# The human 'feel' of touch contributes to its perceived pleasantness

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**Abstract**

This study explored whether a human-like feel of touch biases perceived pleasantness and whether such a bias depends on top-down cognitive and/or bottom-up sensory processes. In two experiments, 11 materials were stroked across the forearm at different velocities (bottom-up) and participants rated tactile pleasantness and humanness. Additionally, in Experiment 1, participants identified the materials (top-down), whereas in Experiment 2, they rated each material with respect to its somatosensory properties (bottom-up). Stroking felt most pleasant at velocities optimal for the stimulation of CT-afferents, a mechanosensory nerve hypothesized to underpin affective touch. A corresponding effect on perceived humanness was significant in Experiment 1 and marginal in Experiment 2. Whereas material identification was unrelated to both pleasantness and humanness, we observed a robust relation with the somatosensory properties. Materials perceived as smooth, slippery, and soft were also pleasant. A corresponding effect on perceived humanness was significant for the first somatosensory property only. Importantly, humanness positively predicted pleasantness and neither top-down nor bottom-up factors altered this relationship. Thus, perceiving gentle touch as human appears to promote pleasure possibly because this serves to reinforce interpersonal contact as a means for creating and maintaining social bonds.

Key words: affective touch; textile design; tactile comfort; nonverbal communication; mechanoreceptor; somatosensory; C-tactile

Significance: This study revealed an overlap in the perceptual properties of touch that we perceive as pleasant and human (e.g., CT-optimal velocity, smooth contact) and showed that both perceptions are strongly positively related.

# Introduction

Touch often attends and emotionally colors social interactions (Fu, Selcuk, Moore, & Depue, 2018; Kirsch et al., 2018; Mayo, Lindé, Olausson, Heilig, & Morrison, 2018; Mohr, Kirsch, & Fotopoulou, 2017; Pawling, Trotter, McGlone, & Walker, 2017; Schirmer & Gunter, 2017; for a review see Gallace & Spence, 2010). A friend's hug can comfort us, a parent's pat on the back can give us courage, and a lover's kiss can excite us. Research exploring how tactile experiences affect emotional change has highlighted bottom-up as well as top-down influences and raised the possibility that the perceived social or human quality of touch is relevant for its positive effect. Here we explicitly tested this idea. Specifically, we examined convergence and divergence in the bottom-up and top-down influences on perceived touch pleasantness and humanness and tested how these two constructs intertwine.

## *The tactile sense*

Touch is a complex sense that arises from the stimulation of multiple types of receptors with special response properties. Some receptors respond to non-painful mechanical impact on the skin (e.g., indentation, stretching, vibration) and support discriminative touch, that is our ability to locate and categorize tactile sensations. These so-called low threshold mechanoreceptors vary in receptive field size, speed of adaptation, and location on the body. For example, Pacinian corpuscles have large receptive fields and are rapidly adapting, whereas Merkel cells have small receptive fields and are slowly adapting (Abraira & Ginty, 2013). Both Pacinian corpuscles and Merkel cells can be found in skin that is glabrous (e.g., palms, soles, external genital organs) (Johnson, 2001) and in skin that is hairy or non-glabrous (e.g., head, trunk, arms) (Vallbo, Olausson, Wessberg, & Kakuda, 1995).

Low threshold mechanoreceptors as well as other receptor types, including thermal, chemical, pruritic and nociceptive, vary in their degree of myelination. Some receptors have myelinated axons and thus promote "fast" somatosensensation. They are referred to as A-fibers and include, among others, a class of low-threshold mechanoreceptors that are called Aβ-fibers and which comprise the two examples given above (Abraira & Ginty, 2013). Other receptors have unmyelinated axons and thus produce "slow" somatosensation. They are referred to as C-fibers and largely comprise thermoreceptors and receptors whose activity is perceived as itch or pain (Abraira & Ginty, 2013; McGlone, Wessberg, & Olausson, 2014). Myelinated and unmyelinated fibres have different projection pathways to the brain where bottom-up somatosensory input is integrated with other mental processes to produce tactile percepts (McCabe, Rolls, Bilderbeck, & McGlone, 2008; Saal & Bensmaia, 2014; Schirmer & Adolphs, 2017). For example, other sensory information (e.g., olfaction (Croy, Drechsler, Hamilton, Hummel, & Olausson, 2016)) or the broader social context (e.g., person who is touching (Coan, Schaefer, & Davidson, 2006)) may shape the brain representation of somatosensory signals.

### ***Perceiving pleasure from touch***

Research suggests that both stimulus-driven as well as higher-order conceptual processes are relevant in the pleasure we derive from touch. As such these processes will be of interest here and examined in a bit more detail. Note, however, that we discuss them separately only because this facilitates our delivery. It is, in fact, not possible to strictly dissociate bottom-up from top-down mechanisms or to pinpoint when a given input to the nervous system becomes modulated and translates from a mere sensory into a clearly conceptual representation.

Different sensory aspects shape stimulus-driven processes including, for example, the pressure (Mullen, Champagne, Krishnamurty, Dickson, & Gao, 2008), velocity, and warmth (Sung et al., 2007) associated with touch (for a review see Schirmer, Wijaya, & Liu, 2016). Moreover, opposite sensory aspects may be equally effective in eliciting pleasure. For example, there is evidence that both deep pressure massages (Mullen et al., 2008) as well as light touch evoke positive affect (Essick, James, & McGlone, 1999; Löken, Wessberg, Morrison, McGlone, & Olausson, 2009).

To date, perhaps the best studied bottom-up mechanism for tactile pleasure has been linked to a special class of low threshold mechanoreceptors. Unlike the Aβ-fibers described above, these receptors are unmyelinated C-fibers and, counter-intuitively, of little relevance to discriminative touch. They are called C-tactile (CT) afferents and have firing properties seemingly tuned to represent affiliative human body-contact of a platonic (Croy, Luong, et al., 2016; Löken et al., 2009) and potentially sexual nature, although evidence for the latter function is still limited (Gallace & Spence, 2014). CT afferents respond most vigorously to gentle stroking at a speed of 1 to 10 cm/s and delivered by an object with typical human skin temperature (Ackerley et al., 2014, 2018). Both slower and faster speeds as well as cooler or warmer temperatures are less effective. Like other C-fibers, CT afferents are thought to project via the spinothalamic tract to the thalamus and from there to cortical regions such as the posterior insula (Jönsson et al., 2018; Olausson et al., 2002) and the posterior superior temporal sulcus (for reviews see McGlone et al., 2014; Schirmer & Adolphs, 2017).

Evidence that CT afferents support tactile pleasure in a bottom-up manner comes from microneurography and psychophysical studies. By recording the activity of both Aβ and CT fibers, it has been established that firing frequency is positively associated with subjective pleasantness for the latter receptor type only (Löken et al., 2009; Ackerley et al., 2014). Additionally, behavioral studies found that CT optimal touch is perceived as more pleasant than CT non-optimal touch. For example, stroking with 1 to 10 cm/s velocity has been shown to elicit higher pleasantness ratings than faster or slower stroking (Essick et al., 1999; Jönsson et al., 2017; Sehlstedt et al., 2016).

Past research examining the top-down modulation of touch has focused largely on whether and how the contextual situation modulates tactile responding. Among others, the associated action (e.g., pushing, hitting) and concurrent verbal, visual, auditory, and olfactory input have been of interest. Looking at specific touch actions revealed that they inform recipients about the toucher's emotional state (Hertenstein, Holmes, McCullough, & Keltner, 2009; Hertenstein, Keltner, App, Bulleit, & Jaskolka, 2006; Hertenstein & Keltner, 2010; Kirsch et al., 2018). The role of verbal input was demonstrated in a study where the description of a cream as "rich" or "moisturizing" impacted the subjective pleasantness of cream application and associated activity in the ventral striatum (McCabe et al., 2008). Visual input has been explored in relation to the multisensory integration of feeling and seeing touch. Thus, it has been demonstrated that touch pleasantness is greater when participants have a clear vision as compared to a pixelated or no vision of the ongoing tactile stimulation (Keizer, de Jong, Bartlema, & Dijkerman, 2017). In fact, strictly visual input is sufficient to evoke activity in the somatosensory brain (Morrison, Björnsdotter, & Olausson, 2011; Schirmer & McGlone, 2018). Other studies examined how unrelated emotional images or facial expressions moderate pleasure from touch. This work showed that positive visual content enhances, whereas negative visual content reduces ratings of tactile pleasantness (Etzi, Zampini, Juravle, & Gallace, 2018; Ravaja, Harjunen, Ahmed, Jacucci, & Spapé, 2017). Similar results were reported for an auditory (Fritz et al., 2017; Tsalamlal, Amorim, Martin, & Ammi, 2018) and an olfactory context (Croy, Drechsler, et al., 2016).

Apart from the context in which touch occurs, one may venture that cultural rules about appropriate touch (McDaniel & Andersen, 1998), familiarity with the toucher (Coan et al., 2006) as well as past tactile experiences shape pleasure in a top-down manner (for a review see Gallace & Spence, 2010). Of particular interest here is that prior exposure to a particular kind of touch may enhance its current perceived affect. This possibility may be inferred from the mere-exposure effect originally identified for simple geometrical shapes (Kunst-Wilson & Zajonc, 1980). It has since been replicated for a range of stimuli including auditory and olfactory ones (Bornstein, 1989; Delplanque, Coppin, Bloesch, Cayeux, & Sander, 2015). Moreover, an attempt to extend the mere-exposure effect to the haptic modality was partially successful. Blind-folded participants were handed different wooden and stone objects during a manual exploration and a judgment phase. Objects occurred 0, 2 or 10 times in the exploration phase and were rated with respect to liking in the judgment phase. Stone, but not wood, elicited increased liking with increased exposure frequency (Jakesch & Carbon, 2012).

***Perceiving humanness from touch***

The fact that gentle human touch may elicit pleasurable sensations has fostered the idea that such touch serves in the establishment and maintenance of social bonds. Moreover, this idea has been further corroborated by a number of studies specifically manipulating the social context of touch. For example, individuals are more likely to adopt a stroking velocity suited to stimulate CT afferents when touching a person as compared to a fake arm (Croy, Luong, et al., 2016). Furthermore, touching another's skin feels softer than touching one's own skin (Gentsch, Panagiotopoulou, & Fotopoulou, 2015) and being touched in a CT appropriate manner enhances socio-emotional processes in the brain (Schirmer & Gunter, 2017; Schirmer et al., 2011).

So far, however, the social function of touch has been approached exclusively from a global conceptual perspective by experimentally manipulating obvious social factors. Moreover, little attention has been paid to the more basic, not necessarily social aspects of touch that may bias its perceived humanness. As for the pleasure perceived from touch, these aspects likely concern a range of mechanisms some of which may be more stimulus-driven and others of which may depend more strongly on the internal and external processing context.

Stimulus-driven mechanisms may be triggered when the physical attributes of touch including its motion, texture, and temperature have a human quality. Such a quality can be expected to have acquired a special significance in the course of human evolution such that its perception is now anchored in our genes. This idea agrees with observations in social species ranging from shoaling fish to parenting rodents, and group living primates. In fish, research showed that the presence of conspecifics as well as tactile stimulation similar to that experienced when moving in a shoal have anxiolytic effects on behavior and biological markers (Mathuru et al., 2017; Schirmer, Jesuthasan, & Mathuru, 2013). In rodents, maternal licking and grooming as well as stroking with a brush have been shown to regulate stress in offspring (D. L. Champagne et al., 2008; F. Champagne, Diorio, Sharma, & Meaney, 2001; Hellstrom, Dhir, Diorio, & Meaney, 2012). Last, in non-human primates, grooming appears to be a primarily social activity that, apart from facilitating hygiene, helps regulate group hierarchies and bonding (Dunbar, 2010; Grandi, 2016). Moreover, in keeping with the idea of stimulus-driven mechanisms, these regulatory effects are mediated by biochemical processes triggered by physical impressions on the skin (Dunbar, 2010; Uvnäs-Moberg, 1998).

Top-down mechanisms may additionally shape the perceived humanness of touch. Again, as for pleasantness, culturally typical touch actions as well as verbal, visual, auditory, and olfactory context may be relevant. For example, already early in life, odors associated with pleasant tactile experiences trigger associative learning mediated by touch-induced endogenous opioid effects (Roth & Sullivan, 2006). Such learning is then likely to shape future tactile experiences. Additionally, past memories associated with a particular tactile experience may influence its perceived humanness. For example, there may be a bias to associate more familiar touch stimuli, like clothes and other wearable materials, with human interactions and, by extension, humanness.

### ***The present study***

Given the important social function of interpersonal touch, it must have a rewarding effect in order to facilitate its occurrence. Moreover, this reward must be fairly specific to human contact as to promote such contact over alternate forms of physical stimulation (e.g., self-touch (Gentsch et al., 2015)). Research suggests that CT afferents provide a mechanism for this. They appear to be primary contributors to the liking of touch and to be specifically tuned to touch with human properties (McGlone et al., 2014; Schirmer & Adolphs, 2017). However, whether CT afferents indeed elicit a "human feel" and what other bottom-up and top-down aspects of gentle touch are relevant for both perceived humanness and tactile pleasure are still open questions.

We addressed these questions as follows. In two experiments, participants were stroked, out of sight, at CT optimal and non-optimal speeds using a range of materials that varied in their physical properties (e.g., rough/smooth) as well as the context and experiences typically linked with touching them (e.g., plastic explored with hands, denim worn on CT innervated skin). Experiment 1 assessed subjective perceptions of tactile pleasantness and humanness with the goal of linking these perceptions to CT optimal speed and a range of memory-relevant measures indexing top-down mechanisms. Experiment 2 aimed to replicate the relationship between tactile pleasantness and humanness observed in Experiment 1 and to explore how their perception is shaped by physical stimulus properties and thus additional bottom-up mechanisms. Together, both experiments were aimed at providing a comprehensive perspective on the convergences and divergence in the factors that shape affective and human touch attributions.

## Experiment 1

Experiment 1 comprised three different blocks in which participants self-reported the pleasantness of touch, its perceived similarity to human touch, and attempted to identify the touching material. In a post-experimental session, participants were handed material by material and asked to rate its familiarity and how frequently they had encountered it previously. Additionally, they were again asked to name the material.

Our predictions focused on the overlap between pleasantness and humanness ratings. First, if bottom-up processes associated with the activation of CT afferents modulate both perceived touch pleasantness and humanness, respective rating scores should be higher for CT optimal as compared with non-optimal stroking. Second, if top-down processes arising from prior tactile experiences modulate both perceived pleasantness and humanness, then memory for and familiarity with the materials used in this present study should bias the two rating scores. Last, we predicted a positive statistical relationship between pleasantness and humanness as the result of convergent bottom-up and top-down influences.

## Methods

*Participants.* Because data collection required individual sessions for a given participant we wished to focus this manuscript on medium to large effects which could be analyzed with good power for a sample ranging between 40 to 50 participants. Moreover, our exact target number of participants was constrained to be a multiple of three due to counterbalancing constraints.

For our primary effect of interest, which was the relation between pleasantness and humanness, we estimated the power of detecting a medium-sized effect equal to 3.6 in odds ratio with 42 participants. To this end, we generated simulated data with two levels of ordinal pleasantness based on three factors: participants (42 levels), materials (11 levels), and humanness (2 levels, low and high) using the MultiOrd package (Amatya & Demirtas, 2015) in R (R Core Team, 2015). Participants and Materials were fully crossed. Roughly half of the materials were assigned to a high humanness level and the others to a low humanness level. We generated 1,000 samples with comparable effect size structure and for each fit a cumulative link mixed effect model, as described below in Data Analysis, with a significance level of p=0.05. The proportion of times the simulated effect was detected in the samples indicated its statistical power with the chosen sample size. Thus, we expected to achieve about 92% power for our effect of interest with 42 participants.

As a secondary goal, we pursued potential differences between male and female participants as reported in previous research (Essick et al., 2010; Schirmer & McGlone, 2018; Schirmer, Ng, & Ebstein, 2018). The examination of such differences in small samples of $\leq$ 20 per group is contentions because even fairly obvious effects such men weighing on average more than women require more than twice the number of participants (Uri Simonsohn as cited by Mikulak, 2013). Yet making comparisons like this is challenging because power depends not on how obvious an effect is but on the distributional shape (e.g., within-group standard deviation) and overlap between groups. As it is, there is no way of knowing whether less observable sex differences in mental processes are smaller or larger than sex differences in weight. For this present purpose, we estimated the power for observing an interaction between sex and humanness on the pleasantness rating in a manner similar to that described above. Moreover, we assumed that females would have a large effect (odds ratio equal 12) and males a small effect (odds ratio equal 1.2). Fitting a cumulative link mixed effect model as described in the Supplementary Materials to 1,000 simulated samples suggested a power of only 57%. However, given our considerations outlined above we proceeded with the identified sample size and considered an analysis of interindividual differences as strictly exploratory (see Supplementary Materials).

Forty-six participants were invited to this study. The data from four participants were discarded due to experimenter error (N=1) and device error (N=3). Of the remaining 42 participants, 21 were female with a mean age of 20.28 years (SD 2.57). Male participants had a mean age of 20.24 years (SD

2.09). According to the Edinburgh Handedness Inventory (Oldfield, 1971), participants were right handed with the exception of one who was ambidextrous. None of the participants reported suffering from a psychological or neurological condition. This research was conducted in accordance with the Declaration of Helsinki. All participants gave informed consent at the beginning of the experiment. They were compensated with course credits or 55 HKD/h (~7USD/h).

*Materials and Apparatus.* The stimuli consisted of 11 materials wrapped around rigid holders made from Polylactic acid (PLA) with a skin contact area of 12 x 5 cm. The materials were selected from a published catalog (Matério, 2007, p. 2) based on their accessibility and frequency of use as well to create a broad range of tactile impressions that would vary with respect to similarity to human skin. Thus, we included silk, velvet, denim, cotton, leather (skin surface), suede (skin under side), fur, plastic, paper, foam, and felt. All materials were kept in the experimental room and were thus acclimatized to air-controlled room temperature (~ 23 ℃) prior to being mounted on the touch device. No further efforts were made to control or measure material temperature.

A custom-built robotic skin stimulation device was used to deliver controlled touch on the left forearm. This device held an exchangeable touch applicator on a set of strings that were actuated by 8 motors (Figure 1) allowing for touch in all 6 degrees of motion – 3 translating and 3 rotating. Touch was applied at 0.5 cm/s or 4 cm/s, which are velocities outside and inside the range preferred by CT afferents, respectively. Unfortunately, slower and faster velocities than these were not accommodated by the robotic device. The stroking area was 22 cm in proximal to distal direction. Pressure was controlled by maintaining the height of the device applicator relative to the skin surface constant.

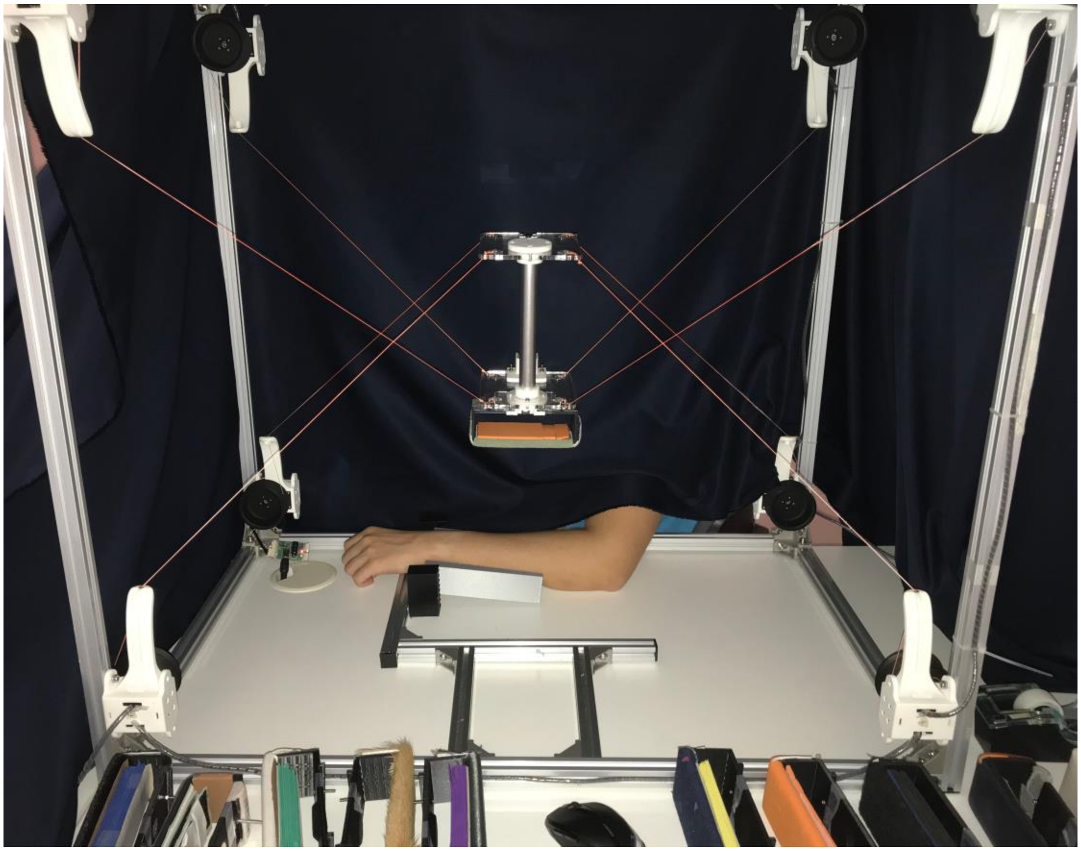


Figure 1. Touch device and touch applicators used to stroke the participants' forearm. The photo was taken by the authors.

*Procedure.* Prior to entering the experimental room, the participant was asked to fill in a consent form and to complete a general questionnaire inquiring about basic person characteristics (e.g., age, sex). The questionnaire also included four questions about the participant's everyday touch experience. Specifically, participants were asked to indicate on a scale from 0 to 7 their level of comfort with (i) touching and being touched by others as well as (ii) with expressing themselves through touch. Moreover, they were asked to provide an estimate of how many times a day they expressed (iii) their thoughts or (iv) their emotions through touch. As the relation between these scales and the experimental data was not of primary interest here and would add to the complexity of the results, we only present a preliminary analysis in the Supplementary Materials focusing on the first most general question (i). The reported effects are mostly non-significant and, if significant, failed to replicate across Experiments 1 and 2. The Supplementary Materials will also provide an overview of the sex effects found in the present data. However, like the touch comfort effects they were mostly non-significant or did not replicate well.

After completing the questionnaire, participants were asked to apply a light body lotion to their left forearm as to equate levels of skin hydration across participants and to reduce static electricity. The lotion was self-applied following instructions from the experimenter regarding the lotion amount and relevant skin area. In the experimental room, the participant was introduced to the touch device used for stimulus presentation and seated to the left of the touch device. S/he was instructed to place the left arm on an arm rest such that the wrist aligned with the front end of the arm rest. As the device made a soft noise when the motors were activated, we asked the participant to use ear plugs, which dampened the noise. This made the touch less natural as typically touch is accompanied by sound and its perception influenced by auditory signals (Guest, Catmur, Lloyd, & Spence, 2002). However, as the sound in our case was not a natural one, we accepted this drawback in favor of eliminating artificial crossmodal effects.  A female experimenter sat to the right of the touch device and controlled it using MATLAB custom-built scripts. Visual presentations occurring on a monitor in front of the participant and on a monitor in front of the experimenter were controlled by Psychopy 1.85.3.

The experimenter measured the participant's arm thickness and entered this information into the program controlling the touch device. Then, a calibration was done to adjust the touch applicator's position according to the arm position and thickness. This was followed by a trial run where touch was applied via the touch applicator without any additional material. After the trial run, a curtain was drawn to prevent the participant from observing the tactile stimulation.

A general instruction presented on the screen informed participants that they would receive touch on their left forearm and asked them to answer some questions based on their impression of the touch. Specific instructions were given at the beginning of each block (see below). A trial started with the name of a material presented on the experimenter's display screen. This prompted the experimenter to install the requested material on the touch applicator and, when ready, to start the touch stimulation. Each stimulation comprised three strokes. During preparation and stimulation the display screen facing the participant remained blank. After the stimulation was completed, the experimenter pressed a button to display the rating scale on the participant's screen. A trial ended after participants entered their rating or when a response time limit was reached (see below).

The experiment was divided into three blocks with block order being counterbalanced using a Latin Square design, resulting in three orderings. Within each block, each material-speed pair was presented once. Presentation order followed two randomized trial lists, each applied to half of the participants.

In one block, the rating screen presented the question "How pleasant was the touch?" together with a visual analog scale (VAS) with the endpoints -50 (extremely unpleasant) to 50 (extremely pleasant). A pleasant touch was described as one that feels enjoyable and that the participant would want to be repeated, while an unpleasant touch was one that feels uncomfortable in some way and that the participant would not want to be repeated. Participants gave their rating by clicking a point along the VAS using a mouse with their right hand. They then saw a number displayed under the scale indicating the value of their choice and clicked on the number to confirm their rating. No time limit was given for participants to enter their rating.

In a second block, the rating screen presented the question "How similar to human touch did this feel?" together with a VAS ranging from 0 (not human-like) to 100 (human-like). Here, we used a unipolar scale because unlike pleasantness, humanness is without a negative counter-pole. A lack of pleasantness doesn't necessarily make something unpleasant, and a lack of unpleasantness doesn't necessarily make something pleasant. However, a lack of humanness does make something non-human.

Participants were asked to base their rating on how similar a stimulus was to the texture and feel of human touch. The remainder of the procedure was comparable to the pleasantness block.

In a third block, participants were asked to guess the material used for the touch. The rating screen presented the question “What was the material?”. Participants could either type their answer in English on an English keyboard using their right hand or verbally communicate their answer in Mandarin or Cantonese to the experimenter in case they did not recall the correct English name. Participants were asked to press enter to confirm their answer. A trial in this block ended if there was no response 10 seconds after the onset of the rating screen. Pilot testing suggested that participants took much longer to offer a material name than to rate pleasantness and humanness. As discussed elsewhere (Gallace & Spence, 2014), this task was harder and participants spent more time weighing different possibilities. To avoid excessive guessing, we decided to limit available response time.

The experiment was followed by a post-experimental session. Here, participants were handed each of the touch materials in turn and were free to visually and manually explore them for as long as they wished. After they had explored a given material, they were asked to answer the following three questions. First, participants indicated whether or not they knew the material (yes, no). Then they were asked to estimate how often they had encountered the material in their life (1 – never, 2 – a few times, 3 – occasionally (~once a month), 4 – frequently (~once a week), 5 – very frequently (~one or more times a day)). We used the general term “encountered” rather than “touched” because at this point the participant’s responses were influenced by both feeling and seeing a given material and because of existing evidence that prior visual experiences with a material can modulate its somatosensory perception (Suzuki & Gyoba, 2008). Last, they had another chance to name the material. A given question disappeared if there was no response 10 seconds after question onset. Materials were presented in random order while the three questions were always presented in the same order.

*Data Analysis*. Pleasantness and humanness ratings were examined in analogous ways. For both, we tested the effect of Velocity (0.5 and 4 cm/s) and material using a cumulative link mixed effect model (i.e., ordered logit regression model) implemented in the clmm function in the Ordinal package (Christensen, 2018) in R (R Core Team, 2015). As recommended (Singmann & Kellen, in press), our models had a maximum random effects structure as to minimize Type 1 error. In separate models, velocity and the different memory measures served as the single fixed effect, and the participants' effect slope and intercept as well as the materials' effect slope and intercept served as the random effects.

In a second step, we assessed the relation between pleasantness and humanness ratings again using the clmm approach described above. Pleasantness was entered as the dependent variable and humanness as the independent variable. This was done because we conceptualized pleasantness as the more basic construct which could be informed by humanness. As mentioned in the introduction, we ventured that gentle human touch biases pleasure because this would motivate individuals seek out such touch. However, it is also likely that the pleasantness associated with a touch influences its perceived humanness. Moreover, from a statistical point of view, whether a given measure served as independent or dependent variable was largely irrelevant. In case a simple fixed effect from the first analysis step was significant, it was subsequently added here as an additional fixed and interaction effect. This served to determine whether the pleasantness-humanness link was modulated by bottom-up (velocity) or top-down (memory) factors.

As mentioned above, we conducted a few exploratory analyses aimed at establishing whether comfort with touch or the participant's sex modulated any of the effects reported below. This was mostly not the case. Moreover, the few significant interactions we observed failed to replicate across the two experiments and are hence not detailed further (see Supplementary Materials).

**Results**

*Material Identification and Prior Experience.* We recorded a number of memory-relevant measures and examined their relation with the tactile experience. Specifically, we measured the participants' ability to name the different materials when presented out-of-sight during touch on CT innervated skin and explored material knowing, naming, and the estimated frequency of encountering a material outside the laboratory when materials were handed to participants after the experiment. The results are illustrated in Figure 2.

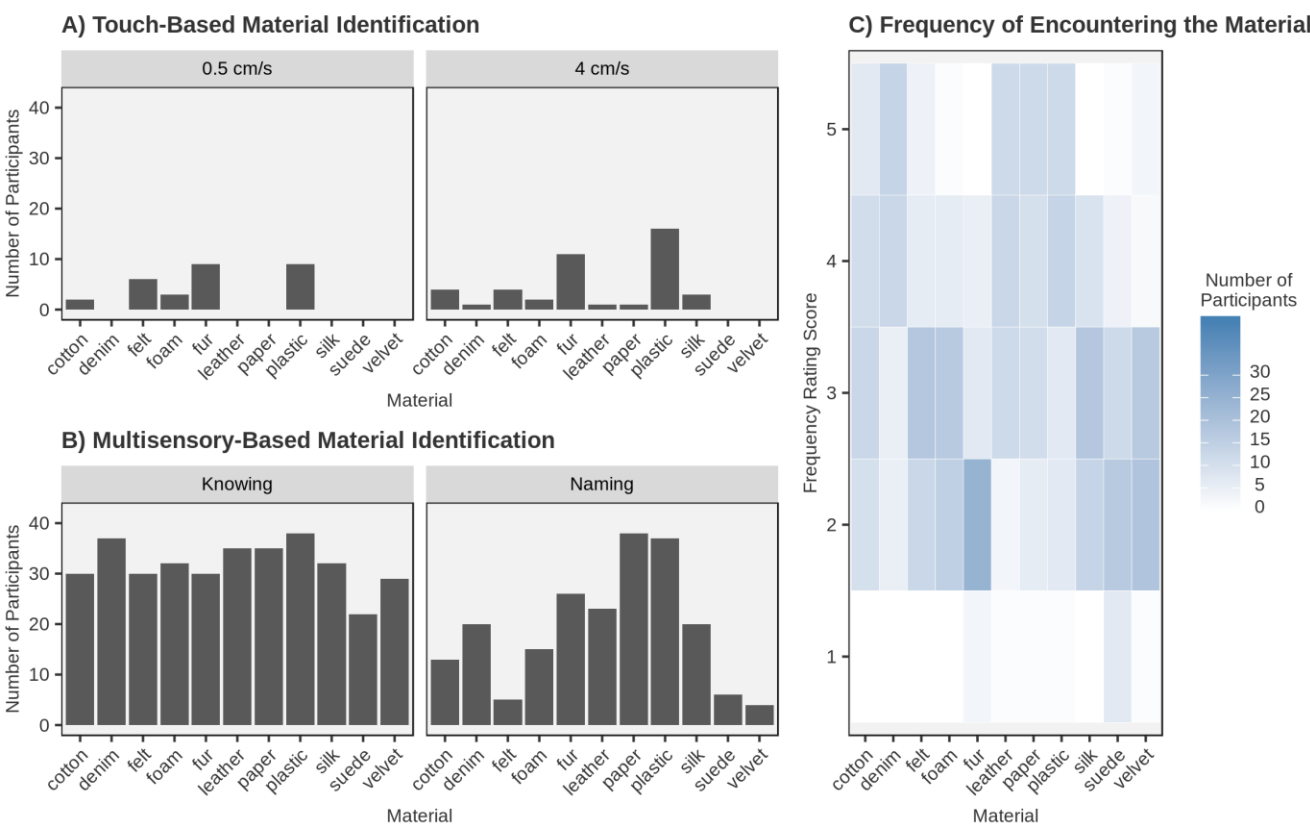



Figure 2. Experiment 1 material identification and prior experience. Panel A shows the material identification accuracy as measured during the experiment from strictly tactile stimulation. Bars

represent the number of participants who correctly named a material at 0.5 (left) or 4 (right) cm/s. Panel B shows the number of participants who report knowing (left) and who were able to correctly name (right) a material when shown the material after the experiment. Panel C shows a heat-map of the rated frequency of encountering a given material in everyday life (1 – never, 2 – a few times, 3 – occasionally (~ once a month), 4 – frequently (~ once a week) and 5 – very frequently (~ one or more times a day)).

Material identification from stroking across the arm was fairly low (Figure 2A). Specifically, for two materials – suede and velvet – none of the participants offered an accurate name at either velocity and for the other materials the number of participants naming the material was at or below 16/42 (~38%). The best recognized material irrespective of velocity was plastic. An ANOVA conducted on ranked identification performance (recommended for data deviating from normality) with Velocity as a repeated measures factor revealed a significant main effect ($F(1,40)=12.52$, $p=.001$, $\eta^2_G=.06$) indicating that naming accuracy was higher at CT appropriate as compared to inappropriate velocity.

Performance improved post-experimentally for the multisensory conditions (Figure 2B). For material knowing, 22 to 38 participants reported familiarity with a given material. The least familiar material was suede and the most familiar material was plastic. For material identification, 4 to 38 participants provided accurate labels for a given material. The materials eliciting the worst and best performance were velvet and paper, respectively. Finally, taking a look at the reported frequency of encountering a material (Figure 2C) we found that participants had the least exposure to fur (mean rating score=2.35, SD 0.8) and the most exposure to denim (mean rating score=3.97, SD 1.04).

Last, we examined whether any of the post-experimental measures could predict the accuracy with which participants identified a material during the experiment when it was simply moved across the forearm. To this end, we fitted a series of binomial mixed effect models with the strictly tactile accuracy score as the dependent variable, a given post-experimental measure as the fixed effect and the slope and intercepts for participants and materials as the random effects. The results were significant for post-experimental material naming ($\beta$=14.3, SE=4.6, z=3.09, p=.002, d=0.48) indicating that both memory-relevant measures were positively related. Other effects were non-significant (ps>.25).

*Pleasantness Rating.* We first took a look at the mean ratings for the different materials. As can be seen in Figure 3A, paper elicited the highest (9.5, SD 19.73) and felt the lowest (-15.49, SD 23.84) pleasantness ratings with a mean difference of 24.99 on a 100-point scale.

To test the effect of Velocity (0.5 and 4 cm/s), we fitted a cumulative link mixed effect model with velocity as the fixed effect and the participants' effect slope and intercept as well as the materials' effect slope and intercept as the random effects. The model fit indicated that stroking at 4 cm/s felt more pleasant than stroking at 0.5 cm/s ($\beta$=0.97, SE=0.23, z=4.22, p<.0001, d=0.65).

To explore whether the different memory-relevant measures predicted pleasantness, we entered them as fixed effects into separate cumulative link mixed effect models. A first model had the strictly tactile material identification as the fixed effect. Respective slopes and intercepts for participants and materials served as the random effects. Model fitting showed that the fixed effect was non-significant (p>.25). For the post-experimental measures, the results were non-significant for the knowing response and the frequency of having encountered a material previously (ps>.25). However, more accurate naming was weakly associated with reduced tactile pleasure ($\beta$=-0.41, SE=0.21, z=-2, p=.04, d=0.31), an effect opposite of what we had predicted.

*Humanness Rating.* Adopting a similar approach as described for the analysis of pleasantness, we found that the 11 materials differed along the humanness continuum. As can be seen in Figure 3A, foam elicited the highest (44.33, SD 25.44) and felt the lowest (19.74, SD 19.39) humanness ratings with a mean difference of 24.59 on a 100-point scale.

When examining Velocity we found that, as predicted, perceived humanness was greater for stroking at 4 cm/s than stroking at 0.5 cm/s ($\beta$=0.66, SE=0.20, z=3.28, p=.001, d=0.51). Notably, however, an estimate of Cohen's d indicated that the effect was smaller than that observed for pleasantness.

Mixed effect modeling of the relation between humanness and touch-based material identification produced no significant effect (p>.25). Also for the post-experimental measures, neither knowing the material, correctly naming the material, nor frequently encountering the material outside the lab predicted its perceived humanness (ps>.25).

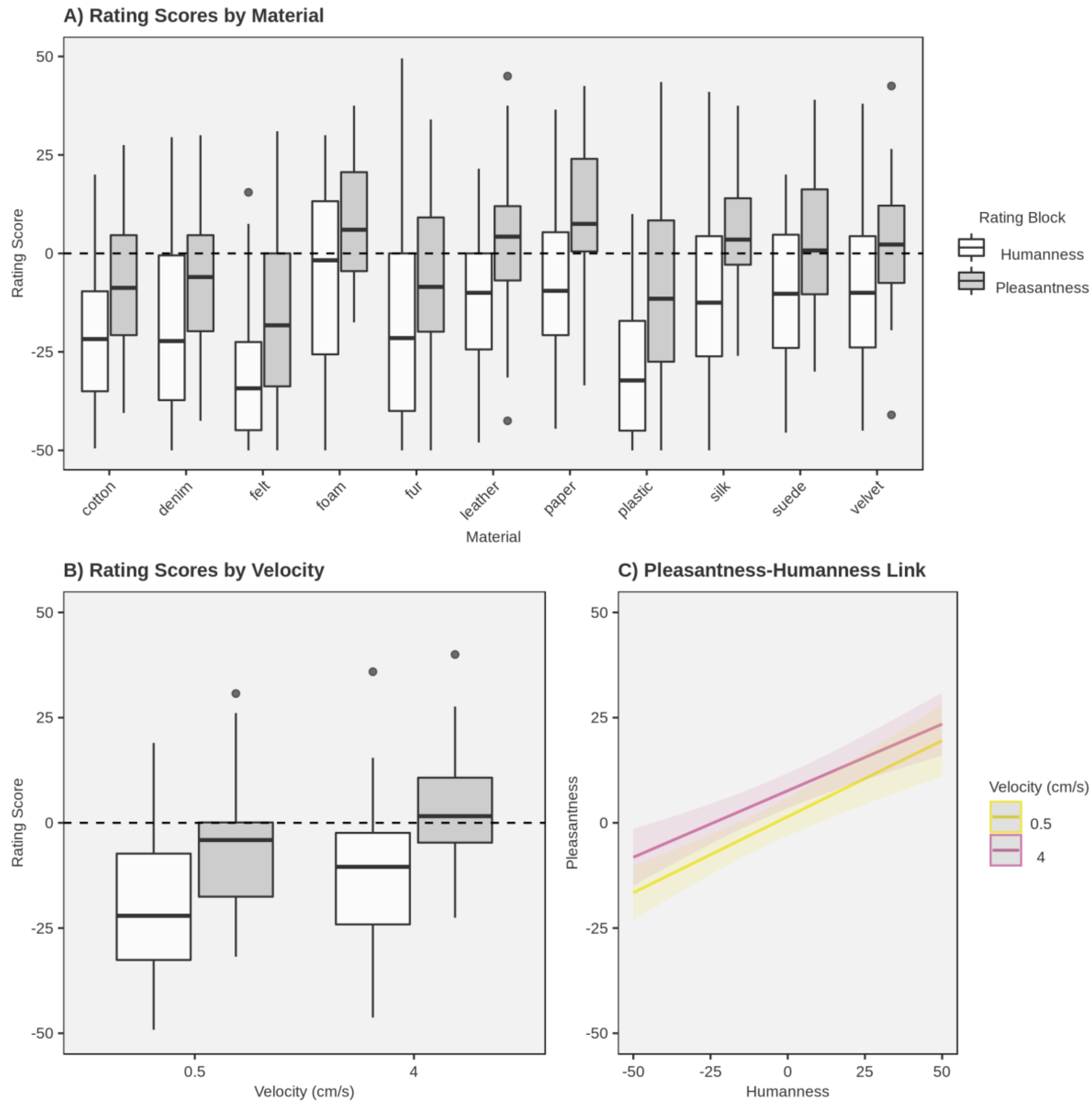



Figure 3. Experiment 1 pleasantness and humanness ratings. For illustration purposes only, humanness was re-scaled to range from -50 to 50 as to allow for better comparison with pleasantness. Panel A and B show box-and-whisker plots. The center black line shows the median value (50$^{th}$ percentile), while the box contains the 25$^{th}$ to 75$^{th}$ percentiles. The upper and lower black whiskers extend from the box to the largest and smallest values, respectively, up to 1.5 times the inter-quartile range (the distance between the 25$^{th}$ and 75$^{th}$ percentiles). Values beyond these are considered outliers, marked with filled circles. Panel A shows rating scores for the different materials averaged across velocities. Panel B

shows rating scores for the different velocities averaged across materials. Panel C shows the results of a linear mixed effect model using humanness ratings to predict pleasantness ratings at the two stroking velocities. Please note that the results from the ordinal model reported in the manuscript, albeit statistically more appropriate, were not in a format readily accessible for plotting.

*Is there a relationship between pleasantness and humanness?* We examined the relation between humanness and pleasantness using an ordinal mixed effect model with pleasantness as the dependent variable, humanness as the fixed effect, and the slopes and intercepts of participants and materials as the random effects. This revealed a large and significantly positive effect ($\beta$=0.04, SE=0.01, z=5.94, p<.0001, d=0.86) that is illustrated in Figure 3C.

Adding velocity or post-experimental naming accuracy to the model corroborated this effect and showed that it was independent of stroking speed or whether the stroking material could be identified post-experimentally (ps>.25). As the other memory-relevant measures produced non-significant effects for both the pleasantness and the humanness analyses, their role in the relationship between pleasantness and humanness was not explored.

**Discussion**

Experiment 1 compared bottom-up and top-down influences on touch pleasantness and humanness and examined a possible positive association between these two psychological constructs.

First, we gauged how the activity of CT afferents contributed to ratings of pleasantness and humanness. Replicating previous work, we found that CT optimal stroking felt more pleasant than CT non-optimal stroking (Essick et al., 1999; Löken et al., 2009). Importantly, a comparable effect showed for humanness in line with the idea that CT activation signals friendly interpersonal touch and as such might enable individuals to discriminate such touch from other forms of somatosensory stimulation (e.g., water falling on the skin).

To determine whether there are shared top-down influences on perceived pleasantness and humanness, we pursued a number of memory-relevant measures. Notably, the identification of materials from touch was very poor ranging from 0 for materials such as silk and velvet to 38% for plastic suggesting that it is quite difficult to discern stimuli that touch hairy skin and that such discernment fails to benefit from prior cloth-wearing experience. Although identification performance increased when participants were able to explore the materials both visually and using their hands it was still far from perfect. Moreover, there was a dissociation between the ability to recall a material's name and the reported frequency of encountering that material. For example, fur was relatively well identified but was a material participants had very limited experience with. On the other hand, felt was relatively more poorly identified but yet had a moderate frequency of experience. We venture that, in everyday life, participants are most concerned with the perceptual properties of materials touching their skin. As such they may know a material but not necessarily remember its name. In line with this, all materials were known by more than half the participants.

Importantly, the strictly touch-based material identification, as well as multisensory material knowing and the encounter frequency failed to predict touch pleasantness and humanness. Only the multisensory identification accuracy was weakly negatively related to pleasantness. Thus, unlike reported for other sensory modalities (Delplanque et al., 2015; Kunst-Wilson & Zajonc, 1980) and, but tentatively, for touch (Jakesch & Carbon, 2012), prior experience failed to boost both the perceived pleasantness and humanness of touch. This failure may be due to the fact that in the present study, touch was delivered to the arm, which is much less discriminative than the hand thus making it hard to identify a touching object and reducing the impact of such identification on the overall touch experience. Interestingly, strictly somatosensory material identification was better during stroking with as compared to without CT appropriate velocity – despite the latter condition by being slower with longer stimulus presentations. Possibly, CT appropriate stroking and perhaps CT afferents themselves offer some discriminative touch benefits.

Last, we examined the relationship between pleasantness and humanness and found it to be significant. Moreover, an effect size of 0.86 (Cohen's d) implied a relatively large effect with likely relevance in everyday life. Notably, this effect size was greater than that observed for all other effects in Experiment 1 suggesting that humanness is of primary importance when it comes to evaluating the pleasantness of touch. Moreover, because none of the top-down and bottom-up variables measured and/or manipulated here modified the pleasantness-humanness link one may speculate that this link is unaffected by the specific aspects of touch and by the extent to which these aspects render touch as human-like.

## Experiment 2

### Introduction

Experiment 2 was designed to replicate and extend the findings of Experiment 1. As such we made a fresh effort at comparing the perceived pleasantness and humanness from touch. Towards this end, we introduced a few methodological changes both in touch delivery as well as in its perceptual assessment.

Touch delivery was extended to include a faster stroking velocity in an effort to further replicate the relation between CT relevant velocities and pleasantness and to show whether and how this relation may map onto that between CT relevant velocities and humanness. This methodological extension was enabled by an optimization of our stimulation system which now supported velocities of up to 10 cm/s without distorting movement trajectory and pressure. A velocity of 10 cm/s presents the upper range of

CT optimal velocities and was expected to produce results comparable to 4 cm/s and different from 0.5 cm/s.

In terms of perceptual assessments, one major change concerned the humanness scale, which previously ranged from 0 to 100. We had used this scale because we conceived of humanness as being one-dimensional and ranging from absent to present. As such we made a conceptual distinction between humanness and pleasantness, the latter of which was rated from -50 to 50. Moreover, we imposed this distinction onto participants who, as a consequence, may have been biased to rate both constructs differently. To address this possibility, Experiment 2 adopted comparable scale endpoints for humanness and pleasantness ratings.

Another major change was that we dropped the memory measures assessing top-down processes in favor of perceptual measures assessing bottom-up processes. Specifically, apart from rating pleasantness and humanness, participants rated each tactile stimulus on five physical dimensions (rough/smooth, dry/wet, firm/soft, hot/cold, slip/grip) identified by prior research as possibly relevant in defining a somatosensory space (Bergmann Tiest & Kappers, 2006; Guest et al., 2011; Hollins, Bensmaïa, Karlof, & Young, 2000). The primary reason for this change was that we wished to extend this earlier work by outlining the relevance of these dimensions for perceived tactile pleasure and humanness and by exploring a possible somatosensory overlap between both psychological constructs.

Our hypotheses for Experiment 2 were as follows. First, we expected to replicate the results of Experiment 1 as concerns the effect of stroking velocity on pleasantness and humanness ratings. Second, we predicted that the physical dimensions previously identified to represent the somatosensory space similarly characterize the pleasantness and humanness of touch. Moreover, rough/smooth in particular – deemed to be touch’s primary dimension (Guest et al., 2011) – was hypothesized to be most relevant for the two psychological constructs examined here. Last, we anticipated that humanness statistically predicts pleasantness and that this prediction is stronger than that observed in Experiment 1.

**Methods**

*Participants.* Sample size was determined similarly as for Experiment 1 with the exception that counterbalancing required our participant number to be a multiple of 6. We invited 50 participants to this study. The data from two participants were discarded because of stimulus presentation software error. Of the remaining participants, 24 were female with a mean age of 25.04 years (SD 5.35) and 24 were male with a mean age of 20.87 years (SD 2.23). All participants were right handed (Oldfield, 1971) and none reported suffering from a psychological or neurological condition. This research was conducted in accordance with the Declaration of Helsinki. All participants gave informed consent at the beginning of the experiment. They were compensated with course credits or 55 HKD/h (~7USD/h).

*Materials and Apparatus.* The touch materials were the same as in Experiment 1. However, the MATLAB program running the touch device was improved as to enable a consistent motion trajectory at faster speeds. This allowed us to stroke participants at 0.5, 4, and 10 cm/s. As adding the third velocity required additional experimental time, we shortened trial length slightly by reducing stroking contact from 22 to 18 cm in the proximal to distal direction.

Additionally, we modified our apparatus. In Experiment 1, the touch applicator was fixed to a vertical rod and calibrated to be at a specific distance above the participant's arm at the beginning of the experiment. During a trial, the applicator moved downward a pre-set distance to touch the participant's arm and then maintained that distance as it moved horizontally. In Experiment 2, the touch applicator was attached to a track along the rod that allowed the applicator to move up and down. This eliminated the need for height calibration since the applicator now adjusted to the participant's arm height as it moved horizontally. In order to ensure that all materials were applied with comparable pressures, the weight of materials and their applicators was equalized.

*Procedure.* The procedure was similar to that of Experiment 1. The following description focuses on the differences only. The experiment was programmed using Psychopy 1.85.6. No arm thickness measurement was taken as the apparatus changes, explained above, made this redundant. Two rather than three strokes were applied on a given trial to keep overall experimental time within a reasonable limit. Again the experiment was divided into three blocks and block order counterbalanced using a balanced Latin Square design, resulting in six orderings. As before, one block entailed a pleasantness rating and another block entailed a humanness rating. However, this time, the verbal endpoints of the pleasantness rating scale were labeled very unpleasant (-50) and very pleasant (50). Moreover, the humanness rating scale was modified as to match the pleasantness scale and now ranged from very different (-50) to very similar (50). Additionally, the humanness rating was preceded by an example of human touch at the three experimental speeds (0.5, 4, and 10 cm/s). Here, the experimenter placed her hand with the palm down on a holder that was attached to the touch applicator. Thus the touch applicator moved the experimenter's hand across the participant's arm. Last, a third block required participants to rate the material used for the touch on five perceptual dimensions including rough/smooth, dry/wet, warm/cold, firm/soft, and slip/grip. On every trial, all five dimensions were rated in random order along a -50 to 50 continuum.

*Data Analysis.* The approach to data analysis was comparable to that used in Experiment 1. Again we used ordinal mixed modeling with the pleasantness or the humanness ratings as the dependent variable. In separate models, we examined the fixed effects of velocity, rough/smooth, dry/wet, warm/cold, firm/soft, and slip/grip. Any given fixed effect was complemented by a maximal random effect structure including slopes and intercepts for participants and materials. Again, as a second step, we examined the relation between pleasantness and humanness and added velocity or a perceptual rating in case those yielded a significant effect in the first analysis step.

As for Experiment 1, we explored whether any of the effects reported below was modulated by the participant's sex or his/her self-reported comfort with touch in everyday life. The results are available in the Supplementary Materials.

## Results

*Pleasantness Rating.* Again, we first explored whether the different materials elicited different pleasantness ratings. As can be seen in Figure 4A, foam elicited the highest (11.46, SD 17.25) and felt the lowest (-19.1, SD 20.04) pleasantness ratings with a mean difference of 36.35 on a 100-point scale.

Next, we subjected pleasantness ratings to an ordinal mixed effect model. Because now velocity had three levels, its fixed effect was pursued by comparing the full model with a "null" model in which the fixed effect was set to 1. A likelihood ratio test including both models was significant (LR.stat=133.51, df=12, $p<.0001$) and was followed-up with a contrast analysis done on the backdrop of the original full model using the emmeans package and Bonferroni correction (Lenth, 2018). This revealed that pleasantness was greater for both 4 ($\beta=0.70$, SE=0.19, $z=3.63$, $p=.0008$, $d=0.52$) and 10 cm/s ($\beta=0.76$, SE=0.23, $z=3.28$, $p=.003$, $d=0.48$) as compared with 0.5 cm/s stroking. However, 4 and 10 cm/s stroking did not differ ($p>.25$).

Pleasantness was also significantly related to the perceptual properties of touch (Figure 5). Ordinal mixed effects modeling produced significant fixed effects for the slip/grip ($\beta=-0.02$, SE=0.01, $z=-3.65$, $p=.0003$, $d=0.55$), rough/smooth ($\beta=0.01$, SE=0.004, $z=3.25$, $p=.001$, $d=0.51$), and firm/soft (β=0.01, SE=0.01, z=2.23, p=.03, d=0.35) dimensions indicating that tactile pleasure felt soft, smooth and slippery. The dry/wet (β=0.01, SE=0.01, z=1.68, p=.10, d=0.26) and hot/cold (p=.25) dimensions showed no significant effect.

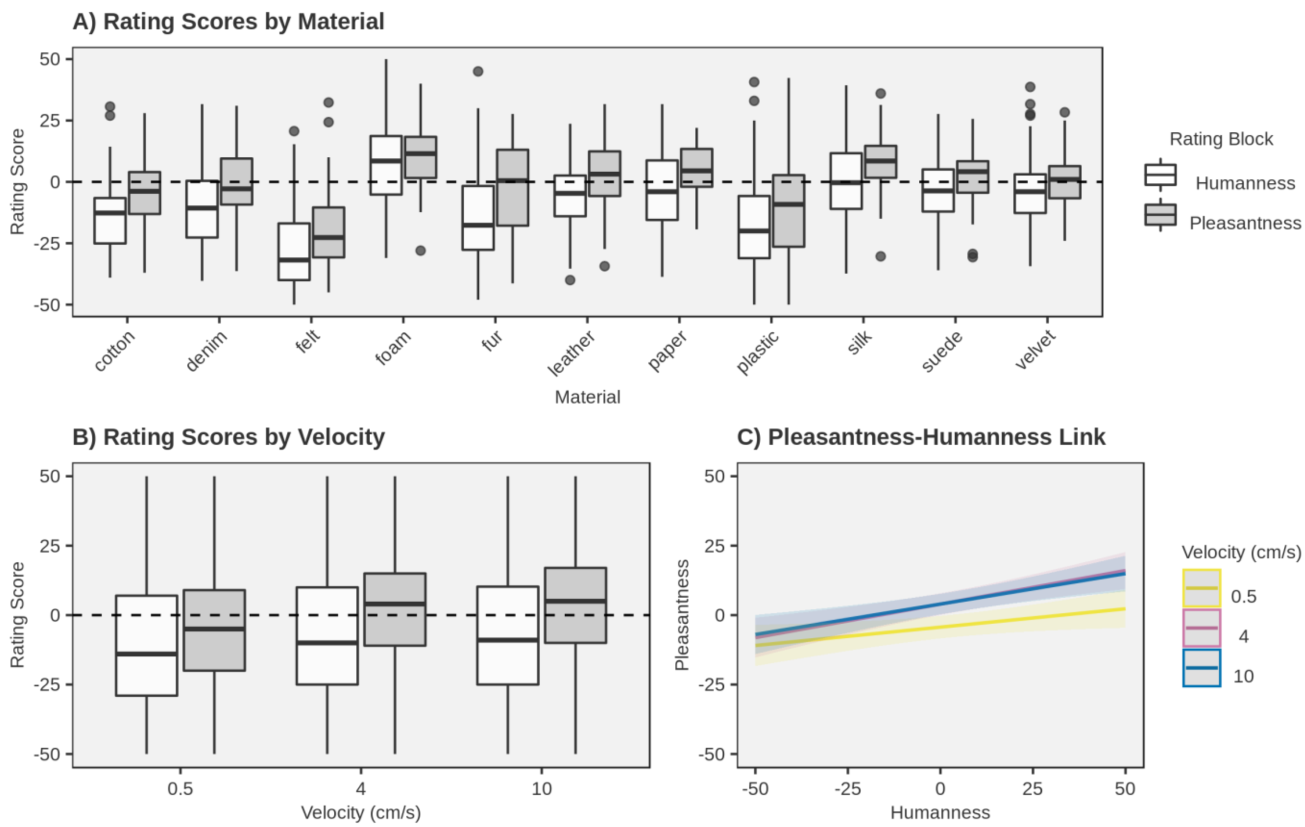


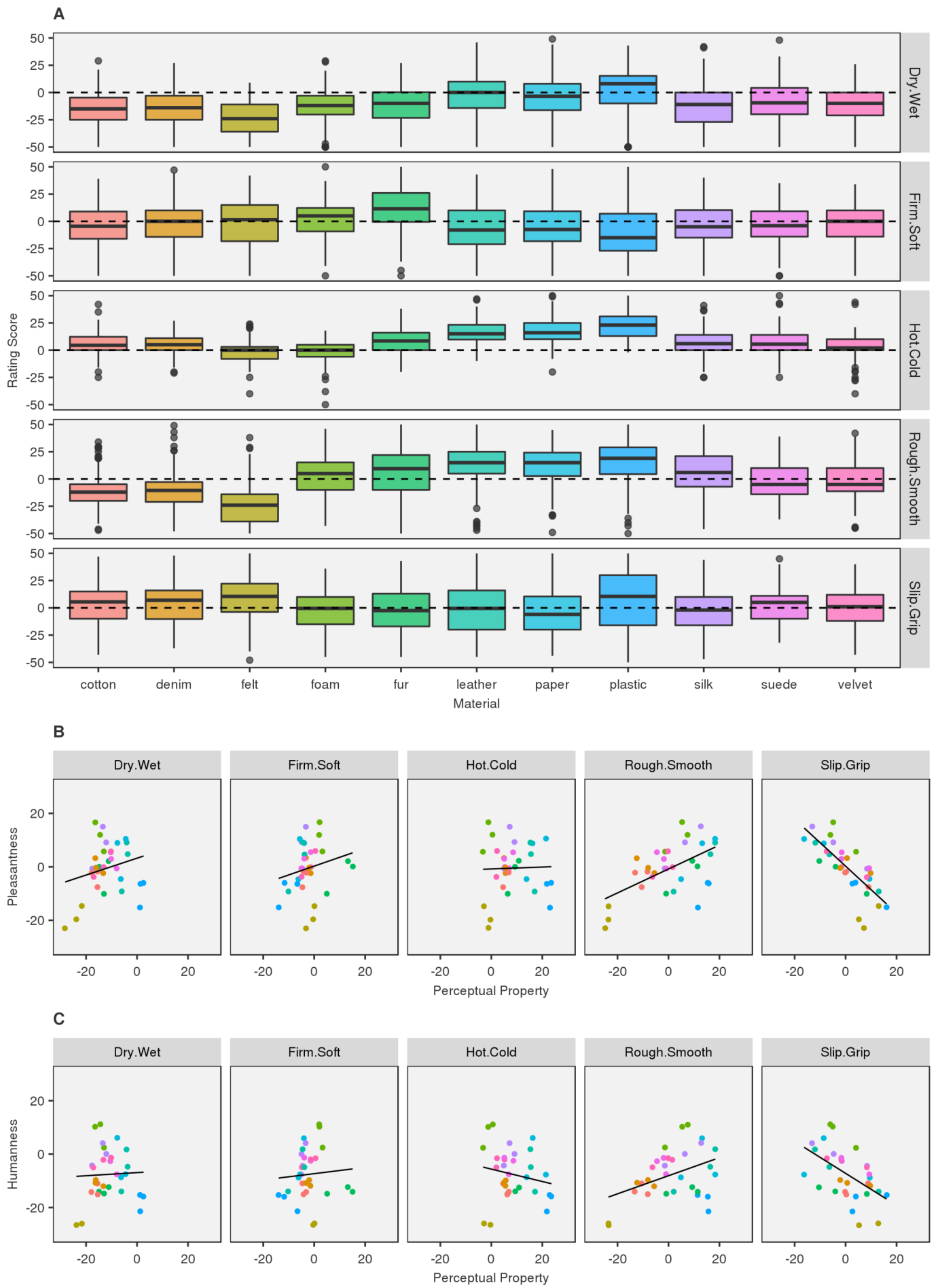

Figure 4. Experiment 2 pleasantness and humanness ratings. Panel A shows a box-and-whisker plot derived by averaging across velocities. Panel B shows a box-and-whisker plot derived by averaging across materials. Panel C shows the results of an LME model using humanness ratings to predict pleasantness ratings at the three stroking velocities. We opted for an LME model as the results from the ordinal model reported in the manuscript were not in a format accessible for plotting. As 4 and 10 cm/s velocity stroking produced comparable effects, both regression lines are overlapping with only the 10 cm/s condition being clearly visible.

*Humanness Rating.* Figure 4A shows the humanness ratings as a function of material. Foam was perceived as most (7.92, SD 21.11) and felt as least (-27.62, SD 21.29) human with a mean difference of 35.54 on a 100-point scale.

Using a likelihood ratio test, we compared a full ordinal mixed effect model with a null model in which velocity fixed effect was set to 1. The result was only marginally significant (LRstat=20.58, df=12, p=.06) and Bonferoni corrected follow-up comparisons were non-significant (ps>.25). To test whether this result would hold if the statistical approach was matched with that used in Experiment 1, we conducted a second analysis in which the 10 cm/s level was removed from the velocity factor. Examination of the full model, unfortunately, failed to converge. We hence removed the slope for materials from the random effects term and observed a marginal fixed effect that was about half the size of that reported in Experiment 1 ($\beta$=0.24, SE=0.13, z=1.85, p=.06, d=0.27).

Analysis of perceptual properties showed again a significant effect for the rough/smooth dimension ($\beta$=0.01, SE=0.004, z=2.36, p=.02, d=0.40). Specifically, greater smoothness was associated with greater humanness. Additionally, the slip/grip dimension showed a small non-significant trend in the same direction as that observed for pleasantness ($\beta$=-0.01, SE=0.01, z=-1.6, p=.11, d=0.26). The effects of all other dimensions were non-significant (ps>.25).

*Is there a relationship between pleasantness and humanness?* As in Experiment 1, pleasantness and humanness were significantly related (Figure 4C). A simple ordinal mixed effect model revealed a significantly positive effect ($\beta$=0.02, SE=0.005, z=4.62, p<.0001, d=0.72). Next, we added Velocity to the model and found that the interaction effect was non-significant (p>.25). Last, we explored whether the perceptual properties showing effects on pleasantness and/or humanness (firm/soft, rough/smooth, slip/grip) would modify their relation. To optimize model fitting, we first normalized the perceptual ratings to a mean of 0 and a standard deviation of 1. We then created three perceptual categories for values below -1, between -1 and 1, and above 1. We then added this categorical variable with main and interaction terms to the original model and compared this with a null model without the interaction term. The results were non-significant ($ps>.25$) indicating that the relationship between pleasantness and humanness was unaffected by the perceptual properties of the touching materials.


A
Rating Score
Dry.Wet
Firm.Soft
Hot.Cold
Rough.Smooth
Slip.Grip
cotton
denim
felt
foam
fur
leather
paper
plastic
silk
suede
velvet
Material
B
Pleasantness
Dry.Wet
Firm.Soft
Hot.Cold
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C
Humanness
Dry.Wet
Firm.Soft
Hot.Cold
Rough.Smooth
Slip.Grip
Perceptual Property

1

Figure 5. Experiment 2 perceptual ratings. Panel A shows box-and-whisker plots for the different perceptual properties as a function of material. Panel B illustrates the relationship between a particular perceptual property (x-axis) and pleasantness (y-axis). Panel C illustrates the relationship between a particular perceptual property (x-axis) and humanness (y-axis). Individual dots in panels B and C represent average ratings for the three velocities and for each material using the same color coding as in Panel A.

**Discussion**

A primary goal of Experiment 2 was to replicate and extend the results of Experiment 1. This was partially successful. Again, CT optimal stroking was perceived as more pleasant than CT non-optimal stroking and this was true for the velocities examined in Experiment 1 as well as for the added, faster velocity. However, our results did not replicate that well for the humanness rating. Here, the velocity effect merely approached significance and follow-up tests were non-significant. Moreover, although again pleasantness and humanness ratings were positively related, the effect was smaller than in Experiment 1. While it is possible that this difference is due to random and uncontrolled differences between the samples recruited for Experiments 1 and 2, it is perhaps more likely that methodological changes altered our results.

One of these changes entailed a human touch sample given prior to the humanness rating block. Perhaps, this sample enabled participants to have a better sense of what humanness means and reduced reliance on other related constructs such as pleasantness when making a response. If true, we may have overestimated the relation between humanness and pleasantness in Experiment 1 and obtained a more accurate value in Experiment 2.  Another change of potential relevance was the rating scale. In Experiment 1, this scale ranged from 0 to 100, whereas in Experiment 2 it ranged from -50 to 50. This scale adjustment was made against our understanding of the concept of humanness as an attempt to better align the rating task across blocks. Possibly, this humanness rating was more challenging and produced less meaningful scores. If true, we may have underestimated the relation between humanness and pleasantness in Experiment 2 and obtained a more accurate value in Experiment 1. Future research manipulating the presentation of a human sample and scale properties separately is needed to dissociate between both possibilities.

A second goal of Experiment 2 was to see how pleasantness and humanness map onto the physical dimensions thought to describe the somatosensory space. Participants perceived touch as more pleasant when it felt slippery, smooth, and soft. Moreover, slip and smoothness were the most important and softness the least important predictors. Like perceived pleasantness, perceived humanness was greater for smooth as compared with rough materials. Although a small similar trend showed for slippery as compared with gripping materials this as well as other effects in the somatosensory space were non-significant.

Of the two physical dimensions that yielded non-significant effects, temperature deserves special attention because it was previously linked to the activation of CT afferents (Ackerley et al., 2014). Temperature ratings varied significantly between materials. As all materials were kept in the same room prior to presentation, their temperature should have been largely comparable and similar to ambient temperature set at ~ 23 ℃ (unfortunately we failed to measure that within materials). However, because materials differed in their conduction properties, heat was flowing more or less easily from hand to material or vice versa thus impacting how warm or cold a material felt on the skin. Notably, this difference was irrelevant for tactile pleasantness, which has been previously shown to be temperature sensitive (Ackerley et al., 2014). That this wasn’t the case here likely relates to the temperature range that is perceived as pleasant in the context of touch. To the best of our knowledge, this range has not yet been explored in much detail. In their seminal study, Ackerley and colleagues explored only three settings (18, 32, 42 ℃) with two falling outside the typical skin temperature range. Compared to those two, the intermediate temperature was perceived as most pleasant and excited CT afferents the most. On this background then, we speculate that the present temperature range was comparatively narrower and largely overlapping with typical skin temperature (Arens & Zhang, 2006) such that it had little impact on rated pleasantness.

## General Discussion

In two experiments, we pursued the possibility that a touch's perceived pleasantness relates to how similar the touch feels to that of human skin. Specifically, we examined how factors that modulate tactile pleasure modulate perceived humanness and statistically related both constructs.

### *What determines touch pleasantness?*

Much research has tackled the factors that make a tactile experience pleasant. Of those factors, the ones activating CT afferents have received most attention with stroking velocity being a major one. Replicating earlier evidence (Essick et al., 1999; Löken et al., 2009; Sehlstedt et al., 2016), we found that CT optimal velocities elicit greater self-reported pleasantness than non-optimal velocities.

Importantly, with the present study we extend existing work by elucidating the role of other bottom-up and top-down factors. We pursued bottom-up factors by asking participants to rate their tactile experience in a somatosensory space with multiple physically relevant dimensions. In doing so, we showed that rough/smooth – the dimension accounting for most of the variance among the textures used here (Figure 5A) and the one that is considered primary in touch (Guest et al., 2011) – is highly relevant for pleasure. Its effects were complemented by slip/grip and firm/soft allowing us to characterize pleasant touch as smooth, slippery, and soft.

We pursued top-down factors by exploring different aspects of the participants' prior experience with the touch materials. The ability to identify a material from mere stroking across the arm was very poor and unrelated to pleasantness. Similarly, no effects emerged for the post-experimental assessment of whether or not participants knew the material and how frequently they had previously encountered it. However, there was a small effect for the naming of materials which now relied not on forearm stroking but on both visual and manual exploration with the latter being supported by the discriminative sensitivity of the palm. Not surprisingly, under these conditions material identification improved. Moreover, rated pleasantness from stroking during the experiment was slightly weaker for those materials with better post-experimental material identification. As post-experimental material identification positively predicted material identification during the experiment we venture that this effect may reflect some subtle influence of memory processes on perceived pleasantness. Possibly, once activated these processes engage mental resources that distract from enjoying an ongoing tactile experience.

Together, our memory-relevant results conflict with the idea that previously encountered and more familiar objects elicit greater liking – a finding established for a range of modalities (Delplanque et al., 2015; Kunst-Wilson & Zajonc, 1980) including touch (Jakesch & Carbon, 2012) as well as cross-modally from visual exposure to the liking of touch but not vice versa (Suzuki & Gyoba, 2008). We speculate that differences between strictly glabrous touch used in prior research and non-glabrous touch used here account at least partially for this conflict. Specifically, object discrimination and recognition with non-glabrous skin is very poor such that there is only limited memory information available to bias pleasantness judgments. Additionally, such biases may be secondary to the affective processing triggered by touch to CT innervated skin and such processing may be compromised by memory related cognitive operations. Last, idiosyncrasies in the present materials may have been important. As we tested only 11 materials, it is possible that, by chance, some of the materials that could be more easily identified because they were more distinctive (e.g., plastic) happened to be less pleasant to touch. Future research needs to explore memory-relevant effects with a larger set of materials.

***How do influences on pleasantness and humanness compare?***

Examining the above-mentioned bottom-up and top-down influences on perceived pleasantness and humanness, revealed both overlap and divergence. Like pleasantness, perceived humanness was greater for CT optimal as compared with non-optimal stroking. However, this effect was significant in Experiment 1 and only marginal in Experiment 2, possibly due to the human touch example and/or the modified rating scale. Additionally, smooth touch seemed more human-like than rough touch but effects for the slip/grip and firm/soft dimensions were non-significant. Last, whereas humanness ratings were unrelated to all the different memory-relevant measures, pleasantness showed a small effect for the post-experimental material identification score.

Taken together, we found that all effects observed for perceived humanness also showed for perceived pleasantness but not vice versa. Moreover, in general, humanness was more weakly associated with the variables measured and/or manipulated here. This may be because the underlying association is weaker. However, it may also be because humanness is a less intuitive construct and thus more difficult to judge when compared with pleasantness. We develop this idea further below.

***Linking the pleasantness and humanness of touch***

Apart from exploring how different bottom-up and top-down factors shape the perception of pleasantness and humanness, this study aimed at statistically relating the two. Across both experiments reported here, we found robust evidence that touch properties eliciting a pleasant touch sensation are likely to have a human feel. In other words, stroking speeds and surface textures associated with higher rated pleasantness are also associated with greater humanness. Moreover, the effect size of the direct association between both constructs was larger than that of the effects reported for the separate pleasantness and humanness analyses and fell within a range that is typically considered strong (Cohen, 1988, 1992).

This observation agrees with current theoretical and empirical perspectives. As mentioned in the introduction of this article, one may reasonably speculate that the importance of bodily contact with conspecifics led to the evolution of a tactile mechanism that specifically represents such contact and that triggers rewarding feelings as to reinforce contact reccurrence. Moreover, extant research suggests that CT afferents and their onward projections to the brain may be part of such a mechanism by, for example, facilitating the activity of neurochemicals such as endogenous opioids and oxytocin which promote positive affect and prosocial behaviors (Dunbar, 2010; for a review see McGlone et al., 2014; Walker, Trotter, Swaney, Marshall, & McGlone, 2017).

Nevertheless, tactile pleasantness and humanness failed to perfectly correlate possibly because the former is more accessible to introspection than latter. Both constructs differ in their relevance for evaluating touch as well as other impressions. Pleasantness or the appetitive value of a stimulus is one of the key properties informing emotion and motivating behavior. It signals to an organism *whether* a stimulus should be pursued or avoided (Arnold, 1961; Russell, 1980; Scherer, 2001). As such it is minutely calibrated based on a wide range of stimulus factors as shown here (e.g., smooth, slippery, soft). By contrast, whether a stimulus is human may be of secondary relevance and more critical for *how* that stimulus should be pursued or avoided. For example, whereas both food and gentle caress may be pleasurable and motivate approach, they would need to be approached differently – one by finding a restaurant and the other by finding an appropriate social partner. Moreover, compared to the perception of pleasantness, the perception of humanness may depend on a more circumscribed set of stimulus factors (e.g., smoothness).

Notably, there are other factors that dissociate the constructs of pleasantness and humanness. By necessity, not all pleasant touch is human. We may derive comfort from a hot shower, wind brushing through our hair, or from being wrapped in a blanket. Moreover, aspects of this comfort may be mediated by fibers other than CT afferents. In line with this, touch to body parts free of CT afferents has been shown to be pleasurable (Rolls et al., 2003; Schirmer & Gunter, 2017). Additionally, the tactile comfort that fish derive from moving in a shoal arises from water currents perceived, most likely, through A-fiber mechanosensation as, at least for now, evidence for the presence of CT afferents in fish is lacking. Likewise, not all human touch is pleasurable. The pleasantness of human physical contact depends on the relationship between toucher and touchee as well as on the nature of touch. Touch, even if gentle, can produce negative affect when given by a stranger (Arnold, 1961; Bradley, Codispoti, Cuthbert, & Lang, 2001; Russell, 1980; Scherer, 2001). Moreover, not all human touch is caressing (Hertenstein et al., 2006). Some forms of touch, irrespective of the toucher, may be neutral or even aversive (e.g., squeezing, tickling, rubbing or hitting).

### ***Directions for future touch research***

The present evidence for overlap in the subjective perception of pleasantness and humanness from touch raises a number of questions for future research. First and foremost is the issue of what exactly characterizes human touch. Previous work implied a potential role for stroking speed that could be substantiated here. Additionally, we show that smoothness contributes to the perception of touch as human-like. However, one might venture that there are additional cues such as the spatial trajectory of touch (e.g., circular vs straight) or dynamic pressure changes (e.g., soft to strong and back to soft) that need further attention.

Second, it will be important to pursue inter-individual differences in touch. Top-down, but also bottom-up, tactile processing is likely to mature as a function of both a person's genetic make-up and his or her tactile experiences. For example, there is much evidence that caregivers interact differently with girls and boys and that these differences extend to how children are being touched (Polanen, Colonnesi, Fukkink, & Tavecchio, 2017). Possibly because of this, women and men report different levels of comfort with touch ((Schirmer et al., 2015); see also Supplementary Materials) and vary in their response to direct and vicarious touch (Essick et al., 2010; Jönsson et al., 2017; Schirmer & McGlone, 2018). Here, we also explored potential effects of touch comfort and sex but obtained mixed results that failed to replicate across our two experiments (see Supplementary Materials). While it is possible that this replication failure was due to the experimental changes we made (i.e., human touch example, rating scale), it may also be due to a sampling bias and the possibility that our studies were insufficiently powered to reliably detect interindividual differences. Future research is needed to clarify these concerns.

Last, we wish to raise the question whether the CT system plays a special role in encoding touch between individuals. So far this system has been conceptualized as a more general affective touch system and pleasure has been emphasized as its primary function (e.g., Löken et al., 2009; McGlone et al., 2014). However, CT firing patterns suggest that this pleasure is fairly specific to touch with human-typical velocity and temperature (Ackerley et al., 2014; Croy, Luong, et al., 2016). Moreover, the softness illusion whereby the skin of another feels softer than one's own skin seems to depend on the toucher adopting a CT appropriate velocity (Gentsch et al., 2015). Last, non-CT touch to glabrous skin can be as pleasurable as touch to CT innervated skin (Schirmer & Gunter, 2017). Thus, one might argue that pleasure is secondary to humanness in CT processing. Input into a primarily social touch system may feed into a more comprehensive affective touch system that is based on both CT and non-CT input. Characterizing the sensitivity of CT afferents to other human touch properties (e.g., softness, touch trajectory, dynamic changes) would help further specifying their functional import.

### ***Conclusions***

In sum, the present data establish humanness as an important aspect in the pleasure of touch. They demonstrate that ratings of humanness and pleasantness depend on partially overlapping bottom-up factors. Stroking velocity predicted both rating constructs significantly in Experiment 1 and marginally in Experiment 2. Additionally, somatosensory properties such as smoothness influenced whether a tactile stimulation was perceived as both pleasant and human-like. Importantly, across both experiments, humanness and pleasantness showed a strong and positive relationship that was independent of whether top-down and bottom-up factors placed a touch low or high on one or both psychological dimensions. Thus, together our findings agree with the idea that the physical nature of gentle human touch naturally biases positive affect thus allowing such touch to promote the creation and maintenance of social bonds.

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