

Hedonic Responses to Touch are Modulated by the Perceived Attractiveness of the Caresser

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Abstract—Previous research has shown that a specific type of C fiber, the C tactile afferents, are involved in detecting gentle, dynamic tactile stimuli on the skin, giving rise to affective responses in the central nervous system. Despite building on such bottom-up information flow, the hedonic perception and the physiological consequences of affective touch are influenced by various sources of top-down information. In the present study we investigated how perception of affective touch is influenced by the attractiveness of hypothetical caressers. Participants were stroked on the arm and the palm while looking at photos of high attractive and low attractive opposite-gender faces, and were instructed to imagine those people as the caressers. In a control condition no photo was paired with the touch. The stroking stimulation was delivered with a soft brush either on the forearm or on the palm, and either with a slower or faster speed. Participants rated the pleasantness of each stimulation, while electrocardiographic recordings were made to extract heart rate variability data. Results showed that participants preferred touch stimuli paired with high attractive faces; they also preferred palm stroking and slower stroking speed. Like subjective pleasantness ratings, heart rate variability responses to affective touch (slow) were higher for high attractive than for low attractive caressers, but were not selective for arm or palm stroking. Overall, the present study confirms that contextual social information plays a major role in affective touch experiences, influencing not only the hedonic quality of the experience but also the physiological state of the body.

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Key words: heart rate variability, affective touch, CT fibers.

INTRODUCTION

Touch and physical contact are pervasive in everyday existence, both in interaction with the inanimate surroundings and in human relationships. It has recently been proposed that human touch associated with emotional content can be functionally distinguished from the more well-known “discriminative touch” (Morrison et al., 2010; Olausson et al., 2010; McGlone et al., 2014), to the extent of being sub-served by a distinct neural network (Morrison, 2016a; Eriksson Hagberg et al., 2019). The soothing, hedonic function of this “affective touch” has been associated with the activation of a particular type of unmyelinated cutaneous afferents called “C tactile” (or CT) afferents, found in the follicle-rich hairy skin but not in the smooth skin of the palm. CT afferents respond most vigorously to gentle, moving touch at a relatively slow velocity (1–10 cm/s) and at skin temperature,

i.e. around 32 °C (Ackerley et al., 2014a). Furthermore, mean CT firing frequency and perceived pleasantness of touch on the skin display a positive correlative relationship (Löken et al., 2009), indicating that the intermediately slow velocities are not only more effective in activating CT fibers compared to very slow and fast velocities, but they also give rise to higher hedonic responses.

These observations have led researchers to propose the “social touch hypothesis” (Morrison et al., 2010), according to which CT afferents are responsive to features of touch that are most likely to occur during social interactions. Therefore, it is not surprising that this type of physical contact is mostly used to communicate positive signals, ranging from support to prosocial and affiliative intentions (Crusco and Wetzel, 1984; Coan et al., 2006; Hertenstein et al., 2007; McIntyre et al., 2019). In accordance with this positive affective value associated with touch, it also has been proposed that social touch can work as a stress buffer to regulate physiological responses (Morrison, 2016b). Previous studies have shown that receiving touch of different types may trigger physiological responses such as decreases in salivary cortisol levels (Field et al., 2005), blood pressure

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Abbreviations: CT, C Tactile; HRV, Heart Rate Variability; RMSSD, Root Mean Square of the Successive Differences.

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(Grewen et al., 2003), heart rate (Triscoli et al., 2017a), and corrugator responses (Mayo et al., 2018).

Nevertheless, despite the relationship between optimal stimulation of CT afferents and a certain degree of felt pleasantness, not all inter-individual touch experiences are perceived as pleasant. As for many other sensory modalities, tactile signals coming from the periphery of the body are modulated by central “top-down” mechanisms that contribute to determine the final hedonic percept (Ellingsen et al., 2016). This means that along with the internal motivations, contextual factors concomitant to the touch experience play a major role in the final hedonic evaluation and influence the behavioral response. Particularly important is the identity of the toucher (Suvilehto et al., 2015), his/her physical characteristics, and intentions. For instance, in one experiment heterosexual men liked the exact same touch better if they believed it was delivered by a female compared to a male experimenter, when in fact the experiment was always female (Gazzola et al., 2012). The coupling of a touch stimulus with different emotional expressions can also modulate the pleasantness of touch; this is true both when these affective cues come from the toucher herself (Ravaja et al., 2017) or when they are simply paired to the touch (Ellingsen et al., 2014). Another important physical characteristic of the toucher might be her/his perceived attractiveness, especially when the touch comes from a stranger and few other cues are available.

Decades of work in social psychology have shown that attractiveness heavily affects first impressions and influences our attitude toward others' actions. For instance, more attractive people are favored in job interviews by other-sex interviewers (Agthe et al., 2011) and new products are rated more favorably when inventors are believed to be attractive (Baron et al., 2006). Within minor inter-individual differences, it has been suggested that humans of all cultures are possess an innate universal attractiveness detector (Langlois and Roggman, 1990), which detects face traits associated with positive personality attributes and health status (Little, 2014). This might be particularly relevant in mate selection, where traits perceived as attractive may have been selected by evolution to signal a greater likelihood of reproductive success (Jokela, 2009). Interestingly, tactile interactions are crucial in the development of affiliation in general, and in sexual relationships in particular (Dunbar, 2010). Therefore, it is likely that the hedonics of tactile interactions with opposite-gender individuals who are potential mates are deeply influenced by the perceived attractiveness of the interactor.

The present work aimed at investigating the effect of attractiveness on affective and physiological responses during tactile interactions with strangers. Previous research (Ellingsen et al., 2014) has shown that attractiveness can modulate subjective responses to somatosensory stimulation, but to our knowledge this is the first study to modulate attractiveness of an imagined toucher to investigate its effects on touch perception and autonomic nervous system reactivity. We therefore measured hedonic responses to touch associated with faces of low and high attractiveness while tracking cardiac

activity for measuring heart rate variability (HRV). HRV is a reliable indicator of vagal nerve function, which represents the contribution of the parasympathetic nervous system to cardiac regulation and is regarded as an index of several self-regulation mechanisms in different domains, e.g. social, affective, and cognitive (Thayer et al., 2010). Although different theories exist about the implication of HRV in psychophysiological research (Porges, 1995; Porges et al., 1999; Thayer and Lane, 2000; Thayer et al., 2009), these share common ground in their reliance on the interpretation of low HRV values (both at rest and in response to stimuli) as an endophenotype for a broad range of dysfunctions, reflecting poor flexibility following environmental stimuli. Furthermore, HRV has been shown to be responsive to tactile interactions, since Triscoli and colleagues have recently showed that long-lasting CT-optimal stroking increases HRV (Triscoli et al., 2017b).

Therefore, we hypothesized a clear distinction between touch paired with low and high attractive faces in both affective and physiological responses: specifically, we expected to see higher pleasantness ratings and higher HRV values during touch paired with high attractive faces compared to touch paired with low attractive faces. Furthermore, in light of the literature on affective touch, we predicted higher ratings and HRV values for slow over fast touch, and for touch on the arm (hairy skin) over touch on the palm (glabrous skin). Finally, we expected to observe a modulation of these effects according to the attractiveness of the concurrent visual stimulus.

EXPERIMENTAL PROCEDURES

Participants

Thirty-eight heterosexual right-handed participants (17 females) were recruited using the Online Recruitment System for Economic Experiments (ORSEE; Greiner, 2015) at Linköping University and were financially compensated for their time. The mean age of the sample was 24.03 years (SD = 4.40; range 19–43). Sample size was determined on the basis of previous studies assessing for autonomic effects of CT-optimal and -non-optimal touch (Pawling et al., 2017; Triscoli et al., 2017a, 2017b; Etzi et al., 2018; Mayo et al., 2018). All participants were skin-disease free and reported no diagnosis of psychiatric illness. All gave written informed consent. Experimental procedures were approved by the Linköping Regional Ethics Board and were in accordance with the declaration of Helsinki.

Experimental set-up

During the experimental phase, participants comfortably sat in front of a computer screen and placed their left arm on a pillow situated on a table. Participants could not see their forearm and hand since a curtain hung just above the table. On the other side of the curtain a female experimenter whom participants met prior to the experiment, delivered brushing stimuli to the participants' skin throughout the experiment with the

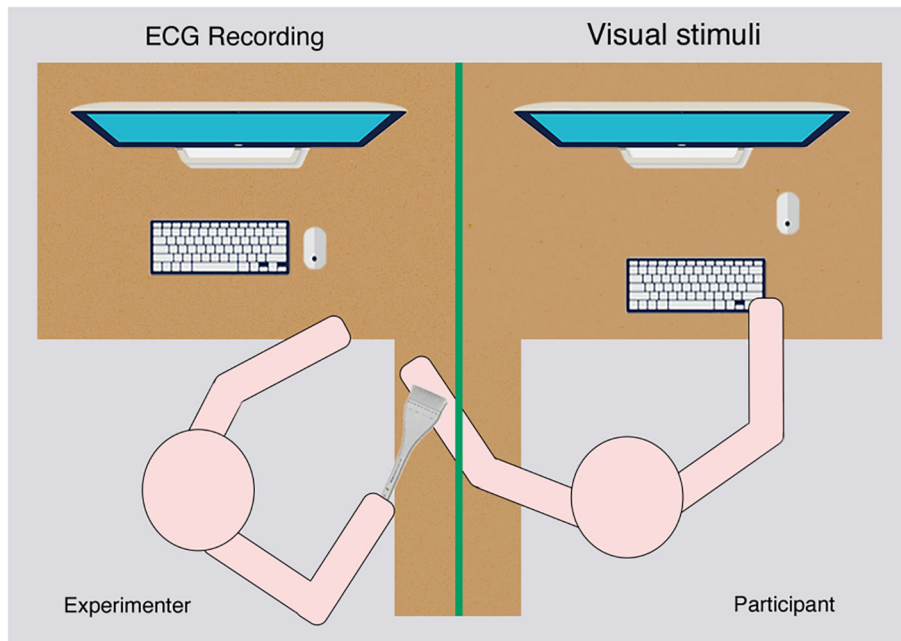


Fig. 1. Schematic illustration of the experimental set-up. Participants were stimulated on the left arm while presented with visual stimuli on a screen positioned in front of them. A curtain (green line) hanging over the left arm prevented the participant from having any visual feedback of the brushing stimulation. Participants used their right hand to rate the tactile stimuli through a visual analog scale presented on the screen.

help of auditory cues heard via headphones (Fig. 1). Prior to the start of the experiment, the same experimenter marked a stimulation area 9 cm long on both skin sites (forearm and palm) by drawing 4 lines every 3 cm.

Behavioral task

The task consisted of five blocks of brush stimulations (Fig. 2) delivered with a 7 cm wide soft goat-hair brush. All stimulations had a duration of 9 s, according to a well-established protocol (Morrison et al., 2011a, 2011b). Each stimulation was interleaved with a pause of 4 s, during which a black fixation cross was displayed on a white screen. At the end of each stimulation, a visual analog scale appeared on the screen for 6 s and participants were asked to report the pleasantness of the last received tactile stimulation using a mouse with their right hand. The extremes of the scale were labeled as 'unpleasant' and 'pleasant' and corresponded to values of -10 and $+10$, respectively. Brushing was applied to both the dorsal forearm and the palm of the hand at two different velocities: approximately 3 cm/s (slow) and 27 cm/s (fast). Nine total strokes were delivered in the slow condition, whereas 27 strokes were delivered in the fast condition. The experimenter delivering the brushing was trained beforehand to apply a constant force throughout the experiment. In the first, third and fifth blocks brush stimulations were paired with faces appearing in the center of the screen, whereas in blocks 2 and 4 no face was presented and a change of color of the fixation cross from black to red signaled the occurrence of the tactile stimulation phase. Hence, each trial belonged to one of 12 conditions produced by the interaction between the factors:

"Attractiveness" (Unpaired, High attractive face, Low attractive), "Site" (Arm, Palm), and "Velocity" (Slow, Fast). There were 6 trials per condition, therefore each participant was presented with 72 stimulations. In the face blocks each face was presented twice across the three blocks with constant site of stimulation but different velocity. In order to avoid the inconvenience of continuously switching the position of the arm to make available the dorsal forearm or the palm, stimulations in each block were grouped in a way that participants had to switch to a different position only once per block. Prior to the experiment participants were instructed to imagine that the person they saw on the screen during each trial of the face blocks was behind the curtain and was touching them. No particular instructions were given for the Unpaired blocks. The task was administered with two different stimulus randomizations to ensure that the first stimulations in the first blocks of each type could be both

arm and palm (the sequence starting with arm stimulation is represented in Fig. 2).

Visual stimuli and manipulation check

Faces were selected from The Oslo Face Database (Chelnokova et al., 2014), a database consisting of 116 female and 95 male faces, rated for attractiveness and trustworthiness. For each gender, we selected the twelve most and the twelve least attractive faces to present to the opposite gender participants. At the end of the task, participants rated the attractiveness of the faces that were previously paired with the tactile stimulations, using a visual analog scale that appeared on the screen for 10 s and whose extremes were labeled as 'unattractive' and 'attractive', corresponding to values of -10 and $+10$, respectively. One-tailed paired-samples t-tests run in SPSS 24 (IBM Software) showed that all but one participant judged the twelve high attractive faces as significantly more attractive (Mean \pm SD: 6.80 ± 1.32) than the low attractive faces (Mean \pm SD: 2.37 ± 1.24 ; $p < 0.01$ for all). The female participant who did not show this significant preference for high attractive faces over low attractive faces ($p = 0.07$) was therefore excluded from analysis.

Electrocardiography

To obtain ECG data, disposable Ag/AgCl snap gel electrodes were placed at the right supraclavicular fossa and mid-axillary on the left and right sides of the participants abdomen. Sites were cleaned with alcohol

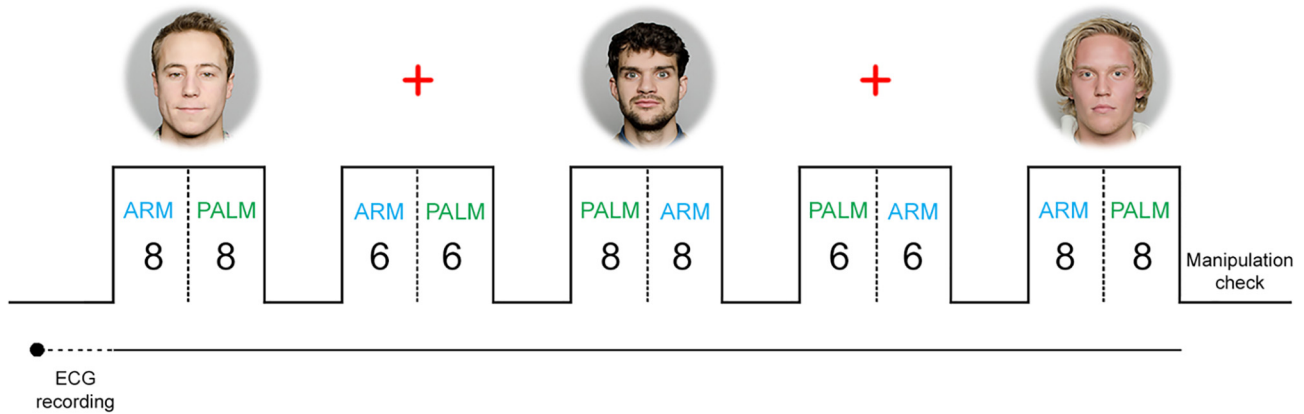


Fig. 2. Example of task timeline. Each participant received 72 stimulations, 6 for each condition and distributed across 5 blocks. Tactile stimulations were either paired or not with faces in alternating blocks. In the unpaired case stimuli occurred when the fixation cross turned from black to red. In each block, stimulation was equally distributed across arm and palm conditions and organized in 2 mini blocks to minimize arm movements (dashed lines indicate switches from arm to palm or viceversa). Throughout the task ECG recording was conducted. At the end of the task participants reported their judgment about the attractiveness of the face stimuli.

prior to electrode placement. Heart rate recording started as soon as the participant seated comfortably in front of the computer, before receiving oral instructions about the task, and being presented with a practice trial. Data were sampled at 1000 Hz and relayed to the ECG100C amplifier, Biopac MP150 system, and Acqknowledge software (Biopac Systems, Inc., Goleta, CA, USA). Since the aim of the study was not to measure a change of HRV during an intervention compared to a rest value, but rather compare different interventions (the 12 conditions listed above), we did not include a baseline recording in our protocol.

Behavioral data analysis

Behavioral data were analyzed with SPSS 24 (IBM Software). Pleasantness ratings from 37 participants (16 females) were submitted to a repeated measure ANOVA with three within-subject factors: “Attractiveness” (High attractive, Low attractive, Unpaired), “Site” (Arm, Palm), and “Velocity” (Slow, Fast); and a between-subject factor: “Gender” (Female, Male). Post hoc tests were run through pairwise comparisons with initial significance level $p = 0.05$, Bonferroni-corrected.

To investigate whether starting with arm or palm could influence affective ratings of brushing stimuli across conditions, we ran a repeated measures ANOVA with “Attractiveness” (High attractive face, Low attractive, Unpaired), “Site” (Arm, Palm), and “Velocity” (Slow, Fast) as within-subject factors and a between-subject factor: “Randomization” (Arm first, Palm first). Post hoc tests were run through pairwise comparisons with initial significance level $p = 0.05$, Bonferroni-corrected.

Electrocardiography data analysis

Acqknowledge software 5.0.1 (Biopac Systems, Inc., Goleta, CA, USA) was used to extract heart rate and heart rate variability (HRV). The automatic function

detecting human ECG complex boundaries implemented in the software was first used to detect QRS complexes in the whole recording. Subsequently, artifacts in the R-to-R series were visually detected and manually corrected. The most common artifacts were missing heartbeats and multiple peak identifications. Missing peaks were also corrected, as suggested by the guidelines of the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (Task Force of the European Society of Cardiology and The North American Society of Pacing and, 1996). Heart rate variability for each stimulation interval was calculated via the Multi-epoch Heart Rate Variability-Statistical analysis present in Acqknowledge (<https://www.biopac.com/application/ecg-cardiology/advanced-feature/heart-rate-variability>). In particular, the software computed the root mean square of the differences between adjacent NN intervals (RMSSD) in all the 9 s intervals in which tactile stimulations occurred. RMSSD is the most used time domain index of HRV and it is considered a stable and valid measure of cardiac vagal tone. Moreover, RMSSD is recommended for HRV measurements in short intervals (Shaffer and Ginsberg, 2017). In addition to the female participant excluded from behavioral analysis, two male participants were excluded from HRV analysis: one because of technical defective ECG trace, the other one because considered an outlier. In fact, to identify outliers a two-step process was conducted: first, single trial values within each participant were excluded if they exceeded 3 standard deviations from the participant mean value; then, a participant was excluded if their newly calculated mean value exceeded 3 standard deviations from the whole sample mean. For the remaining 35 participants (16 females) RMSSD values were first log-transformed to conform normality and subsequently submitted in SPSS 24 to a repeated measure ANOVA with three within-subject factors: “Attractiveness” (High attractive, Low attractive, Unpaired), “Site” (Arm, Palm), and “Velocity” (Slow, Fast); and a between-subject factor: “Gender” (Female, Male). Post

hoc tests were run through pairwise comparisons with initial significance level $p = 0.05$, Bonferroni-corrected.

RESULTS

Pleasantness rating

Mean and standard errors of pleasantness rating for each condition are reported in Table 1. The results of the repeated measures ANOVA showed a main effect of “Attractiveness” ($F = 43.306$, $p < 0.001$, $\eta_p^2 = 0.553$), which *post-hoc* comparisons explained in terms of a preference for unpaired touch and touch paired with high attractive faces over touch paired with low attractive faces ($p < 0.001$ for both comparisons), whereas unpaired and high attractive conditions did not differ ($p = 0.488$). The same analysis also showed a significant main effect for factors “Site” ($F = 15.552$, $p < 0.001$, $\eta_p^2 = 0.308$) with a preference for the palm over the arm (Fig. 3A) and a significant main effect of “Velocity” ($F = 36.727$, $p < 0.001$, $\eta_p^2 = 0.512$) with a preference for slow over fast stimulations. Furthermore, as shown in Fig. 3B, a significant interaction between “Attractiveness” and “Velocity” ($F = 22.338$, $p < 0.001$, $\eta_p^2 = 0.390$) was observed, indicating that pleasantness ratings to slow touch significantly changed across the three Attractiveness conditions (unpaired > high attractive > low attractive; $p < 0.003$ for all comparisons), whereas for fast touch this applied only to trials with faces (high attractive > low attractive, $p < 0.001$) with no significant difference between unpaired and high attractive trials ($p = 0.205$). Finally, a main effect of the between factor “Gender” was found ($F = 5.144$, $p = 0.033$, $\eta_p^2 = 0.124$), with males showing higher pleasantness ratings than females. This was particularly true for face stimuli (high attractive and low attractive) compared to unpaired stimuli, as shown by the significant interaction between “Attractiveness” and “Gender” ($F = 4.536$, $p = 0.024$, $\eta_p^2 = 0.115$); in fact, *post hoc* comparisons showed that males showed higher ratings than females for high attractive ($p = 0.002$) and low attractive faces ($p = 0.032$), whereas there was no difference in unpaired trials ($p = 0.906$).

When looking at the results of the ANOVA with “Randomization” as between-subject factor, we observed a significant three-way interaction between the factors “Attractiveness”, “Site” and “Randomization” ($F = 8.002$, $p = 0.002$, $\eta_p^2 = 0.186$), indicating that participants who started with palm touch rated touch on the palm paired with high attractive faces significantly higher than participants who started with touch on the arm ($p = 0.034$). No other main effects or interactions were found significant, in particular the interaction between the factors “Site” and “Randomization” ($F = 3.362$, $p = 0.075$, $\eta_p^2 = 0.088$).

Heart rate variability

Mean and standard errors of the pre-transformed RMSSD values for each condition are reported in Table 2. The results of the repeated measures ANOVA on the

log-transformed data showed no main effects of “Attractiveness” and “Velocity”, and also the main effect of site was not significant ($F = 3.656$, $p = 0.065$, $\eta_p^2 = 0.100$). We observed instead a significant interaction between factors “Attractiveness” and “Velocity” ($F = 3.863$, $p = 0.026$, $\eta_p^2 = 0.105$), with *post-hoc* tests showing that slow touch rather than fast touch led to higher HRV only when paired to high attractive faces ($p = 0.021$) and not when paired with low attractive faces ($p = 0.314$) or when unpaired ($p = 0.483$, Fig. 3C). We also observed a significant interaction between factors “Attractiveness” and “Gender” ($F = 4.553$, $p = 0.020$, $\eta_p^2 = 0.121$), which indicated that female participants tended to have higher HRV values than males, especially in the low attractive condition ($p = 0.057$).

DISCUSSION

In this study we investigated how a contextual factor, namely attractiveness, shapes hedonic perception in tactile interactions with imagined unfamiliar touchers. We brushed participants’ skin while they viewed opposite gender faces and were instructed to imagine that that person was caressing them. By manipulating face attractiveness level (high vs low), velocity (CT-optimal vs CT-non-optimal) and site (forearm vs palm) of the touch, we were able to show that: (1) touch is most pleasant when it is paired with an attractive face; (2) attractive faces particularly enhance subjective responses to slow caresses; (3) touch delivered to the palm is preferred over touch delivered to the forearm, regardless of the imagined toucher’s attractiveness; (4) heart rate variability increases only for slow touch paired with attractive faces.

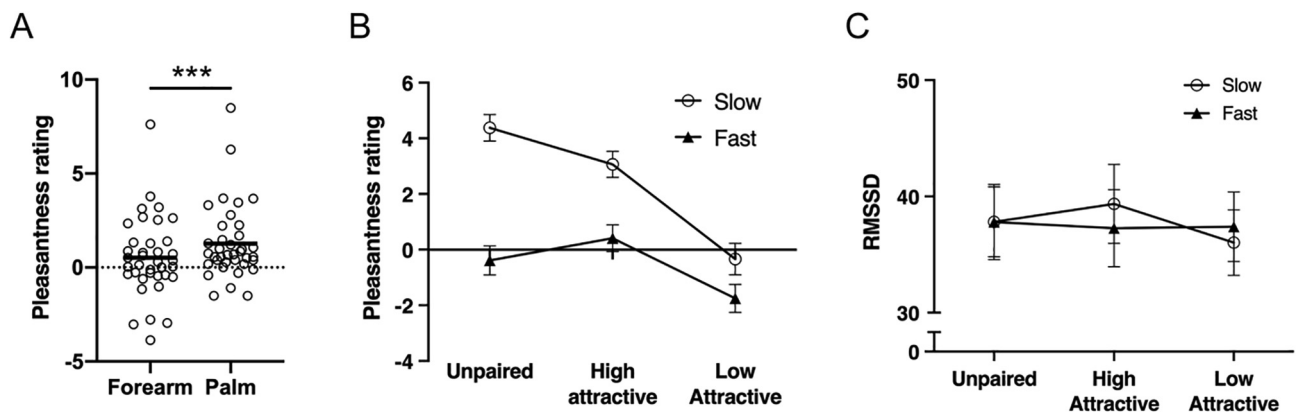
Tactile interactions are critical throughout human life and constitute an important platform for establishing social connections. Therefore, it is not surprising that research about touch and social interactions in the recent past has mostly focused on the beneficial effects of interpersonal touch and the detrimental consequences of the lack of it (Gallace and Spence, 2010; Field, 2014; Sailer and Ackerley, 2019). Nevertheless, the context in which social interactions occur may completely alter the valence of the affective experience of the touch from another person from positive to negative. The present study suggests that in tactile interactions with strangers, attractiveness might be an important factor determining the ultimate hedonic perception of the experience. The evidence for such a claim comes from both behavioral and psychophysiological data.

Behavior

On the behavioral level, touch paired with high attractive faces was preferred over touch paired with low attractive faces but was not hedonically discriminated from unpaired touch. This indicates that face information can influence the hedonic perception of touch, with touch experienced as less pleasant unless the face is perceived as attractive. Interestingly, despite slow touch being preferred over fast touch in each condition, the

Table 1. Mean and standard errors of the pleasantness rating

		Females		Males	
		Mean	SEM	Mean	SEM
Unpaired	Slow Forearm	3.51	0.87	4.87	0.55
	Fast Forearm	-0.51	0.53	-1.04	0.86
	Slow Palm	4.15	0.79	4.74	0.60
	Fast Palm	0.62	0.62	-0.44	0.78
High Attractive	Slow Forearm	1.39	0.75	3.69	0.39
	Fast Forearm	-1.07	0.66	0.43	0.68
	Slow Palm	1.74	0.79	4.72	0.53
	Fast Palm	0.26	0.63	1.63	0.63
Low Attractive	Slow Forearm	-2.21	0.95	0.45	0.55
	Fast Forearm	-3.12	0.77	-1.34	0.58
	Slow Palm	-1.15	1.03	0.90	0.58
	Fast Palm	-2.27	0.84	-0.74	0.65

**Fig. 3.** The graph in panel (A) shows the individual mean values for forearm and arm stimulations to visualize the main effect of Site in the pleasantness rating. The other two graphs show the interaction effect between the factors “Attractiveness” and “Velocity” in the behavioral data (B) and in the HRV data (C).**Table 2.** Mean and standard errors of the RMSSD values.

		Females		Males	
		Mean	SEM	Mean	SEM
Unpaired	Slow Forearm	41.15	5.10	36.77	3.84
	Fast Forearm	40.66	5.01	38.60	4.87
	Slow Palm	38.42	4.58	35.51	3.96
	Fast Palm	36.72	4.40	35.49	4.79
High Attractive	Slow Forearm	41.96	5.90	39.01	4.79
	Fast Forearm	41.27	5.23	35.81	5.47
	Slow Palm	40.44	5.08	36.64	3.93
	Fast Palm	38.78	4.29	34.08	4.29
Low Attractive	Slow Forearm	40.83	4.14	33.86	3.91
	Fast Forearm	39.80	4.80	33.86	3.77
	Slow Palm	38.38	4.00	32.18	3.92
	Fast Palm	42.73	4.51	34.39	4.38

significant interaction between velocity of touch and context of touch (unpaired, high attractive toucher or low attractive toucher) shows that the emotional response to slow touch differentiates the three conditions. Namely, unpaired touch elicited more positive responses than touch paired with high attractive faces, which in turn was preferred over slow touch paired with low attractive faces. In contrast, affective responses to fast touch were significantly lower to touch paired with low attractive faces, but they did not differ between unpaired touch and touch from high attractive faces.

The slow touch used in this study (3 cm/s) is among the most used experimental stimulations in paradigms studying social touch and falls in the range of touch velocities (1–10 cm/s) that correspond to spontaneous affective touch interactions, e.g. caresses (Hertenstein et al., 2007; Morrison et al., 2010; Croy et al., 2016). It should be noticed, however, that a very recent study has shown that when asked to spontaneously stroke other people (e.g., their partner, friend or even a stranger), participants tend to do so with a mean velocity falling between 10 and 20 cm/s (Strauss et al., 2020). Since a consistent investigation on the psychophysical responses to touch within this interval is not currently available, future studies will address whether the slow touch used in this study is physiologically and affectively distinguishable from that delivered in the 10–20 cm/s range. Nevertheless, in the light of current evidence, it is not surprising that responses to the slow touch are well differentiated across conditions, and they indicate that when tactile interactions with imagined touchers occur with a velocity associated with higher affective value, the attractiveness of the toucher plays a major role.

One potential mediator of such effect is believed to be a class of afferent nerves so far found in the hairy skin only, but not on the glabrous skin of the palms and soles. These CT fibers, show greatest increases in firing frequency for stimuli in the aforementioned velocity range (1–10 cm/s), as well triggering the most positive affective responses, compared to very slow (< 1 cm/s) or fast velocities (> 10 cm/s). Accordingly, we expected to see a general preference for touch on the forearm (hairy skin) over touch on the palm (glabrous skin). This was not the case, and instead we found a preference for touch on the palm. Whereas the initial evidence had suggested a general preference for touch on the hairy skin over glabrous skin (Löken et al., 2009), a growing number of studies employing various paradigms have shown an undifferentiated hedonic response to arm and palm stroking (Ackerley et al., 2014b; Perini et al., 2015; Kirsch et al., 2018).

Furthermore, affective ratings for hairy and glabrous skin stimulation have been shown to heavily depend on the order of stimuli presentation, with preceding hairy skin stimulations positively influencing the perception of pleasantness of following palm stimulations, even in block designs (Löken et al., 2011). In our study there was a significant three-way interaction between the factors “Face”, “Site” and “Randomization” indicating that participants who started with palm touch rated touch on the palm paired with high attractive faces significantly

more pleasant than participants who started with touch on the arm. Such an effect was not observed for arm touch. Therefore, if anything, we observed a facilitating effect of initial palm touch on subsequent palm stimulations, specific to high attractive faces and regardless of velocity. A possible explanation for such difference compared to the results of Löken and colleagues (Löken et al., 2011) might lie in the more complex structure of our task, possibly indicating that the presence of other factors like attractiveness, or more generally tactile interactions with unfamiliar touchers, might influence the intrinsic hedonic properties of forearm touch in favor of palm touch. Nonetheless, more controlled experiments which specifically look at how attractiveness and type of skin stimulated interact in affectively rich tactile experiences are needed to cast light on this aspect.

More generally, the crucial conditions of this study (high and low attractive faces) involved the presentation of two types of sensory stimuli (tactile and visual), and required participants to integrate them to produce a hedonic response, whereas another condition (no face) did not require such multisensory integration. This differential recruitment of sensory and attentional resources could explain the pattern of hedonic responses to touch in our study. There is indeed existing research showing that attention and allocation of cognitive resources influence tactile perception (Schubert et al., 2008; Lier et al., 2018), especially when attention must be directed to concomitant stimuli from other sensory modalities (Hanke et al., 2016). If the presentation of an additional stimulus (photo) competing for attention with the brushing stimulus affected behavioral responses, this would equally influence both high attractive and low attractive trials in comparison to unpaired trials. Nevertheless, whereas affective responses to touch paired with low attractive faces were consistently lower than unpaired touch, this was not the case for touch paired high attractive faces, which was rated as pleasant as unpaired touch when the touch was delivered at higher speed. Therefore, even if attention plays a general role in shaping hedonic responses to touch, the interaction between the attractiveness of the paired faces and the velocity of the touch speaks for the intervention an additional factor. Whether this factor is attributable to differential CT response or other mechanisms will require further investigations.

Another interesting behavioral observation comes from the comparison between males’ and females’ affective ratings. Indeed, males showed consistently higher ratings across all touch conditions. On a first glance, this result would seem to contradict the findings of a recent meta-analysis regarding sex differences in response to affective touch (Russo et al., 2020). Across 13 studies it was found that females perceive affective touch as more pleasant than males. Nevertheless, some of the included studies (Triscoli et al., 2013; Ackerley et al., 2014b; Jönsson et al., 2015) did not find such a difference. On the other hand, our result is corroborated from other evidence in the touch literature: for instance, recent work has shown that female touch is generally considered more pleasant than male touch across both

genders (Suvilehto et al., 2015). Furthermore, our results can also be interpreted as a more specific gender difference when the considered variable is touch from strangers. Indeed, when Suvilehto et al. computed the ‘touchability index’ for their participants, the only figure whom males would allow to touch more than females were in fact female strangers (Suvilehto, pers comm)¹. This applies regardless of all the other factors tested in our experiment, since no interactions between the gender and site, velocity or context of touch were found. Therefore, it appears that males’ and females’ affective responses to touch are differentially modulated by a broad range of contextual factors. In this regard, a potential confound in our experiment might be that the brushing stimuli were delivered by a female experimenter whom participants met before the experimental session started.

Heart rate variability

On the psychophysiological level, heart rate variability (HRV) results confirm that the attractiveness of the toucher plays a major role in the hedonic perception of tactile interactions. Slow touch was associated with higher HRV than fast touch only during trials with high attractive faces. Specifically, slow touch significantly increased HRV compared to faster touch, but only when the imagined toucher was perceived as attractive. This occurred regardless of the site of the stimulation (hairy or glabrous skin).

According to several theories (Porges, 1995; Thayer and Lane, 2000) heart rate variability is a reliable index of the capacity of the central nervous system to control cardiac activity through parasympathetic influence and in turn adjust metabolic strategies to adapt to constantly changing environmental demands (Thayer et al., 2010). Both resting and task related higher HRV values are generally associated with better performances across many domains, like emotion and cognitive regulation, possibly reflecting higher flexibility. For instance, psychological stressors often cause decreases in heart rate variability (Chandola et al., 2008; Dimitriev and Saperova, 2015). Accordingly, higher values of heart rate variability are thought to reflect better adaptation to stressors (Kim et al., 2018). Hence, the observation of higher HRV values during slow touch received by an attractive person may indicate a more favorable reaction to a potentially stressful and affective meaningful interaction with a stranger, which is not observed for the touch of a low attractive person.

An alternative interpretation is related to the suggested link between HRV and social cognition. For instance, it has been shown that HRV is positively related to performances in social tasks (Quintana et al., 2012), whereas many psychiatric disorders that show impairment of social cognition skills are associated with

reduced HRV (Kemp and Quintana, 2013; Chalmers et al., 2014). In this framework, the affective touch of an attractive person might have represented a highly salient stimulus which needed increased social attention compared to the other stimuli.

Furthermore, it should be noted that our data also showed a significant interaction between context of the touch and participants’ gender, which hinted at higher HRV values for females compared to males, especially for touch paired with low attractive faces. Heart rate variability has been shown to vary quite consistently between males and females across many experimental settings (Koenig and Thayer, 2016). Females are usually reported as having greater vagal tone, hence higher values of HRV, which is in keeping with what we observed in our data. In our sample females showed higher HRV values than males in a consistent manner across all conditions, though it did not reach significance probably due to high variability in the sample. Therefore, rather than a specific effect of our task, we interpret this result as reflecting a general tendency for female to have greater basal levels of vagal activity.

Although our results show a striking correspondence between pleasantness ratings and HRV values, the complex relationship between subjective affective touch and physiological responses remained to be clarified. To date, research investigating this relationship has produced inconclusive and contradicting results. For instance, studies investigating facial muscles reactivity to slow touch have either found an increased zygomatic response (associated with positive affect) unlinked to emotional ratings (Pawling et al., 2017), or relaxation in the corrugator muscles (activation of which is associated with negative affect) without effects on zygomatic activity (Mayo et al., 2018; Ree et al., 2019).

This uncertainty also applies to research investigating the relationship between subjective reports to touch and HRV response. On the one hand, prolonged slow touch has already been shown to decrease heart rate (Triscoli et al., 2017a) and enhance HRV (Triscoli et al., 2017b), thus providing evidence for a significant influence of slow touch on the autonomic nervous system. In the latter study, slow brushing delivered with a robot was compared to a vibratory stimulus and HRV was measured as SDNN (standard deviation of normal to normal R-R intervals). Unlike Triscoli and colleagues, we measured HRV as RMSSD, another time-domain measurement, that (compared to SDNN) is more influenced by the parasympathetic nervous system and is more adapted for measuring HRV in shorter intervals (Shaffer and Ginsberg, 2017). On the other hand, another study (Ree et al., 2020) in which healthy participants repeatedly received short skin-to-skin slow touch stimulations on their forearm for about 60 min did not find an increase of RMSSD values compared to a rest period.

Compared to both these studies, a chief novelty of our work lies in the evidence of how the manipulation in a variable which is “external” to the touch per se (attractiveness of the toucher) can modulate slow touch effects on a psychophysiological index like HRV. Altogether, this evidence points to the importance of the

¹ On our request, Suvilehto and colleagues tested whether males would allow females strangers to touch them more than females would allow male strangers to touch them. They ran an ANOVA with the factors “Toucher gender” and “Subject gender” and found a significant interaction ($F = 12.310, p < 0.001; \eta_p^2 = 0.002$), meaning that males reported to allow more touch from a stranger than females, as long as the toucher is a female (see Fig. 4 in Suvilehto et al., 2015).

measures used for quantifying HRV and to the contextual manipulations occurring meanwhile touch is delivered. In fact, in line with the findings of Ree and colleagues (Ree et al., 2020), in the present study slow touch did not result in a general HRV increase, at least compared to fast touch. We found instead a specific interaction with the attractiveness factor, indicating that HRV might increase following slow touch only in specific circumstances. It must be also noted that unlike Ree and colleagues' study, we did not measure baseline HRV. Therefore, our design is not suitable for detecting specific changes in HRV following slow touch. Interestingly, whereas we stimulated both forearm and palm in our study, the forearm was the only skin site stimulated with slow touch in both Triscoli and colleagues' and Ree and colleagues' works, but with two different modalities: in the former brushing was used, similar to the present study; in the latter instead, skin-to-skin touch was delivered by an experimenter. Despite hand and brush touch are rated similarly by healthy participants (Strauss et al., 2019), future studies will be needed to investigate whether touch modality plays a role in modulating HRV responses.

Finally, contrary to our hypothesis, arm touch did not elicit significantly higher HRV than palm touch. This is in keeping with the behavioral data, in which palm touch was preferred over arm touch. This result suggests that unlike touch velocity, skin type (hairy or glabrous) might not be a factor in the physiological response to touch. This lends support to the proposition that activation of CT-fibers is not a necessary component of affective touch responses (Ackerley et al., 2014b), with many cognitive factors like learning, motivation and expectation playing an important role (Ellingsen et al., 2016). Nevertheless, in our knowledge this is the first study collecting HRV responses while touch is delivered to both hairy and glabrous skin, therefore further studies focusing on this aspect will be needed to clarify this question.

Limitations

Overall, the present study provides a further evidence of how contextual factors, specifically attractiveness, change the pleasantness of social tactile interactions. However, it is limited by several considerations. First, we cannot rule out that participants' knowledge of the identity of the brusher could have influenced their behavioral and psychophysiological responses. Though these touch interactions were mediated by a brush, males' more than females' responses might have been highly influenced by their impression of the experimenter. Furthermore, this may have represented an uncontrolled source of heterogeneity external to the task which could have overshadowed the real effects of the independent variables.

Secondly, knowing the identity of the brusher might have dampened the participants' engagement in the imagination task, making more difficult for them to think that the touch they were receiving was in fact delivered by the person they saw on the screen. Future studies will implement real touch from strangers with different grades of attractiveness to refine our answer to the

question of how much attractiveness of a person affects emotional and physiological responses to tactile interactions.

Finally, we should consider that some important confounding variables for measuring HRV were not considered in this study. For instance, Laborde and colleagues list a series of different stable (e.g., smoking, alcohol consumption, weight and height) and transient (e.g., normal sleep routine and no caffeine consumption prior to the experiment) variables which should be investigated in the sample (Laborde et al., 2017). Nevertheless, we believe that these confounds only apply to the group comparisons, since the male and female subgroups might differ significantly in some of those parameters. Otherwise, in our experimental design, the crucial comparisons are protected from the within-subjects design. Related to this last aspect, our study did not include a baseline measurement. Despite collecting a baseline measurement is encouraged to allow detection of changes in HRV after intervention (Shaffer and Ginsberg, 2017), our main goal was the comparison between conditions, rather than measuring changes from rest.

Affective and physiological responses to tactile stimulations which are imagined to be received by opposite-gender unfamiliar people are modulated by the attractiveness of the imagined toucher. In particular, the slow velocity touch is considered most pleasant when it is associated to high attractive faces compared to low attractive faces, and it also induces a higher heart rate variability. Overall, these results point to the importance of the attractiveness in tactile interactions with unfamiliar people, especially when other information is not available.

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