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RESEARCH ARTICLE

The arousing power of everyday materials: an analysis of the physiological and behavioral responses to visually and tactually presented textures

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Abstract Previous research has shown that during multisensory perception, vision frequently dominates over the other sensory modalities. However, it is still unclear whether sensory dominance also implies the generation of a greater state of arousal. Here, we assess the psycho-physiological reactions to different materials when presented tactually (Group 1) or visually (Group 2). In Group 1, the participants' forearm was stroked with different textures (satin, tinfoil, leather, sandpaper and abrasive sponge), by either a male or a female experimenter. The speed of stimulation was set to elicit a vigorous response of C-tactile afferents, involved in the perception of the more pleasant aspects of touch. The participants were asked to rate the pleasantness of the stimulation. In Group 2, the same textures were presented only visually, and the participants were asked to rate the imagined pleasantness of being touched by those stimuli. Skin conductance responses were recorded in both groups. The results revealed that the tactile presentation of the stimuli led to higher skin conductance responses than the visual presentation; this difference was higher for women than for men. Smooth materials were perceived as more pleasant than rough materials, but no differences in terms of skin conductance responses were found among them. Moreover, the textures were rated as less pleasant when presented visually than when presented tactually. These findings are relevant to understand how physiological arousal is modulated by different senses and to elucidate the mechanisms involved in hedonic tactile perception.

Keywords Affective touch · Vision · Textures · Arousal · Skin conductance response

Introduction

When two sensory modalities provide discrepant information about an object, people tend to rely more on the modality considered as the most appropriate, precise and accurate for the specific task/action to be performed (e.g., Ernst and Banks 2002; Ernst and Bülthoff 2004; Welch and Warren 1980). Nevertheless, there is extensive literature showing that in humans vision frequently dominates over the other sensory modalities under perceptual or attentional tasks (see e.g., Cho et al. 2015; Hartcher-O'Brien et al. 2008; Koppen and Spence 2007; Posner et al. 1976; Rock and Victor 1964; Sinnett et al. 2007). For instance, it has been known for more than 30 years that people often fail to detect auditory stimuli when simultaneously presented with visual stimuli, an example of visual dominance known as the "Colavita effect" (e.g., Colavita 1974; Colavita and Weisberg 1979; Koppen and Spence 2007; Sinnett et al. 2007; Spence 2009; see also Hartcher-O'Brien et al. 2008, for a visuo-tactile version of the Colavita effect).

Previous research attempted to assess whether arousal modulates the occurrence of visual dominance. Shapiro et al. (1984), using the Colavita paradigm, found that vision no longer dominates over audition when the individual's arousal is increased by a brief electric shock or the threat to receive it. In a more recent study, Van Damme et al. (2009) reported that the Colavita visual dominance effect still occurs when a state of greater arousal is induced by pairing either visual or, surprisingly, auditory stimuli with unpleasant electrocutaneous stimuli. Although these studies provide clear examples of the role played by arousal in

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modulating visual dominance, it is important to notice here that they just assumed a greater state of arousal induced by fear-conditioning stimuli, since no direct measures of physiological reactions were collected. Moreover, all of the studies on this topic compared vision with audition (as in the original version of Colavita effect; Colavita 1974; Colavita and Weisberg 1979; Koppen and Spence 2007; Sinnett et al. 2007; Spence 2009), but not vision with touch.

Importantly, touch is considered a "contact sensory modality" as compared to distal senses such as vision and audition. That is, it provides information that is directly in contact with our body. As a consequence, reactions to tactile stimuli should be quick and fast, given that once a stimulus is on our body surface there is little time to make computations and predictions on its nature and/or its threatening value (see Gregory 1967). From a physiological point of view, fast alerting responses to touch are likely mediated by Aβ fibers, known to be a class of fast-conducting afferents (Kandel et al. 2000). Following on from these considerations, one might conclude that touch should have a greater alerting capability than vision. Nevertheless, research has shown that just as it occurs for auditory stimuli, also tactile stimuli are often extinguished when paired with visual stimuli (Hartcher-O'Brien et al. 2008, 2010; Hecht and Reiner 2009). 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 and Spence 2010; Hertenstein et al. 2006; see Lenschow and Brecht 2015, for a recent cell-recording study showing that responses to social touch differ from conventional tactile responses in rats). Furthermore, the valence of the stimuli presented (a variable that is known to affect arousal responses; MacDowell and Mandler 1989; Ramachandran and Brang 2008), might also change the relative dominance of one sense over another. For instance, unpleasant tactile stimuli might extinguish visual neutral stimuli, under certain conditions of stimulus presentation. Nevertheless, following on from these considerations, one might conclude that the apparent dominance of touch by vision or vice versa might be completely independent from their respective alerting or arousing capabilities.

Touch is often considered as one of the most arousing senses (Field 2001, 2014; Gallace and Spence 2014), but its role in driving emotional/affective behaviors and evaluations is probably still underestimated (for a review see Gallace and Spence 2010; Hertenstein et al. 2006). For instance, interpersonal touch is fundamental for the psycho-physical well-being and for the social bonding (Gallace and Spence 2010; Hertenstein et al. 2006; Walker and McGlone 2013), both in humans and primates (Dunbar 2010). Recent evidence demonstrated that affective 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, for a review), 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 (0.3–2.5 mM; Vallbo et al. 1999) and slow (1–10 cm/s; Löken et al. 2009) stimulation at a neutral temperature (32 °C as the typical skin; Ackerley et al. 2014a). Importantly, during such stimulation the discharge frequency of CTs is significantly correlated with the participants' hedonic ratings (e.g., Ackerley et al. 2014a; Löken et al. 2009). Furthermore, psycho-physiological studies have shown that the stimulation of the hairy skin is rated as more pleasant than the stimulation of the glabrous skin (Essick et al. 2010; Guest et al. 2011; Löken et al. 2009) and strokes at slow velocity (1–10 cm/s) are preferred over faster strokes (Ackerley et al. 2014b; Löken et al. 2009; Morrison et al. 2011; Perini et al. 2015; Triscoli et al. 2014). It is worth mentioning that pleasant tactile sensations also come from glabrous body areas, which are innervated by Aβ, but not by CT fibers (McGlone et al. 2012, 2014).

Importantly, the specific materials used to stimulate the skin also play an important role in modulating hedonic ratings. That is, the smoother the texture is, the more pleasant is perceived by participants (e.g., Ackerley et al. 2014c; Ekman et al. 1965; Essick et al. 2010; Etzi et al. 2014; Guest et al. 2009; Rolls et al. 2003; Verrillo et al. 1999). Similarly, the rougher a texture is rated, the greater is the self-reported arousal associated with it (Guest et al. 2011). Despite these findings, we still do not know 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 our study, we investigate this question by recording the electrodermal activity, which is acknowledged as an indicator in the domains of emotion and arousal (e.g., Boucsein 2012). Very few studies have assessed the effect of affective/hedonic touch on human skin conductance responses (SCRs), and the great majority of them made use of some forms of skin-to-skin contact. For example, Chatel-Goldman et al. (2014) reported that interpersonal touch increases coupling of electrodermal activity between interacting partners. To the best of our knowledge, no study has ever measured SCRs to different materials presented visually or tactually.

Here, the participants were presented, either tactually 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 assessing whether visual and tactile stimulations affect differently the individual psycho-physiological 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 and Gordon 1998; Tousignant-Laflamme and Marchand 2006). The role of a high-order factor, such as the gender of the person performing the tactile stimulation, in affecting participants' responses was also considered (see Gazzola et al. 2012).

From an applied point of view, the results of the present study might provide important insights for the development and design of more effective multisensory environments, materials, products and packaging.

Experiment

Methods

Participants

Forty volunteers (mean age: 23.2 ± 2.58 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., the stroking of the materials on their skin). 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 the stimuli without 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 1991 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

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 during the tactile stimulation. Each texture had a size of 10 × 10 cm, but given the curved shape of the rolls, during the tactile stimulation just a smaller portion of the texture (approximately 2 × 10 cm) was in contact with the skin.

Procedure

The participants were seated comfortably in front of the experimenter, resting both arms on a desk. Two Ag–AgCl electrodes (Model 1081 FG) with constant voltage (0.5 V) 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, and 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/s for 2 s. 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 about 8 s from the end of each stimulation, the experimenter informed the participants in Group 1 that they could move up the blindfold and evaluate the pleasantness of the stimulation on a 10 cm visual analogue scale (VAS) anchored to the labels "unpleasant" and "pleasant." The VASs were presented on the center of A4 sheets of paper. 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 2 s (the same duration of the tactile stimulation of Group 1), the experimenter hid the texture from the participant's view. Four seconds after the texture was hidden, the participant was required to answer the following question: "How much pleasant would it be to be stroked with this material on the forearm?" on a 10 cm VAS anchored to the labels "unpleasant" and "pleasant." For both groups, each texture was presented 3 times during the whole experimental session. Moreover, the presentation of the textures was pseudo-randomized in a way that prevented the same texture to be presented two times in a row.

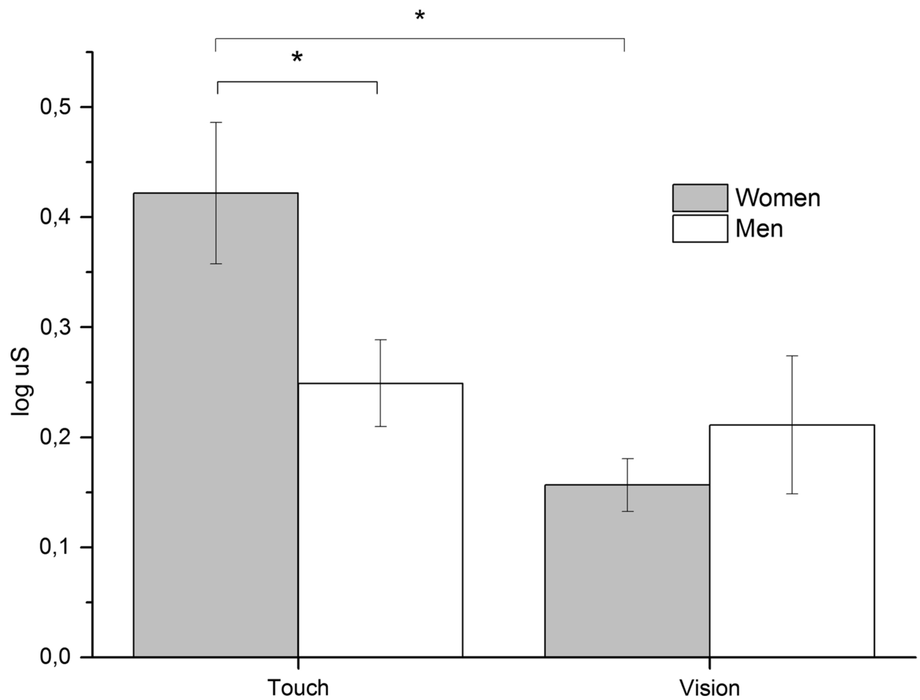

Fig. 1 Mean SCRs (log uS) to the tactile and visual presentation of the materials. *Error bars* represent the standard error of the means and asterisks indicate significant differences ($p < .05$)

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 and 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 to 6 s after the offset 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.

Results

Skin conductance responses

Effects of sensory modality, participants' gender and texture A mixed ANOVA with the between-factor "sensory modality" and "participant gender," and the within-factor "texture" was performed on the SC 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 tactile than for 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 response compared to men ($p = .01$) during tactile stimulation but not during the visual stimulation ($p = .41$; see Fig. 1). 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" [$F(4, 144) = 1.05$, $p = .37$] resulted in no significant differences.

Effect of experimenter's gender In order to analyze the effect of the "experimenter's gender" on the SCR of Group 1, a mixed ANOVA with the within-subjects factor of "texture" (five levels: satin, tinfoil, leather, sandpaper and abrasive sponge) and the between-subjects factors of "experimenter gender" and "participant gender" was conducted. The main effect of "participant gender" resulted to be significant [$F(1, 16) = 6.82$, $p = .01$]. Female participants ($M = 0.42$, SD $= 0.20$) showed greater skin conductance responses compared to the male participants ($M = 0.24$, SD $= 0.12$). Neither the main effects of "experimenter gender" [$F(1, 16) = .31$, $p = .58$] and "texture" [$F(4, 64) = .71$, $p = .58$] nor the interactions between "experimenter gender" and "subject gender" [$F(1, 16) = .48$, $p = .49$], "texture" and "experimenter gender" [$F(4, 64) = .89$, $p = .47$], "texture" and "subject gender" [$F(4, 64) = .81$, $p = .51$], "texture," "experimenter gender" and "subject gender" [$F(4, 64) = .47$, $p = .75$] resulted to be significant.

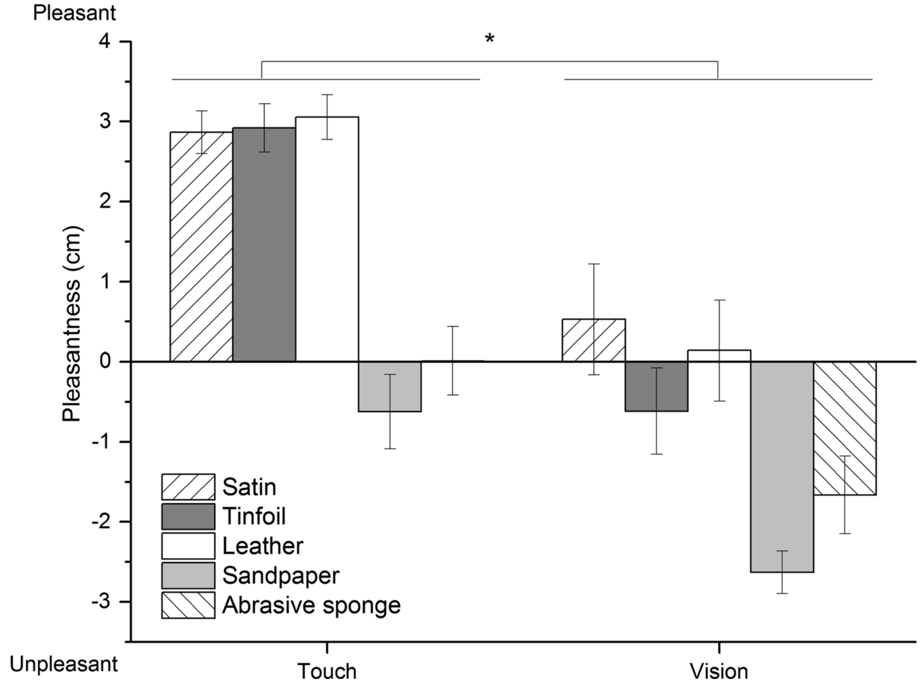

Fig. 2 Participants' mean ratings of the materials on the "pleasantness" scale. Note that in the tactile condition, the participants evaluated the pleasantness of the tactile stimulation, while in the visual condition they evaluated the imagined tactile pleasantness of the material. Significant differences between each pair of textures are only reported in text (see pp. 11–12). *Error bars* represent the standard error of the means and *asterisks* indicate significant differences ($p < .05$)

Ratings

Effects of sensory modality, participants' gender and texture A mixed ANOVA with the between-subjects factors of "sensory modality" and of "participant gender," and the within-subjects factor of "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 presented tactually receiving higher ratings (more pleasantness) than stimuli presented visually (see Fig. 2). A significant main effect of texture was also found [$F(4, 144) = 28.94$, $p < .001$]. The most pleasant materials resulted to be leather, while the most unpleasant was sandpaper. A Newman–Keuls post hoc test on this main 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" [$F(4, 144) = 0.73$, $p = .56$] did not result to be significant.

Effects of experimenter's gender In order to analyze the effect of the "experimenter's gender" on the pleasantness scale of tactile stimulation, a mixed ANOVA with the within-participants factor of "texture" (five levels: satin, tinfoil, leather, sandpaper and abrasive sponge) and the between-subjects factors of "experimenter gender" and "participant gender" was conducted. The main effect of "texture" resulted to be 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 ps $< .001$). The effect 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" [$F(4, 64) = 0.31$, $p = .86$] did not result to be significant.

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

General discussion

The present study assessed the effect of the visual and tactile presentation of common materials varying in texture, on skin conductance response and on the pleasantness experienced by the participants. The results showed that being stroked with textures led to higher SCR 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 and Reiner 2009), the results reported in the present study reveal that touch is physiologically more arousing than vision, at least when different materials are presented on 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 one. However, it is important to note here 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 and 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, one might hypothesize 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. Since when the hairy skin is slowly stroked CTs discharge rate positively correlates with subjective ratings of pleasantness, these fibers are hypothesized to mediate the perception of pleasant touch (Ackerley et al. 2014a; Löken et al. 2009). Moreover, CT afferents have been shown to project to the posterior insular cortex (Björnsdotter et al. 2009; Morrison et al. 2011; Olausson et al. 2002, 2008), an area involved in maintaining the homeostatic control over the body (Craig 2002, 2009; Paulus 2007). These findings have been taken to suggest that CT afferents might provide a peripheral mechanism to signal pleasant skin-to-skin contact, thus promoting interpersonal touch and affiliative behavior (McGlone et al. 2014; Olausson et al. 2002). As a consequence, our psycho-physiological 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 had higher SCR 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 collected (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 and Spence 2010), as well as in strengthening the mother–baby bond (e.g., Feldman et al. 2003; Kennell and McGrath 2005).

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

As far as the materials presented are concerned, we found that satin evoked the highest SCR while tinfoil the lowest SCR as compared to the other textures (see Fig. 1). 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. In fact, 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 be taken to 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.

Importantly, there is evidence showing an increased arousal in response to unpleasant stimuli presented on the skin (MacDowell and Mandler 1989; Ramachandran and 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, 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.

It is worth noting that the tactile presentation of the textures led to higher hedonic ratings by the participants as compared to their visual presentation. This result might suggest that people somehow 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 tactually presented, and rough materials as more unpleasant than when tactually 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 et al. 2011; Ludden et al. 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, our findings suggest that when common materials are used, implicit physiological responses do not correlate with explicit ratings. Moreover, our 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 et al. 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 results of the present study also provide insights to the applied fields of marketing, product design and art fruition. In particular, from our findings one might infer that shoppers or museum visitors might be more aroused when tactile contact with an object/product is allowed than when no contact is allowed. In fact, touching a product or a sculpture might convey more pleasant feelings and a greater state of physiological arousal than just watching it (see Gallace and Spence 2008; Spence and Gallace 2008, for the importance of touch in museums). Following on from our finding, showing that tactile pleasantness of common materials is underestimated by vision alone, if one's aim is to try to induce people to touch products or objects on exposition (note that all marketers know that sales are more likely when the product is in the hand of the costumer; McCabe and Nowlis 2003; Spence and Gallace 2011), more efforts will need to be done in order to increase people's expectation of tactile pleasantness. 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.

References

Ackerley R, Carlsson I, Wester H, Olausson H, Wasling HB (2014a) Touch perceptions across skin sites: differences between sensitivity, direction discrimination and pleasantness. Front Behav Neurosci 8:54

Ackerley R, Saar K, McGlone F, Wasling HB (2014b) Quantifying the sensory and emotional perception of touch: differences between glabrous and hairy skin. Front Behav Neurosci 8:34

Ackerley R, Wasling HB, Liljencrantz J, Olausson H, Johnson RD, Wessberg J (2014c) Human C-tactile afferents are tuned to the temperature of a skin-stroking caress. J Neurosci 34:2879–2883

Balaji MS, Raghavan S, Jha S (2011) Role of tactile and visual inputs in product evaluation: a multisensory perspective. Asia Pac J Market Logist 23:513–530

Benedek M, Kaernbach C (2010) A continuous measure of phasic electrodermal activity. J Neurosci Methods 190:80–91

Björnsdotter M, Löken L, Olausson H, Vallbo Å, Wessberg J (2009) Somatotopic organization of gentle touch processing in the posterior insular cortex. J Neurosci 29:9314–9320

Boucsein W (2012) Electrodermal activity. Springer, Berlin

Chatel-Goldman J, Congedo M, Jutten C, Schwartz JL (2014) Touch increases autonomic coupling between romantic partners. Front Behav Neurosci 8:95

Cho Y, Craig JC, Hsiao SS, Bensmaia SJ (2015) Vision is superior to touch in shape perception even with equivalent peripheral input. J Neurophysiol. doi:10.1152/jn.00654.2015

Colavita FB (1974) Human sensory dominance. Percept Psychophys 16:409–412

Colavita FB, Weisberg D (1979) A further investigation of visual dominance. Percept Psychophys 25:345–347

Craig AD (2002) How do you feel? Interoception: the sense of the physiological condition of the body. Nat Rev Neurosci 3:655–666

Craig AD (2009) How do you feel-now? The anterior insula and human awareness. Nat Rev Neurosci 10:59–70

Dunbar RI (2010) The social role of touch in humans and primates: behavioural function and neurobiological mechanisms. Neurosci Biobehav Rev 34:260–268

Ekman G, Hosman J, Lindstrom B (1965) Roughness, smoothness, and preference: a study of quantitative relations in individual subjects. J Exp Psychol 70:18–26

Ernst MO, Banks MS (2002) Humans integrate visual and haptic information in a statistically optimal fashion. Nature 415:429–433

Ernst MO, Bülthoff HH (2004) Merging the senses into a robust percept. Trends Cogn Sci 8:162–169

Essick GK, McGlone F, Dancer C, Fabricant D, Ragin Y, Phillips N, Jones T, Guest S (2010) Quantitative assessment of pleasant touch. Neurosci Biobehav Rev 34:192–203

Etzi R, Spence C, Gallace A (2014) Textures that we like to touch: an experimental study of aesthetic preferences for tactile stimuli. Conscious Cogn 29:178–188

Feldman R, Weller A, Sirota L, Eidelman AI (2003) Testing a family intervention hypothesis: the contribution of mother-infant skin-to-skin contact (kangaroo care) to family interaction, proximity, and touch. J Fam Psychol 17:94–107

Field T (2001) Touch. MIT Press, Cambridge

Field T (2014) Massage therapy research review. Complement Ther Clin Pract 20:224–229

Gallace A, Spence C (2008) A memory for touch: The cognitive science of tactile memory. In: Chatterjee E (ed) Touch in museums: policy and practice in object handling. Berg, Oxford, pp 163–186

Gallace A, Spence C (2010) The science of interpersonal touch: an overview. Neurosci Biobehav Rev 34:246–259

Gallace A, Spence C (2014) In touch with the future: the sense of touch from cognitive neuroscience to virtual reality. Oxford University Press, Oxford
Gazzola V, Spezio ML, Etzel JA, Castelli F, Adolphs R, Keysers C (2012) Primary somatosensory cortex discriminates affective significance in social touch. Proc Natl Acad Sci 109:E1657–E1666
Gregory RL (1967) Origin of eyes and brains. Nature 213:369–372
Guest S, Essick G, Dessirier JM, Blot K, Lopetcharat K, McGlone F (2009) Sensory and affective judgments of skin during inter-and intrapersonal touch. Acta Psychol 130:115–126
Guest S, Dessirier JM, Mehrabyan A, McGlone F, Essick G, Gescheider G, Fontana A, Xiong R, Ackerley R, Blot K (2011) The development and validation of sensory and emotional scales of touch perception. Atten Percept Psychophys 73:531–550
Hartcher-O'Brien J, Gallace A, Krings B, Koppen C, Spence C (2008) When vision 'extinguishes' touch in neurologically-normal people: extending the Colavita visual dominance effect. Exp Brain Res 186:643–658
Hartcher-O'Brien J, Levitan C, Spence C (2010) Extending visual dominance over touch for input off the body. Brain Res 1362:48–55
Hecht D, Reiner M (2009) Sensory dominance in combinations of audio, visual and haptic stimuli. Exp Brain Res 193:307–314
Hertenstein MJ, Verkamp JM, Kerestes AM, Holmes RM (2006) The communicative functions of touch in humans, nonhuman primates, and rats: a review and synthesis of the empirical research. Genet Soc Gen Psychol Monogr 132:5–94
Kandel ER, Schwartz JH, Jessell TM (eds) (2000) Principles of neural science. McGraw-Hill, New York
Kennell J, McGrath S (2005) Starting the process of mother–infant bonding. Acta Paediatr 94:775–777
Koppen C, Spence C (2007) Seeing the light: exploring the Colavita visual dominance effect. Exp Brain Res 180:737–754
Kring AM, Gordon AH (1998) Sex differences in emotion: expression, experience, and physiology. J Pers Soc Psychol 74:686–703
Lenschow C, Brecht M (2015) Barrel cortex membrane potential dynamics in social touch. Neuron 85:718–725
Liu Q, Vrontou S, Rice FL, Zylka MJ, Dong X, Anderson DJ (2007) Molecular genetic visualization of a rare subset of unmyelinated sensory neurons that may detect gentle touch. Nat Neurosci 10:946–948
Löken LS, Wessberg J, McGlone F, Olausson H (2009) Coding of pleasant touch by unmyelinated afferents in humans. Nat Neurosci 12:547–548
Ludden GD, Schifferstein HN, Hekkert P (2009) Visual–tactual incongruities in products as sources of surprise. Empir Stud Arts 27:61–87
MacDowell KA, Mandler G (1989) Constructions of emotion: discrepancy, arousal, and mood. Motiv Emot 13:105–124
McCabe DB, Nowlis SM (2003) The effect of examining actual products or product descriptions on consumer preference. J Consum Psychol 13:431–439
McCabe C, Rolls ET, Bilderbeck A, McGlone F (2008) Cognitive influences on the affective representation of touch and the sight of touch in the human brain. Soc Cogn Affect Neurosci 3:97–108
McGlone F, Olausson H, Boyle JA, Jones-Gotman M, Dancer C, Guest S, Essick G (2012) Touching and feeling: differences in pleasant touch processing between glabrous and hairy skin in humans. Eur J Neurosci 35:1782–1788
McGlone F, Wessberg J, Olausson H (2014) Discriminative and affective touch: sensing and feeling. Neuron 82:737–755
Morrison I, Björnsdotter M, Olausson H (2011) Vicarious responses to social touch in posterior insular cortex are tuned to pleasant caressing speeds. J Neurosci 31:9554–9562
Olausson H, Lamarre Y, Backlund H, Morin C, Wallin BG, Starck G, Ekholm S, Strigo I, Worsley K, Vallbo Å, Bushnell MC (2002) Unmyelinated tactile afferents signal touch and project to insular cortex. Nat Neurosci 5:900–904
Olausson HW, Cole J, Vallbo Å, McGlone F, Elam M, Krämer HH, Rylander K, Wessberg J, Bushnell MC (2008) Unmyelinated tactile afferents have opposite effects on insular and somatosensory cortical processing. Neurosci Lett 436:128–132
Paulus MP (2007) Neural basis of reward and craving-a homeostatic point of view. Dialogues Clin Neurosci 9:379–387
Perini I, Olausson H, Morrison I (2015) Seeking pleasant touch: neural correlates of behavioral preferences for skin stroking. Front Behav Neurosci 9:8
Posner MI, Nissen MJ, Klein RM (1976) Visual dominance: an information-processing account of its origins and significance. Psychol Rev 83:157–171
Ramachandran VS, Brang D (2008) Tactile-emotion synesthesia. Neurocase 14:390–399
Rock I, Victor J (1964) Vision and touch: an experimentally created conflict between the two senses. Science 143:594–596
Rolls ET, O'Doherty J, Kringelbach ML, Francis S, Bowtell R, McGlone F (2003) Representations of pleasant and painful touch in the human orbitofrontal and cingulate cortices. Cereb Cortex 13:308–317
Shapiro KL, Egerman B, Klein RM (1984) Effects of arousal on human visual dominance. Percept Psychophys 35:547–552
Sinnett S, Spence C, Soto-Faraco S (2007) Visual dominance and attention: the Colavita effect revisited. Percept Psychophys 69:673–686
Spence C (2009) Explaining the Colavita visual dominance effect. Prog Brain Res 176:245–258
Spence C, Gallace A (2008) Making sense of touch. In: Chatterjee E (ed) Touch in museums: policy and practice in object handling. Berg, Oxford, pp 21–40
Spence C, Gallace A (2011) Multisensory design: reaching out to touch the consumer. Psychol Market 28:267–308
Tousignant-Laflamme Y, Marchand S (2006) Sex differences in cardiac and autonomic response to clinical and experimental pain in LBP patients. Eur J Pain 10:603–614
Triscoli C, Olausson H, Sailer U, Ignell H, Croy I (2013) CT-optimized skin stroking delivered by hand or robot is comparable. Front Behav Neurosci 7:208
Triscoli C, Ackerley R, Sailer U (2014) Touch satiety: differential effects of stroking velocity on liking and wanting touch over repetitions. Plos One 9:e113425
Tröndle M, Greenwood S, Kirchberg V, Tschacher W (2012) An integrative and comprehensive methodology for studying aesthetic experience in the field: merging movement tracking, physiology, and psychological data. Environ Behav 46:102–135
Tschacher W, Greenwood S, Kirchberg V, Wintzerith S, van den Berg K, Tröndle M (2012) Physiological correlates of aesthetic perception of artworks in a museum. Psychol Aesthet Creat Arts 6:96–103
Vallbo ÅB, Olausson H, Wessberg J (1999) Unmyelinated afferents constitute a second system coding tactile stimuli of the human hairy skin. J Neurophysiol 81:2753–2763
Van Damme S, Crombez G, Spence C (2009) Is visual dominance modulated by the threat value of visual and auditory stimuli? Exp Brain Res 193:197–204
Venables PH, Christie MJ (1980) Electrodermal activity. Tech Psychophysiol 74:3–67
Verrillo T, Bolanowski SJ, McGlone FP (1999) Subjective magnitude of tactile roughness. Somatosens Mot Res 16:352–360
Walker SC, McGlone FP (2013) The social brain: neurobiological basis of affiliative behaviours and psychological well-being. Neuropeptides 47:379–393
Welch RB, Warren DH (1980) Immediate perceptual response to intersensory discrepancy. Psychol Bull 88:638–667