 | reminds me of pacing, with backpack. i was counting in my head. Couldn't wait for it to end. Cause intervals ? The first one felt more organic, this one is more steady | 14 |

## SLOW HUMAN TOUCH VERBAL FEEDBACK



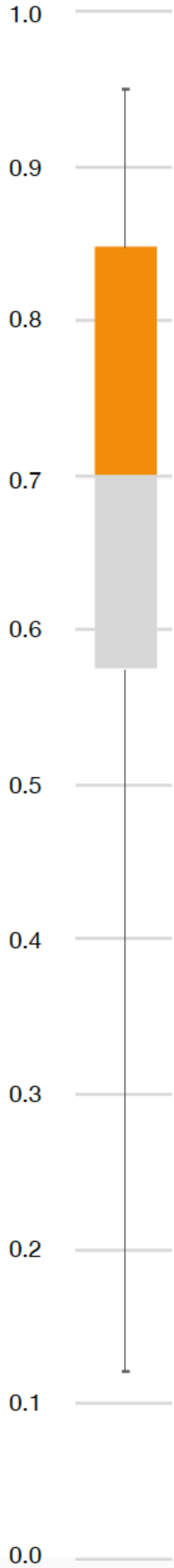

| Rating | Verbal comment (Researcher notes) | STQ |
|---|---|---|
| 0.97 | This is the best one I felt. When previously trying for these different sensations, I couldn't remember the other touches except like a mother's touch. This time is the same. But I can't remember what my comment about the other touches but I remember my comment about this (slow) human touch. | 26 |
| 0.95 | at the beginning felt like ASMR. This feeling decaying (as it continues). | 51 |
| 0.93 | caring, trustful, soft. Trustful because: temperature, the right pressure, skin like, the sound (the most pleasant) | 26 |
| 0.92 | relaxing similar to Brush Slow. Difference is the body warmth which makes me more comfortable. | 29 |
| 0.92 | it is slow, more intense. Feels better than previous one (human fast) | 30 |
| 0.88 | more relaxing compare to HF | 28 |
| 0.87 | really comfortable, soothing, pleasant, relaxed | 38 |
| 0.87 | relaxation. If I don't have to sit up, I might fell asleep | 29 |
| 0.86 | quite pleasant. Getting warmer. The longer it went on, I want to start giggling. Don't know why, maybe a bit ticklish. | 36 |
| 0.86 | at first didn't really like it, make me remember my mum when she's nervous she'd rub my hand, or family members' hand. Kind of relax me | 14 |
| 0.84 | very gentle, comfortable. Very relaxing. Effect much stronger in the last one, which was the most intensive(can not be more intensive). | 20 |
| 0.79 | at the beginning, I was with busy guess (what it is). Not overly uncomfortable | 39 |
| 0.72 | Warm, felt more like human hand | 40 |
| 0.68 | Two things came to my mind. I have hair on my arm. It was okay, pleasant, nothing negative. Remind me of cat - my master is stroking me. | 20 |
| 0.66 | it was warm, compare to the previous (BF). I can tell it's a person, it felt human. But it's just a finger. This wasn't a normal way you get ouched, cause normally one use a whole hand. This wasn't a normal way you get ouched, not within the vocabulary | 27 |
| 0.64 | more relaxing. Slower, more calming. More plsaurable. (the) fast (one) is like random touch, so the speed makes the difference. | 21 |
| 0.62 | soothing. Every time pause and start felt unexpected. Soothing cause: hand is dry (if hand sweaty would be entirely different (negatively)). | 43 |
| 0.61 | was nicer. Like touching velvet, more smoother. Warmer than the Human Fast touch. | 40 |
| 0.57 | it was more localised than brush and robot touch, particularly than the brush touch, due to the shape of the brush. The lighter fur of the brush reassuring level of pressure. It is less stimulating than the brush for the similar level of pressure. | 24 |
| | | |
| 0.45 | it feels okay. This touch is intentional, like it's for sth. | 53 |
| 0.39 | first was awckward. As time goes by became different. Somebody touching my skin is very awkward. It came from my experience when I was younger. The group of girls hated me, I didn't communicate with those girls. I don't like to be touched. At the end it felt ddifferent, annoyed. | 47 |
| 0.39 | I wanted to resist. The first five rounds I wanted to resist, then I just gave up (resisting). Didn't feel like another touch you | 49 |

## FAST HUMAN TOUCH VERBAL FEEDBACK



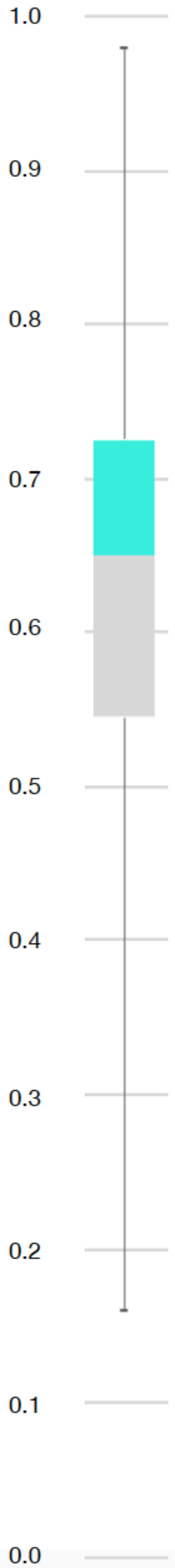

| Rating | Verbal comment (Researcher notes) | STQ |
|---|---|---|
| 0.95 | | 51 |
| 0.90 | more pleasant than anything else. More intense, nicer feeling. | 30 |
| 0.81 | It felt harder than the other brush (participant thought this was brush). It felt longer every time. | 20 |
| 0.80 | sleepy at first. A little more energy than just caressing. Comfortable but alerting | 29 |
| 0.78 | The touch felt human, so felt warmer. | 20 |
| 0.77 | I kind of like it. Feels like touching myself | 53 |
| 0.74 | pleasant, soft, remind me of plant called rabbit ear | 36 |
| 0.70 | the first moment in immediately know it is your hand. I would say I didn't use my imagination as more as last time. This time I even almost fall asleep. | 26 |
| 0.68 | different. Still cuddling, but without affection, cause a bit too fast. | 28 |
| 0.68 | felt like the brush | 40 |
| 0.65 | initially feel hot. The sound make me conscious of dry skin. The movement made me felt like I'm being painted. Felt mechanical, level of pleasure slowly. | 27 |
| 0.63 | nice. The demo was a slighter touch and more stimulation. But it's vary person to person the intensity. | 24 |
| 0.58 | wasn't as nice as the one before (HS). When first starting, I thought a lot. Then I just get used to it. Stopped thinking | 39 |
| 0.57 | like somebody touching you but doing it in the wrong way. Still nice, but weird. | 26 |
| 0.55 | slightly stronger activation than HS. Ddin't make me feel that much different than HS. | 43 |
| 0.51 | less pleasant than brush. Not as calming as brush. Prefer brush | 21 |
| 0.50 | different from others, not anything that I could associate with. I wasn't counting, I felt like concentrated. | 14 |
| 0.50 | first few ones felt nervous, reason was don't' want other people touching me. Last few rounds felt okay, like human fingers | 49 |
| 0.33 | didn't like it. Felt like touching something synthetic. It was something to do with the sound, also the warm temperature-like biting a wool jumper. | 40 |
| 0.28 | a bit annoying. If it continue without the break it be frustrating | 29 |
| 0.15 | is not the best, like jumping around. Didn't make me comfortable. It's not irritating, but not comfortable. I am not anxious but would prefer not to have it. Like it's annoying. I prefer shorter time than longer. Probably because stronger pressure | 38 |
| 0.02 | very tickling. Felt like my skin is worn out, bleached and sting. | 47 |

## SLOW BRUSH TOUCH VERBAL FEEDBACK




| Rating | Verbal comment (Researcher notes) | STQ |
|---|---|---|
| | at biginning a little ichy, want to move my arm, then the ichy dissappeared. When got used to it, quite comfortable | 51 |
| 0.95 | feel like my dog. So soft make me sleepy and cuddly. Very relaxing. | 29 |
| 0.95<br>0.95 | felt cozy, lots of love. Make me think of my cat nezlling next to me. Like him showing me affection. However at the end of each stroke, before it turn directions, the tip of the brissles make the sensation from nice to not the same sensation, tickles hairs. | 14 |
| 0.88 | I liked it more than the fast brush. Cause it's slower. It is as pleasant as the cuddling machine (MS). More relaxing | 28 |
| 0.86 | very nice, soft as a cat. Quite pleaaurable and relaxing. | 30 |
| 0.85 | slow, sensitive, careful, like feather playing around when we were kid | 26 |
| 0.84 | calmed. Really pleasant feeling | 27 |
| 0.84 | it's satisfying, slightly ticklish | 39 |
| 0.73 | quite relaxing. Make think about eyelash/brush | 36 |
| 0.73 | qute pleasant and soft. Slowness is very relaxing, sleepy, calm. It is less arousing. | 21 |
| 0.71 | not much difference than BF | 53 |
| 0.69 | seems less human, as it was always the same. Every time exactly same as before. Human hand would have had more variety so that feels better and less mechanical. | 20 |
| 0.67 | feels more ichy than brush fast | 49 |
| 0.65 | felt more gentle than the Brush Fast touch. Not sure felt the hair. Quite smooth. | 40 |
| 0.63 | very soothing and calming. With more time the pressure become stronger, slightly anxious, wonder if it will be even more strong. | 38 |
| 0.62 | spike, ticklish. Neutrual negative | 40 |
| 0.56 | felt reassuring, but less stimulating. Felt like slightly stronger pressure (than Brush Fast). Subtle difference from more stimulating to reassuring. | 24 |
| 0.54 | felt like ticklish, but very mild, so I can think of other things, (means not attension seeking) | 43 |
| 0.50 | Feel differently from beginning to end. There is a range of difference(the tip of the brush and the body of the brush). | 26 |
| 0.40 | borderline ticklish. Unusual | 29 |
| 0.37 | with machine I can go for a long time. Others no and I waited to stop | 20 |
| 0.12 | uncomfortable, stinging and hurt a bit. Skin sensitive. | 47 |

## FAST BRUSH TOUCH VERBAL FEEDBACK




| Rating | Verbal comment (Researcher notes) | STQ |
|---|---|---|
| 0.98 | ichy. Relax, soft, make me want to sleep. Fur feeling. Not strong feeling but comfortable | 49 |
| 0.91 | remind of my cat, tickly, playful | 26 |
| 0.83 | this is faster. More alerting, compare with Human Fast. Sleepier. | 29 |
| 0.76 | very soothing, it's the brush itself& soft. Remind me of the dog I touched today, cause I know/familiar with the material so feel comfortable. Pleasant. Really active. | 38 |
| 0.76 | definitely more pleasarable. More active. Felt more superficid, like it was interacting with hair on my skin. When pressure is harder felt more in the skin. Interaciting with hair makes it more active. Definitely an anticipation effect. | 24 |
| 0.73 | this one is softer, more pleasant. Less intense. Feels less, but more pleasant. | 21 |
| 0.71 | Very simular to slow brush. Like someone's brush away some dirty stuff off my arm. Sensation really really similar to the other brush (slow brush). | 20 |
| 0.70 | feel nice. My hair makes it less intense, it going against my hair. If there were no hair, it maybe felt more pleasant | 28 |
| 0.69 | the activation reduces over time, as novelty wanes. The repetition make me associate with machine, not with a person. Cat's tail. Felt less living | 27 |
| 0.69 | Definitely feels better than previous one (MF). Like a gentle touch. | 53 |
| 0.68 | First few second still give me some imagination in my mind, ranging from a naughty cat. The first one want you to play with him or her, but you ignore him or her, then my mind stopped thinking. For the previous three, I could completely forget or fall asleep, however this one felt a bit difficult to ignore. | 26 |
| 0.62 | my skin is familiar with this sensation. No obvious changes | 51 |
| 0.62 | less relaxing and more energising. Less pleasurable. Feel somethong happing not specifically nice or not nice. As it is always the same position on the arm for some time, caused losing of sensitivity. | 30 |
| 0.60 | felt like the distance between you and the object is further away. First time is next to my skin, the movement is more enjoyable. | 40 |
| 0.60 | more like cat fur | 40 |
| 0.59 | very soft, nice. Other than that not much different than brush slow(BS) | 43 |
| 0.53 | at start (felt) ticklish, then it's not ticklish. Not as nice as slow brush. Slightly make me think of my cat | 39 |
| 0.41 | same touchness when I brush face with cosmetics. Little bit more comfy than (Human Fast). I prefer robot/machine. Human and brush touch are more tickling, robot touch is less tickling. | 47 |
| 0.40 | felt rougher than last one (BS). At beginning make me think spider. Arm felt colder. | 36 |
| 0.38 | a bit more abrasive and direct in the movement. The first one(HS) allow me to have a calm thought process. This one I find it difficult to concentrate. | 29 |
| 0.31 | I dislike it more and more as it went on. | 20 |
| 0.16 | a little on the annoying side when brush on the arm hair | 14 |

## *Appendix 15. Skin safety certificate for material Ecoflex™ 00-30 and 00-35 FAST*

Downloaded from the company website: https://www.smooth-on.com/products/ecoflex-00-30/ and https://www.smooth-on.com/products/ecoflex-00-35/

**TEST FACILITY**

**Consumer Product Testing Company**
**70 New Dutch Lane**
**Fairfield, NJ 07004-2514**
**(973) 808-7111**

**CLIENT**

**Smooth-On, Inc.**
**5600 Lower Macungie Rd.**
**Macungie, PA 18062**

| Test Report No: V19-3483-4 | Date: June 13, 2019 |
| --- | --- |

**SAMPLE ID:** The client identified the following test material as **"Ecoflex 00-30".**

**SAMPLING DETAIL:** Test sample was submitted to the laboratory directly by the client. No special sampling conditions or sample preparation were observed by Consumer Product Testing Company.

**TESTING PERIOD:** June 5, 2019 - June 7, 2019

**TEST REQUESTED:** To predict skin irritation potential of neat test substances in the context of identification and classification of skin irritation hazard according to the EU classification system. The Modified EpiDerm Skin Irritation Test allows discrimination between irritants of category 2 and non-irritants. This study was conducted based on the requirements of OECD 439, in accordance with the EU classification R38 and GHS category 2 requirements: Tests for irritation and skin sensitization.

**TEST RESULTS:** The test article submitted has passed and is classified as a non-irritant in accordance with the OECD Guideline for the Testing of Chemicals No. 439.

**STUDY DIRECTOR:** Steven Nitka, B.S. (Vice President, Laboratory Director)

**Prepared For:**

**Tim Boyer**
**Technical Director**

| **TEST FACILITY** | **CLIENT** |
|---|---|
| **MB Research Laboratories**<br>1765 Wentz Road<br>PO Box 178<br>Spinnerstown, PA 18968<br>215-536-4110 | **SMOOTH-ON, INC**<br>5600 Lower Macungie Road<br>Macungie, PA 18062<br>610-252-5800 |

| **Test Report No: MB 15-23728.19** | **Date: August 17, 2015** |
|---|---|

**SAMPLE ID:** The client identified the following test material as **"Ecoflex 00-35".**

**SAMPLING DETAIL:** Test samples were submitted to the laboratory directly by the client. No special sampling conditions or sample preparation were observed by MB Research Laboratories.

**DATE OF RECEIPT:** Samples were received at MB Research Laboratories facilities on July 17, 2015.

**TESTING PERIOD:** July 28, 2015

**AUTHORIZTION:** Signed project number MB 15-23728.19 signed by Rodney Conn.

**TEST REQUESTED:** To predict dermal irritation potential of test articles in the context of identification and classification of skin irritation hazard according to the European Union (EU) classification (R38 or no label), United Nations Globally Harmonized System of Classification and Labeling of Chemicals (GHS) classification system (Category 2 and non-irritants), and OECD Guideline for the Testing of Chemicals No. 439 – In Vitro Skin Irritation: Reconstructed Human Epidermis Test Method. This study is designed based on MatTek protocol *in vitro* EpiDerm™ Skin Irritation Test.

**TEST RESULTS:** The test article is classified as a non-irritant.

**Prepared For:**

**Rodney Conn**
**Technical Compliance Specialist**
**SMOOTH-ON, INC.**

### *Appendix 16. Personal account on practice*

#### The messiness of making

Knowledge acquisition in making new technology is not straightforward. Making soft robots is motivated by my intense curiosity: however, to make them and to make them work involved a steep learning curve. The new knowledge I needed to acquire included 3D modelling, resin casting, pneumatic actuation design, mechatronics, and coding. Often, the awareness of what knowledge I needed only arose when making was happening, which reflects the 'learning-by tinkering' culture from maker communities (Martin, 2015). The knowledge needed could not be found 'off the shelf', but had to be scouted for, from online tutorials, robotic engineering research labs, the technical instructors at the RCA 3D printing hub[22] and resin workshop, e-textile communities, maker space communities and even hackathons. As a result, I spent a significant amount of time at London Hackspace [23] (Millner, 2013), working with Adrian Godwin, who generously supported my exploration with his knowledge, tutoring and skills. At first, the knowledge from these different sources was collaged through experimental making, which served as a method of artefact production but also as a method of learning. There was always an uncertainty about what could be achieved until the results of the experimentation were known. At the same time, feedback from the participatory workshops enhanced my understanding of the affective qualities of different material configurations. Overtime, this new knowledge gradually became internalised and took form as part of my tacit knowledge base, when I felt more fluently in commanding the digital, physical and mechatronic materials I was using. At this later stage, I was able to generate original ideas about making, with visions of particular material configurations towards a specific affective quality, such as the S-CAT device.

Finding the most suitable physical materials was also an arduous job and the design was in constant negotiation with the constraint of the physical and digital materials. The 'off the shelf' materials

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[22] RapidFormRCA is the central knowledge hub and go to facility for all 3D printing and scanning requirements within the College.

[23] https://london.hackspace.org.uk/. I was frequently there between 2015 and 2018, during the explorative stage of my practice, for it has the biggest collection of tools and workshops comparing to other maker spaces accessible to me, conveniently located and provides a sense of community.

seldom fit as they are mostly for pneumatic equipment of much larger capacities. Finding the right solution in terms of materials, and eventually sourcing them from manufacturers or building from scratch, could easily take months. Figure Appendix 16-1 below shows an example of the evolution of the physical materials used in two iterations of AffectNodes2 and the S-CAT device, from messier, bulkier settings to a smaller size, quieter solution with finer control of the touch patterns.

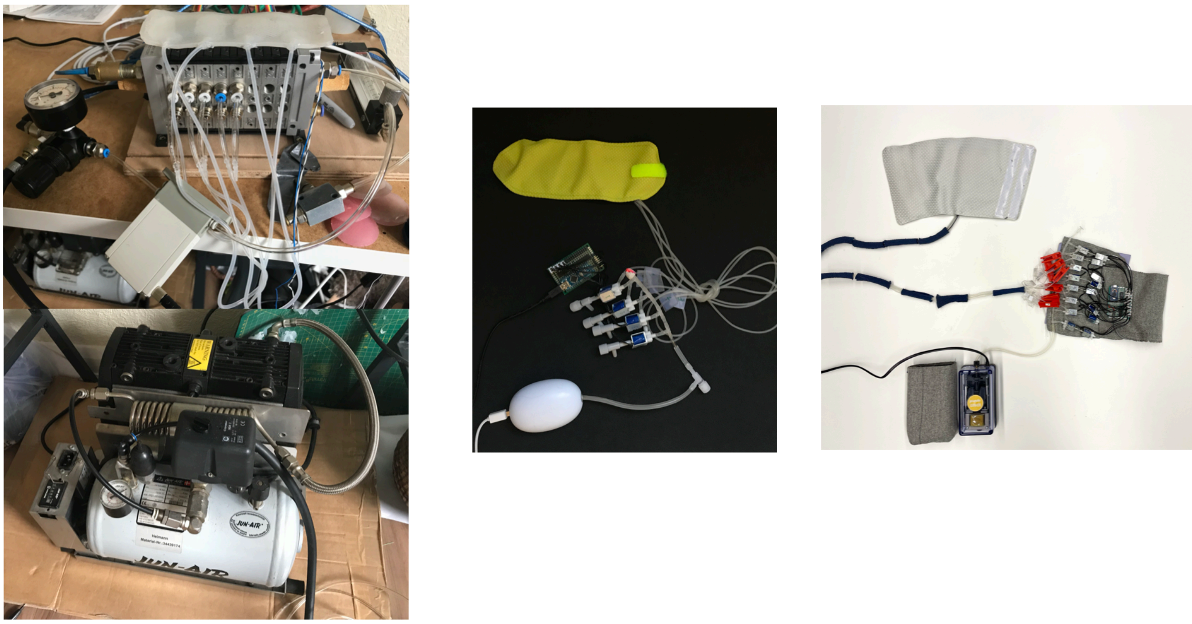

Figure Appendix 16-1. Left: prototyping with compressor and valve block of larger sizes. Middle: AffectNodes2 with mini valves and pump. Right: S-CAT device with further control of flow rate to achieve gentler touch and stroking pattern

### The shifting aesthetic consideration

I came from a background of fashion practice, whereby design work is often expected to embody the aesthetics of the visual elements and to articulate the artefact directly to the body. My practice in the initial stage involved exploration of the visual elements, including colours, shapes, and playful wearing on the body. When I made the decision to focus on designing the qualities of affective touch sensations from the SPSR material, I found that my focus was no longer on visual elements. The feel of touch is felt, rather than seen. The impacting elements instead shifted to the felt force, acceleration of force, duration of force, pressure and flow rate, etc. However, what was frustrating was that to arrive at the point of being able to work on the aesthetics of touch - that is, the affective quality of touch, it took a year before I developed a workable artefact. During this year, I often felt that I was not doing any 'design work' but was stuck in addressing technical problems to make the technology work. After I had achieved a satisfying stroking touch through the S-CAT device, I found that the S-

CAT device is also a system, a toolkit, in the sense that a spectrum of characteristics of touch, can be experimented with. This is enabling. It enables the exploration of and the experimentation with the qualities of touch. Thus, I came to the realisation that tuning the aesthetic quality of touch from technologies is its itself a novel territory of design practice. Just as that human touch is full of nuance to convey different meaning and intention. The aesthetic qualities of touch from technology can enable a whole spectrum of novel interactive experiences. For example, touch technology for the purpose of care, alleviating pain, support playful engagement from children in a social robot, or augment a thriller movie in a 4D theatre would require dramatically different sensorial qualities. To this end, I knew that I have *always* been doing design work: the tuning of aesthetic qualities of touch *is* my design practice, even though the work is with technological materials. In fact, part of my current postdoctoral work is about framing the tuning of aesthetic quality of touch from technology as a novel design space.

### Shifting of identity and design repertoire

At the beginning of my PhD research, I would identify myself as a fashion practioner and a member of the e-textile community. The material I worked with was textiles, yarns, accessory materials, e-textiles - including conductive yarns, fabric, and associated mechatronic components. What I designed was clothing and wearable accessories. My skillset included fashion making (e.g. design, pattern making, sewing, knitting) and e-textile making (e.g. simple circuit design, simple coding). At the end of my PhD research, I now identify myself as a researcher and practioner working in affective interaction design, with expertise in articulating the experiential qualities of affective touch using soft robotics. As a recognition of this identity, I have been awarded a post-doc fellowship by the Digital Futures Research Centre at KTH Royal Institute of Technology[24]. My design repertoire has been extended significantly through my practice from my PhD research. The materials I work with now also range from haptic actuators including pneumatic actuators, and mechatronics, codes, together with e-textiles and fashion making. Essentially, what I design, is the quality of touch experience from

[24] The fellowship is for a 2-year research funding for my proposed project, 'Design Guidelines for Recognisable Digital Social Touch from Soft Robotic Haptic Technologies'. Link to webpage: https://www.digitalfutures.kth.se/research/postdoc-fellowships/design-guidelines-for-recognisable-digital-social-touch-from-soft-robotic-haptic-technologies/

technologies, through the orchestration of the performance of surface materials, actuating hardware and controlling software – in Vallgårda's words, 'the Trinity of forms' (Vallgårda, 2014). I am comfortable and content with this shifted identity as I continue the research initiated from my PhD research. Meanwhile, I believe my research identity is still being defined as I continue to work as a researcher-practitioner in this new space.