RUNNING HEAD: MULTISENSORY CONTRIBUTIONS TO AFFECTIVE TOUCH

Multisensory contributions to affective touch

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ABSTRACT

Just as for any other sensory system, researchers have long wanted to discriminate between the sensory discriminative and hedonic aspects of tactile perception. Supporting such a distinction, researchers have, in recent decades, uncovered the existence of a dedicated system of receptors in the hairy skin (C-Tactile, CT, afferents) that appear to be preferentially tuned to pleasant stroking (i.e., caressing) touch. No matter what kind of touch one is talking about, though, it is important to recognize that human perception is fundamentally multisensory, meaning that what we feel, not to mention what we think about the experience, is modulated by the inputs that are available to the other senses. This review summarizes the latest evidence concerning these multisensory contributions to tactile perception focusing, in particular, on the case of affective touch. Given that CT afferents for pleasant touch are far more common in the hairy (as compared to the glabrous) skin, the question is further raised as to whether the relative contribution of the various senses to tactile perception may differ as a function of the skin site stimulated (i.e., glabrous vs. hairy skin) or the kind of judgment (sensory-discriminative vs. hedonic) that is being made.

KEYWORDS: AFFECTIVE TOUCH; MULTISENSORY; SENSORY-DISCRIMINATIVE; CROSSMODAL.

Introduction

Researchers have long discriminated between the sensory discriminative and hedonic (or affective) aspects of somatosensory perception (Major, 1895; McGlone, Wessberg, & Olausson, 2014). However, the existence of a dedicated system of receptors in the hairy skin (C-tactile afferents) that appear to be specifically tuned to detecting pleasant stroking touch makes this sense rather special (McGlone & Spence, 2010), if not entirely unique, given that sweet taste receptors might be considered part of a gustatory system dedicated to detecting innately pleasurable taste stimuli (Bartoshuk & Klee, 2013). Somatosensory perception is fundamentally multisensory, meaning that what we feel, not to mention what we think about the experience, is often modulated by inputs from the other senses (see Gallace & Spence, 2014, for a review). This opinion piece summarizes the latest evidence concerning such multisensory contributions to tactile perception focusing, in particular, on what is known about affective touch. Given that somatosensory perception includes low threshold mechanoreceptors, and well as sensory receptors that code for pain, itch, and temperature, the integration of the various submodalities of somatosensation (Nafe, 1934; Saal & Bensmaia, 2014; Schiller, 1956) might itself be considered as a form of multisensory integration. That said, it is currently something of an open question as to whether the same rules of multisensory integration operate within the various sub-modalities of somatosensation (see also McGlone & Spence, 2010).

Pleasant affective touch

The last quarter of a century or so has seen an explosive growth of interest in C-Tactile afferents, a class of somatosensory receptors that are found primarily in the hairy skin and which are associated with pleasant, or affective, touch (Croy, Drechsler, Hamilton, Hummel, & Olausson, 2016; Watkins, Dione, Ackerley, Wasling, Wessberg, & Löken, 2021). These unmyelinated tactile afferents project to insular cortex (Olausson, Lamarre, Backlund, Morin, Wallin, Starck, Ekholm, Strigo, Worsley, Vallbo, & Bushnell, 2002). Our understanding of this particular channel of the somatosensory system has grown rapidly in recent years, building on our pre-existing knowledge concerning the c-nociceptor system (e.g., Dubin & Patapoutian, 2010; McGlone & Spence, 2010).

Various attributes of stimulation affect the pleasantness of affective touch targeting the C-tactile afferent system. These include the optimal range of stroking speeds (c. 1-10 cm/sec; Croy, Luong, Triscoli, Hofmann, Olausson, & Sailer, 2016; McGlone, & Spence, 2010; though see also Luong, Bendas, Etzi, Olausson, & Croy, 2017; Sailor, Hausman, & Croy, 2020), the thermal aspects of tactile stimulation (unsurprisingly, body temperature touch is rated as more pleasant than ambient temperature touch; Ackerley, Backlund Wasling, Liljencrantz, Olausson, Johnson, & Wessberg, 2014). Intriguingly, significant differences in the preferred stimulation parameters have been reported as a function of the skin site, gender, and age of the person being stimulated (e.g., see Cruciani, Zanini, Russo, Mirabella, Palamoutsi, & Spitoni, 2021; Essick, McGlone, Dancer, Fabricant, Ragin, Phillips, Jones, & Guest, 2010). Even the human 'feel' of touch, when participants were gently stroked with a range of materials, contributes to its pleasantness (Wijaya, Lau, Horrocks, McGlone, Ling, & Schirmer, 2020). Given all of the various contributing factors, it is easy to imagine how pleasure may be constructed by the brain based on the combination more basic sensory and/or evaluative processes. It is certainly interesting to see how the growing interest in the CT afferent system in the hairy skin has led to an upsurge in research directed to skin sites other than the tips of the fingers which, as Gallace and Spence (2014) highlighted a few years ago, has always been by far the most extensively studied area of the skin surface.

While the gentle warm stroking of the hairy skin provides one means of delivering pleasant affective touch (that also helps to relieve stress; Walker, Cavieres, Peñaloza-Sancho, El-Deredy, McGlone, & Dagnino-Subiabre, 2020), it is important to stress that it is by no means the only kind of tactile stimulation that people find pleasant. Indeed, the majority of the objects that we inspect (and rate the pleasantness of) via the glabrous skin of the fingertips do not directly involve the stimulation of the CT afferents. One might naturally therefore wonder how people make affective judgments of tactile stimuli under such conditions. Of course, much the same question arises for the other senses that do not have such a dedicated affective receptor system. Many people find that a warm/hot bath delivers a highly pleasant form of tactile (thermal) stimulation (Cullen, Clarke, Hill, Menzies, Pugh, Steward, & Thake, 2020; Tonkin, 2021; see also Hoshino, Koge, Hachisu, Kodama, & Kajimoto, 2015). Sunbathing is also a very pleasant thermal (i.e., tactile) sensation for many people (Obrador-Pons, 2009), with some scientists even suggesting that the experience may become 'addictive' due to the resulting release of feel-good β-endorphins (Fell, Robinson, Mao, Woolf, & Fisher, 2014). The main

point to note here is that only a subset of pleasant affective tactile stimulation relies on the stimulation of the CT afferent system.

At the same time, however, it is important to recognize that affective (pleasant) touch never occurs in (unimodal or unisensory) isolation. That is, the multisensory attributes of (not to mention our beliefs about) the stroker, as well as the atmosphere, or context, in which affective touch takes place, can also influence the behavioural and neural markers of this phenomenon (Ellingsen, Leknes, Løseth, Wessberg, & Olausson, 2016). Even our perception of the thermal comfort turns out to be influenced by the colour properties of the environment in which we happen to find ourselves (see Spence, 2020c, for a review).

Here, it is perhaps worth noting that researchers have recently demonstrated that people tend to associate specific emotions with particular temperatures (Barbosa Escobar, Velasco, Motoki, Byrne, & Wang, 2021). The latter researchers, for example, recently demonstrated that people from different countries tend to associate different temperatures with different regions of the circumplex model of affect. According to the latter model of affect, the two underlying neurophysiological systems of valence and arousal subserve all affective states (Russell, 1980). In particular, temperatures of 0˚C and 10˚C were associated with negatively-valenced, low-arousal emotions; temperatures of 20˚C and 30˚C were associated with a positive valence, and low-to-medium and high-arousal emotions, respectively; and a temperature of 40˚C was associated with high-arousal and either positively- or negatively-valenced emotions. Such findings fit into a growing body of literature concerning the crossmodal correspondences that exist between a range of tactile stimulus attributes and stimuli presented in other sensory modalities (cf. Etzi, Spence, Zampini, & Gallace, 2016). Indeed, a growing body of evidence now demonstrates that emotional mediation often plays a key role in helping to explain the crossmodal correspondences that have been documented to date (see Spence, 2020a).

Multisensory contributions to the pleasantness of affective touch

Below, I briefly review the latest insights concerning the multisensory influences on the pleasantness of affective touch, highlighting the similarities with the already well-established multisensory influences on inanimate touch of surfaces/materials (e.g., Chang, 2010; Demattè, Sanabria, Sugarman, & Spence, 2006; Koijck, Toet, & Van Erp, 2015; Laird, 1932; Sijben, Hensel, Rodriguez-Raecke, & Freiherr, 2021; Spence, 2020b; cf. Özcan, Cupchik, &

Schifferstein, 2017), including cosmetic products, and even one's own hair (Churchill, Meyners, Griffiths, & Bailey, 2009). The role of olfactory cues in cosmetics and skin creams is a particularly intriguing, given that such products are specifically designed to feel pleasant to those who are applying them to their own skin (Abriat, Barkat, Bensafi, Rouby, & Guillou, 2004a; Abriat, Camarty, Christensen, & Williams, 2004b; Guest, McGlone, Hopkinson, Schendel, Blot, & Essick, 2013).

Auditory contributions to affective touch

Research on the 'parchment skin' illusion has revealed that the feeling of our own skin is modulated by the auditory cues that are associated with self-touch (Jousmäki & Hari, 1998). Similarly, our rating of the roughness and pleasantness of the feel of other inanimate surfaces such as, for example, sandpaper, are also influenced by the contact sounds we hear (Guest, Catmur, Lloyd, & Spence, 2003). Furthermore, the emerging field of research on sonification also reveals that the pleasantness of sounds that are synchronized with bodily movements can influence their rated (un-)pleasantness (see Stanton & Spence, 2020). So, for example, synchronizing the sound of a creaking door with the bending of the lower back in a group of individuals with lower back pain had a negative effect on affective ratings in one intriguing study (Stanton, Moseley, Wong, & Kawchuk, 2017).

Perhaps more surprisingly, the music that people happen to be listening to also affects their perception of the softness of the material that they happen to be evaluating at the time (Imschloss & Kuenhl, 2019). Moreover, the rated sexiness of another's touch also appears to be modulated by the 'sexiness' of the background music, even if that caress happens to be delivered by a robot (Fritz, Brummerloh, Urquijo, Wegner, Reimer, Gutekunst, Schneider, Smallwood, & Villringer, 2017). Such crossmodal effects are often explained in terms of the phenomenon of 'sensation transference', namely that what we feel about one stimulus (the music in this case) may carry over to bias what we feel about another stimulus (i.e., the tactile stimulation; this phenomenon termed 'affective ventriloquism' by Spence & Gallace, 2011). At the same time, however, one should presumably also acknowledge the possibility that music can, on occasion, give rise to musical chills and goosepimples. Such piloerection presumably also exert an influence over how the tactile stimulation of the hairy skin is experienced (Grewe, Nagel, Kopiez, & Altenmüller, 2005).

Olfactory contributions to affective touch

Several recent studies have extended earlier findings demonstrating that the pleasantness of affective tactile stimulation is modulated by the presence of ambient fragrance (Croy, Drechsler, Hamilton, Hummel, & Olausson, 2016). Perhaps unsurprisingly, interpersonal touch is rated as feeling more pleasant in the presence of a pleasant, as compared to an unpleasant ambient odour (Croy, D'Angelo, & Olausson, 2015; see Spence, 2020d for a review of the affective consequences of ambient scent/odour). Ambient scent also influences interpersonal trust (Lobmaier, Probst, Fischbacher, Wirthmüller, & Knoch, 2020; van Nieuwenburg, de Groot, & Smeets, 2019) and an individual's self-confidence (Roberts, Little, Lyndon, Roberts, Havlíček, & Wright, 2009; and see Syrjänen, Fischer, Liuzza, Lindholm, & Olofsson, 2021; Spence, 2021b, for reviews). Such ubiquitous crossmodal influences might also be expected to influence the rated pleasantness of interpersonal touch indirectly.

Here, one might also consider those sweet smells that have been shown to reduce pain, which can, perhaps be considered another kind of affective tactile sensation (or at least is often treated as such). For example, Prescott and Wilkie (2007) demonstrated that exposing their participants to a sweet pleasant scent resulted in being able to withstand the pain of the cold pressor test for significantly longer than if no scent or else a low sweetness scent was presented. Similarly, pleasurable thermal skin sensations are also modulated by inputs from the other senses, with the benefits of taking a bath being enhanced by the presence of a pleasant ambient scent (Field, Cullen, Largie, Diego, Schanberg, & Kuhn, 2008; Spence, 2021a).

Visual contributions to affective touch

A long history of research has highlighted the visual contributions to, and often dominance over, tactile perception of surface qualities (Guest & Spence, 2003a, b; Hutmacher, 2019). At the same time, however, when it comes to the perception of our own body, visual cues have often been shown to exert a dominant role, as in the now-classic rubber hand illusion (Botvinick & Cohen, 1998; Ehrsson, Spence, & Passingham, 2004). One of the unexplained anecdotal observations from the early days of rubber hand research was that the stroking of the (as it

happens) hairy skin appeared to lead to a larger RHI than the tapping of the skin. Nowadays, such findings make sense in terms of affective touch (stroking) leading to greater incorporation of the seen body into the body image. In such cases, note, the type of touch (affective or not) modulates the extent of vision's dominance over proprioception, and thus bodily incorporation (Jenkinson, Papadaki, Besharati, Moro, Gobbetto, Crucianelli, et al., 2020; Panagiotopoulou, Filippetti, Tsakiris, & Fotopoulou, 2017; though see also Spaccasassi, Frigione, & Maravita, 2021).

Gustatory/retronasalolfactory contributions to affective touch

Finally, here when considering the multisensory contributions to pleasant tactile sensations, it is important to consider oral-somatosensory food textures, such as creamy, that are typically found to be both pleasant and desirable. One might presumably consider this as yet another form of affective touch, though it has to be said that researchers interested in the sense of touch rarely tend to delve into the oral cavity (though see Gallace & Spence, 2014; Haggard & de Boer, 2014, for exceptions). If one accepts the suggestion that the asymmetrical distribution of C-tactile afferents (i.e., being present in hairy, but not glabrous, skin) reflects their evolutionary role in encouraging grooming behaviours, then that would seem to be little reason to believe that they would be found in the oral cavity. That said, I am not aware of any research on this question.

We are drawn to those textures/mouthfeel characteristics that are associated with the presence of energy-dense fat in food and drink. However, the difficulty associated with trying to generate well-parameterized sets of oral-somatosensory food textures has slowed research in this area. Nevertheless, what little research there is does appear to suggest that the creamy mouthfeel of foods can be enhanced by the presence of the appropriate olfactory cues (Bult, de Wijk, & Hummel, 2007), though in this case, experienced retronasally rather than orthonasally (see Wilson, 2021, on this important distinction). Cold, fatty, and sweet sensations such as provided by ice-cream also tend to be rated as giving rise to extremely pleasant mouth sensations (see Hyde & Witherly, 1993).

One other area that has recently seen growing interest is the way in which the tactile attributes of the surfaces we touch while eating and drinking (such as the surface of cans, cups, and cutlery) may affect the consumer's perception of the sensory-discriminative and hedonic

responses to that which they are tasting (see Carvalho, Moksunova, & Spence, 2020; Van Rompay & Groothedde, 2019; see also Mesz & Tedesco, 2021). Indeed, another intriguing, but little studied, area of research concerns the role of the lips, which are likely to be highly sensitive to the affective processing of ingested materials (see Gallace & Spence, 2014; Weinstein, 1968).

Sensory dominance in tactile perception

As we have seen time-and-again throughout this opinion piece, what we feel and what we think about the experience of touching, or being touched, is very often modulated by the sensory cues that happen to be presented at around the same time in other sensory modalities. Such crossmodal effects appear to occur regardless of whether the non-tactile stimuli are meaningfully-related to the toucher, or what is being touched. Thus far, no obvious distinction has been documented between the patterns of sensory dominance for sensory discriminative versus affective aspects of touch; nor has there been any noticeable differences in sensory dominance as a function of whether tactile stimulation occurs on glabrous versus hairy skin (cf. Ellingsen et al., 2016; von Mohr, Kirsch, Loh, & Fotopoulou, 2019). This might be considered surprising inasmuch as the CT afferents that would appear to be specifically-tuned to pleasant interpersonal touch have only been documented in the hairy skin. In the future, it will be interesting to directly to compare the multisensory influences on sensory-discriminative and affective touch as a function of the skin site that is stimulated (i.e., glabrous vs. hairy skin). Perhaps the most relevant analogy here when contemplating the possibility of different patterns of multisensory interaction at different skin sites concerns research showing that the visual sensory dominance over taste/flavour perception is reduced in supertasters, as compared to non-tasters (see Zampini, Wantling, Phillips, & Spence, 2008, Figure 5). Note that supertasters are likely to have a far higher density of taste buds on their tongue than non-tasters (Miller & Reedy, 1990).

Here, it is also worth considering how C-nociceptor activation would appear to demonstrate an 'interrupt function' when stimulated, regardless of what other sensory systems are normally dominant (Troche, Houlihan, Connolly, Dick, McGrath, Finley, & Stroink, 2015). That is, there is sense that pain will break-through and capture our attention no matter what. A similar story can be told for the other 'warning' cutaneous c-fibre, the itch nerve (van Laarhoven, van

Damme, Lavrijsen, van Ryckeghem, Crombez, & Evers, 2018). An open question in this regard is whether the c-tactile has a similar interrupt function? At the same time, however, it should be noted that attentional capture is by no means synonymous with sensory dominance, as was once believed (Posner, Nissen, & Klein, 1976).

Conclusions

As this review of the literature has hopefully made clear, affective touch always occurs in a multisensory context, be it the multisensory attributes of the person/object being touched or of the person who may be caressing us, or be it the multisensory attributes of the atmosphere in which tactile stimulation takes place. A growing body of research now highlights the fact that there are a multitude of multisensory influences on both the sensory-discriminative and hedonic aspects of touch. That said, there is currently simply insufficient data to assess whether the patterns of sensory dominance in the case of affective touch are modulated by the skin site being stimulated (i.e., glabrous vs. hairy skin) or the kind of perceptual judgment that people make. Looking to the future, it would be particularly interesting to extend the multisensory study of affective touch into the oral cavity (cf. Gallace & Spence, 2014).

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