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Behavioral and physiological correlates of pleasant touch perception in multisensory contexts

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Summary

People everyday enjoy the pleasant sensations originating from touching and being touched. Feeling the softness of a blanket, caressing or being caressed by a romantic partner, feeling the fresh breeze on the face; they all represent clear examples of the great pleasure that we can experience through the skin. A recent body of research suggested that the tactile pleasantness felt during the stimulation of the hairy skin is mediated by a subclass of unmyelinated fibers called C-Tactile afferents (e.g., Löken, Wessberg, McGlone, & Olausson, 2009; McGlone, Wessberg, & Olausson 2014; Olausson, Wessberg, Morrison, & McGlone, 2016). Neuroimaging studies have revealed that receiving pleasant touch induces the activation of a wide network of areas including the insular cortex, involved in the processing of emotions and in the homeostatic control of the body (Olausson et al., 2002, 2008a), and the orbitofrontal cortex, crucial for the processing of pleasure and reward-related contents (Berridge & Kringelbach, 2013; Kringelbach, 2005). However, so far, very little is known about the reaction of the autonomic nervous system to pleasant tactile stimulation. Moreover, the interactions occurring among pleasant touch and other senses are still poorly explored.

The present dissertation investigates the effects of the tactile stimulation on the pleasantness experienced and on the arousal response. In particular, it assesses how the qualities of the tactile stimulation (e.g., texture, velocity), the interactions with the other sensory modalities (e.g., vision, audition) and information about the person delivering the stimulation (e.g., experimenter's gender) affect subjective evaluations about the hedonic tactile experience and the electrodermal activity in response to the stimulation.

The psychophysiological effects of different kinds of tactile stimulation delivered to the hairy skin were examined in Study 1. The forearm was stroked (at high or low velocities)

or tapped (in a spatial fixed or random order) by using a brush, for brief and longer sessions (9 or 60 seconds). The results revealed that being stroked was more arousing than being tapped, and that fast stroking was more arousing than slow stroking, regardless of the duration of the stimulation. However, the more general arousal level was not affected differently by fast or slow stroking.

The arousal responses to touch and vision were compared in Study 2. Everyday materials were either haptically or visually presented. Being stimulated on the forearm was found to be more arousing than observing the materials and imagining to receiving the stimulation, especially for women. The materials explored were evaluated as more pleasant in the tactile than in the visual condition. Women were also physiologically more aroused (in terms of higher skin conductance responses) than men when caressed. Moreover, being stroked by a male or a female experimenter did not affect the arousal responses and the pleasantness evaluations.

The behavioral effects of the interaction occurring between touch and vision were assessed in Study 3. The forearm was stroked through everyday materials and pictures depicting emotional or non-emotional events were simultaneously shown. While pleasantness tactile evaluations were modulated by the visual presentation, the evaluations of the visual presentation were not affected by the tactile stimulation. Both emotionally salient and emotionally neutral stimuli modulated the tactile judgments. As expected, smooth materials were evaluated as more pleasant than rough materials.

The hedonic perception of virtual haptic surfaces rendered by means of a haptic device was the focus of attention in Study 4. Haptic surfaces were presented paired with pictures representing everyday materials and with sounds resulting from the tactile exploration of materials. Both pleasantness and roughness judgments, as well as time of exploration, varied as a function of the combinations of the visuo-tactile and the audio-tactile stimuli presented. As for real textures, the smoother a surface was perceived, the more pleasant it was rated.

The results of the four studies reported here contribute to shed light on the behavioral and physiological reactions to pleasant tactile stimulation and on the role of the context in which touch is delivered. Furthermore, these results demonstrate how other sensory modalities influence tactile preferences, both when real and virtual surfaces are explored. These findings provide precious insights for material engineers, designers, marketing and advertising experts interested in taking advantage of sensory stimulation in different applied fields. Future research will need to take into consideration other autonomic measures (e.g., heart rate, respiration rate, electromuscular activity) to provide a physiological signature of the effects of pleasant touch.

Chapter 1

INTRODUCTION

1.1. Perception and processing of pleasant touch

The sense of touch has always received little attention by scientists, especially if compared to research on the other sensory modalities, such as vision and audition (see Gallace & Spence, 2011, 2014). This is rather surprising since touch represents the most extended sensory organ in the body (Montagu, 1971), is the first sense to develop in the fetus (Bremner, Lewkowicz, & Spence, 2012; Fitzgerald & Gibson, 1984), and, in integration with the other senses, is fundamental to promote our survival and psychophysical well-being. The tactile modality allows us to explore our surroundings by feeling the texture, the solidity, the weight and the temperature of the objects we interact with. However, touch is not just limited to the mediation of discriminative aspects. Stroking or being stroked by the partner, shaking someone's hand, or hugging a friend represent examples of another essential function of the somatosensory system. Sensory and discriminative tactile information is in fact often associated with an affective/emotional meaning (Gallace & Spence, 2010; Hertenstein, Keltner, App, Bulleit, & Jaskolka, 2006; Hertenstein, Holmes, McCullough, & Keltner, 2009; Morrison, Löken, & Olausson, 2010). Whereas the discriminative aspects of touch have always been object of scientific research, it is just in the last decade that there has been a considerable increase of studies focused on the hedonic aspects of touch (for reviews see McGlone et al., 2014; McGlone, Vallbo, Olausson, Löken, & Wessberg 2007; Olausson et al., 2016).This increasing interest mostly arises from the relatively recent identification in humans of the C-Tactile afferents (CTs; Johansson, Trulsson, Olsson, & Westberg, 1988; Nordin, 1990; Vallbo, Olausson, & Wessberg, 1999), which are hypothesized to mediate the perception of pleasant tactile information through the hairy skin (Olausson et al., 2002; Löken et al., 2009; McGlone et al., 2014; Morrison et al., 2010; Vallbo, Olausson, Wessberg, & Norrsell, 1993). CTs represent a particular class of unmyelinated fibers linked to low threshold mechanoreceptors (LTMRs; Bessou, Burgess, Perl, & Taylor, 1971; Iggo & Kornhuber, 1977; Zotterman, 1939). They innervate exclusively the hairy skin (not the glabrous) and conduct signals at low velocities (speed: 0.5-2 m/s; Vallbo et al., 1999). Notably, these fibers respond to the innocuous mechanical stimulation of the skin and preferentially discharge to slowly (1-10 cm/s) and gently (0.4 N) moving stimulations (Löken et al., 2009) at neutral temperatures (32°C, typical skin temperature; Ackerley et al., 2014a). Intriguingly, CTs' firing frequency in response to this specific kind of stimulation (in terms of velocity, force and temperature) positively correlates with pleasantness ratings (Ackerley et al., 2014a; Löken et al., 2009). CT afferents synapse in lamina I and II of the dorsal horn of the spinal cord and are thought to ascend to the thalamus through the spinothalamic pathway (Andrew, 2010; see Abraira & Ginty, 2013 for a review). Studies conducted on neuronopathy patients lacking Aβ fibers seem to suggest that CTs project to the posterior insula (Olausson et al., 2002, 2008a). Importantly, neuroimaging studies revealed that CT-optimal stimulation is associated with the activation of posterior insula (Björnsdotter, Löken, Olausson, Vallbo, & Wessberg, 2009; Gordon et al., 2013; Morrison, 2016; Olausson et al., 2002; Perini, Olausson, & Morrison, 2015), which interestingly seems to be organized in a somatotopic manner (Björnsdotter et al., 2009). It is worth noting that the insular cortex is implicated in emotion processing, tactile memory, interoception and homeostatic body control (Craig, 2002, 2003, 2008, 2009; Gallace & Spence, 2009; Moseley, Gallace, & Spence, 2012; Paulus, 2007; Stein, Simmons, Feinstein, & Paulus, 2007). However, there is also evidence indicating that a smaller part of CT projections reaches the secondary somatosensory cortex (S2) on the parietal operculum (Morrison, 2016). Moreover, other areas such as S1 (Bolognini, Rossetti, Convento, & Vallar, 2013; Gazzola et al., 2012), the superior temporal gyrus and sulcus (STG and STS; Bennet, Bolling, Anderson, Pelphrey, & Kaiser, 2014; Davidovic, Jönsson, Olausson, & Björnsdotter, 2016; Gordon et al., 2013), the orbitofrontal cortex (OFC; Francis et al., 1999; McCabe, Rolls, Bilderbeck, & McGlone, 2008; McGlone et al., 2012; Rolls et al., 2003) and the pregenual anterior cingulate cortex (ACC; Lindgren et al., 2012; Sliz, Smith, Wiebking, Northoff, & Hayley, 2012) are implicated in the processing of pleasant touch.

CTs' preferential response to caress-like stimulation, the correlation between their firing rate and pleasantness ratings, and the activation of neural areas involved in the emotional, homeostatic and reward processing, have led researchers to speculate that these fibers represent a special pathway for social touch (McGlone et al., 2014; Morrison et al., 2010; Olausson et al., 2002, 2016). Pleasant touch might then serve as a foundation for affiliative behavior (Morrison et al., 2010), as a mechanism for forming and strengthening social bonds (Gallace & Spence, 2010) and as a means to communicate emotions (Hertenstein et al., 2006, 2009). Also primates have been shown to use reciprocal grooming (allogrooming) for social, beyond hygienical reasons (Dunbar, 2010). Interpersonal touch is acknowledged as fundamental for the human well-being (Field, 2010; Gallace & Spence, 2010). Such importance is clearly evident from our earliest days of life. Just to cite a few examples, mother-baby tactile interactions accelerate infants' cognitive and neurobehavioral development (Feldman & Eidelman, 2003; Field, 2014) and reduce infants' physiological reactivity to stress (Feldman, Singer, & Zagoory, 2010). The lack of touch leads to phenomena defined as "tactile deprivation" and "touch hunger", which reflect how people are strongly in need of interpersonal contact (Field, 2014). Moreover, interpersonal touch (i.e., passive touch) is evaluated as more pleasant than intrapersonal touch (i.e., self-active touch; Etzi, Spence, & Gallace, 2014; Guest et al., 2011), and other people's skin is evaluated as more pleasant than one’s own skin (Guest et al., 2009). Of course the intensity and frequency of tactile approaches are shaped by culture (Dibiase & Gunnoe, 2004; Suvilehto, Glerean, Dunbar, Hari, & Nummenmaa, 2015) and personal traits (Nuszbaum, Voss, & Klauer, 2014; Wilhelm, Kochar, Roth, & Gross, 2001). Still, human tendency to engage in interpersonal tactile contact is undeniable and is highly functional in evolutionary terms (Morrison et al., 2010). Although the reciprocal modulations occurring between pleasant touch and the neurochemical system have not been well-defined yet, neuropeptides (e.g., oxytocin) and opioids (e.g., endorphin) are known to mediate the necessity and the desire for social tactile contact (Dunbar, 2010; Ellingsen et al., 2014; Ellingsen, Leknes, Løseth, Wessberg, & Olausson, 2015; Nummenmaa et al., 2016; Walker & McGlone, 2013). Being touched by another human, even when we are not aware of, can affect our behaviors. A number of studies have in fact revealed that people tend to be more generous or have a more positive attitude when are briefly touched by someone. For instance, customers tend to tip more at a restaurant when they are touched when returning the change (the so-called Midas touch effect; Crusco & Wetzel, 1984). People feel better and evaluate more positively the library where they are, if the librarian casually touches their hand (Fisher, Rytting, & Heslin, 1976); they rate more favorably salesman in a car showroom (Erceau & Guguen, 2007); customers are more compliant and spend more time in a supermarket if touched by a store assistant (Hornik, 1992); people give back left money found in a public phone to the previous caller (Kleinke, 1977) and give away cigarettes more often (Joule & Gueguen, 2007). Being touched by someone reduces the stress level (Ditzen et al., 2007; Grewen, Anderson, Girdler, & Light, 2003; Lindgren et al., 2010; Whitcher & Fisher, 1979), alleviates the feeling of pain (Krahé, Drabek, Paloyelis, & Fotopoulou, 2016; Post-White et al., 2003), and provides psychological support (Connor & Howett, 2009; Debrot, Schoebi, Perrez, & Horn, 2013; Eaton et al., 1986). Hence, the beneficial effects of interpersonal touch are both psychological and physiological

(Field, 2010; Gallace & Spence, 2010; Jakubiak & Feeney, 2016; Lindgren, Jacobsson, & Lämås, 2014).

Here, it is also necessary to clarify that the perception of tactile pleasantness is not limited to CT-mediated touch. Otherwise, we would not perceive any pleasure when touching or being touched on the glabrous skin, where CTs are absent. Although the stimulation of the hairy skin is usually rated as more pleasant as compared to the glabrous (Essick et al., 2010; Etzi et al., 2014; Guest et al., 2011), this is not always true (Löken, Evert, & Wessberg, 2011; McGlone et al., 2012). On this point, McGlone and colleagues (2012) speculated that CT-mediated touch might represent an innate process and Aβ-mediated touch the result of an analytic process dependent on previous tactile experience. According to them, this view would be supported by the fact that the stimulation of the hairy skin induces the activation of the limbic and paralimbic-related cortex (posterior insula and mid-anterior OFC; implicated in emotional processing), while the stimulation of the glabrous skin activates the somatosensory cortices.

Research on Aβ-mediated touch is mainly focused on the role played by the tactile attributes describing textures. Thanks to the density and the properties of its receptors, glabrous skin is extremely sensitive to variations in the microgeometric properties of tactile stimuli (Johansson & Vallbo, 1979; Sathian & Zangaladze, 1996). The smoothness/roughness perceived has been shown to be a crucial factor contributing to the pleasantness felt (Essick et al., 2010; Etzi et al., 2014; Guest et al., 2011). Furthermore, from a physical point of view, hedonic ratings vary in function of the moisture skin level (Klöcker, Arnould, Penta, & Thonnard, 2012) and the magnitude of the frictional forces involved during the exploration of a surface (Klöcker, Wiertlewski, Théate, Hayward, & Thonnard, 2012, Klöcker, Oddo, Camboni, Penta, & Thonnard, 2014). However, it is not possible to differentiate between Aβ and CT contributions over pleasant touch perception in neurologically healthy people, as the stimulation of the hairy skin involves both of them. As a consequence, the mechanisms underlying the perception of pleasant touch are still unclear.

1.2. Top-down modulation of pleasant touch

As already mentioned, the tactile pleasantness felt varies depending on bottom-up factors (e.g., force, velocity, temperature and texture of the stimuli). However, the pleasure experienced when being touched is also largely influenced by top-down factors (Ellingsen et al., 2015; Kveraga, Ghuman, & Bar, 2007). Top-down factors include mood, motivational state, previous experience, affective valence and other sensory information (for a review see Ellingsen et al., 2015). A caress can be perceived differently depending on the gender of the person delivering the stroking. For instance, Gazzola and colleagues (2012) let participants believe to be stroked by a male or a female experimenter when they were actually touched always by the same female experimenter. To do so, they were prevented to see the real stimulation occurring and were presented with videos showing an elegant woman or a sloppy man as experimenter. As result of this trick, the caresses delivered by the woman were rated as more pleasant than those delivered by the man, both for female and male participants. Moreover, the participants had a higher arousal state (measured as skin conductance response) in response to the stimulation delivered by the man. Hedonic tactile perception is also modulated by the origin culture of the person being caressed and the emotional bond between him/her and the caresser. By using topographic maps, Suvilhento et al. (2015) showed that Russian culture uses touch in a more conservative way than Italian, French, English and Finnish cultures. Also, this study showed (as expected) that strangers are allowed to touch a more limited body area as compared to emotionally closer individuals, and the higher the emotional bond, the larger the bodily area available for touching (see Fig. 1). Another important role in modulating touch is played by the qualities of the stimuli that the participants think to be stroked with and the motivational approach to the stimulation. McCabe and colleagues (2008) showed that the words and the description chosen to present stimuli applied to the skin, in this case a cream presented as a “rich body cream” as compared to a “normal cream”, were able to change people’s hedonic judgments on the cream and on the overall experience. Furthermore, from a motivational point of view, being repetitively stroked at the same velocity leads to a decrease in the pleasantness experienced and in the desire for having more stimulation (Triscoli, Ackerley, & Sailer, 2014).

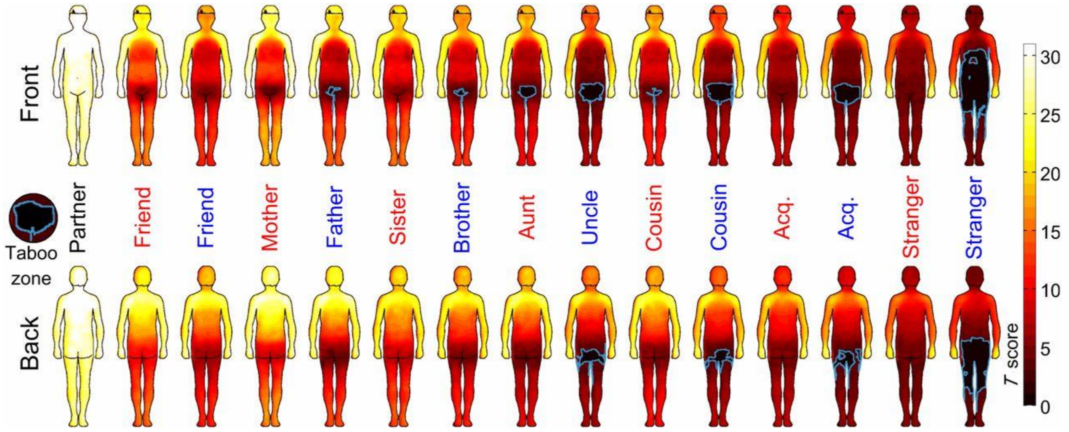

Figure 1. Relationship-specific touch-area maps. The blue-outlined black areas highlight the taboo zones, where a person with that relationship is not allowed to touch. The data are thresholded at $P < 0.05$. Color bar indicates the t statistic range. Blue and red labels signify male and female subjects, respectively. Figure taken from Suvilehto, Glerean, Dunbar, Hari, & Nummenmaa (2015).

Also being simultaneously presented with multisensory information affects hedonic tactile perception. For instance, disgusting odors smelled when being stroked make perceive the tactile stimulation as less pleasant in comparison to an odorless condition (Croy, D’Angelo, & Olausson, 2014). Moreover, the emotional expression of a face shown when receiving tactile stimulation modulates hedonic judgments. Seeing a sad face makes perceive a slow stroking (optimal for CT afferents) as less pleasant than when seeing a smiling face (Ellingsen et al., 2014). Here, it is worth noting that these studies revealed that hedonic tactile evaluations were modulated by stimuli coming from different sensory modalities despite they were non-informative as regards touch, and despite they were clearly not originating from the tactile stimulation. In fact in both the studies just reported, it is clearly stated that the participants were fully aware that the odors were not released by the caresser body (Croy et al., 2014) and that the face they were seeing was not that one of the caresser (Ellingsen et al., 2014). This phenomenon might be explained by referring to the affective ventriloquism effect, whereby the hedonic attributes of a stimulus perceived via one sensory modality can bias the hedonic evaluations of the stimulus derived from other sensory modalities into alignment (Spence & Gallace, 2011). The hedonic value is in fact considered one of the mediators accounting for crossmodal interactions (Crisinel & Spence, 2010; Demattè, Sanabria, Sugarman, & Spence, 2006; Etzi, Spence, Zampini, & Gallace, 2016; Velasco, Woods, Deroy, & Spence, 2015). Importantly, this phenomenon also informs about the effects of crossmodal interactions on perception. Beyond hedonic valence, also the perception of other sensory attributes of tactile stimuli can be modulated by other senses. Just to mention a few examples, it has been shown that tactile perception of surfaces can be modulated by presenting different odors (Demattè et al., 2006) or by changing the auditory feedback resulting from the body contact with the surface. By amplifying the high frequencies of the sounds emitted during the stimulation, the skin of the palms can feel drier during hand-rubbing (parchment-skin illusion; Guest, Catmur, Lloyd, & Spence, 2002; Jousmäki & Hari, 1998); samples of abrasive paper can feel rougher when touched (Guest at al., 2002); and potato chips can be perceived as crisper and fresher during the biting action (Zampini & Spence, 2004). Although these multisensory interactions do not involve hedonic ratings, they are extremely relevant for the study of pleasant touch since they include attributes (e.g., softness, smoothness) strictly linked to tactile pleasantness (Essick et al., 2010; Etzi et al., 2014, 2016; Guest et al., 2011). As far as sensory relationships are concerned, the dominance of vision over the other senses has been claimed for a long time (e.g., Hartcher-O’Brien, Gallace, Krings, Koppen, & Spence, 2008; Koppen & Spence, 2007; Posner, Nissen, & Klein, 1976; Rock & Viktor, 1964; Sinnett, Spence, & Soto-Faraco, 2007) However, there is evidence suggesting that sensory dominance depends on the specific task to be performed (i.e., modality appropriateness; Ernst & Banks, 2002; Ernst & Bülthoff, 2004; Welch & Warren, 1980). For instance, people are thought to rely more on vision rather than touch when evaluating the spatial density of a surface (due to the greater ability of vision in processing spatial information; Lederman, Thorne, & Jones, 1986), but rely more on touch rather than vision when evaluating the roughness of a surface (since touch seems to be more ecologically suited than vision in assessing the microgeometric properties of a surface; Guest & Spence, 2003b; Lederman et al., 1986). Taking into consideration crossmodal interactions involving touch and the supposed dominance of vision on the other sensory modalities, future studies will need to better explain how pleasant touch is affected by information coming from the other senses.

With regard to neural processing, it is still uncertain where top-down information interacts with the tactile information conveyed by the CTs. Some studies using somatosensory evoked potential (SEPs) suggest that such modulations might occur in the primary somatosensory area (S1; Fiorio et al., 2012; Schubert et al., 2008). Alternatively, these modulations might involve a descending modulation in the spinal cord (Ellingsen et al., 2015). Certainly more investigation is still needed in order to identify the cerebral mechanisms underpinning the modulation of pleasant touch.

1.3. Pleasant touch in product design and marketing

The insights coming from the study of pleasant touch are extremely useful for the applied fields of product design, marketing and advertising. Through the palms of the hands people daily interact with objects for both functional (e.g., using a tool to assemble a piece of furniture) and non-functional reasons (e.g., enjoy or playing with an object in order to relieve stress; Sonneveld & Schifferstein, 2008). Since long time, designers and consumer experts have realized that vision is not the only sensory modality involved when exploring an item and eventually making a purchase decision (Spence & Gallace, 2011). Most of the time people look at the products placed on the shelves and, after a preliminary stage of visual selection, grab and hold in the hand one of them in order to make a closer inspection. Doing so, other essential qualities such as the shape, the texture, the weight and the heat emanated by the object can be appreciated (Peck & Childers, 2003a). However, it is worth noting that the tendency and the need to touch a product when shopping depend on the product under evaluation (McCabe & Nowlis, 2003; Marlow & Jansson-Boyd, 2011). For instance, touch is certainly the sensory modality more appropriate to explore hand tools (e.g., mouse for computer; Fenko, Schifferstein, & Hekkert, 2009) and clothes (McCabe & Nowlis, 2003). By contrast, vision is more appropriate when the items vary in terms of geometric properties (e.g., shape; McCabe & Nowlis, 2003). Also, the individual traits shape the tendency to and the manner we interact with objects. On this point, the “Need for Touch” scale has been created in order to measure the individual inclination to touch products (Peck & Childers, 2003b). In addition, the scores obtained in the two sub-parts of the NTF scale inform about the style and aim of the touching behavior, which can be more “autotelic” (indicating hedonic-oriented touch aimed at itself, just seeking for pleasure) or “instrumental” (reflecting outcome-directed touch with the final aim of making a purchase). After highlighting the importance of manually interacting with products, it might be argued that the massive use of packaging boxes negatively affects the haptic experience. However, rather than seeing it as a disadvantage, designers have taken the "limit" of a poor tactile interaction with the product itself as a challenge to evoke product-congruent feelings through the packaging (Gallace, 2015). The case of the packaging made by the designer Naoto Fukusawa represents a very incisive example of how it is possible to make the act of drinking some fruit juices more enjoyable and also hyper-realistic (Spence & Gallace, 2011; see Fig. 2).

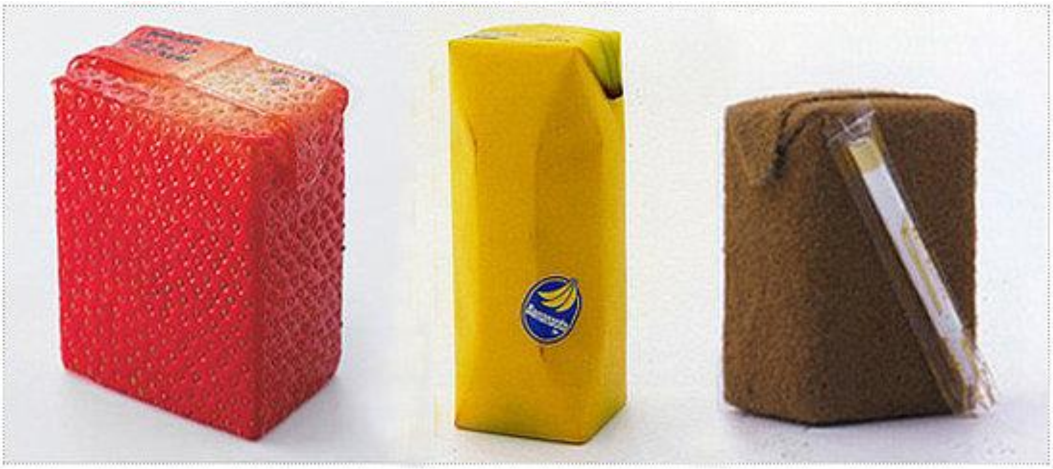

Figure 2. Fruit juice packaging designed by the Japanese industrial designer Naoto Fukusawa.

Despite the importance of studying and looking at touch in isolation and investigating sensory dominance mechanisms, it should be kept in mind that perception is inherently multisensory (Stein, 2012). Hence, the marketing and design fields would beneficiate from the study of how touch interacts with the other senses and how one modality is frequently associated with another one because of crossmodal correspondences. As far as sensory interactions are concerned, it is interesting to see how for example a piece of fabric is rated as softer when presented in combination with a lemon odor (Demattè et al., 2006) or potato chips are perceived as crisper if the high frequencies of the biting sound are amplified (Zampini & Spence, 2004). Speaking about crossmodal correspondences, it would be important to know more about how a dimension in one sensory modality is matched with a tactile dimension (see Spence, 2011, 2012). For instance, sensory attributes such as brightness and quietness are evaluated as correspondent to smooth materials (Etzi et al., 2016), and heaviness is associated with darkness and low-pitched sounds (Walker, Scallon, & Francis, 2016).

Making a step behind before standing in front of a shelf full of products, a reference to pleasant touch can be still made by means of advertising. It is not necessary to be in physical contact or proximity with an object to promote it by using insights coming from consumer neuroscience and experimental psychology. In fact, specific tactile sensations can be elicited also by visually presenting products being used. Neural responses are evoked even when pleasant touch is not experienced on the own skin but just observed when being delivered to another person (McCabe et al., 2008; Morrison, Björnsdotter, & Olausson, 2011). Similarly, pleasant tactile feelings can be induced by using sensory adjectives to describe a product. Advertising in fact often makes use of tactile adjectives such as “soft” and “smooth” when promoting fabric conditioners, hair conditioners or body creams, in order to evoke pleasant feelings in the users (Gallace & Spence, 2014). The formulation of neologisms such as “Neuromarketing” or “Neurodesign” proves the growing interest in the scientific study of consumer neuroscience expressed by the more applied fields. In order to satisfy these needs, in the years to come, more research focused on the customers/users’ explicit and implicit reactions to products has to be done.

1.4. Aims of the experimental studies

So far, research has focused on the behavioral and neural responses to pleasant touch but the autonomic body responses remain little investigated. Electrodermal activity (EDA), heart rate (HR), electric muscular activity (EMG) and other physiological measures might vary depending on the velocity of the stroking, the person delivering the stimulation and the qualities of the objects used to stroke. Moreover, the actual studies assessed how bottom-up factors (e.g., velocity and force of the stimulation) affect hedonic perception but the effects of top-down factors on pleasant touch remain relatively unexplored. Such cognitive modulations include the integration and the interaction among tactile and other sensory modality information, past experience, recognition of the stimuli, social interaction with the person delivering the stimulation, etcetera.

In the present dissertation, four experimental studies are reported. These studies were designed in order to assess the behavioral and physiological effects of hedonic tactile perception, both in unisensory and multisensory conditions of stimulus presentation. In particular, investigations on how skin conductance and subjective evaluations vary by presenting different kinds of tactile stimuli (textures, surfaces and brushes), alone or in combination with visual and auditory stimuli, have been conducted. The effects of social interaction and emotional contents, and the exploration of virtually-simulated surfaces were also examined.

In Study 1, the psychophysiological effects of different kinds of touch delivered by means of a soft brush were investigated. Tapping (varying in temporal and spatial sequence) and stroking (varying in velocity) touches were delivered to the participants' forearm for brief (9 seconds) and long periods (60 seconds). Skin conductance response (SCR) and level (SCL), as well as sensory and emotional ratings, were measured.

In Study 2, the effects of the sensory modality of exploration of textures on physiological arousal state and hedonic judgments were investigated. Participants were either haptically or visually presented with a set of everyday materials (e.g., sandpaper, satin). In the haptic condition either a female or a male experimenter delivered the stimulation. Skin conductance responses and ratings on the tactile pleasantness experienced (touch condition) or imagined (visual condition) were collected.

Study 3 assessed whether emotional or non-emotional contents visually presented affect the evaluation of tactile stimuli. Participants were slowly (3-5 cm/s) stroked on the forearm with everyday materials while watching pictures depicting daily events. Ratings on the pleasantness of the tactile stimulation, on the roughness and softness of the materials, as well as skin conductance, were collected. The effect of the tactile stimulation on the evaluation of the pictures was also assessed.

In Study 4, the sensory and hedonic perception of virtual surfaces was investigated. The surfaces were rendered by means of a force-feedback haptic device and were presented paired with pictures of everyday materials (e.g., glass, steel) or sounds, resulting from the exploration of sheets of paper and sandpaper. Hedonic and roughness ratings, as well as the duration of exploration, were collected.

Chapter 2

STUDY 1: AROUSAL RESPONSE TO STROKING AND TAPPING

2.1. Background and aim of the study

The sense of touch, particularly in its affective and interpersonal components, plays a fundamental role in contributing to the development and maintenance of the human cognitive and emotional wellness (Field, 2014; Gallace & Spence, 2010). The beneficial effects of interpersonal touch are in fact both psychological and physiological (Field, 2010; Gallace & Spence, 2010; Lindgren, Jacobsson, & Lämås, 2014). Touch is crucial in supporting the forming and strengthening of social and romantic bonds (Gallace & Spence, 2010) and serves as a communication channel able to convey emotions (Hertenstein et al., 2006, 2009; Morrison et al., 2010). Converging evidence would seem to suggest that the perception of social touch delivered to the hairy skin is physiologically mediated by C-Tactile afferents (CTs; Löken et al., 2009; McGlone et al., 2014; Morrison et al., 2010; Olausson et al., 2010; Vallbo et al., 1999). These fibers respond vigorously to caress-like stimulations (Ackerley et al., 2014a; Löken et al., 2009; Vallbo et al., 1999) and their firing rate correlates with the pleasantness felt during the stimulation (Löken et al., 2009).

Despite the recent considerable increment of research investigating pleasant touch (whose a large part is designed to involve CT afferents), its effects on the autonomic nervous system are still poorly explored. Among the different techniques available to assess the individual physiological state, the measurement of the electrodermal activity (EDA) is widely used to evaluate the emotional arousal evoked by external stimuli (Boucsein, 2012). So far, a few studies have examined the arousal response to pleasant touch in terms of skin conductance response (SCR; the phasic component of EDA). Gazzola and colleagues (2012) have shown that the gender of the person delivering the tactile stimulation affects the SCR. Both women and men were more aroused by caresses delivered by a man rather than a woman. Etzi and Gallace (2016; see also Chapter 3) found that the qualities of the object used to deliver a 2-second long tactile stimulation do not modulate the physiological arousal response. In fact, SCR did not change as a function of the pleasantness/unpleasantness of the materials utilized (but see Chapter 4 for the results of a 9-second long stimulation). Moreover, the study of Chatel-Goldman and colleagues (2014) revealed that interpersonal touch occurring between romantic partners increases the coupling of their electrodermal responses, thus demonstrating that pleasant touch contributes to create and support an emotional bond.

Surprisingly, no studies have compared the specific contribute of CTs in the modulation of the physiological arousal, for relatively brief and long periods of time (see Olausson et al., 2008b, for an exception on neuronopathy patients lacking Aβ fibers). Moreover, it is still unknown whether the pleasantness felt when being stroked correlates with the related arousal response. The present study aims to shed light on these issues by measuring skin conductance (both phasic -SCR- and tonic -skin conductance level, SCL- components) and by means of subjective evaluations. Hence, four different types of tactile stimulation were delivered to the forearm. Stroking (slow -3 cm/s- or fast -30 cm/s-) and tapping stimulations (random or fixed spatio-temporal sequence-order) were presented for brief (9 seconds) or long periods (60 seconds). Here it is important to highlight that only the slow stroking condition was CT-targeted. The tapping was introduced in the paradigm in order to provide a non-stroking stimulation and to evaluate the role of the spatial sequence (random or repetitive) in modulating hedonic perception. As fixed order tapping, the procedure effective in inducing the cutaneous rabbit illusion was used (Geldard & Sherrick, 1972; Miyazaki, Hirashima, & Nozaki, 2010). This somatosensory illusion consists in delivering fast sequential taps first to one location and then to another on the skin, to induce the illusion that the tapping is occurring at intermediate locations between the actual stimulus sites, as if a small rabbit was hopping along the skin from the first site to the second position. Here, this illusion served as a control for the role of the perception of a movement on the skin, without activating the specific receptors.

Despite SCR does not provide any information regarding the affective valence of the physiological reaction (i.e., positive or negative; Boucsein, 2012), unpleasant and painful stimuli have been shown to induce higher arousal responses than pleasant and positive stimuli (Eriksson, Storm, Fremming, & Schollin, 2008; MacDowell & Mandler 1989; Ramachandran & Brang 2008). Therefore, one might hypothesize that a less pleasant stimulation (such as the fast stroking as compared to the slow) induces a higher SCR than a more pleasant stimulation. Speaking of the effects of the stimulation on the more general arousal state, a lower SCL for the slow stroking as compared to the fast is expected, given the positive and relaxing effect of gentle and slow touch (Ditzen et al., 2007; Feldman et al., 2010; Field, 1998). Moreover, receiving tapping on the forearm is expected to be less pleasant (as found by Kress, Minati, Ferraro, & Critchley, 2011) and then rather salient for the individual. Being less common in daily life and not having any particular social function, it might in fact induce a great alert state and thus a higher arousal response to stroking, or at least to slow stroking.

2.2. Experiment

2.2.1. Methods

Participants

Thirty volunteers (15 females; one left-handed; mean age 26±4) took part in the experiment. All the participants reported normal tactile sensitivity and the absence of peripheral nerve damage. The study was performed in accordance with the ethical standards laid down in the Declaration of Helsinki and received ethical approval from the local ethics committee. All the participants gave their informed consent before taking part in the study and received course credits for their participation.

Procedure

The participants were seated comfortably in front of the experimenter, resting both the arms on a desk. Two Ag-AgCl electrodes (Model 1081 FG) with constant voltage (0.5 Volt) were attached to the medial phalanges of the index and the middle fingers of the non-dominant hand. Electrodermal activity was recorded by means of a SC2071 device (BioDerm, UFI, Morro Bay, California). Saline conductor gel was used to improve the signal-to-noise ratio. The gain parameter was set at 10 µSiemens (µS)/Volt, the analog-to-digital (A/D) resolution was 12 bit, allowing to record responses ranging from 0.1 to 100 µS, with a sample rate of 10 Hz. The experimenter (female) used a soft circular brush (diameter: 2 cm) to stroke a 9 cm-long skin portion on the dorsal part of the participants' dominant forearm. The skin portion delimited for the stimulation was located exactly at the same distance from the elbow and the wrist. Participants received two sessions of stimulation. The longer session consisted in 60 second-long stimulations, while the brief consisted in 9 second-long stimulations. The presentation order of the two sessions was counterbalanced. Each session was composed of 12 trials: 4 types of touch were delivered, each one repeated for three times throughout the session. Type 1: slow stroking (3 cm/sec); type 2: fast stroking (30 cm/sec); type 3: random order tapping (pressure of points on the skin in a randomized order; each point was located at a distance of 3 cm from another); type 4: fixed order tapping (pressing twice the same point on the skin with 800 ms as interstimulus interval (ISI) and then pressing a 9-cm distant second point with an ISI of 80 ms in order to induce the cutaneous rabbit illusion; see Geldard & Sherrick, 1972; Miyazaki et al., 2010). The presentation order of the four types of stimulation was pseudo-randomized. In order to limit CT habituation, the experimenter stroked different parts of the skin along the same portion of the forearm. The experimenter wore earphones and used auditory signals to provide the correct stimulation in the correct temporal sequence. At the end of each stimulation, participants were asked to evaluate it by using four visual analogue scales (VASs): pleasantness, intensity, relax and type of touch. These scales were 10 cm-long and were anchored by the words ‘not at all’ and ‘very much’, with the exception of the type of touch scale which was anchored by the words ‘social touch’ and ‘mechanical touch’. In order to prevent the influence of other sensory cues, participants were blindfolded and wore sound-proof headphones during the stimulation.

Data analysis

The SC data were analyzed by using LEDALAB (version V3.4.7), a software implemented in MATLAB (version R2012a), by using a continuous decomposition analysis approach (Benedek & Kaernbach, 2010). The average phasic driver within response window was considered as measure for the analysis of the SCR. Since the length of the response window is known to affect electrodermal activity data (Boucsein, 2012), two separated analyses were performed for the brief and the long stimulations. The response window was set from 2 to 9 seconds after the onset of the stimulation in the case of the brief stimulation, and from 2 to 60 seconds in the case of the long stimulation. An analysis of the SCL was also performed for the long stimulation. Tonic component (SCL) is worth investigating when response windows last at least 30-60 seconds (Boucsein, 2012), thus an analysis of the SCL was not performed for the brief stimulation. As recommended by Venables and Christie (1980), the SC data were logarithmically transformed with the following formula: $y=\log(1+x)$ before the statistical analysis, in order to normalize the data distribution. With regard to the ratings, each VAS was converted in measures ranging from -5 cm to +5 cm, in order to have negative values indicating unpleasantness and positive values indicating pleasantness. In the case of the VASs, brief and long stimulations were analyzed together. Statistical analyses were performed through the software STATISTICA, Version 6.0 (StatSoft, Italy). Both the SC and each VAS were submitted to mixed repeated measure analyses of variance (ANOVAs) by using the between-subject factor "gender" (females vs. males) -and "duration" (brief vs. long) for the VASs- and the within-subject factor "touch" (slow vs. fast vs. random order vs. fixed order). When significant effects were found, post-hoc tests (corrected with the Newman-Keuls method) were conducted. Two-tailed Pearson correlations were performed to assess the relationship between SC data and participants' ratings.

2.2.2. Results

Skin conductance

Brief stimulation - Phasic component (SCR)

The main effect of "touch" was significant [$F(3, 84)=10.62$, $p<.001$]. Fast stroking induced higher SCRs than slow stroking ($p=.04$), random order ($p<.001$) and fixed order ($p<.001$). Slow touch induced higher SCRs than random order ($p=.009$) and fixed order ($p=.02$). Random and fixed order did not differ in terms of the SCRs induced ($p=.47$; see Fig. 3). The effects of "gender" [$F(1, 28)=0.37$, $p=.54$] and "touch" by "gender" [$F(3, 84)=1.78$, $p=.15$] were not significant.

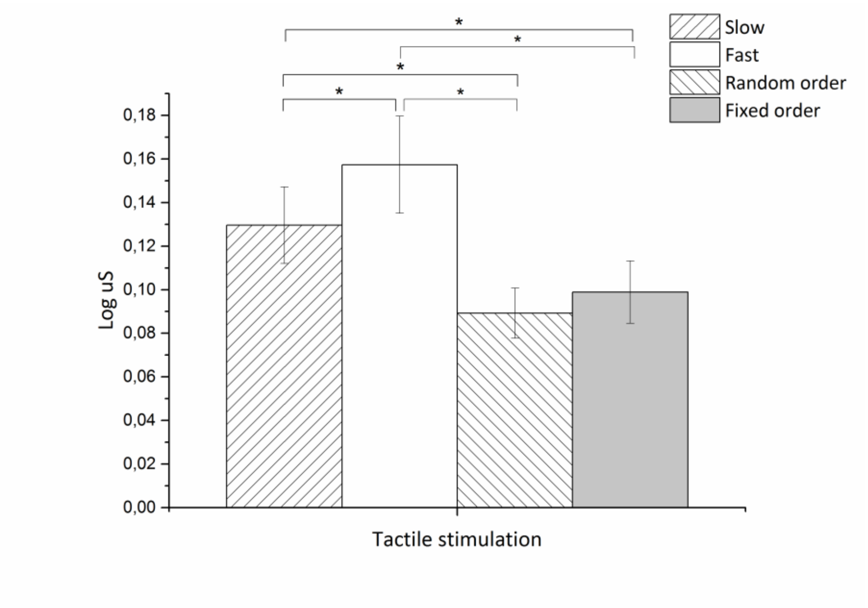

Figure 3. Mean SCRs (log uS) measured during the brief stimulation to slow and fast strokes, and to random and fixed order taps. Error bars represent the standard error of the means and asterisks indicate significant differences (p<.05).

Long stimulation - Phasic component (SCR)

The main effect of "touch" was significant [F(3, 84)=11.94, p<.001]. Fast stroking induced higher SCRs than slow (p=.03), random order (p<.001) and fixed order (p<.001). Slow stroking induced higher SCRs than random order (p=.002) and fixed order (p=.04). Random and fixed order did not differ (p=.12; see Fig. 4). The effects of "gender" [F(1, 28)=0.03, p=.85] and "touch" by "gender" [F(3, 84)=1.11, p=.34] were not significant.

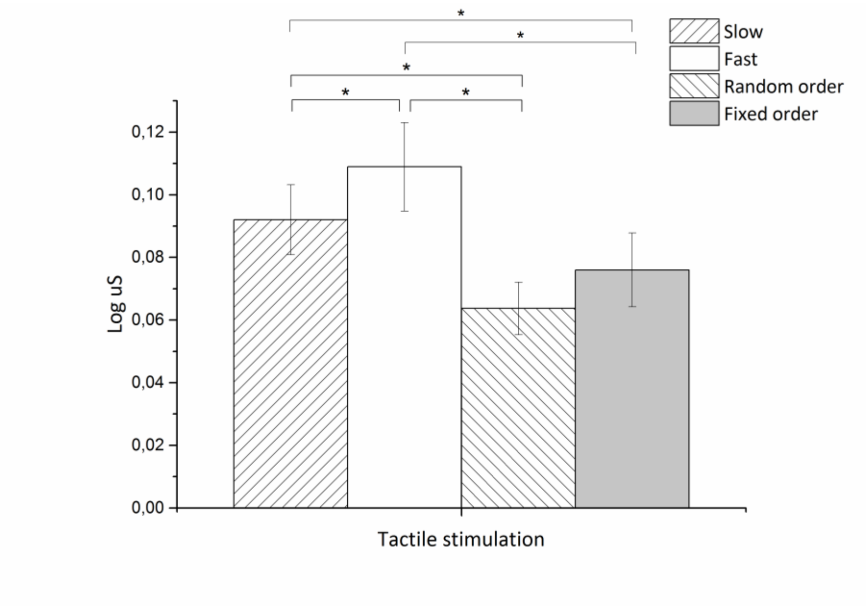

Figure 4. Mean SCRs (log uS) measured during the long stimulation to slow and fast strokes, and to random and fixed order taps. Error bars represent the standard error of the means and asterisks indicate significant differences (p<.05).

Long stimulation - Tonic component (SCL)

The main effect of "touch" was significant [F(3, 84)=5.54, p=.001]. Fast and slow strokes did not differ (p=.73). Fast and slow strokes induced higher SCLs than random (p=.004; p=.007, respectively) and fixed order (p=.04; p=.03, respectively) taps. Random and fixed order tapping did not differ (p=.32; see Fig. 5). The effects of "gender" [F(1, 28)=12.03, p=.16] and "touch" by "gender" [F(3, 84)=1.97, p=.12] were not significant.

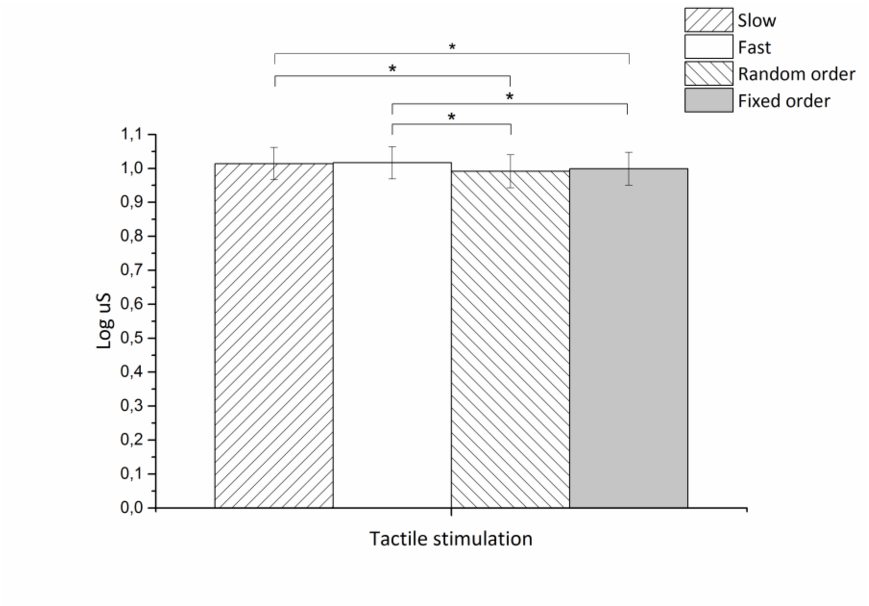

Figure 5. Mean SCL (log uS) measured during the long stimulation to slow and fast strokes, and to random and fixed order taps. Error bars represent the standard error of the means and asterisks indicate significant differences (p<.05).

Ratings

Pleasantness

The main effect of “touch” [F(3, 84)=34.90, p<.001] was significant. Slow stroking was rated as more pleasant than fast stroking (p<.001), random order (p<.001), and fixed order (p<.001). Fast stroking was rated just as pleasant as the random (p=.92) and a trend suggested that it was more pleasant than fixed order (p=.06) tapping. Random order was rated as more pleasant than fixed order (p=.02). The interactive effect “duration” by “touch” [F(3, 84)=3.07, p=.03] was significant as well. Fast stroking was rated as more pleasant during the brief than during the long stimulation (p=.02; see Fig. 6). The effects of “duration” [F(1, 28)=0.13, p=.71], “gender” [F(1, 28)=1.33, p=.25], “duration” by “gender” [F(1, 28)=2.01, p=.16], “touch” by “gender” [F(3, 84)=0.68, p=.56] and “duration” by “touch” by “gender” [F(3, 84)=1.56, p=.20] were not significant.

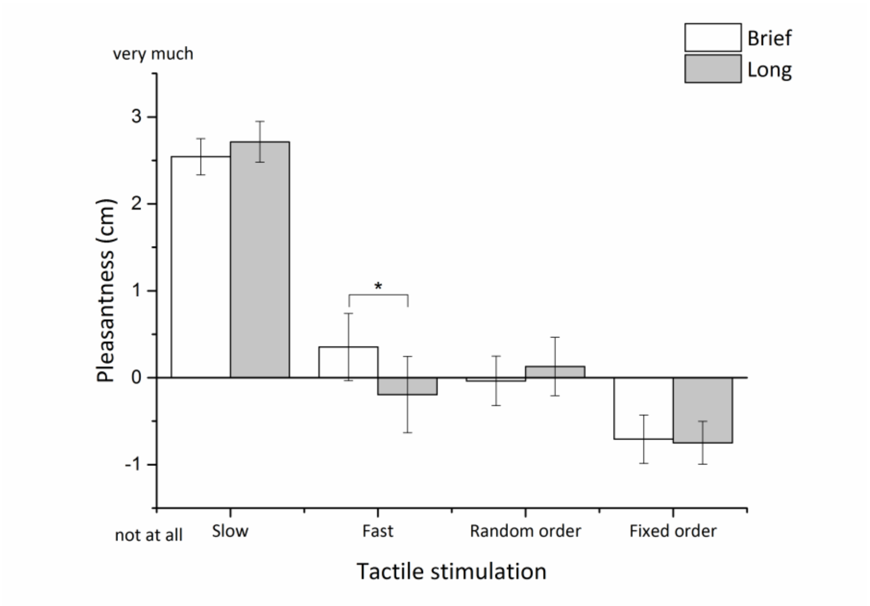

Figure 6. Mean ratings of the different touches on the scale “pleasantness”, both for the brief and the long stimulations. Error bars represent the standard error of the means and asterisks indicate significant differences (p<.05).

Intensity

The main effect of “touch” [F(3, 84)=18.82, p<.001] was significant. Fast stroking was rated as more intense than slow stroking (p<.001), random order (p<.001) and fixed order (p=.02). Fixed order tapping was more intense than slow stroking (p<.001) and random order (p<.001). Slow stroking and random order did not differ (p=.93). The interactive effect “duration” by “touch” [F(3, 84)=4.28, p=.007] was significant as well. Both fast stroking and fixed order were rated as more intense in the long than in the brief session (respectively p<.001 and p=.04; see Fig. 7). The effects of “duration” [F(1, 28)=3.15, p=.08], “gender” [F(1, 28)=2.49, p=.12], “duration” by “gender” [F(1, 28)=0.10, p=.74], “touch” by “gender” [F(3, 84)=0.23, p=.87] and “duration” by “touch” by “gender” [F(3, 84)=0.43, p=.72] were not significant.

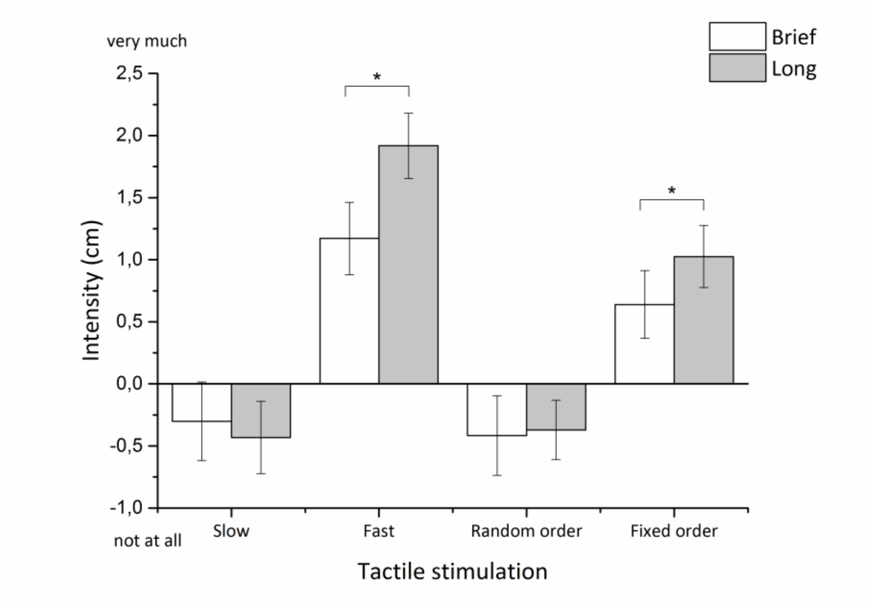

Figure 7. Mean ratings of the different touches on the scale “intensity”, both for the brief and the long stimulations. Error bars represent the standard error of the means and asterisks indicate significant differences (p<.05).

Relax

The main effect of “touch” [F(3, 84)=41.95, p<.001] was significant. Slow stroking was rated as more relaxing than fast stroking (p<.001), random order (p<.001) and fixed order (p<.001). Random order was more relaxing than fixed order (p=.02; see Fig. 8). The effects of “duration” [F(1, 28)=0.19, p=.66], “gender” [F(1, 28)=0.21, p=.64], “duration” by “touch” [F(3, 84)=2.38, p=.07], “duration” by “gender” [F(1, 28)=3.68, p=.06], “touch” by “gender” [F(3, 84)=0.81, p=.48] and “duration” by “touch” by “gender” [F(3, 84)=2.29, p=.08] were not significant.

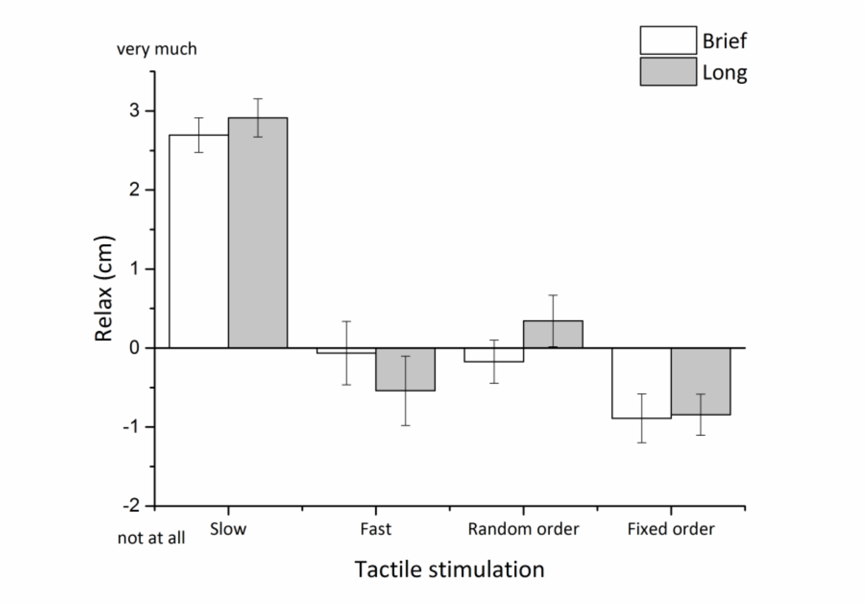

Figure 8. Mean ratings of the different touches on the scale “relax”, both for the brief and the long stimulations. Error bars represent the standard error of the means and asterisks indicate significant differences (p<.05).

Type of touch

The main effect of “touch” [F(3, 84)=28.33, p<.001] was significant. Slow stroking was rated as more social than fast stroking (p<.001), random (p<.001) and fixed order (p<.001). Fixed order tapping was rated as more mechanical than fast stroking (p=.006) and random order (p=.002; see Fig. 9). The effects of “duration” [F(1, 28)=0.26, p=.61], “gender” [F(1, 28)=2.26, p=.14], “duration” by “touch” [F(3, 84)=1.00, p=.39], “duration” by “gender” [F(1, 28)=0.09, p=.76], “touch” by “gender” [F(3, 84)=1.01, p=.39] and “duration” by “touch” by “gender” [F(3, 84)=1.61, p=.19] were not significant.

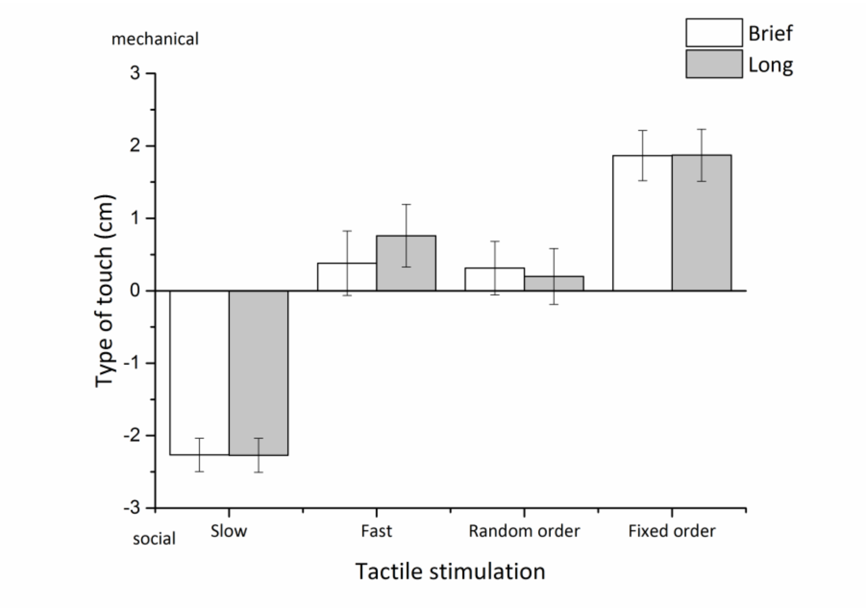

Figure 9. Mean ratings of the different touches on the scale "type of touch", both for the brief and the long stimulations. Error bars represent the standard error of the means and asterisks indicate significant differences (p<.05).

Correlational analyses

Brief stimulation

Pleasantness (p=.08), intensity (p=.23), relax (p=.20), type of touch (p=.56) ratings did not correlate with SCR.

Long stimulation

Pleasantness (p=.99), intensity (p=.13), relax (p=.20), type of touch (p=.71) did not correlate with SCR.

There was no significant correlation between pleasantness (p=.60), intensity (p=.46), relax (p=.12), type of touch (p=.77) and SCL.

2.3. Discussion

The present study investigated the psycho-physiological correlates of receiving stroking and tapping stimulations for brief and long periods of time. Speaking in terms of arousal responses, the results revealed that fast stroking led to higher skin conductance responses than slow stroking. This result might be due to the fact that a stimulation quickly delivered to the skin is likely interpreted as potentially dangerous and then as more salient as compared to a slow one. The saliency of the stimulus and the participant's need to prevent potential tissue damages might thus explain the higher arousal reaction. Since fast stroking induces a less vigorous activation of CT afferents as compared to slow stroking (Ackerley et al., 2014; Löken et al., 2009), it can be inferred that a weak CT stimulation leads to a higher arousal state as compared to a vigorous CT activation. This effect has been replicated during both brief and long stimulation sessions, indicating that the higher physiological response remained constant for at least 60 seconds. When examining variations on the skin conductance level, no differences emerged between the effects induced by slow and fast strokes.

Despite gentle touch seems to be effective in reducing the activity of the sympathetic nervous system and thus stress levels (e.g., Ditzen et al., 2007; Lindgren et al., 2010, 2014; Maville, Bowen, & Benham, 2008), this result suggests that when slow stroking (CT-targeted) was delivered for 60 seconds, the autonomic general body state was not affected differently by the preferential activation of CTs. The greater feeling of relax reported by the participants during slow as compared to fast stroking is thus not supported by changes in the skin conductance level. Nevertheless, it is likely that the duration of the 60-second long stimulation was not sufficiently extended in order to produce variations in the more general arousal state. As regards a prolonged stimulation of CT afferents, it is important to note that CTs are affected by a habituation effect (Nordin, 1990; Vallbo et al., 1999) but still, long-lasting stroking is perceived as pleasant as short-lasting stroking and is processed in the same neural areas (Sailer et al., 2016).

Concerning the comparison between the two main types of tactile stimulation provided, for both brief and long stimulations, the analyses reveled that fast and slow strokes led to higher responses (SCRs) and higher general arousal states (SCLs) than random and fixed order taps. On this point, it is interesting to note that stroking has been shown to be more pleasant and to elicit a greater response in the posterior insula (acknowledged to play a central role in processing pleasant touch; e.g., Morrison, 2016; Olausson et al., 2002, 2008a) than tapping (Kress et al., 2011). However, it is also likely that the longer skin contact occurred during stroking as compared to tapping contributed to the higher arousal state. No differences were found between women and men in terms of skin conductance, although higher SCRs have been reported in women during CT-targeted stroking with different textures (Etzi & Gallace, 2016; see also Chapter 3). One might hypothesize that the nature of the tactile stimuli used (brush vs. textures) and the duration of the tactile stimulation (9 or 60-seconds vs. 2-seconds) induce different physiological reactions depending on the gender of the person receiving the touches. Women may show a higher reaction just in the first few seconds of the stimulation, due to the necessity of a very high responsiveness to tactile contact during mother-baby interactions.

Regarding to the subjective evaluations of touch, slow stroking induced a more pleasant but a less intense feeling than fast stroking. Moreover, slow stroking was judged as the most relaxing stimulation and the most “social” type of touch as compared to the others conditions, confirming that it represents a typical example of social physical contact (Löken et al., 2009; McGlone et al., 2014; Morrison et al., 2010). With reference to fast stroking and fixed order tapping, the unpleasantness (and also the intensity for fast stroking) perceived was/were even higher when the stimulation lasted for 60 seconds. This might depend on the phenomenon named as “touch satiety”, whereby the experience of tactile pleasantness changes with repeated exposure (Triscoli, Ackerley, & Sailer, 2014). Since this effect has been shown to vary as a function of the stroking paradigm adopted, this view would be consistent with the lack of differences between the two temporal sessions for the slow stroking and random order tapping. Moreover, the fixed order tapping was rated as unpleasant as the fast stroking but as less intense, and it was rated as the most “mechanical” touch as compared to the others. Since the random order tapping was rated as more pleasant, less intense, more relaxing and more “social” than the fixed order is not the tapping per se’ the responsible of these evaluations. Although tapping stimulation has been shown to be less pleasant than stroking (Kress et al., 2011), here the effect seems to be driven by the stimulation spatial sequence. The repetition of the same sequence of tapping would seem to induce a slightly unpleasant experience and it was compared by participants to a human-machine interaction. It is worth noting that several studies have made use of a robot to deliver a controlled tactile stimulation in terms of force and velocity (rotary tactile stimulator, RTS; e.g., Essick et al., 2010; McGlone et al., 2012). However, in those cases the robot delivered stroking stimulations and not tapping and there is evidence showing that the experience of being stroked by a human or a robot is comparable (Triscoli, Olausson, Sailer, Ignell, & Croy, 2013).

Taken together, the results reported here contribute to shed light on the psychophysiological underpinnings of interpersonal tactile stimulation. Different kinds of touch were delivered (i.e., stroking and tapping) in order to evaluate how they affect the arousal state, at both implicit (EDA) and explicit (evaluations) levels. Moreover, the role played by CT afferents in modulating arousal response has been assessed. Since it has been recently shown that the perception of pleasant touch is impaired in some psychiatric diseases such as the autism spectrum disorders (ASD; e.g., Cascio et al., 2012; Croy, Geide, Paulus, Weidner, & Olausson, 2016; Kaiser et al., 2016; Voos, Pelphrey, & Kaiser, 2013) and anorexia nervosa (AN; Crucianelli, Cardi, Treasure, Jenkinson, & Fotopoulou, 2016), there is a growing interest in the abnormal processing of CT-mediated touch. In particular patients diagnosed with these diseases showed atypical evaluations of CT-targeted touch (Croy, Geide, Paulus, Weidner, & Olausson, 2016; Crucianelli et al., 2016; Kaiser et al., 2016) and reduced activity in the limbic cortex (Kaiser et al., 2016), as compared to control groups. The study reported here shows that the electrodermal activity can be effectively used to test implicit responses to affective and non-affective touch, and it also provides data from a neurologically normal population. In the future, more research will be needed to test whether patients affected by affective disorders exhibit anomalous or normal physiological responses to touch.

Chapter 3

STUDY 2: COMPARING AROUSAL RESPONSE TO MATERIALS EXPLORED BY VISION OR TOUCH

[This research has been published in: Etzi & Gallace (2016). The arousing power of everyday materials: An analysis of the physiological and behavioral responses to visually and tactually presented textures.*Experimental Brain Research*, *234*, 1659-1666].

3.1. Background and aim of the study

Visual stimuli have often been shown to suppress stimuli simultaneously presented by the other sensory modalities under perceptual or attentional tasks, and for this reason vision is widely considered as the dominant sense (see e.g., Colavita, 1974; Colavita & Weisberg, 1979; Cho, Craig, Hsiao, & Bensmaia, 2015; Hartcher-O'Brien, Gallace, Krings, Koppen, & Spence, 2008; Koppen & Spence, 2007; Posner et al., 1976; Rock & Victor, 1964; Sinnett et al., 2007). However, it is worth noting that the theory of visual dominance has been questioned by proving that sensory dominance depends on the task to be performed and then on the sense more appropriate to the specific case (Ernst & Banks, 2002; Ernst & Bülthoff, 2004; Welch & Warren, 1980). So far, it is still not clear whether the individual state of arousal modulates the occurrence of sensory dominance. Vision has been shown not to dominate over audition when the individual's arousal is increased by a brief electric shock or the threat to receive it (Shapiro, Egerman, & Klein, 1984). But by contrast, another study found that visual dominance occurs when a state of greater arousal is induced by pairing either visual or, surprisingly, auditory stimuli with unpleasant electrocutaneous stimuli (Van Damme, Crombez, and Spence, 2009). It is important to note here that in these studies a greater state of arousal induced by fear-conditioning stimuli is just assumed, since no physiological reactions were measured. All of the studies on this topic compared vision with audition (as in the original version of Colavita effect; Colavita, 1974, 1979; Koppen & Spence, 2007; Sinnett et al., 2007; Spence, 2009), but not vision with touch. As regards the sensory dominance occurring when both vision and touch are involved, research has shown that tactile stimuli are often extinguished when paired with visual stimuli (Hartcher-O’Brien et al., 2008; Hartcher-O'Brien, Levitan, & Spence, 2010; Hecht & Reiner, 2009). Nevertheless, speaking of arousal, touch might have a greater alerting capability than vision since reactions to tactile stimuli need to be quicker than reactions to visual stimuli, given that once a stimulus is on our body surface there is little time to make computations and predictions on its nature and its threatening value (see Gregory, 1967). One might then wonder if this apparent incongruence between the potential alerting role of touch and the results of the studies on sensory dominance is related to the nature of the stimuli presented. Note, in fact, that the majority of the experiments performed on this topic so far have made use of emotionally neutral stimuli. However, the alerting capability of touch, and its arousing power, might be higher than those of vision when stimuli with an emotional, hedonic or social value are presented (Gallace & Spence, 2010; Hertenstein et al., 2006; see Lenschow & Brecht, 2015, for a recent cell-recording study showing that responses to social touch differ from conventional tactile responses in rats), given the saliency of these kinds of stimuli. Furthermore, the valence of the stimuli presented (a variable that is known to affect arousal responses; MacDowell & Mandler, 1989; Ramachandran & Brang, 2008) might also change the relative dominance of one sense over another. For instance, it might be speculated that unpleasant tactile stimuli might extinguish visual neutral stimuli, under certain conditions of stimulus presentation.

Touch is often considered as one of the most arousing senses (Field, 2001, 2014; Gallace & Spence, 2014), but its role in driving emotional/pleasant behaviors and evaluations is probably still underestimated (for a review see Gallace & Spence, 2010; Hertenstein et al., 2006). Interpersonal touch is fundamental for psychophysical well-being and for social bonding (Gallace & Spence, 2010; Hertenstein et al., 2006; Walker & McGlone, 2013), both in humans and primates (Dunbar, 2010). Recent evidence demonstrated that pleasant touch is mediated, at least in part, by a class of thin and slow-conducting afferents, called C-tactile fibers (CTs; Löken et al., 2009; see McGlone et al., 2014), which have been found only in the hairy skin (e.g., Liu et al., 2007; Vallbo et al., 1999). CT afferents discharge preferentially to light (Vallbo et al., 1999) and slow (Löken et al., 2009) stimulation at a neutral temperature (Ackerley et al., 2014a). Importantly, during such stimulation the discharge frequency of CTs is significantly correlated with participants' hedonic ratings (e.g., Ackerley et al., 2014a; Löken et al., 2009).

The specific material used to stimulate the skin also plays an important role in modulating hedonic ratings. That is, the smoother the texture is, the more pleasant it is perceived by participants (e.g., Ackerley, Saar, McGlone, & Wasling, 2014c; Essick et al., 2010; Etzi et al., 2014; Guest et al., 2009; Rolls et al., 2003; Verrillo, Bolanovski, & McGlone, 1999) and, the rougher a texture is rated, the greater is the self-reported arousal associated with it (Guest et al., 2011). Despite of these findings, it is still unknown whether and how different materials also differ in terms of the physiological responses generated by their presentation. Moreover, it remains unclear whether physiological responses differ for visual and tactile presentations of materials. In this study, these issues have been assessed by recording the electrodermal activity, which is acknowledged as an indicator in the domains of emotion and arousal (Boucsein, 2012). A very few studies have assessed the effect of hedonic touch on human skin conductance responses (SCRs), and the great majority of them made use of some forms of skin-to-skin contact (e.g., Chatel-Goldman et al., 2014). To the best of our knowledge, no study has ever measured SCRs to different materials presented visually or haptically.

Here, the participants were presented, either haptically or visually, with different textures varying in terms of their perceived level of pleasantness (see Etzi et al., 2014, for a study with similar stimuli). This study aimed at investigating whether visual and tactile stimulations affect differently the individual psychophysiological response, and whether this response changes depending on the specific texture presented. Both male and female participants were invited to take part in the study, in order to assess the presence of any differences between the genders in the perceptual or physiological reactions to the different materials (e.g., Kring & Gordon, 1998; Tousignant-Laflamme & Marchand, 2006). The role of a high-order factor in affecting participants' responses, such as the gender of the person performing the tactile stimulation, was also considered (see Gazzola et al., 2012).

3.2. Experiment

3.2.1. Methods

Participants

Forty volunteers (mean age: 23±2 years; 19 female) took part in the experiment. The sample was randomly split in two groups, each one composed of twenty participants. People belonging to Group 1 (10 female, 2 left-handed) received the tactile stimulation (i.e., stroking the skin with the materials). All the participants in this group reported normal tactile sensitivity and the absence of peripheral nerve damage. Participants in Group 2 (9 female, 3 left-handed) were only shown with the stimuli without allowing any tactile contact with them (i.e., visual presentation of the materials). All the participants in this group reported normal or corrected-to-normal vision. The study was performed in accordance with the ethical standards laid down in the Declaration of Helsinki and received ethical approval from the local ethics committee. All the participants gave their informed consent before taking part in the study and received course credits for their participation.

Stimuli

Five common materials (satin, tinfoil, leather, sandpaper and abrasive sponge) varying in terms of their microstructural properties (i.e., texture) were used in the experiment. The materials were glued on rigid cardboard rolls to allow a comfortable stimulation of the participants' skin. Each texture had a size of 10 x 10 cm, but given the curved shape of the rolls, during the tactile stimulation just a smaller portion of the texture (approximately 2 x 10 cm) was in contact with the skin.

Procedure

The participants were seated comfortably in front of the experimenter, resting both the arms on a desk. Two Ag-AgCl electrodes (Model 1081 FG) with constant voltage (0.5 Volt) were attached to the medial phalanges of the index and the ring fingers of the non-dominant hand. SCR was recorded by means of a SC2071 device (BioDerm, UFI, Morro Bay, California). Saline conductor gel was used to improve the signal-to-noise ratio. The gain parameter was set at 10 µSiemens (µS)/Volt, the analog-to-digital (A/D) resolution was 12 bit, allowing to record responses ranging from 0.1 to 100 µS, with a sample rate of 10 Hz. In Group 1, for each trial a 10 cm portion of the participants' dominant dorsal forearm was stimulated with one of the textures. Each stimulation consisted in one gentle stroke along the elbow-wrist direction. By means of a metronome, the experimenters stimulated the participants' skin at the velocity of 5 cm/sec for two seconds. Two experimenters, a female and a male, delivered the stimulation. The participant was stimulated either by the female or by the male experimenter. The experimenters were trained to deliver the stimulation at a constant force for all the participants, although this parameter was not measured (see Triscoli et al., 2013, for a study showing that the perceived pleasantness of a stimulation delivered by a human or a computer controlled robotic arm is comparable). The participants were blindfolded and wore earplugs, in order to avoid the effect of any visual or auditory cues resulting from the stroking of the skin on their responses. After six seconds from the end of each stimulation, the experimenter informed the participants in Group 1 that they could lift up the blindfold and evaluate the pleasantness of the stimulation on a 10 cm visual analogue scale (VAS) anchored by the labels “unpleasant” and “pleasant”. Participants belonging to Group 2 wore earplugs, but not the blindfold. They were required to keep their gaze straight in front of them and to look at the texture when prompted by the experimenter. The stimuli were always presented from the participant’s dominant side of the body. After two seconds (the same duration of the tactile stimulation of Group 1), the experimenter hid the texture from the participant’s view. Six seconds after the texture was hidden, the participant was required to evaluate the imagined tactile pleasantness of the material on a 10 cm VAS anchored to the labels “unpleasant” and “pleasant”. For both groups, each texture was presented 3 times throughout the whole experimental session, for a total of 15 trials. Moreover, the presentation order of the textures was pseudo-randomized in a way that prevented the same texture to be presented two times in a row.

Data analysis

The SC data were analyzed by using LEDALAB (version V3.4.7), a software implemented in MATLAB (version R2012a), by using a continuous decomposition analysis approach (Benedek & Kaernbach, 2010). The sum of SCR-amplitudes of significant SCRs within response window was considered as measure for the analysis. The response window was set from 2 sec to 6 sec after the onset of the stimulation. As recommended by Venables and Christie (1980), the SC data were logarithmically transformed with the following formula: $y = \log(1+x)$ before the statistical analysis.

3.2.2. Results

Skin conductance responses

Effects of sensory modality, participants' gender and texture

A mixed repeated measure analysis of variance (ANOVA) with the between-subject factors "sensory modality" (vision vs. touch) and "participant gender" (male vs. female), and the within-subject factor "texture" (satin vs. tinfoil vs. leather vs. sandpaper vs. abrasive sponge) was performed on the skin conductance responses. The results revealed a significant main effect of "sensory modality" [F(1, 36)=10.57, p=.002], with skin conductance responses being higher for the tactile than for the visual presentation of the stimuli, and a significant interaction between "sensory modality" and "participant gender" [F(1, 36)=5.94, p=.01]. A Newman-Keuls post-hoc test on this interaction revealed that the difference between touch and vision was present in women (p=.001), but not in men (p=.56). Moreover, this analysis revealed that women had higher skin conductance responses compared to men (p=.01) during tactile stimulation but not during the visual stimulation (p=.41; see Fig. 10). The main effects of "participant gender" [F(1, 36)=1.61, p=.21] and "texture" [F(4, 144)=0.48, p=.74]; as well as the interactions between "texture" and "sensory modality" [F(4, 144)=1.11, p=.35]; "texture" and "participant gender" [F(4, 144)=0.62, p=.64]; "texture", "participant gender" and "sensory modality" [F(4, 144)=1.05, p=.37] were not significant.

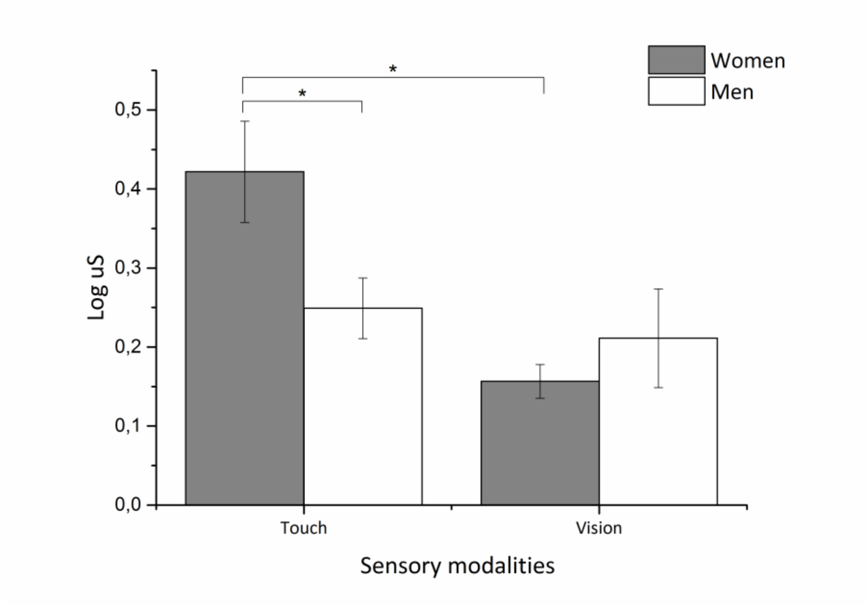

Figure 10. Mean SCRs (log uS) to the tactile and visual presentation of the materials. Error bars represent the standard error of the means and asterisks indicate significant differences (p<.05).

Effect of experimenter's gender

In order to analyze the effect of the experimenter's gender on the SCR of Group 1, a mixed repeated measure ANOVA with the within-subject factor of "texture" and the between-subject factors of "experimenter gender" and "participant gender" was conducted. The main effect of "participant gender" was significant [F(1, 16)=6.82, p=.01]. Female participants showed greater skin conductance responses compared to male participants. Neither the main effects of "experimenter gender" [F(1, 16)=0.31, p=.58] and "texture" [F(4, 64)=0.71, p=.58], nor the interactions between "experimenter gender" and "subject gender" [F(1, 16)=0.48, p=.49], "texture" and "experimenter gender" [F(4, 64)=0.89, p=.47], "texture" and "subject gender" [F(4, 64)=0.81, p=.51], "texture", "experimenter gender" and "subject gender" [F(4, 64)=0.47, p=.75] were significant.

Ratings

Effects of sensory modality, participants' gender and texture

A mixed repeated measure ANOVA with the between-subject factors "sensory modality" and "participant gender", and the within-subject factor "texture" was performed on the participants' ratings on the pleasantness scale. The results revealed a significant main effect of "sensory modality" [F(1, 36)=34.37, p<.001], with stimuli haptically presented receiving higher ratings (more pleasantness) than stimuli presented visually (see Fig. 11). A significant main effect of texture was also found [F(4, 144)=28.94, p<.001]. A Newman-Keuls post-hoc test on this effect revealed that satin (p<.001), tinfoil (p<.001), leather (p<.001) and abrasive sponge (p=.04) were rated as more pleasant than sandpaper. Moreover, satin, tinfoil and leather were rated as more pleasant than abrasive sponge (all p<.001). The main effect of "participant gender" [F(1, 36)=0.01, p=.89]; the interactions between "participant gender" and "sensory modality" [F(1, 36)=0.00, p=.99]; "texture" and "sensory modality" [F(4, 144)=1.69, p=.15]; "participant gender" and "texture" [F(4, 144)=0.64, p=.62]; "participant gender" ,"texture" and "sensory modality" [F(4, 144)=0.73, p=.56] were not significant.

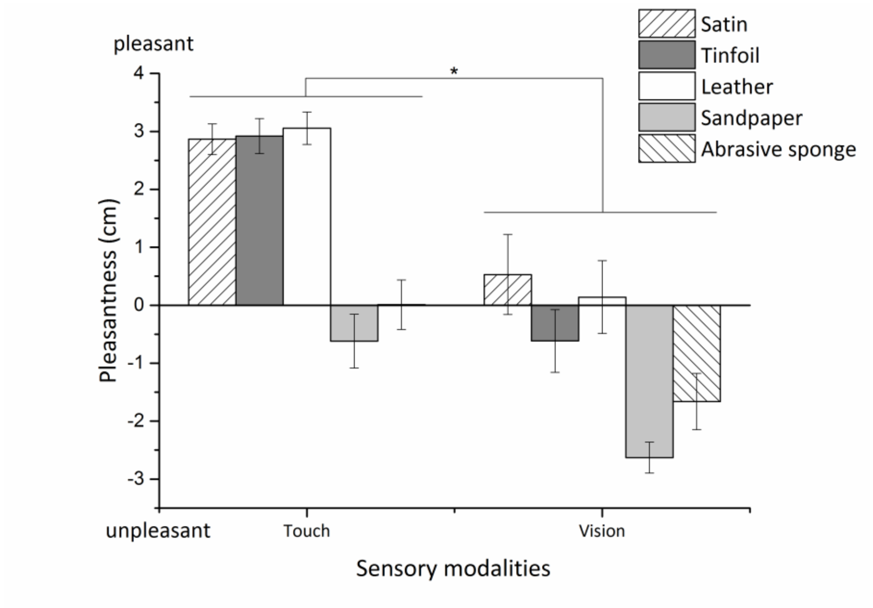

Figure 11. Participants' mean ratings of the materials on the "pleasantness" scale. Note that in the tactile condition the participants evaluated the pleasantness of the tactile stimulation, while in the visual condition they evaluated the imagined tactile pleasantness of the material. Error bars represent the standard error of the means and asterisks indicate significant differences (p<.05) .

Effect of experimenter's gender

In order to analyze the effect of the experimenter's gender on the pleasantness scale of tactile stimulation, a mixed repeated measure ANOVA with the within-subject factor of "texture" and the between-subject factors of "experimenter gender" and "participant gender" was conducted. The main effect of "texture" was significant [F(4, 64)=38.87, p<.001]. A Newman-Keuls post-hoc test revealed that satin, tinfoil and leather were perceived as significantly more pleasant than sandpaper and abrasive sponge (all p<.001). The effects of "experimenter gender" [F(1, 16)=0.67, p=.42]; "participant gender" [F(1, 16)=0.01, p=.90]; the interactions between "experimenter gender" and "participant gender" [F(1, 16)=0.02, p=.88]; "experimenter gender" and "texture" [F(4, 64)=2.33, p=.06]; "participant gender" and "texture" [F(4, 64)=1.90, p=.12]; "experimenter gender", "participant gender", and "texture" [F(4, 64)=0.31, p=.86] were not significant.

Correlational analysis

In order to assess whether there was a relationship between the pleasantness ratings for each texture and the corresponding skin conductance responses to the stimulation, a two-tailed Pearson correlational analysis was performed. The result did not reveal any significant effect: [r=-0.01, p=.85].

3.3. Discussion

The present study assessed the effect of the visual and tactile presentation of everyday materials on skin conductance response and on the pleasantness felt by the participants. The results showed that being stroked with textures led to higher SCRs than looking at them while imagining to be touched by such surfaces. Although vision has been shown to dominate over touch in several cases (e.g., Hartcher-O'Brien et al., 2008, 2010; Hecht & Reiner, 2009) the results reported here reveal that touch is physiologically more arousing than vision, at least when different materials are used to stroke the participants' skin. Following on from this finding, one might conclude that sensory dominance cannot be explained by the greater arousing power of a given sensory modality over another. However, it is important to note that in the present study perceptual dominance was not assessed, and that visual and tactile stimuli were not simultaneously presented, as it occurs in the majority of studies on sensory dominance. Furthermore, we made use of more complex stimuli as compared to those that are generally used in order to study sensory dominance (e.g., flashes, beeps, vibrations; Koppen & Spence, 2007; Hartcher-O'Brien et al., 2008).

The speed of stimulation in this study was set to elicit a vigorous response of CT fibers. Thus, it might be hypothesized that the higher physiological arousal found for the tactile presentation of the stimuli, as compared to the visual presentation, was specifically determined by the discharge fire of these fibers. CT afferents are considered as a peripheral mechanism to signal pleasant skin-to-skin contact, aimed at promoting interpersonal touch and affiliative behavior (McGlone et al., 2014; Olausson et al., 2002). As a consequence, the central and autonomic nervous systems might be more engaged by stimulations that elicit the activation of this ecologically relevant neural pathway.

Another interesting result of the present study refers to the fact that women showed higher SCRs than men in response to the tactile, but not to the visual, stimulation. Gender-related differences have been reported in previous studies where the electrodermal responses to diverse kinds of stimuli were measured (Boucsein, 2012). This result might be explained by the fact that, from an evolutionary point of view, social/hedonic touch might play a more relevant role in women than in men. That is, a greater responsiveness to tactile contact during the early mother-baby interactions, it is likely to play a fundamental role in a healthy cognitive and physical development of the baby (Field, 2001; Gallace & Spence, 2010), as well as in strengthening the mother-baby bond (e.g., Feldman, Weller, Sirota, & Eidelman, 2003; Kennell & McGrath, 2007). The fact that gender differences emerged in the SCRs but not in the subjective evaluations might reflect a difference between respectively unconscious and conscious responses to hedonic touch. Women might thus be more aroused than men only at an unconscious level and only for short periods of time (e.g., few seconds).

Importantly, the results of this study showed that the participants' psychophysiological reactions to the tactile stimuli are not modulated by the gender of the person delivering the stimulation. This result is not consistent with the results reported by Gazzola et al. (2012) in their experiment, where they found that tactile contact was perceived by men as less pleasant and generated higher SCRs when performed by a person of the same gender than a person of the opposite gender. However, it is worth noting here, that there are fundamental differences between the study of Gazzola et al. and this study regarding the body area stimulated, the experimenters’ behavior and appearance, and the imaginary scenario proposed to the participants. By summarizing, this would seem to highlight the important role of the context (and of its meaning) in which the pleasant stimulation is delivered in modulating the physiological and behavioral reactions to the stimuli presented.

As far as the materials presented are concerned, it has been found that satin evoked the highest SCR while tinfoil the lowest SCR as compared to the other textures. However, no significant differences were reported among all the stimuli. Significant differences were instead found on the scales used to measure the perceived pleasantness of the different materials. Smooth textures were preferred over the rough ones, just as previously reported (e.g., Essick et al., 2010; Etzi et al., 2014). These results might suggest that the physiological arousal elicited by the presentation of common materials on the skin (or at least by those used in the present experiment), do not change as a function of the perceived pleasantness of the stimuli (but see Chapter 4 for differences during longer stimulations). Previous research has showed an increased arousal in response to unpleasant stimuli presented on the skin (MacDowell & Mandler, 1989; Ramachandran & Brang, 2008). Note, however, that the unpleasant stimuli used in the present experiment were probably not sufficiently unpleasant (and certainly not painful) to elicit a greater physiological reaction just after 2 seconds, as compared to the other stimuli adopted. Thus, it might be possible that in order to generate significant changes in the participants’ level of physiological arousal, more salient tactile stimuli need to be presented and for longer periods of time.

The tactile presentation of the textures led to higher hedonic ratings by the participants as compared to their visual presentation. This result suggests that people underestimate the pleasantness of textures (and conversely overestimate their unpleasantness) when they can only look at them or when they can only imagine their hedonic value. That is, visually presented smooth materials are perceived as less pleasant than when haptically, and rough materials as more unpleasant than when haptically presented. This result clearly supports the important role of cognitive expectations on the participants' evaluation of common materials (McCabe et al., 2008; see also Balaji, Raghavan, & Jha, 2011; Ludden, Schifferstein, & Hekkert, 2009, for the role of vision in tactile expectations). However, as mentioned above, it might also be possible that the materials used in this experiment were not the most appropriate for conveying higher levels of expected tactile pleasure. Future experiments on this topic should certainly make use of materials that are specifically designed and engineered to convey a given expectation when seen.

To the best of our knowledge, this is the first study that has investigated the physiological reactions to the visual and tactile presentation of materials varying in terms of their hedonic qualities. The results reported here may contribute to shed light on the potential differences between explicit and implicit responses to hedonic touch. In particular, these findings suggest that when everyday materials are used, implicit physiological responses do not correlate with explicit ratings. Moreover, these results are useful to understand how hedonic stimuli are perceived when presented from different sensory modalities. In fact, much more is known on the physiological correlates of visual hedonic/aesthetic perception (e.g., Tröndle, Greenwood, Kirchberg, & Tschacher, 2012; Tschacher et al., 2012) than on those of tactile perception. In the future, it would be of interest to investigate whether and how different materials affect other physiological measures (e.g., heart rate, blood pressure, respiration and pupil dilation).

The present findings also provide insights to the applied fields of marketing, product design and art fruition. For instance, one might infer that shoppers or museum visitors might be more aroused when tactile contact with an object/product is allowed than when it is not. Touching a product or a sculpture might convey more pleasant feelings and a greater state of physiological arousal than just watching it (see Gallace & Spence, 2008; Spence & Gallace, 2008, for the importance of touch in museums). Designers, engineers and cognitive neuroscientists will certainly need to work more together on these aspects in order to create more appealing materials, products and packaging in the years to come.

Chapter 4

STUDY 3: VISUAL EMOTIONAL MODULATION OF CT-MEDIATED PERCEPTION

4.1. Background and aim of the study

Affective touch plays a pivotal role in mammals’ life (Harlow, 1958; Harlow & Zimmerman, 1959; for reviews see Dunbar, 2010; Hertenstein et al., 2006). In humans, in particular, it has been shown to be crucial for a healthy early cognitive development (Field, 2010) and tactile deprivation has been claimed to lead to a phenomenon known as ‘touch hunger’ (Field, 2003). Interpersonal tactile contact promotes the psychophysical well-being (Field, 2010; Gallace & Spence, 2010; Hertenstein et al., 2006) and, by inducing an increase of oxytocin release (e.g., Light, Grewen, & Amico, 2005; Morhenn, Beavin, & Zak, 2012), it facilitates social bonding (Feldman, 2012; Van Ijzendoorn & Bakermans-Kranenburg, 2012).

As described in the Introduction of this dissertation, it has been hypothesized that pleasant tactile sensations coming from large part of the body are mediated by C-Tactile afferents (CTs; Löken et al., 2009; Morrison et al., 2010), which preferentially respond to caress-like stimulations (Löken et al., 2009; Vallbo et al., 1999). The pleasant stimulation of the hairy skin activates areas involved in the emotional and reward processing (Craig, 2002; Kringelbach, 2010; Olausson et al., 2002, 2008a). Moreover, there is evidence that the perception of the CT-targeted stimulation can be modulated by both sensory and cognitive factors (Croy et al., 2014; Ellingsen et al., 2014, 2015; Gazzola et al., 2012; McCabe et al., 2008).

The present study aims at assessing the specific role of emotional stimuli visually presented in modulating the perception of the hedonic and emotional aspects of touch. Previous research has already shown that tactile perception is affected by certain emotional states (Kelley & Schmeichel, 2014; Shi, Jia, & Müller, 2012). Interestingly, emotional visual stimuli have been shown to modulate pain tolerance (De Wied & Verbaten, 2001; Meagher, Arnau, & Rhudy, 2001) and autonomic reaction to painful stimuli (e.g., Rhudy, Bartley, & Williams, 2010; Rhudy, McCabe, & Williams, 2007). In particular, physical pain is perceived as less intense and SCRs are lower when positive emotional stimuli are concurrently shown; by contrast it is perceived as more intense and induces higher SCRs when negative emotional pictures are shown. One might thus wonder whether also hedonic touch is affected by emotional related contents, especially if visually presented. Since vision has been shown to dominate over touch in several tasks (Hartcher-O'Brien et al., 2008, 2010; Hecht & Reiner, 2009), it is even more likely that the visual presentation of emotional contents modulates the perception of pleasant touch. Moreover, it would be interesting to assess whether, despite visual frequent dominance, hedonic touch can modulate evaluations of the visual stimuli. In order to do so, three experiments were conducted. Emotional pictures coming from the widely used International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008) were presented simultaneously to passive tactile stimulation delivered by means of a range of different textures. In Experiment 1, pictures with positive and negative valence were presented simultaneously with a tactile stimulation. Participants were asked to rate the pleasantness of the tactile stimulation. In Experiment 2, participants were presented with pictures with positive and negative valence and the same tactile stimulations used in Experiment 1, but here they were asked to rate the pleasantness of the pictures. In Experiment 3, positive, neutral and negative pictures were presented simultaneously to the tactile stimulation. A unisensory tactile condition was also introduced. Here, participants evaluated the pleasantness of the tactile stimulation, and some attributes of the materials such as their roughness and softness. In order to assess the physiological effects of the visuo-tactile emotional/hedonic stimulation, skin conductance responses (SCRs) were also measured. Considering the frequent dominance of vision and the saliency of emotional pictures, visual modulation of the hedonic tactile evaluation is expected. Following on from this reasoning, the presentation of positive and negative pictures, but crucially not the presentation of neutral pictures, should affect the pleasantness ratings. The expectations about the visual modulation of roughness and softness evaluations are more uncertain since the emotional contents of the pictures should be irrelevant for the evaluations of the more sensory properties of the textures. Still, vision might affect tactile perception regardless of the relevance or irrelevance of the contents. With regard to the evaluation of the pictures, no tactile modulation is expected, considering the frequently reported phenomenon of visual dominance over touch and the salience of the pictures.

4.2. Experiment 1

4.2.1. Methods

Participants

Fourteen volunteers (9 female), with a mean age of 25±2 years, took part in this experiment. All the participants reported to be right-handed, to have normal tactile sensitivity and normal or corrected-to-normal vision. The study was performed in accordance with the ethical standards laid down in the Declaration of Helsinki and received the approval of the local ethical committee. All the participants gave their informed consent before taking part in the study. The volunteers received course credits as reward for their participation.

Stimuli

Participants were presented with visual and tactile stimuli. The visual stimuli consisted in 64 pictures, 32 pictures depicting contents classified as positive (e.g., families, babies, puppies) and 32 depicting contents classified as negative (e.g., mutilated bodies, attacks, war scenes), selected from the IAPS (Lang et al., 2008). Pictures evoking similar arousal responses (although it has been shown that pictures depicting unpleasant events induce higher arousal states as compared to pictures depicting pleasant events; Lang et al., 2008) were selected. Four textures were presented as tactile stimuli: satin, tinfoil, sandpaper and abrasive sponge. These textures were selected on the basis of the results of a previous study assessing pleasantness and roughness ratings of a range of different materials (Etzi et al., 2014). Each texture sample had a dimension of 10 x 10 cm and was applied on a cardboard roll in order to allow for a comfortable stimulation of the skin. Given the curved shape of the rolls, during the stimulation a smaller portion of the texture (approximately 4 x 10 cm) was in contact with the skin.

Procedure

The participants comfortably seated at a table and in front of them a LCD screen (screen size: 30 cm in height and 47.5 cm in width, 1280*800 pixels of resolution) was placed at a distance of about 50 cm. For each trial, one visual and one tactile stimulus were simultaneously presented. While the participants' left forearm was stroked by means of a texture, they were requested to watch a picture projected in full screen modality. The tactile stimulation was passively provided by a female experimenter at the velocity of 5 cm/sec, in order to induce a high firing rate of CT fibers. The proper velocity of stimulation was set by replicating the movement of a cursor appearing on another screen visible only to the experimenter. A portion of 10 cm of the participants' ventral forearm was stimulated. The stimulation consisted in three consecutive strokes (along the elbow-wrist direction), so that each visuo-tactile stimulation period lasted for 6 seconds. Participants were prevented to see their left forearm and the stimulation occurring by means of a black curtain. At the end of each stimulation, they were asked to rate the pleasantness of the tactile stimulation by ignoring the pictures. The ratings were expressed by means of a visual analog scale (VAS) anchored to the words "unpleasant" and "pleasant". Each scale had a length of 10 cm and was subsequently converted by the experimenter in measures from -5 cm (unpleasant) to +5 cm (pleasant). Along the experimental session, the participants wore earplugs to prevent the effect of any auditory information resulting from the contact and friction of the tactile stimuli with the skin. Each texture was presented 8 times for each valence, for a total of 64 trials. The presentation order of valence and texture was pseudo-randomized.

4.2.2. Results

The ratings were submitted to a repeated measure analysis of variance (ANOVA) with 2 factors: "vision" (positive vs. negative) and "touch" (satin vs. tinfoil vs. sandpaper vs. abrasive sponge). This analysis revealed a main effect of "vision" [F(1, 13)=17.89, p<.001] and of "touch" [F(3, 39)=24.72, p<.001]. When presented in combination with positive pictures, the textures were rated as more pleasant than when presented with negative pictures (see Fig. 12). Furthermore, the materials were rated as different in terms of pleasantness. Newman-Keuls' corrected post-hoc tests revealed that the stimulation performed by means of satin and tinfoil was significantly more pleasant as compared to the simulation performed with sandpaper and abrasive sponge (all p<.001). No differences between satin and tinfoil (p=.64) or between sandpaper and abrasive sponge (p=.77) were found. The interaction between "vision" and "touch" was not significant (p=.41).

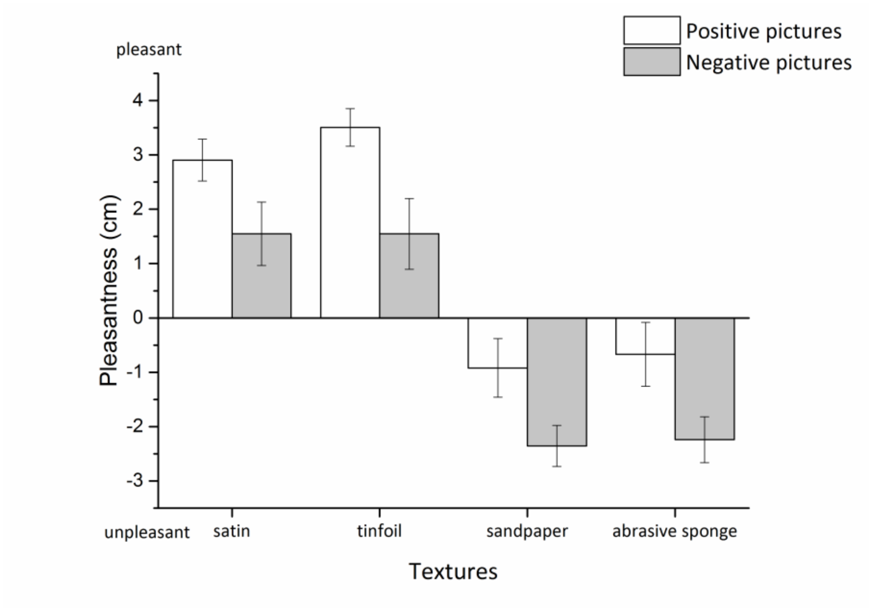

Figure 12. Participants' mean ratings of the textures on the "pleasantness" scale. Error bars represent the standard errors of the mean.

4.2.3. Discussion

The results of Experiment 1 clearly suggested that the presentation of emotional pictures affected the hedonic evaluation of the tactile stimulation. Specifically, the tactile pleasantness felt was higher when textures were combined with positive pictures as compared to negative pictures, and lower when combined with negative pictures as compared to positive pictures. The visual modulation occurred despite the participants were explicitly instructed to rate only the tactile stimulation and to ignore the pictures. Hence, as previously reported (Hartcher-O' Brien et al., 2008, 2010; Hecht & Reiner, 2009), vision modulated tactile evaluations. Here, the modulatory effect might be enhanced or facilitated by the very salient contents of the visual stimuli presented. Furthermore, the presentation of affective pictures has also already been shown to modulate tactile perception (Shi, Jia, & Müller, 2012), the feeling of pain experienced (e.g., De Wied & Verbaten, 2001; Kenntner-Mabiala & Pauli, 2005; Meagher et al., 2001; Rhudy et al., 2007, 2010) and the autonomic response to pain

(Rhudy et al., 2007, 2010). With regard to tactile preferences, smooth textures (satin and tinfoil) were preferred over rough textures (sandpaper and abrasive sponge), as expected on the basis of previous results (e.g., Etzi et al., 2014; Guest et al., 2011).

The present results extend the knowledge about the visual modulatory mechanisms by showing that also hedonic tactile perception is affected by the presentation of visual emotional contents. Importantly, this effect does not depend exclusively on the state of arousal induced by the pictures. Although negative contents have been shown to be more arousing than positive contents (Lang et al., 2008), here the results of Experiment 1 revealed that both the affective valences (i.e., positive and negative) modulated the tactile judgments.

4.3. Experiment 2

4.3.1. Methods

Participants

Twenty participants (15 females), with a mean age of 22±4years, took part in the experiment. All the participants reported to be right-handed, to have a normal tactile sensitivity and a normal or corrected-to-normal vision. People who took part in Experiment 1 were not allowed to participate in Experiment 2. The study was performed in accordance with the ethical standards laid down in the Declaration of Helsinki and received the approval of the local ethical committee. All the participants gave their informed consent before taking part in the study. The volunteers received course credits for their participation.

Stimuli

The same stimuli adopted in Experiment 1 were used in Experiment 2 (satin, tinfoil, sandpaper and abrasive sponge). Also, another tactile stimulus, consisting in the experimenter's finger skin (the glabrous part) was presented. This further texture was introduced in order to present a very salient and more social kind of stimulus. In addition to the 64 pictures presented in Experiment 1, other 16 pictures (8 positive and 8 negative) were used. The presentation order of valence and texture was pseudo-randomized.

Procedure

The procedure of the stimulation was similar to the procedure of Experiment 1, with a few exceptions. Here, the participants were required to rate the pleasantness of the pictures by ignoring the tactile stimulation. Moreover, the experimenter stimulated the dorsal forearm in 10 participants and the ventral forearm in the other 10, in order to assess the presence of any differences in the pleasure felt from the two body sites.

4.3.2. Results

A mixed ANOVA, with one between-subject factor "forearm" (dorsal vs. ventral) and two within-subject factors "vision" (positive vs. negative valence) and "touch" (satin, tinfoil, sandpaper, abrasive sponge and skin), was performed. The analysis revealed a main effect of "vision" [F(1, 18)=431.54, p<.001]. Positive pictures were rated as more pleasant than negative pictures (see Fig. 13). Neither the effect of "forearm" [F(1, 18)=1.90, p=.18], nor the effect of "touch" [F(4, 72)=1.50, p=.20] were significant. The interactions between "touch" and "forearm" [F(4, 72)=0.66, p=.62], "vision" and "forearm" [F(1, 18)=0.82, p=.37], "vision" and "touch" [F(4, 72)=1.75, p=.14], and "vision", "touch" and "forearm" [F(4, 72)=0.78, p=.53] were not significant.

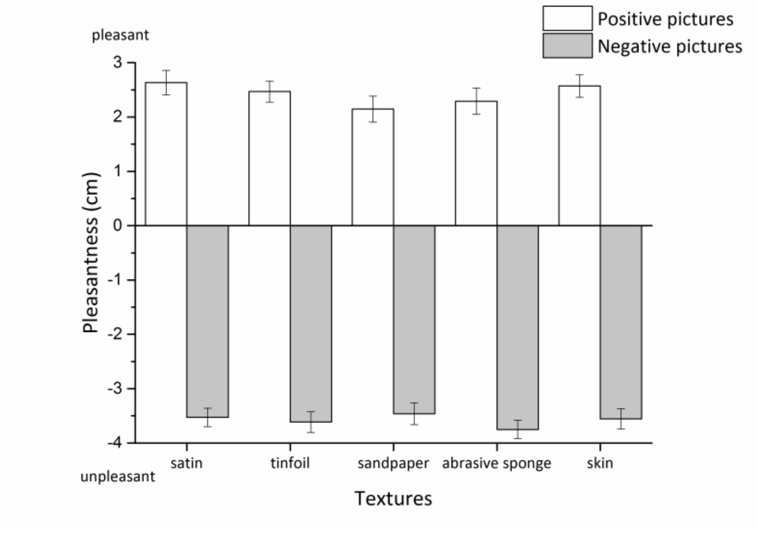

Figure 13. Participants' mean ratings of the pictures on the "pleasantness" scale. Error bars represent the standard errors of the mean.

4.3.3. Discussion

The results of Experiment 2 revealed that the ratings of the visual stimuli were not affected by the simultaneous tactile stimulation. Not surprisingly, the positive pictures were rated as more pleasant than the negative pictures. Importantly, neither the stimulation by means of the textures, nor the contact with the experimenter's skin (although being a kind of social contact and then likely more salient than textures) modulated participants' judgments about the pictures. This result might reflect a visual dominance effect over touch, as previously shown in the perceptual domain (e.g., Colavita, 1974; Posner et al., 1976; Hartcher-O'Brien et al., 2008, 2010; Hecht & Reiner, 2009). This effect might be reinforced by the utilization of very salient stimuli as the emotional pictures. In fact, emotional pictures have been extensively shown to modulate behavioral and physiological responses (Cuthbert, Schupp, Bradley, Birmauber, & Lang, 2000; De Wied & Verbaten, 2001; Meagher, et al., 2001; Rhudy et al., 2007, 2010). Hence, it would be interesting to assess whether the use of very salient tactile stimuli (such as caresses or any form of touch involving social contact) might lead to different results. In the present experiment, one of the tactile stimulation consisted in the experimenter's skin, which might be considered a very salient stimulation. However, since the participants were prevented to see the stroking of their skin and no questions were asked after completing the testing session, it is not possible to know whether the participants were aware that one of the tactile stimuli implied a skin-to-skin contact with the experimenter.

4.4. Experiment 3

4.4.1. Methods

Participants

Twenty right-handed volunteers (15 females; mean age of 22±2 years) took part in the experiment. All the participants reported normal tactile sensitivity and normal or corrected-to-normal vision. People who took part in Experiment 1 and 2 were not allowed to participate in Experiment 3. The study was performed in accordance with the ethical standards laid down in the Declaration of Helsinki and received ethical approval from the local ethical committee. All the participants gave their informed consent before taking part in the study. The volunteers received course credits for their participation.

Stimuli

On the basis of the results of Experiment 1 and 2, three out of four/five textures were selected. Sandpaper was selected as a very unpleasant stimulus, satin as a very pleasant and, in order to assess also the role of the human skin on touch ratings, the experimenter stroked participants with the glabrous skin of her own finger. As visual stimuli, 36 images from IAPS database were used (12 positive, 12 negative and 12 neutral). In order to make this selection, the pictures coming from the IAPS database were split in three groups on the basis of the valence mean rating received by each picture (0-3: negative; 4-6: neutral; 7-10: positive).

Procedure

The procedure adopted here is similar to the procedure of Experiment 1 and 2. A portion of 9 cm of the participants' dorsal forearm of the right limb was stroked through the textures. The velocity of stimulation was set at 3 cm/sec and the experimenter (female) used a metronome to provide the stimulation at the correct velocity. Each stimulation lasted for 9 seconds. During the same amount of time, the participants watched at the pictures presented on the screen. Participants were also presented with trials where only tactile stimulation was provided and a blank screen was presented. Electrodermal activity was measured throughout the experimental session. Two Ag-AgCl electrodes (Model 1081 FG) with constant voltage (0.5 Volt) were attached to the medial phalanges of the index and the middle fingers of the non-dominant hand. SCR was recorded by means of a SC2071 device (BioDerm, UFI, Morro Bay, California). Saline conductor gel was used to improve the signal-to-noise ratio. The gain parameter was set at 10 µSiemens (µS)/Volt, the analog-to-digital (A/D) resolution was 12 bit, allowing to record responses ranging from 0.1 to 100 µS, with a sample rate of 10 Hz. After each trial, participants rated the pleasantness of the tactile stimulation, the roughness and the softness of the materials on VASs anchored by the words "pleasant and "unpleasant", "smooth" and "rough", "soft" and "hard". Each condition was presented for 3 times and in total the session consisted in 48 trials. The presentation order of the conditions was pseudo-randomized. At the end of the experiment participants were asked to name the materials used for the tactile stimulation.

Data analysis

The skin conductance (SC) data were analyzed by using LEDALAB (version V3.4.7), a software implemented in MATLAB (version R2012a), by using a continuous decomposition analysis approach (Benedek & Kaernbach, 2010). The average phasic driver within response window (skin conductance response; SCR) was considered as measure for the analysis. The response window was set from 2 to 9 seconds after the onset of the stimulation. As recommended by Venables and Christie (1980), the SC data were logarithmically transformed with the following formula: $y= \log(1+x)$ before the statistical analysis. Because of technical problems during the recording, the data of three out of twenty participants were not available for the analysis. Statistical analyses were performed through the software STATISTICA, Version 6.0 (StatSoft, Italy). Both the SCRs and each VAS were submitted to mixed repeated measure analyses of variance (ANOVAs) by using the within-subject factors “touch” (sandpaper vs. satin vs. skin) and “vision” (positive vs. neutral vs. negative vs. no picture). When significant effects were found, post-hoc tests (corrected with the Newman-Keuls method) were conducted. For each rating scale a separated ANOVA was performed. Two-tailed Pearson correlations were performed to assess the relationship between SCRs and ratings.

4.4.2. Results

Skin conductance response

A main effect of “touch” was found [$F(2, 32)=14.13$, $p<.001$]. The sandpaper induced higher SCRs than satin and skin (both $p<.001$), but there was no significant difference between satin and skin ($p=.88$; see Fig. 14). The effect of “vision” [$F(3, 48)=0.93$, $p=.43$] and “vision” by “touch” were not significant [$F(6, 96)=0.78$, $p=.58$].

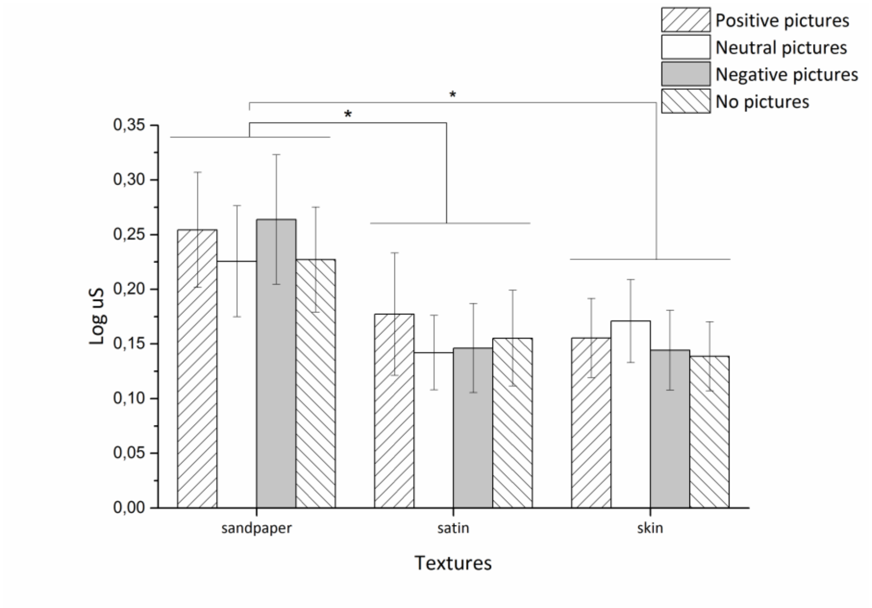

Figure 14. Mean SCRs (log uS) to visuo-tactile presentation of the stimuli. Error bars represent the standard error of the means and asterisks indicate significant differences (p<.05).

Ratings

Pleasantness

The main effects of “touch” [F(2, 38)=20.90, p<.001], and “vision” [F(3, 57)=12.76, p<.001], and the interactive effect between “touch” and “vision” [F(6, 114)=3.33, p=.004] were significant. The satin and the skin were rated as more pleasant than the sandpaper (both p<.001), but there was no difference between them (p=.13). The tactile stimulation was rated as more unpleasant when associated with negative pictures as compared to the other visual conditions (all p<.001; see Fig. 15). The interactive effect revealed that the satin was more pleasant when presented with positive pictures or no photo than neutral (both p=.002) or negative (both p<.001) pictures, but not when no photos were presented (p=.89). Neutral pictures also led to a greater pleasantness of the satin as compared to negative pictures (p<.001). The sandpaper was rated as more unpleasant in combination with negative pictures than positive (p<.001), neutral (p=.001) and no photo (p=.01). Moreover, this texture was evaluated as more pleasant in combination with positive as compared to neutral (p=.01) and no picture (p=.001). However, there was no difference in terms of pleasantness when the sandpaper was presented with the neutral pictures or without any picture (p=.28). As far as regards the use of the skin to stimulate the participants, this condition was rated as less pleasant when presented with negative pictures as compared to positive, neutral and no photo (all p<.001); but there were no differences between positive and neutral (p=.19), positive and no photo (p=.91), and between neutral and no photo (p=.11) conditions.

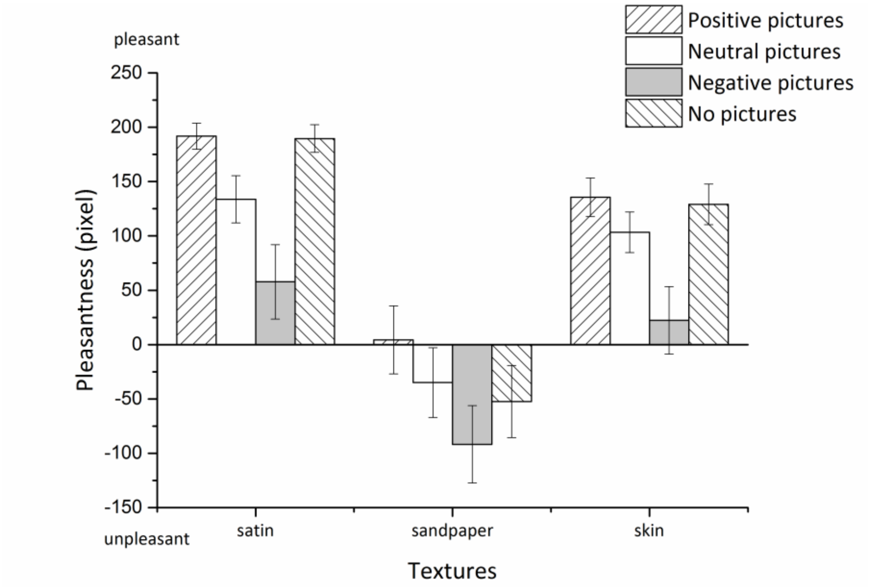

Figure 15. Participants’ mean ratings of the textures on the “pleasantness” scale. Error bars represent the standard errors of the mean.

Roughness

Main effects of “touch” [F(2, 38)=438.53, p<.001] and “vision” [F(3, 57)=6.92, p<.001] were found. The satin was rated as smoother than the skin (p=.006) and the sandpaper (p<.001); the skin as smoother than the sandpaper (p<.001). When participants watched neutral or negative pictures, materials were perceived as rougher than whey they watched positive pictures (p=.02; p=.001 respectively) or when they did not watch any picture (p=.02;

p=.003 respectively; see Fig. 16). There were no differences between negative and neutral pictures (p=.25), and between positive and no picture (p=.64). Although the interaction effect between the two variables showed a trend, it was not significant [F(6, 114)=1.96, p=.07].

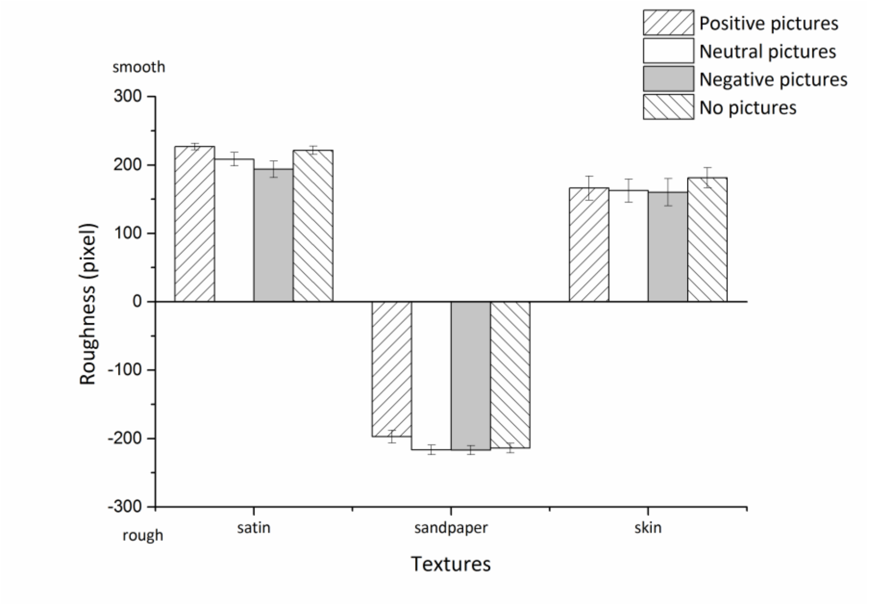

Figure 16. Participants' mean ratings of the textures on the "roughness" scale. Error bars represent the standard errors of the mean.

Softness

Main effects of "touch" [F(2, 38)=97.12, p<.001] and "vision" [F(3, 57)=4.10, p=.01] were found. Sandpaper was rated as harder than satin (p<.001) and skin (p<.001), but there was no difference between satin and skin (p=.63). During the vision of positive pictures the materials were rated as softer than during neutral pictures (p=.005) and a non-significant trend suggested that positive pictures were rated as softer also when negative (p=.08) or no picture were presented (p=.07; see Fig. 17). There were no differences between the other levels of the variable (all p>.05). The interactive effect between "vision and "touch" was not significant F(6, 114)=0.89, p=.49].

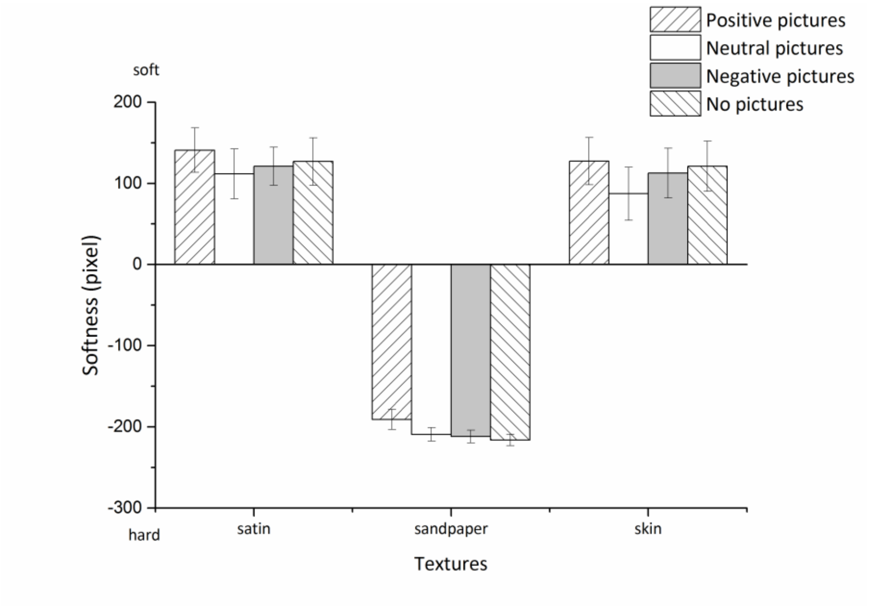

Figure 17. Participants' mean ratings of the textures on the "softness" scale. Error bars represent the standard errors of the mean.

Correlational analysis

The skin conductance response correlated with the roughness ratings (r=-.137, p=.052) with the rougher the material, the higher the scr. No significant correlation was found between SCR and pleasantness ratings (p=.99), and SCR and softness ratings (p=.39). Pleasantness ratings correlated with roughness (r=-.55, p<.001) and softness (r=.54, p<.001). The smoother and the softer the material was rated, the more pleasant it was evaluated. Moreover, roughness correlated with softness ratings (r=-.84, p<.001). The rougher the material was, the harder it was rated.

Recognition task

The skin was recognized by the majority (70%) of the participants. The sandpaper was recognized by 30% of participants, and the satin was named as "textile" by 15% of participants.

4.4.3. Discussion

Watching emotional pictures when being stroked with materials affected the hedonic and sensory evaluation of the tactile stimulation. Negative pictures reduced the pleasantness perceived of all the materials, as compared to both positive and neutral pictures and to the unisensory tactile condition. Positive and neutral pictures modulated the hedonic tactile perception as well, but in a less clear manner. Depending on the specific texture, the valence of the pictures and the unimodal condition affected differently the evaluations. In some cases, positive pictures led to higher pleasantness ratings than neutral (i.e., for satin and sandpaper) and unimodal condition (for sandpaper); and the unimodal condition led to higher pleasantness ratings than neutral pictures (for satin). Hence, there were no fixed rules when comparing positive, neutral and unisensory tactile condition, but they all made textures as more pleasant than negative pictures. As far as sensory attributes are concerned, the materials were rated as smoother when presented with positive pictures and no photo, as compared to negative and neutral visual conditions; and softer with positive pictures than neutral pictures. Although these results do not provide precise insights on how and why emotional valence specifically impacts on the evaluations of each material, they confirm the results of Experiment 1 (for positive and negative pictures) and demonstrate that visual stimuli depicting both emotionally salient and emotionally neutral contents modulate tactile judgments. The mere presentation of the visual stimuli would seem thus to be responsible of the modulations of tactile judgments, rather than their emotional content.

The skin conductance responses were not affected differently by the visuo-tactile or the unisensory tactile conditions. Within the visuo-tactile condition, SCRs were not affected differently either by the emotional valence of the pictures presented, despite the fact that negative pictures tend to induce higher arousal responses as compared to positive pictures (Lang et al., 2008). It might be argued that, although participants watched the pictures, they were instructed to focus on the tactile stimulation occurring on their body. However, this explanation would not account for the modulatory effects found for the ratings. Speaking of the autonomic reaction to the materials used to perform the stimulation, the sandpaper induced higher SCRs as compared to satin and skin. Here, it is interesting to note that a material rated as unpleasant, rough and hard induced a greater arousal response as compared to materials presenting the opposite sensory attributes. This result is in line with earlier evidence showing that unpleasant stimuli are more physiologically arousing than pleasant ones (Eriksson et al., 2008; MacDowell & Mandler 1989; Ramachandran & Brang 2008). Intriguingly, by comparing these results with the results of Study 2 presented in this dissertation (see Chapter 3), it seems that the sandpaper induced higher arousal responses, as compared to more pleasant and smoother materials, just when used to perform stroking movements lasting longer than 2 seconds. Moreover, the results suggested that the rougher a texture was perceived, the higher were the SCRs generated (although the coefficient of the correlation was pretty low: r=-.137).

The materials rated as smoother and as softer than the sandpaper (i.e., satin and skin) were also rated as more pleasant (see Etzi et al., 2014 for a study on tactile preferences for everyday materials). Satin and skin were evaluated as equally pleasant and equally soft (but with satin as smoother than skin) despite they are examples of different categories of stimuli (i.e., fabric, human skin-to-skin contact). It is also particularly important to note that the participants showed to be aware (above the chance level) that the stimulations were provided with the hand or with a material (not identified though). Thus, it can be concluded that being stroked with a piece of fabric or being caressed with the hand did not lead to any major differences in terms of the pleasure felt or the physiological response generated, at least when stimulations were slowly and gently delivered to the hairy skin.

4.5. General Discussion

The present study explored the effects of visuo-tactile interactions on skin conductance response and on subjective evaluations in the affective/hedonic domain. The results showed that the evaluations of the tactile stimulation were modulated by the visual stimuli simultaneously presented. This effect was found despite the contents of the pictures were totally irrelevant and non-informative about the tactile textures. Specifically, in Experiment 1 the tactile stimulation was rated as more pleasant in combination with emotional positive pictures and as less pleasant in combination with emotional negative pictures. These results were replicated and extended in Experiment 3, by showing that also the presentation of emotional neutral pictures modulated tactile evaluations. These findings would seem to suggest that visual stimuli modulate hedonic tactile judgments regardless of the emotional salience or the relevance of the pictures. Considering previous evidence about top-down and sensory modulation over hedonic touch (Croy et al., 2014; Demattè et al., 2006; Ellingsen et al., 2014; Gazzola et al., 2012; McCabe et al., 2008; see also Chapter 5), this effect seems reasonable. In fact, hedonic touch perception results to be particularly malleable and the valence attributed to stroking can be easily flipped by the valence of other information associated with the stimulation. It is also interesting to note that the impact of positive and neutral pictures, and the unisensory tactile condition is not consistent for all the textures. By contrast, negative pictures made the participants perceive textures as more unpleasant for all the materials than in all the other visual conditions. One might then speculate that negative contents are more salient than positive (and certainly more than the neutral), as also shown by Croy et al., (2014) in a study focused on olfactory-tactile interactions. Interestingly, also the evaluations of the sensory attributes of the materials (i.e., roughness and softness) were affected by the pictures presented. The textures were rated as rougher in combination with negative pictures than when presented together with positive pictures or in the unisensory tactile condition; also they were evaluated as softer when presented with positive than with neutral pictures. Since both roughness and softness were also significantly correlated with pleasantness, it is likely that the hedonic value of the stimuli played a role in mediating the occurrence of these interactions. The role of the hedonic value is in fact often taken into consideration in order to account for the existence of at least a part of crossmodal correspondences and interactions found in the extant literature (Crisinel & Spence, 2010; Demattè et al., 2006; Etzi et al., 2016; Velasco et al., 2015). Surprisingly, the arousal response measured through the SC was not affected by the visual stimulation, despite the emotional saliency of the positive and especially negative pictures (which are generally considered more arousing that the former; Lang et al., 2008). Hence, as regard the physiological reactions, visuo-tactile interactions did not induce any difference as compared to when only tactile stimuli were presented.

As far as the effects of visual-tactile interactions on visual judgments are concerned, the results revealed that the evaluation of the pictures was not affected by the properties of the tactile stimulation. In fact, in Experiment 2, the evaluation of the pictures varied only in function of their emotional valence (i.e., positive and negative). This result is not unexpected since the presentation of visual stimuli has been often shown to dominate over tactile perception (e.g., the extended Colavita effect; Hatcher-O' Brien et al., 2008, 2010; Hecht & Reiner, 2009). Vision is in fact frequently prioritized as compared to the other sensory modalities (e.g., Posner et al., 1976; Rock & Harris, 1967; Rock & Victor, 1964). Moreover, it is worth noting here that the tactile stimuli used in the present experiments are likely not enough salient to generate such a modulatory effect.

Although the emotional aspects of touch are now widely recognized (Gallace & Spence, 2010; Hertenstein et al., 2006; Löken et al., 2009; McGlone et al., 2007, 2014; Morrison et al., 2010; Olausson et al., 2002, 2008a), it is still not clear whether slow stimulation by means of materials can effectively induce variations in the emotional individual state. The skin-to-skin contact might be more salient as compared to the stimulation by means of textures, but in Experiment 2 it was not possible to ascertain whether participants were aware of that particularly relevant stimulus since no information about a potential recognition of the textures is available. However, the data collected in Experiment 3 suggested that in most of the cases participants identified the skin of the experimenter as one the tactile stimuli. By using this result to explain those of Experiment 2 it would seem that despite being correctly recognized, social contact (e.g., a caress) was not able to modulate visual judgments.

With regard to tactile preferences, the pleasantness ratings of the textures varied as a function of both the material presented (varying in terms of microgeometric properties) and the valence of the images simultaneously showed. Moreover, the skin stimulation performed by means of the smooth and soft-rated textures (tinfoil, skin and satin) was preferred over the stimulation with the rough and hard-rated textures (sandpaper and abrasive sponge), thus providing additional evidence regarding the role of smoothness and softness dimensions in modulating tactile pleasure (Essick et al., 1999; Etzi et al., 2014; Guest et al., 2011). The analysis of the SCRs revealed that the sandpaper induced a higher arousal response as compared to the satin and the skin. These results extend the knowledge about the autonomic reactions to texture stroking on hairy skin and suggest that the duration of CT-targeted stimulation affects the arousal response. In this study, the strokes were delivered for 9 seconds. By contrast, in a recent study has been shown that the same kind of tactile stimulation (by means of satin and sandpaper), lasting only for 2 seconds, do not induce any variation in the arousal response (Etzi & Gallace, 2016; see Chapter 3).

Taken together, these results contribute to delineate the behavioral and physiological effects of crossmodal interactions, particularly between vision and touch, on the processing of hedonic and affective information. Once more, vision has been shown to have a great power of modulation. Nevertheless, in the future more research is needed to investigate whether visual affective/hedonic judgments can be flipped by using other kinds of high salient tactile stimuli.

Chapter 5

STUDY 4: VISUAL AND AUDITORY MODULATION OF HAPTIC VIRTUAL SURFACE PERCEPTION

5.1. Background and aim of the study

In daily life, the exploration of a surface is not just a matter of tactile sensations. Most of the time, we look at the surface that we are touching and, even if we do not pay much attention to it, sometimes we also hear the sound resulting from the contact of our hand with the material. The information coming from touch, vision and audition are then integrated in order to create a unique and coherent percept (e.g., Meredith & Stein, 1986; Stein, 2012; Stein & Stanford, 2008). However, two or more sensory modalities can also provide discrepant inputs. In this case, one modality can dominate over the other. Even though vision has been considered as the dominant sense for a long time (e.g., Hartcher-O'Brien et al., 2008; Koppen & Spence, 2007; Posner et al., 1976; Rock & Viktor, 1964; Sinnett et al., 2007), it seems that sensory dominance is not absolute but rather context-dependent. The dominant sense is then the sense evaluated as the most appropriate for the specific task to be performed (Ernst & Banks, 2002; Ernst & Bülthoff, 2004; Welch & Warren, 1980). Nevertheless, sometimes the perception of a stimulus is more of a blend of attributes provided by the different modalities and sensory dominance does not occur. For example, haptic surface perception varies when the auditory feedback resulting from the surface exploration is altered (e.g., Guest et al., 2002; Jousmäki & Hari, 1998; Zampini & Spence, 2004). Also, visual and tactile information seems to be combined during surface perception by equally mixing the information provided by the two senses (Jones & O'Neil, 1985; Lederman &Abbott, 1981; but see Guest & Spence, 2003b).

Most research on surface and texture perception has focused on the sensory dimensions defining tactile perception. The rough/smooth continuum has been identified as the primary dimension (Bergmann Tiest & Kappers, 2006; Hollins, Bensmaïa, Karlof, & Young, 2000; Hollins, Faldowski, Rao, & Young, 1993), followed by the hard/soft (Hollins et al., 1993, 2000; Picard, Dacremont, Valentin, & Giboreau, 2003), and the sticky/slippery dimensions (Hollins et al., 2000). Notably, this list does not include hedonic/emotional dimensions (see Guest et al., 2011 for an exception), and also suggests that the aesthetic aspects of touch have been neglected for a long time (Gallace, 2011; Gallace & Spence, 2011, 2014). However, everyday, we make judgments about the pleasantness of what we touch and we often engage in further contacts with objects, only following a first positive hedonic evaluation. Although we are used to describe in aesthetic terms what we see, but not what we touch (Gallace & Spence, 2011), tactile pleasantness is an important dimension in our evaluations of external stimuli. The studies performed on the topic of tactile aesthetics have also revealed that smooth textures are systematically preferred over rough textures (Essick et al., 2010; Etzi et al., 2014) and that tactile pleasantness depends on the body site that comes into contact with a surface. For example, textures are perceived as more pleasant when stroked on the hairy skin of the forearm than on the glabrous skin of the palm (Etzi et al., 2014; Guest et al., 2011). Intriguingly, this effect might be due to the activity of a class of slow-conducting unmyelinated fibers present only in hairy skin, the C-Tactile afferents (CTs), which seem to contribute to the perception of pleasant touch (Löken et al., 2009; Vallbo et al., 1999; Olausson et al., 2010).

The topic of haptic and multisensory surface perception has been extensively explored by the extant literature (e.g., Guest & Spence, 2003a; Heller, 1982; Klatzky & Lederman, 2010; Lederman & Klatzky, 2004). Nevertheless, most of the studies focused on the perception of real surfaces and there is little research dealing with the perception of materials simulated by haptic devices (e.g., Campion, Gosline, & Hayward, 2008; Klatzky & Lederman, 2006;

Kornbrot, Penn, Petrie, Furner, & Hardwick, 2007; Lederman, Klatzky, Tong, & Hamilton, 2006). Notably, it is still unclear whether a virtual surface rendered to resemble a specific and real material is efficient in conveying the same perceptive effects. On this point, it has been shown that although real and correspondent copies of virtual sandpapers are perceived as equally rough, virtual surfaces still tend to be perceived as slightly rougher than the real ones (Jansson et al., 1999). Moreover, a tactile aesthetics of virtual textures has not been established yet (Gallace & Spence, 2014). Here, the present study aims at contributing to fill this gap in knowledge by investigating how haptic virtual surfaces are perceived and evaluated in terms of sensory (roughness) and hedonic (pleasantness) properties.

It is also worth mentioning that the effects of multisensory inputs on haptic virtual perception have received little attention so far. This is quite surprisingly given that multisensory stimulation might be fundamental in enriching the quality of tactile sensations rendered, especially considering the good level of reproduction achieved for visual and auditory sensations in virtual reality environments (Gallace, Ngo, Sulaitis, & Spence, 2011). Thus, even more importantly, this study intends to assess whether simultaneously-presented visual or auditory inputs affect the perception of tactile properties when touching a virtual surface. In particular, the present study aimed at determining whether haptic virtual surfaces rendered by means of a force feedback haptic device are perceived differently depending on their visual appearance (Experiment 1) or on the sound resulting from their tactile exploration (Experiment 2). By considering previous research on multisensory perception of real surfaces (e.g., Guest & Spence, 2003a; Jones & O’Neil, 1985; Lederman &Abbott, 1981; Lederman et al., 1986), visual and auditory modulations of haptic perception are expected. In particular, information about roughness coming from the different sensory modalities is thought to be crucial in affecting the participants’ hedonic and perceptual judgments.

5.2. Experiment 1

5.2.1. Methods

Participants

Twenty-four right-handed volunteers (fourteen female; mean age: 24±4 years) took part in the experiment. All the participants reported normal tactile sensitivity and normal or corrected-to-normal vision. The study was performed in accordance with the ethical standards laid down in the Declaration of Helsinki and received ethical approval from the local ethical committee. All the participants gave their informed consent before taking part in the study.

Stimuli

Four virtual surfaces were rendered by varying the static and dynamic frictional coefficients (see Table 1) of a Geomagic® Touch haptic device. The different frictional coefficients were chosen in order to present surfaces perceived as varying on a continuum of roughness. As visual stimuli, the pictures of the flat side of four materials (glass, rubber, steel and plastic, previously evaluated for pleasantness, roughness and recognition by a separated sample of participants; see Figure 18a) were selected. The experimental setup was implemented through the H3DAPI development platform (http://www.h3dapi.org).

Frictional coefficients	**Virtual surfaces**			
	1	2	3	4
Static	0.1	0.2	0.5	0.9
Dynamic	0.1	0.2	0.4	0.9

Table 1. Static and dynamic frictional coefficients used in Experiment 1.

Procedure

The participants were seated at a desk on which a Geomagic® Touch haptic device and a LCD screen (screen size: 30 cm in height and 47.5 cm in width; 1280*800 pixels of resolution) were placed. Before starting the experiment, participants were instructed about how to use the stylus connected to the haptic device and underwent a phase of familiarization for about 2 minutes. They were also informed that exploring a virtual surface using the haptic device is not the same as directly touching a surface with the hand but is more similar to perceiving a surface by using a rigid tool as mediator (e.g., a stick or a pen). Then, participants were asked to wear a pair of sound-proof headphones in order to prevent that any noise coming from the haptic device could affect their performance. Each virtual surface was presented in five conditions: combined with the four images and without any image. Each condition was presented three times and the order of presentation was pseudo-randomized, then the experiment was composed of 60 trials. Importantly, in visuo-tactile trials, when exploring the surface temporally and spatially congruent movements of the stylus on the visual texture were shown on the screen (see Figure 18b). During tactile trials participants were blindfolded and only haptic virtual surfaces were presented. For each trial participants explored the surface as long as they liked and exploration times were recorded by the experimenter. At the end of each trial they rated the pleasantness and the roughness of the surface explored by using two 10 cm-long visual analog scales (VASs). The VASs were anchored to the words “unpleasant” and “pleasant” for the evaluation of the hedonic dimension, and “rough” and “smooth” for the evaluation of the surface properties.

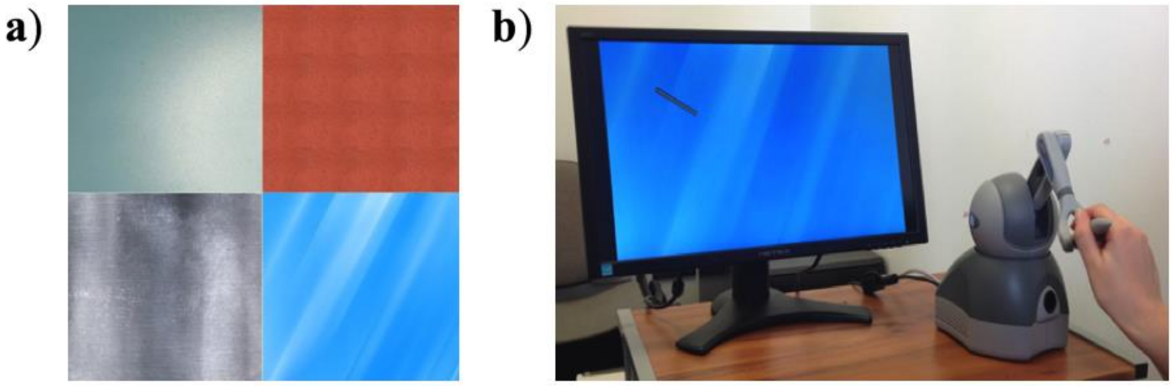

Figure 18. a) Visual stimuli (from left to right and from up to down: plastic, rubber, steel, glass) used in Experiment 1; b) Photo of the experimental setup adopted in Experiment 1.

Data analysis

Each VAS was converted in measures ranging from -5 cm to + 5 cm. Pleasantness, roughness and time of exploration were considered as dependent variables and were submitted to repeated measure analysis of variance (ANOVAs) with the factors “virtual surface” (four levels) and “visual texture” (five levels: four pictures, plus one unisensory tactile condition). When significant effects were found, post-hoc tests (corrected with the Newman-Keuls method) were conducted. Two-tailed Pearson correlations were performed to assess the relationship between pleasantness and roughness, and between pleasantness and exploration time.

5.2.2. Results

Pleasantness

The analysis revealed the presence of significant effects of “virtual surface” [F(3, 69)=20.27, p<.001], “visual texture” [F(4, 92)=3.30, p=.01] and of their interaction [F(12, 276)= 2.67, p=.002]. Both virtual surface #1 and #4 were preferred over surface #2 (both p<.001) and #3 (both p<.001) but there was no significant difference between them (p=.10; see

Fig. 19). Participants significantly preferred virtual surfaces presented with no picture, over the same surface presented in combination with the rubber (p=.03) and the steel pictures (p=.009). A similar trend, although not significant, was found for the surfaces presented together with the glass (p=.06) when compared to the surfaces presented without any image. Virtual surface #1 was rated as more pleasant when no picture was presented as compared to the simultaneous presentation of the rubber picture (p=.03). Also, a trend suggested that surface #2 was rated as more pleasant when presented with the glass than with the steel (p=.07) picture. Virtual surface #3 was perceived as less pleasant when simultaneously presented with the glass picture compared to the presentation of the rubber picture (p=.003) and the no picture condition (p=.01).

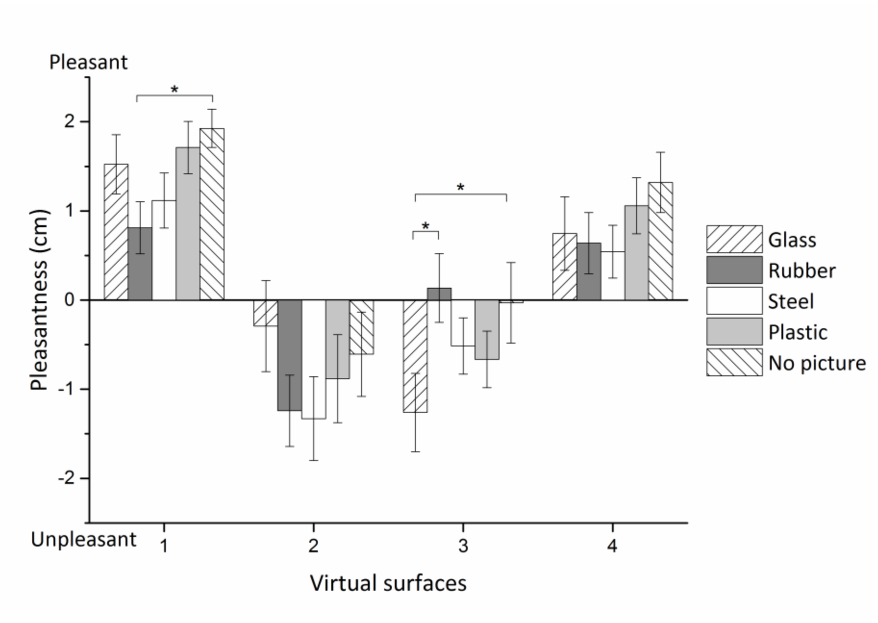

Figure 19. Participants' mean ratings on the "pleasantness" scale of Experiment 1. Error bars represent the standard error of the means and asterisks indicate significant differences (p<.05).

Roughness

The analysis revealed main effects of "virtual surface" [F(3, 69)=25.37, p<.001], "visual texture" [F(4, 92)=5.94, p<.001] and of their interaction [F(12, 276)=2.18, p=.01]. Surface #1 was perceived as smoother than surface #2 (p=.04), #3 (p<.001) and #4 (p=.002).

Surface #3 was perceived as rougher than surface #2 (p<.001) and #4 (p<.001). There was no significant difference between surface #2 and #4 (p=.14; see Fig. 20). Surfaces were rated as smoother when presented with the glass, than with the rubber (p<.001) and the steel (p=.007) images. The haptic surfaces were rated as smoother when presented with the plastic and without any picture than when presented with the rubber (respectively: p=.01; p=.009) and the steel (respectively: p=.07; p=.03). Virtual surface #1 was rated as smoother when presented in combination with the picture of the glass than when presented with the picture of the rubber (p=.002) and the steel (p=.003); a similar trend was found for the surfaces presented with the plastic when compared to the rubber (p=.06) and the steel (p=.058). Another trend suggested that surface #2 was rated as smoother when presented with no picture than when presented with the picture of the steel (p=.07). Virtual surface #3 was rated as rougher when simultaneously presented with the picture of the rubber as compared to when presented together with the picture of the glass (p=.02) and the plastic (p=.054). Virtual surface #4 was rated by the participants as rougher when presented with the picture of the rubber compared to when presented with the pictures of the glass (p=.009), the steel (p=.04), and the plastic (p=.02) or when no picture was presented (p=.008).

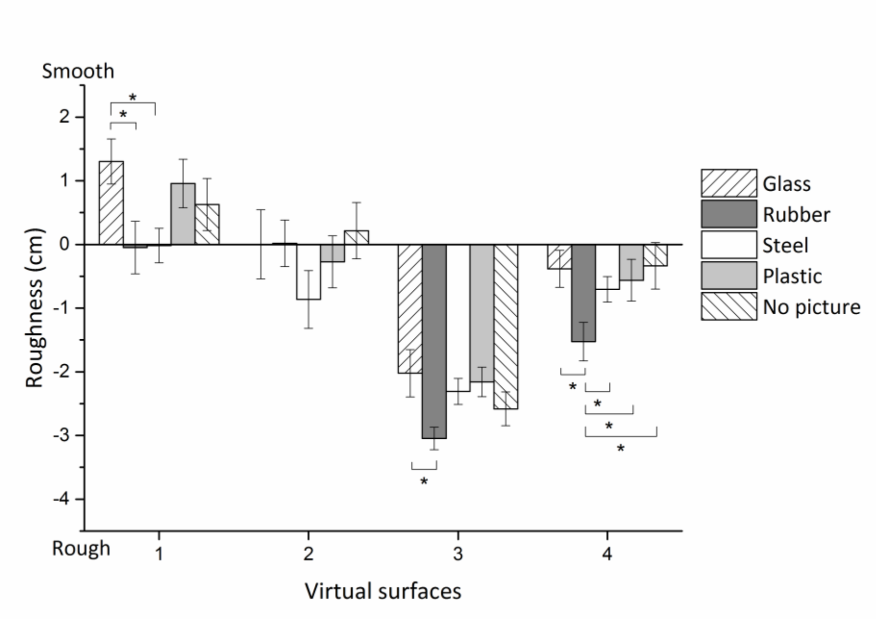

Figure 20. Participants' mean ratings on the "roughness" scale of Experiment 1. Error bars represent the standard error of the means and asterisks indicate significant differences (p<.05).

Exploration time

The analysis revealed significant main effects of "virtual surface" [F(3, 69)=5.64, p=.001] and "visual texture" [F(4, 92)=9.25, p<.001]. Virtual surface #2 required more exploration time compared to virtual surface #1 (p=.02) and #4 (p<.001) and a similar trend was found as compared to surface #3 (p=.06; see Fig. 21). Another trend revealed that surface #3 required more time than #4 (p=.07). When presented with no picture, more time was required as compared to all the visuo-tactile conditions, respectively: glass (p<.001), rubber (p<.001), steel (p=.001) and plastic (p<.001) pictures. A trend suggested that the steel required more time than the glass (p=.07). The interaction between "virtual surface" and "visual textures" was not significant (p=.36)

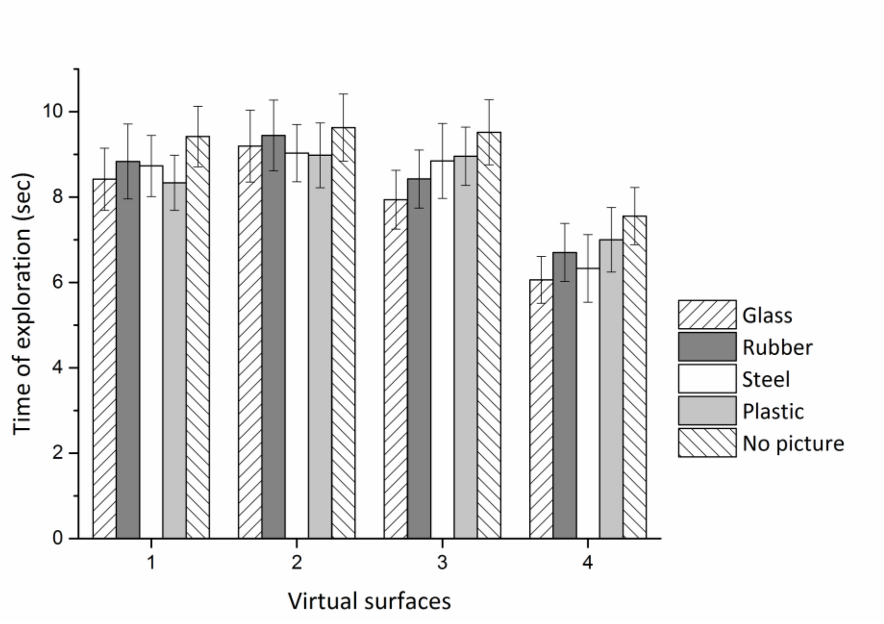

Figure 21. Participants’ mean exploration times of Experiment 1. Error bars represent the standard error of the means and asterisks indicate significant differences (p<.05).

Correlational analysis

The correlation analyses between the pleasantness and roughness judgments [r=.479, p<.001] and between pleasantness and exploration time [r=.091, p=.04] revealed that they were positively correlated. Then, the rougher a surface was perceived, the more unpleasant it was rated by participants (see also Etzi et al., 2014). Also, the more pleasant the surface was perceived, the more the time spent touching it.

5.2.3. Discussion

The results of the present study showed that the participants’ evaluation of the haptic virtual surfaces was affected by the simultaneously presented visual stimuli. In particular, the virtual surfaces were perceived as less pleasant and rougher when presented in combination with the pictures of the rubber and the steel than when presented together with the glass, the plastic and when no picture was presented. Since smooth materials are preferred over rough materials when real surfaces are presented (Essick et al., 2010; Etzi et al., 2014), one might infer that pictures of rough materials made the participants perceive the virtual surfaces as rougher and consequently as less pleasant as compared to pictures of smooth materials. However, the fact that surface #3 (characterized by medium-high frictional coeffients and rated as the roughest) is rated as less pleasant when presented with the glass picture, might also suggest that a perceptive incongruence between what is touched and what is seen might play a role in modulating hedonic judgments. That is, the experience of touching a surface perceived as very rough, but seeing a picture representing a very smooth material, might be experienced as rather 'unrealistic' and thus unpleasant. Surfaces #1 and #4 received the higher ratings for pleasantness, despite being characterized one by the lowest and the other by the highest frictional coefficients. Thus, here the more extreme values of frictional coefficients were preferred over the intermediate ones. Moreover, it is worth noting that although surface #4 was characterized by the highest frictional coefficients, surface #3 was rated as rougher than surface #4. But it is also true that surface #3 was the only one characterized by a small variance between the static and dynamic frictional coefficients and this might explain why it was rated as the roughest one.

Interestingly, the surfaces rated as the most unpleasant (#2 and #3) were explored for significantly more time than surfaces #1 and #4. In fact, although we found a significant positive correlation between pleasantness and exploration time, the coefficient was very low. This might seem a bit counter-intuitive and comes as unexpected given that a person would tend to explore for less time a stimulus that he/she does not like. Studies on visual aesthetics support this view by showing that people watch for longer those artworks which they like the most (Brieber, Nadal, Leder, & Rosenberg, 2014). The results have also shown that more time was needed to explore surfaces when only haptically presented as compared to conditions where visual stimuli were concurrently presented, then suggesting a multisensory facilitation effect over perception (e.g., Stein, 2012).

5.3. Experiment 2

5.3.1. Methods

Participants

Twenty volunteers (eleven female; mean age: 25±3) took part in the experiment. All the participants reported normal tactile sensitivity and normal hearing. The study was performed in accordance with the ethical standards laid down in the Declaration of Helsinki and received ethical approval from the local ethics committee. All the participants gave their informed consent before taking part in the study.

Stimuli

Three virtual haptic surfaces were presented. Each surface was rendered by varying the static and dynamic coefficients of the Geomagic® touch device, in order to simulate the perception of three different virtual surfaces varying in roughness. Differently from Experiment 1, here each virtual surface was characterized by a variance between the static and dynamic frictional coefficients (e.g., 0.5 and 0.4 respectively; see Table 2). As audio stimuli, two audio files were presented. They were created by recording the sound resulting from rubbing a fingertip (at a speed of about 10 cm/s) on a sheet of copy paper and on a piece of high grit sandpaper. Also this experimental setup was implemented through the H3DAPI development platform (http://www.h3dapi.org).

Frictional coefficients	**Virtual surfaces**		
	1	2	3
Static	0.1	0.5	0.9
Dynamic	0	0.4	0.8

Table 2. Static and dynamic frictional coefficients used in Experiment 2.

Procedure

Participants were seated at a desk with a Geomagic® touch device placed on it. They wore a blindfold and a pair of headphones. Before starting, they were instructed about how to use the stylus of the haptic device in order to explore the virtual surfaces. The participants also underwent a 2 minute-session of familiarisation with the device by using a demo specifically created for that aim. In each trial the participants were required to handle and move the stylus to explore the surface as long as they liked. The movements of the stylus (e.g., the start, the stop and the pauses during the exploration) were synchronized with the sound being played. Moreover, the participants were trained to explore the surfaces at a velocity of 10 cm/s in order to perform movements synchronised with those used when recording the sounds. At the end of each trial participants rated the pleasantness and the roughness of the virtual surface by using two 10 cm-long VASs anchored to the words “unpleasant” and “pleasant”, “smooth” and “rough”. Also, the time of exploration of each surface was recorded by the experimenter. Each virtual surface was presented in three conditions: combined with the two sounds and without any sound. Each condition was repeated for three times, then the experiment was composed of 27 trials. Also, the presentation of the trials was pseudo-randomised. At the end of the experiment, the participants were presented with each sound once and were asked to rate the imagined pleasantness of a material producing that sound when rubbed on a VAS anchored to the words “unpleasant” and “pleasant”.

Data analysis

Each VAS was converted in measures ranging from -5 cm to +5 cm. Pleasantness, roughness and time of exploration were considered as dependent variables and submitted to repeated measure analyses of variance (ANOVAs) with the factors “virtual surface” (three levels) and “sound” (three levels: paper, sandpaper, no sound). When significant effects were found, post-hoc tests (Newman-Keuls corrected) were conducted. One two-tailed t-test was performed in order to test for any difference between the two audio files in terms of the imagined pleasantness of the materials. Two-tailed Pearson correlational analyses were performed in order to assess the relationship among pleasantness, roughness and time of exploration.

5.3.2. Results

Pleasantness

The analysis revealed significant main effects of “virtual surface” [F(2, 38)=53.60, p<.001] and “sound” [F(2, 38)=26.00, p<.001], as well as interactive effect between “virtual surface” and “sound” [F(4, 76)=3.32, p=.01]. Surface #1 was preferred over surface #2 (p<.001) and surface #3 (p<.001); surface #2 was preferred over surface #3 (p<.001). Surfaces presented in combination with the sandpaper sound were rated as less pleasant than in combination with the paper sound (p<.001) and the no sound condition (p<.001; see Fig. 22); moreover a trend suggested that the surfaces, when simultaneosuly presented with the paper sound, were rated as less pleasant than with the no sound condition (p=.07). Surface #1 was rated as more pleasant when presented with the no sound than with the paper (p<.001) and sandpaper (p<.001) sounds; and more pleasant with the paper sound than the sandpaper sound (p<.001). Similarly, surface #2 was rated as more pleasant when presented with no sound than with the sandpaper sound (p<.001); a similar trend was found comparing the no sound condition with the paper sound (p=.07). Also, surface #2 was rated as more pleasant with the paper sound than the sandpaper sound (p<.001). Surface #3 was rated as less pleasant when presented in combination with the sandpaper sound as compared to the paper (p<.001) and the no sound (p<.001), but no significant difference was found by comparing the presentation with no sound and paper sound (p=.58).

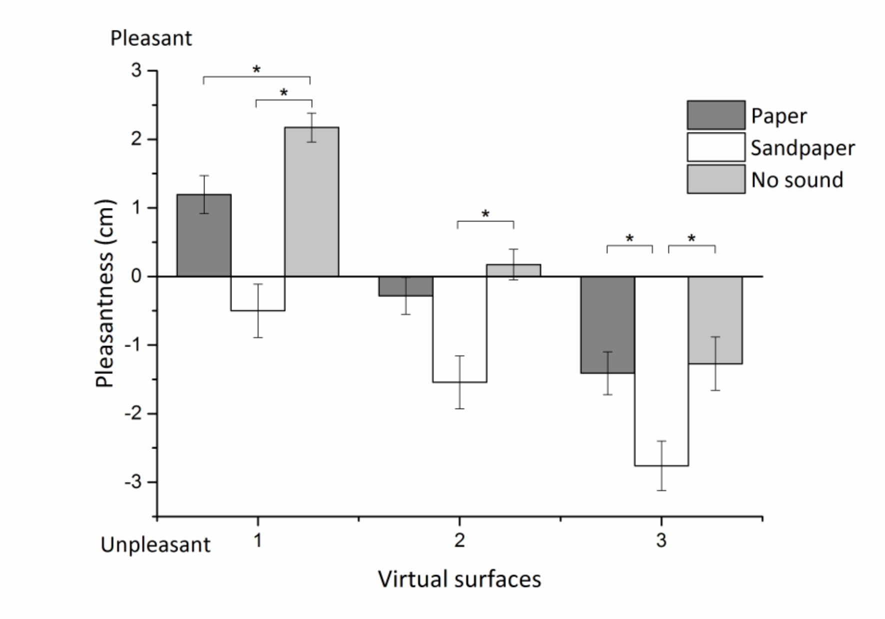

Figure 22. Participants' mean ratings on the "pleasantness" scale in Experiment 2. Error bars represent the standard error of the means and asterisks indicate significant differences (p<.05).

Roughness

The analysis revealed significant main effects of "virtual surface" [F(2, 38)=52.38, p<.001] and "sound" [F(2, 38)=7.29, p=.002]. The interactive effect between "virtual surface" and "sound" was not significant (p=.11). Surface #1 was rated as smoother than surface #2 and #3 (both p=.001). There was no significant difference between surface #2 and surface #3 in terms of roughness (p=.37). Surfaces simultaneously presented with the sandpaper sound were rated as rougher than when presented with no sound (p=.004) and the paper sound (p=.003; see Fig. 23). There was no significant difference between surfaces when presented with the paper sound than with the no sound condition (p=.77).

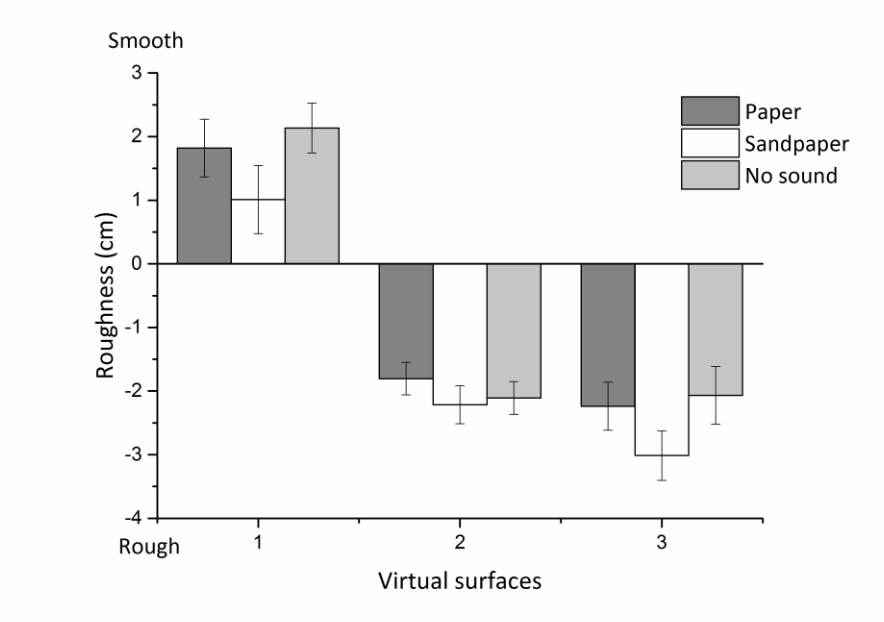

Figure 23. Participants' mean ratings on the "roughness" scale in Experiment 2. Error bars represent the standard error of the means and asterisks indicate significant differences (p<.05).

Exploration time

The main effect of "virtual surface" was significant [F(2, 38)=5.64, p=.007] but no significant main effect of "sound" was found (p=.20). Surface #1 required less time of exploration as compared to surface #2 (p=.006) and surface #3 (p=.02; see Fig. 24). The interaction between "virtual surface" and "sound" was not significant (p=.09).

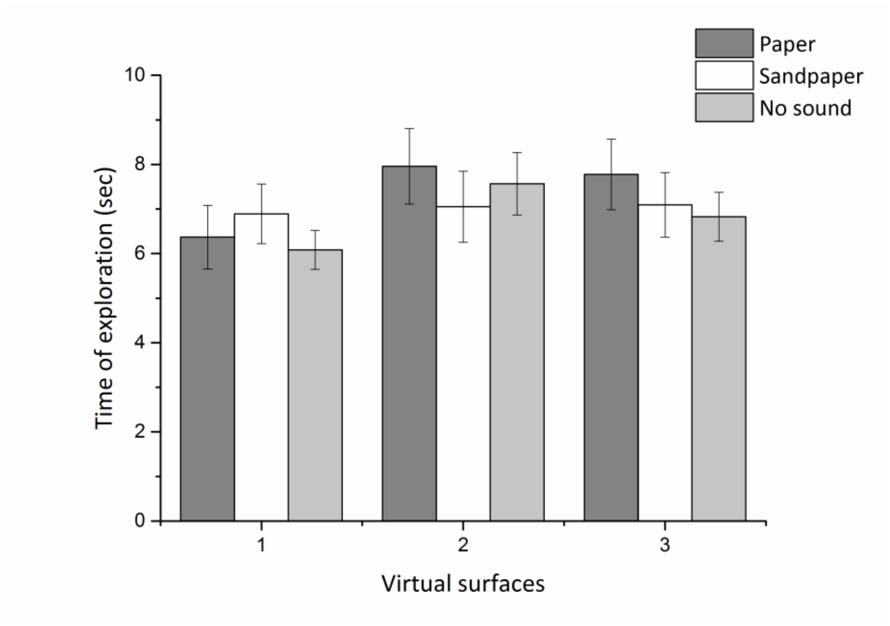

Figure 24. Participants' mean exploration times of Experiment 2. Error bars represent the standard error of the means and asterisks indicate significant differences (p<.05).

Imagined pleasantness of sound

The sound coming from the sandpaper was rated as less pleasant than that one coming from the paper [t(19)=9.33, p<.001].

Correlational analysis

A significant and positive correlation was found between pleasantness and roughness (r=.628, p<.001). A trend suggested instead a negative correlation between pleasantness and time of exploration (r=-.136, p=.06). The correlation between roughness and exploration time was not significant (p=.80).

5.3.3. Discussion

The results of Experiment 2 clearly revealed that the evaluation of the virtual surfaces explored by means of the haptic device was modulated by the sounds paired with their exploration. In particular, the sound resulting from the exploration of the sandpaper affected the haptic perception of the surfaces, increasing the perceived roughness and decreasing the pleasantness experienced. Also, the presentation of the paper sound made the participants perceive surface #1 as less pleasant, but crucially not rougher as compared to the no sound condition. This effect might be due to the fact that the paper sound might be considered as not congruent/correspondent with the experience of exploring a very smooth-rated tactile stimulus, such as surface #1. That is, the perception of such audio-tactile incongruence might have reduced the perceived pleasantness. Moreover, although surface #2 was rated as more pleasant than surface #3, they were perceived as equally rough, then suggesting once more that roughness is likely not the only dimension affecting the hedonic ratings. It is also interesting to note that the virtual surface rated as the smoothest and the most pleasant (surface #1) was explored for less time than the other two surfaces. As said in the discussion of Experiment 1, this result might seem counter-intuitive. In fact, one might expect that unpleasant sensations lead to a lower time of exloration related to a sort of avoidance behavior. However, here it is worth noting that more time is needed to explore the entire area of a surface characterized by high frictional forces, as compared to surfaced characterized by lower frictional forces that make the surface slippery.

5.4. General discussion

The present study investigated how virtual surfaces are perceived in terms of pleasantness and roughness, and how visual and auditory information affects such evaluations. The results clearly showed that virtual haptic perception can be modulated by the simultaneously presented visual and auditory stimuli. In fact, both the pleasantness and roughness evaluations made by the participants varied as a function of the pictures and the sounds paired with the haptic surfaces simulated. Although the results revealed that the smoother a surface is perceived, the more pleasant is rated (in line with previous research with real surfaces, Essick et al., 2010; Etzi et al., 2014; Guest et al., 2011), the force effects generated by the device (responsible of the roughness perceived) resulted to be not the only factors involved in contributing to the pleasantness experienced. For instance, in Experiment 1 surfaces #1 and #4 were rated as equally pleasant, despite surface #1 was rated as smoother than surface #4. In Experiment 2, the surfaces were rated as equally smooth if presented with no sound or paired with the paper sound, but surface #1 was rated as less pleasant when in combination with the paper sound than when presented with the no sound. Furthemore, the congruence between the haptic and the visual or the auditory information presented might have contributed to modulate the perceived pleasantness of the simulated materials as well. In fact, in Experiment 1, surface #3 (rated as the roughest) was perceived as more unpleasant when paired with the picture of a glass-made surface as compared to the picture of a rubber-made surface which in turn made the participants perceive surface #1 (rated as the smoothest) as more unpleasant. Unexpectedly, the surfaces which were rated as more unpleasant required more time of exploration. However, this feeling of unpleasantness might be induced by the inability of the participants to recognize the surface. That is, they might have been unable to associate the virtual surface to a surface known in the real world and this might have led to a negative evaluation of the stimulus together with longer exploration times. As said above, this effect might also depend on the fact that when exploring low frictional coefficients surfaces (rates as the smoothest) the movement of the stylus is more fluid than when exploring high frictional coefficients surfaces (rated as the roughest). As a consequence, the participant manages to explore a larger area of the surface in less time when smoother-rated surfaces are presented.

The results of the present study revealed that when rendering virtual surfaces by means of haptic devices, multisensory interactions can modulate people’s sensory experiences of the materials. They can be also taken to suggest the presence of some similarities between the hedonic perception of real and virtual surfaces (e.g., Croy et al., 2014; Ellingsen et al., 2014). However, more research is still needed in order to investigate the role of roughness and congruency between the multisensory stimuli in mediating the hedonic perception, and also to induce more pleasant and realistic sensory experiences. Furthermore, it would be interesting to investigate what is the parametric variation in terms of frictional coefficients necessary to induce different hedonic feelings. Also, the effects on perception of the specific attributes of the visual textures (e.g., colour, spatial density) and of the sounds (e.g., frequency) paired with the haptic surfaces deserve to be further explored. Such findings would be of paramount importance when rendering virtual multisensory objects under conditions where there is no possibity to directly touch the surfaces. For instance, in the field of marketing and on-line shopping, the use of a haptic device migh allow to touch virtual reproduction of fabrics and clothes before buying them, which has been shown to be crucial for consumers in real or in-field situations (McCabe & Nowlis, 2003). In fact, the feeling coming from touching a product, or eventually its packaging, plays a fundamental role in evaluating and appreciating goods (Gallace, 2015; Spence & Gallace, 2011). The fact that items are not available for haptic exploration limits people's ability of experiencing all of the characteristics of the products before purchasing them. Also, the field of art fruition would beneficiate from the use of such technologies given that, excluding rare exceptions, touching is forbidden in museums (Gallace, 2011; Spence & Gallace, 2008).

Chapter 6

GENERAL DISCUSSION AND CONCLUSIONS

In daily life we spend a lot of time haptically and tactually interacting with objects and other individuals. Nevertheless, we usually pay attention to tactile stimuli only when they convey highly relevant information, as for example when we feel a strong sense of unpleasantness (e.g., touching a very rough material) or when, on the contrary, we experience a really good feeling (e.g., receiving a caress by a beloved person). The relatively recent discovery of C-Tactile afferents (CTs) in humans, has led to a huge increase of interest and an increasing number of scientific studies on the perception of pleasant touch. However, so far, research has focused more on the peripheral and neural pathways of CT-mediated perception. Less has been done to investigate how pleasant touch impacts on the physiological responses and how top-down factors shape people's tactile perception and feelings.

The present dissertation represents an attempt to contribute to define the behavioral and physiological correlates and to elucidate the mechanisms underlying the perception of pleasant touch. The role played by the multisensory environment in which hedonic tactile stimuli are usually explored has also been evaluated. In particular, by assessing electrodermal activity and subjective evaluations, the studies here reported investigated how the autonomic nervous system reactions and the emotional states vary depending on the sensory stimulations presented.

6.1. Arousal response to pleasant touch

Being caressed is widely considered as pleasant and relaxing. It represents one of the very first experiences that babies enjoy right after birth and new-mothers are in fact encouraged to look for tactile contact with their newborns. Receiving a caress activates an extended brain network including the posterior insula (PI; Morrison, 2016; Olausson et al., 2002, 2008a), the orbitofrontal cortex (OFC; Francis et al., 1999; McGlone et al., 2012; Rolls et al., 2003) and the anterior cingulate cortex (ACC; Lindgren et al., 2012; Sliz et al., 2012), crucial areas in the processing of pleasant and rewarding stimuli (Kringelbach, 2005; Berridge & Kringelbach, 2013) and in the maintenance of the body homeostasis (Craig, 2003, 2009; Paulus, 2007). This evidence contributes to explain why pleasant tactile contact is so satisfying.

The results of Study 1 confirmed that slow touch (3 cm/s), optimal for a vigorous activation of CT afferents, was experienced as more pleasant and more relaxing than fast touch (30 cm/s). Nevertheless, the differences between slow and fast touch expressed by the subjective evaluations were not supported by variations in the general arousal level, as demonstrated by the analysis of the skin conductance level (SCL). It is likely that longer stimulation sessions (e.g., 5-10 minutes) are needed in order to induce stable changes in the SCL. Differences were instead found in the arousal response more stimuli-related. In fact slow stroking led to a lower skin conductance response (SCR) than the fast. This result is line with previous research showing that unpleasant or less pleasant stimuli induce a higher SCR than more pleasant stimuli (Eriksson et al., 2008; MacDowell & Mandler 1989; Ramachandran & Brang 2008).

The evaluation of CT-targeted touch does not vary only depending on the velocity of the stimulation, but also in function of its static/dynamic nature (Löken et al., 2009; Vallbo et al., 1999). In fact, as revealed by the subjective evaluations, tapping (especially when repetitively provided in the identical spatial sequence) was not considered as a social kind of contact, as compared to the stroking of the skin. Moreover, both the SCRs and the SCLs were higher for stroking than tapping, thus demonstrating that, within the tactile modality, different arousal responses in terms of magnitude can be induced by diverse kinds of stimulation.

Touch is often considered as one of the most arousing senses (see Gallace & Spence, 2014, for a discussion on this point) but no studies so far confirmed this claim by physiologically analyzing the arousal response to touch as compared to vision. One might argue that vision is likely more powerful in terms of modulating people's arousal, since it often extinguishes or dominates touch in different tasks (e.g., Hartcher-O'Brien et al., 2008). Nevertheless, visual dominance might not necessarily imply a greater arousal state as compared to touch. The results of Study 2 showed that the arousal response to the haptic exploration of everyday materials was higher than the response to the visual presentation. Therefore, touch seems to have a greater arousing power than vision, at least when textures are presented. Interestingly, no differences were found when comparing the arousal response to unisensory or multisensory (visuo-tactile) stimulation (Study 3), thus indicating that the interaction between multisensory affective stimuli of the same polarity (e.g., both positive and negative) does not induce an increase of magnitude in the physiological reaction.

As far as regards the arousal responses to different tactile textures, in Study 2 no differences in terms of SCR were found, despite some of the textures used were evaluated as more pleasant than others. By contrast, in Study 3, presenting a material rated as very rough and unpleasant (e.g., sandpaper) induced higher SCRs. The crucial difference between the two studies consists in the duration of the tactile stimulation. In fact, in Study 3 the stimulation lasted much longer (9 seconds) than in Study 2 (2 seconds). In order to appreciate a higher arousal response to an unpleasant texture, it might be that the feeling of unpleasantness needs to be experienced for a certain amount of time (thus provoking an exacerbation of the sensation). On this point, it is interesting to note that the results of Study 1 showed that fast stroking was perceived as even more unpleasant when experienced for a long session (9 vs. 60 seconds). Hence, by summarizing, the results of the present dissertation suggested that both the pleasantness/unpleasantness of a tactile stimulation and its duration (leading to the phenomenon of “touch satiety”; Triscoli et al., 2014) can modulate the arousal response related.

The arousal response is known to differ between women and men depending on the kind of stimulation provided (e.g., emotional clips; Kring & Gordon, 1998; Tousignant-Laflamme & Marchand, 2006). As concern the existence of gender differences in the arousal response to pleasant touch, the results of Study 2 revealed that women were more aroused than men (higher SCRs were recorded) when haptically stroked with different textures. This effect might lead to the speculation that women are endowed with a higher hedonic sensitivity to touch (as compared to men, generally less involved in the very first interactions with newborns) given the affiliative function of CT-mediated touch. In fact, as said above, tactile interactions between mother and baby are extremely important for a healthy cognitive development of the child (Field, 2001; Gallace & Spence, 2010). Nevertheless, In Study 1, no differences in the arousal response to tactile stimulations between women and men were found. Neither the velocity, nor the nature of the stimulation (stroking vs. tapping) resulted into differential arousal responses between the two genders. However, it has to be noted that Studies 1 and 2 differ in terms of the nature of the tactile stimuli used (brush vs. textures, respectively) and the duration of the stimulation provided (9-60 seconds vs. 2 seconds, respectively), factors which certainly affect physiological responses. Speaking of gender-related effects, the results of Study 2 also showed that being haptically stimulated by a female or a male experimenter did not induce differences in the SCRs. Hence, these results did not support the findings of other studies demonstrating that people show a higher arousal response when stimulated by a male as compared to when stimulated by a female experimenter (e.g., Gazzola et al., 2012). However, many differences between Study 1 and Gazzola's paradigm are likely responsible of this incongruence in the results. What it is interesting to note thus, is that the context in which the pleasant touch is delivered dramatically impacts on the autonomic individual response.

6.2. Visuo-tactile and audio-tactile interactions

So far, we focused on the tactile sensory modality in isolation, however in daily life, perception is always multisensory (Stein, 2012). Pleasant touch has already been shown to be affected by other sensory modalities even though is not clear yet what are the mechanisms underlying these modulatory effects (Ellingsen et al., 2015). In Study 3, it has been confirmed that stimuli which are non-informative to the task are still capable to affect hedonic tactile perception (see also Croy et al., 2014; Ellingsen et al., 2014). In fact, although irrelevant, emotional and non-emotional pictures modulated the perception of the pleasantness, the roughness and the softness of the materials concurrently presented to the participants. Vision affected the tactile judgments even when the visual stimuli were not particularly salient (emotional neutral pictures), and modulated also the perception of sensory tactile attributes, completely unrelated with the pictures presented. These findings highlight the great power that vision has on tactile perception.

In Study 3 and in the extent literature, sensory modulations on tactile perception have been investigated only for real tactile stimuli (i.e., textures, stroking). The results of Study 4 provided evidence of the presence of hedonic multisensory interactions also when tactile perception is virtually-simulated through a haptic device. Pleasantness and roughness evaluations on virtual haptic surfaces were in fact modulated by pictures of materials (e.g., glass, steel) and sounds resulting from the exploration of materials (i.e., paper, sandpaper). In particular, two factors seemed to explain the characteristics of the modulation. The roughness of the materials depicted in the pictures, and the sounds presented (eliciting the perception of interacting with materials of different roughness), altered the perception of the roughness of the haptic surfaces and also the pleasantness evaluations. Moreover, the perceived congruence/incongruence between visual-tactile and auditory-tactile stimuli impacted on the results, causing a decrease in the pleasantness perceived.

Despite pleasant touch perception was modulated by visual stimuli, the evaluation of these visual stimuli was not modulated by the simultaneous tactile stimulation, at least when textures were presented. The results of Study 3 did not provide a clear explanation of the reasons of this lack of tactile modulation. However, it might be argued that the tactile stimuli used in such study were not enough relevant and salient (as compared to the emotional pictures) to have any effect on the visual judgments. One of the tactile stimuli (i.e., experimenter’s skin) might be considered as a salient stimulus given its social relevance but still it is likely not as salient as the high emotional contents depicted in the emotional pictures (e.g., people hugging, dead bodies). More relevant tactile stimuli, such as higher pressure stimuli for example, might be used in future studies in order to investigate more deeply the existence of potential reciprocal interactions between vision and touch. Furthermore, since there are no resources including tactile stimuli (e.g., textures) classified in terms of valence and arousal, the development of a tactile database would be certainly useful for research aims.

6.3. Tactile preferences

Stimulations resembling the characteristics of a caress are unanimously considered as very pleasant. In Study 1, the slow stroking stimulations provided with a brush were in fact preferred over the fast stroking and the tapping stimulations. Also, they were rated as the most "social" and the most "relaxing". As shown by previous studies, innocuous stimuli slowly moving on the hairy skin induce an increase of the CT discharge rate (Ackerley et al., 2014a; Löken et al., 2009) and lead to the activation of areas crucial for the experience of pleasure (e.g., OFC; Berridge & Kringelbach, 2015; Kringelbach, 2005).

When materials were used to provide a tactile stimulation, smooth and soft materials were preferred over rough and hard materials, as shown in Study 3 (see also Essick et al., 1999; Etzi et al., 2014; Guest et al., 2011). Also, the rougher and the softer the textures were rated, the higher were the related pleasantness ratings. With regard to tactile preferences for virtually-simulated materials, the surfaces characterized by lower frictional static and dynamic coefficients (resulting in a feeling of smoothness) were liked more than those characterized by higher static and dynamic frictional coefficients. However, here, it has to be noted that this occurred only when there was a variance between the static and dynamic coefficients (e.g., 0.5 and 0.4), a factor that increases the feeling of resistance when the exploration of the surfaces begins. When this variance was not present (e.g., 0.9 and 0.9), even though the frictional coefficients were high, the surfaces were rated as equally pleasant as those with lower coefficients (e.g., 0.1 and 0.1). Thus, we might conclude that when tactile surfaces are rendered by means of force-feedback devices, particular attention has to be paid to technical factors responsible of great variation in perception and consequently in hedonic evaluations.

Throughout this dissertation, it has often been claimed that touch, although very relevant to our perception, is generally underestimated by common people and is little investigated as compared to other senses (such as vision for example). This view is supported by the results of the hedonic ratings of Study 2, which revealed that materials were appreciated more when touched than when just observed trying to imagine the pleasantness of the tactile contact with them. This result provides a confirmation of the great and still unexplored power of touch, and suggests that the fields of medicine, marketing, design, and advertising should take advantage of it.

6.4. Concluding remarks

Taken together, the results coming from the four studies presented here showed how we react to and perceive hedonic aspects of tactile stimulation. Pleasantness evaluations varied depending on the velocity of stimulation (i.e., slow or fast) and type of touch (i.e., stroking or tapping) delivered, and on the microgeometric properties (i.e., roughness and softness) of the stimuli. Arousal responses (measured by means of skin conductance) varied depending on the velocity and type of touch as well. Moreover, they varied as a function of the microgeometric properties, but in this case only depending on the duration of the stimulations.

The results reported here also revealed how visual or auditory stimuli modulated haptic perception, even when they were not informative for the task to be performed. This happened for both real textures and virtual surfaces, proving that hedonic tactile perception did not vary depending on the “tool” used to explore a texture (i.e., a hand or a haptic device).

The study of these aspects is certainly of paramount importance from a theoretical point of view since there is still little research on this topic. Also, the medical and psychiatric fields would beneficiate of a precise definition of the behavioral and physiological responses to the perception and the processing of the pleasant aspects of touch in healthy individuals.

Affective touch for instance has already been shown to be anomalous in some psychiatric diseases (Cascio et al., 2012; Croy et al., 2016; Crucianelli et al., 2016; Kaiser et al., 2016; Voos et al., 2013). Therefore, findings such as those reported here might provide important information for creating new tests for the diagnosis (and perhaps treatment) of certain affective disorders. The findings reported would be very useful also for other applied fields, such as those related to design, marketing and art fruition. Results coming from studies on tactile preferences in fact provide interesting suggestions and insights about human tactile needs. The texture is not the only attribute of a tactile object. Shape, temperature and weight also provide us with important information when interacting with a product. Importantly, knowing how sensory interactions including touch impact on hedonic feelings would allow designers, material engineers and marketers to offer more enjoyable and appealing objects. This approach would allow them to offer the consumers with better experiences and objects able to induce an increase of pleasant feelings in daily life. For instance, the pleasantness evoked by touching an object or its packaging might be higher if accompanied by semantically or crossmodal correspondent information coming from vision (e.g., colors, shapes). In addition, as proposed by Gallace and Spence (2011), the attributes of an object explored by touch might recall feelings coming from other sensory modalities into alignment and thus induce a higher feeling of pleasantness, as result of the affective ventriloquism effect.

By summarizing, the studies reported in this dissertation revealed that subjective evaluations and arousal responses to hedonic tactile stimulation are affected by both bottom-up and top-down factors. The qualities of the stimuli, the parameters of the stimulation, the other sensory modalities and the gender of the person being stimulated modulated emotional feelings and the response of the autonomic nervous system to the pleasure provided through the tactile somatosensory channel. More research will need to identify more precisely the factors involved and the mechanisms underlying hedonic tactile perception. Moreover, other studies will need to assess other physiological and homeostatic responses (e.g., heart rate, electromyography, respiration, thermoregulation) to pleasant touch.

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