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Physiological and Behavioral Responses Reveal 9-Month-Old Infants' Sensitivity to Pleasant Touch

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Abstract

Caregiving touch has been shown to be essential for the growth and development of human infants. However, the physiological and behavioral mechanisms that underpin infants' sensitivity to pleasant touch are still poorly understood. In human adults, a subclass of unmyelinated peripheral nerve fibers has been shown to respond preferentially to medium-velocity soft brushing. It has been theorized that this privileged pathway for pleasant touch is used for close affiliative interactions with conspecific individuals, especially between caregivers and infants. To test whether human infants are sensitive to pleasant touch, we examined arousal (heart rate) and attentional engagement (gaze shifts and duration of looks) to varying velocities of brushing (slow, medium, and fast) in 9-month-old infants. Our results provide physiological and behavioral evidence that sensitivity to pleasant touch emerges early in development and therefore plays an important role in regulating human social interactions.

Keywords
infant development, cognitive development, social interaction

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Touch is one of the earliest forms of parent-child interaction (Barnett, 2005; Field, 2001). The importance of touch for social and physiological development in infants has been highlighted by orphan-deprivation studies and implementation of postnatal "kangaroo care" (Feldman, Weller, Sirota, & Eidelman, 2003; Field, 2010). The mechanism by which touch relates to developmental processes has been explored in nonhuman primates (Harlow & Zimmermann, 1959), but relevant work in human infants is sparse (Feldman, Singer, & Zagoory, 2009; Shibata et al., 2012).

Findings from microneurography and psychophysics in human adults have shown that hedonic properties of touch are mediated by a class of unmyelinated, low-threshold afferents: the C-tactile fibers, also known as C low-threshold mechanoreceptors (CLTMs; Löken, Wessberg, Morrison, McGlone, & Olausson, 2009). In contrast to Aβ afferents—mechanoreceptors with thick, myelinated axons subserving discriminative touch—this specialized class of receptors has been shown to be tuned to pleasant touch, that is, the afferent firing rate is high in the presence of moderate-velocity touch stimuli (Löken et al., 2009). The role of CLTM afferents in positive hedonic function has been further corroborated by selective activation of the apparent mouse-homologue CLTM afferent in vivo. Pharmacogenetic activation of CLTMs in mice promoted conditioned place preference, which indicates that such activation was positively reinforcing and perhaps anxiolytic (Vrontou, Wong, Rau, Koerber, & Anderson, 2013). In both humans and mice, CLTM afferents are present throughout the body in hairy

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skin but have not been found in glabrous skin (Olausson, Wessberg, Morrison, McGlone, & Vallbo, 2010).

The identification of a peripheral pathway mediating pleasant affiliative touch has highlighted the role of the human skin as a social organ (Morrison, Löken, & Olausson, 2010). To selectively study the role of CLTM afferents in affiliative behavior and physiology has previously been challenging, because light touch typically activates both CLTM and Aβ afferents simultaneously. However, the firing rates of CLTM and Aβ afferents show unique tuning curves in response to varying brush velocity, which allows one to differentiate their effects on physiology and behavior. Specifically, CLTM afferents respond with vigorous discharge rates to soft brush stroking at velocities of 1 to 10 cm per second, when the stimulus is also perceived as being most pleasant, but show low activity to slow (e.g., 0.3 cm/s) and fast velocities (e.g., 30 cm/s).

In contrast to this inverted-U-shape function, myelinated afferents increase their firing rate linearly with increasing brush velocity (Löken et al., 2009). This simple manipulation contrasts the optimal CLTM condition (medium velocity, so-called pleasant touch) with one control condition in which both myelinated Aβ fiber and CLTM firing is low (slow stroking) and another in which CLTM firing is low and Aβ firing is high (fast stroking). On the basis of previous work in adults, one expects to see a significant effect of pleasant touch at the medium velocity, during which CLTM firing is high and does not increase when Aβ signals are stronger.

In the current study, we tested whether human infants are sensitive to medium-velocity pleasant touch by assessing how activating the CLTM afferent system by soft brush stroking affects physiology and behavior. Specifically, we examined 9-month-old infants' physiological arousal (heart rate) and behavioral engagement (gaze shifts and duration of looks) during varying velocities of stroking (slow, medium, and fast). To do so, we used an experimental paradigm similar to the one employed by Löken and colleagues (Löken et al., 2009; Löken, Evert, & Wessberg, 2011). The 9-month age group was chosen because infants around that age have been shown to reliably locate and visually orient toward tactile stimulation (Bremner, Mareschal, Lloyd-Fox, & Spence, 2008). We decided to use heart rate as a physiological measure of arousal, because it provides an objective readout of the infant's response to brush velocity (Weiss, 1992).

Measuring changes in heart rate has been particularly useful in the study of cognitive and perceptual development in preverbal infants, because measures of complex behaviors or verbal responses are not suitable at this age (Reynolds & Richards, 2008). It is thought that whereas heart rate acceleration denotes a defensive response and activation of the sympathetic nervous system, heart rate deceleration reflects parasympathetic activity facilitating an orienting reflex (Graham & Jackson, 1970). The physiological and biochemical effects of touch in both nonhumans and human adults are suggestive of increased parasympathetic activity; such effects include decreases in heart rate, blood pressure, and cortisol and increases in oxytocin levels (Aureli, Preston, & de Waal, 1999; Drescher, Gantt, & Whitehead, 1980; Drescher, Whitehead, Morrill-Corbin, & Cataldo, 1985; Field, 2010; Uvnas-Moberg, Bruzelius, Alster, & Lundeberg, 1993; Wilhelm, Kochar, Roth, & Gross, 2001). In the current study, the physiological measures were complemented by behavioral measures (number of gaze shifts and duration of looks) commonly used to examine infants' attentional engagement during a task. In addition, we asked the primary caregivers of the infants to complete the Social Touch Questionnaire (STQ; Wilhelm et al., 2001) in order to examine whether and how caregivers' attitude to giving, receiving, and observing social touch relates to infants' responses to pleasant touch. The STQ measure allowed us to investigate potential individual differences in infants' sensitivity to social touch and the association between that sensitivity and parental factors.

Method

Participants

Twenty healthy infants (12 girls, 8 boys; age range: 8–10 months; mean age: 9 months, 2 days, *SD* = 28 days) were recruited from a database of parents who had agreed to participate in child development studies. Testing was done at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig, Germany. After receiving a thorough explanation of the study, parents gave written informed consent for their children's participation. Infants received a toy for participating. Of the 20 data sets, 3 (1 girl and 2 boys) were removed from the cohort because of excessive arm withdrawal during stimulation.

Procedure

The infants were allowed to play for about 10 min before the test session so they could familiarize themselves with the experimental room. Infants were then seated in a baby seat (Bumbo Babysitter, Toronto, Ontario, Canada) held on the lap of the attending parent. The parent and child were placed in a walled-off section of the lab facing a monitor and video-recording device (LifeCam Studio Q2F-00013, Microsoft, Redmond, WA) at an approximate distance of 70 cm. A pulse oximeter (Contec Medical, CMS 60C, Qinhuangdao, Hebei Province, China) was attached to the large toe of the infants' right foot using a specialized infant clip and medical tape. While the pulse oximeter was attached, the child started watching the silent distractor film (one of two films from the Czech cartoon series, "*Krteček*," or "*The Little Mole*," by Zdeněk Miler). Because photoplethysmography (PPG) can be affected by movement, the baby seat ensured that infants' legs were restrained to some degree; if necessary, the attending parent held the infant's leg (Fig. 1a). After it was established that the pulse-oximeter signal was consistently recording, data collection was started, with tactile stroking stimuli beginning after 1 min of baseline heart rate data were obtained.

Using a procedure described by Löken and colleagues (2011), the nondominant dorsal forearm was stroked by the experimenter using a Chinese hake paintbrush (5-cm width) at one of three defined velocities (0.3, 3, or 30 cm/s). The three speeds of stroking were administered with four repeats each, the order of which was pseudorandomized across infants such that there were no immediate repetitions of one velocity, and one particular velocity did not always precede another. Seated next to the parent, a female experimenter administered brush strokes over a marked-out 10-cm area on the dorsal side of the infant's left lower forearm (i.e., on hairy skin). The experimenter stroked from epicondyle to wrist (i.e., in the proximo-distal direction), with each stimulation lasting 10 s (Fig. 1a). The experimenter had practiced the three speeds of brush strokes. The handheld manipulation has been used with success previously (Löken et al., 2011; Morrison et al., 2010) and has recently been validated in direct comparison with robotic stimulation (Triscoli, Olausson, Sailer, Ignell, & Croy, 2013).

We were able to control for the amount of force the experimenter applied to the brushstrokes because of the von Frey effect. This effect assumes that the force required to bend the nylon hairs of the brush when pressed against the skin is constant and, therefore, can be used to apply a very accurate force on specific areas of the skin. Furthermore, the brush did not induce changes in temperature (as a hand could have), and contact area was controlled across participants. The protocol was similar to one in which neural recordings were obtained, which allowed us to make more direct links to previously published results (Löken et al., 2009; Löken et al., 2011). Additionally, with our parametric manipulation, we attempted to control for context with minimal social contact; the experimenter was instructed to make minimal eye contact with the infant, and stroking was performed indirectly through a paintbrush rather than by hand or with a socially relevant object. The experimenter was prompted by a hidden screen as to the velocity of the stroking and was blind to the order of conditions.

Between each 10-s stroking stimulus, there was a 40-s rest period to prevent receptor fatigue as well as to allow for a 10-s prestimulus baseline heart rate measurement (Fig. 1b). Parents were instructed to have as little physical contact as possible with the child during testing. Moreover, parents were in no way cued to the order or content of the conditions. At the end of testing, the primary caregiver completed a German translation of the STQ. The STQ is a self-report measure that examines the individual's approach and response to situations

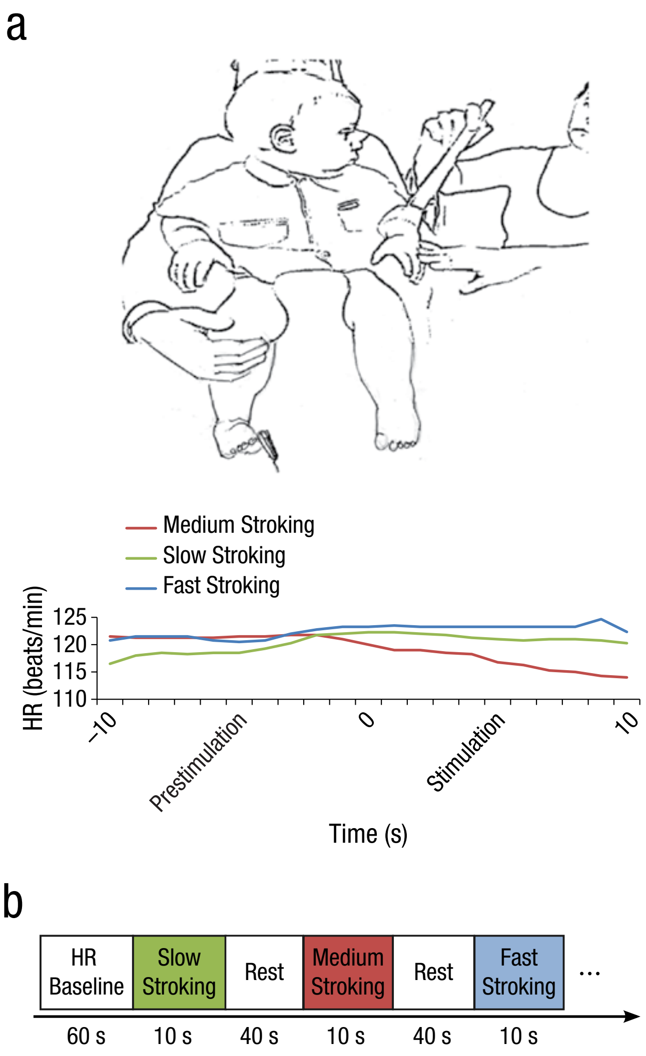

Fig. 1. Experimental paradigm (a) and sample timeline (b). The illustration shows the experimental setup. The infant was seated in a Bumbo baby seat placed on the lap of the parent. Parent and infant faced a monitor, which played a distractor film. The experimenter was seated beside the infant so she could easily stroke the infant's nondominant dorsal forearm with an artist's paintbrush at one of three velocities (slow: 0.3 cm/s, medium: 3 cm/s, fast: 30 cm/s). A response in arousal was measured by a special infant pulse-oximeter probe placed on the large toe of the right foot. The graph shows an individual infant's heart rate (HR) during the 10 s before stimulation and the 10 s during stimulation as a function of stroking velocity. As the sample timeline (b) shows, baseline HR was recorded before the start of trials, and then stroking stimuli (in pseudorandomized order) alternated with short rest periods throughout the trials.

involving social touch. Responses to items such as "I generally seek physical contact with others" or "I feel embarrassed if I have to touch someone in order to get their attention" provided a measure of the caregiver's sensitivity to social touch. Lower scores on this measure indicate a greater preference for social touch, whereas higher scores index a greater aversion to giving, receiving, and observing social touch. In this sample, internal consistency (Cronbach's α) of the 20 questions was .60.

Physiological measurement and analysis

PPG, or pulse oximetry, is a technique developed to monitor blood-volume changes in the microvascular bed of tissue and is now commonplace in various clinical scenarios (Allen, 2007). As an alternative to electrocardiogram (ECG), the pulse-oximeter device (recording at 500 Hz) was used with a specialized infant probe (Kamlin et al., 2008). Although the technique is sensitive to motion artifacts, video recordings allowed for the exclusion of trials during which excessive movement precluded the use of the heart rate data. In the absence of excessive movement, the signal from pulse oximetry is comparable to that from the ECG (Schäfer & Vagedes, 2013).

Pulse-oximeter data were extracted from Contec Medical's proprietary software (SpO2 Assistant; Contec, Qinhuangdao, Hebei Province, China). The software identifies maxima in the pulse-oximeter waveform data and from these determines successive R-wave-to-R-wave (R-R) intervals. R-R intervals were then visually inspected to identify infrequent missed beats, which were replaced by interpolation with neighboring R-R intervals. After examining the video recordings and cardiac data, we removed trials in which excessive movement resulted in noise. Preprocessing was performed with Microsoft Excel 2002, and statistical analyses were run using SPSS (alpha level of .05). To obtain a mean heart rate before and during stimulation for each stroking velocity, we separately averaged pulse values during stroking (0–10 s from stimulus onset) and during the 10 s immediately preceding stimulus onset. These values were then averaged across repeats per velocity. The percentage signal change in pulse rate for each stimulus was calculated by expressing the difference between the relative stimulation and prestimulation means as a percentage of the prestimulation mean value (Loggia, Juneau, & Bushnell, 2011).

Behavioral measurement and analysis

Throughout the test, infants were seated in front of a screen playing a distractor video from which they could shift their gaze to engage visually with the experimenter or the paintbrush. Using video recordings, a first observer separately coded factors during the 10 s before and then during stroking, including foot and general body movement, anticipation of the upcoming stimulus (anticipatory arm withdrawal or gaze shift), arm withdrawal, duration and number of gazes toward the experimenter, and duration and number of gazes toward the paintbrush. The first observer coded all the videos, after which a second observer coded the same information for one-third of the videos. Interrater reliability for looking-time duration and number of gaze shifts was acceptable (Pearson's rs = .67 and .73, respectively). For the analyses of behavioral engagement (gaze shifts), we used a single factor calculated by dividing the duration of shifts by the number of shifts. This yielded a ratio that took into account the duration of individual gaze shifts. We conducted one-way repeated measures analyses of variance (ANOVAs) and follow-up post hoc t tests to compare stroking conditions. An alpha level of .05 was applied for all statistical tests. Unless otherwise noted, we report two-tailed p values throughout.

Results

On the basis of adult behavioral studies of touch (Drescher et al., 1980; Drescher et al., 1985), we hypothesized that the specificity of the response of the C-tactile fibers to medium-velocity stroking would be evident from both the physiological heart rate data and from the behavioral responses. Specifically, we expected a significant decrease in heart rate and a significant increase in behavioral engagement, as measured by longer individual gazes toward the stroking stimulus during medium-velocity stroking than during slow- or fast-velocity stroking.

As predicted, our cardiac data revealed a U-shaped relationship between brushing velocity and heart rate, as measured by percentage signal change (slow: M = 1.02, SE = 1.51; medium: M = −1.21, SE = 1.40; fast: M = 1.19, SE = 1.46; see Fig. 2a). Specifically, heart rate decelerations were observed in the medium-velocity condition, whereas slight accelerations were observed in the slow- and fast-velocity conditions. Post hoc t tests showed significant differences between the slow- and medium-velocity conditions, $t(15) = 1.97$, one-tailed $p = .03$, two-tailed $p = .065$, and between the medium- and fast-velocity conditions, $t(15) = 2.9$, $p = 0.01$. No significant difference was seen between the slow- and fast-velocity conditions ($p = .89$).

We next examined the number of gaze shifts between the distractor film and the stimulation and the duration of looks made to either the paintbrush or the experimenter during the 10 s of brushing. Separately, these factors showed little or no effect of the manipulation. The

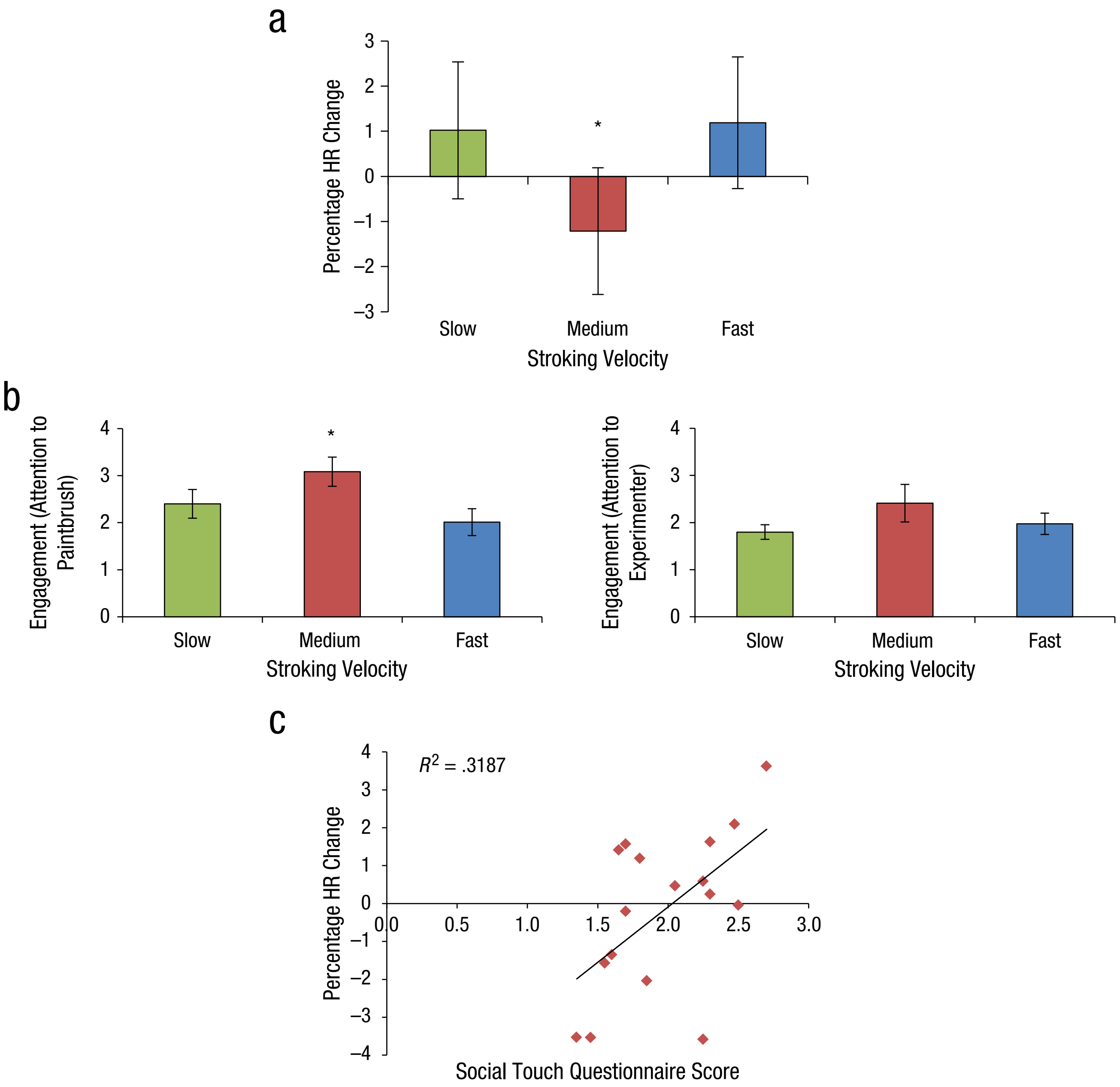

Fig. 2. Results. Mean percentage heart rate (HR) change (a) is shown as a function of stroking velocity. Attentional engagement (b) is shown as a function of stroking velocity, separately for engagement with the paintbrush (left) and with the experimenter (right). Engagement was calculated as the duration of gazes divided by the number of gaze shifts. In (a) and (b), error bars represent standard errors, and an asterisk indicates a significant difference relative to the other two conditions ($p < .05$). The scatter plot (c; with best-fitting regression line) shows the correlation between mean percentage HR change for each infant in the medium-velocity condition and his or her parent's score on the Social Touch Questionnaire (Wilhelm, Kochar, Roth, & Gross, 2001). Lower scores indicate greater preference for social touch.

number of gaze shifts toward the experimenter (slow: M = 1.16, SE = 0.13; medium: M = 1.42, SE = 0.25; fast: M = 1.52, SE = 0.21) and toward the paintbrush (slow: M = 1.35, SE = 0.12; medium: M = 1.61, SE = 0.15; fast: M = 1.78, SE = 0.24) were similar across velocity conditions, as were the duration of looks toward the experimenter (slow: M = 1.73 s, SE = 0.23; medium: M = 2.33 s, SE = 0.39; fast: M = 2.58 s, SE = 0.40) and toward the paintbrush (slow: M = 3.03 s, SE = 0.30; medium: M = 3.69 s, SE = 0.45; fast: M = 3.51 s, SE = 0.54).

Durations and frequencies for each velocity condition were then used to create a single "engagement" parameter assessing both the attentional switch and sustained attention, separately toward the paintbrush and toward the experimenter. Across conditions, a one-way repeated measures ANOVA showed a significant effect of brushing velocity, *F*(2, 48) = 3.28, *p* = .04, with significantly longer attention (engagement) toward the paintbrush during the medium- relative to the fast-velocity, *t*(15) = 3.66, *p* = .0021, and slow-velocity condition, *t*(15) = 3.84, *p* = .0014 (slow: *M* = 2.40, *SE* = 0.30; medium: *M* = 3.09, *SE* = 0.31; fast: *M* = 2.01, *SE* = 0.29; see Fig. 2b). Despite a similar trend, no significant main effect was seen in the measure of engagement with the experimenter (slow: *M* = 1.70, *SE* = 0.15; medium: *M* = 2.39, *SE* = 0.37; fast: *M* = 1.93, *SE* = 0.22).

Next, we compared infants' physiological responses with their parent's responses on the STQ. As shown in Figure 2c, our analysis revealed a significant positive correlation between the infant's response in heart rate (deceleration) and the parent's STQ score (*r* = .56, *p* = .02), but only in the medium-velocity condition. This correlation was not significant in the slow- (*r* = .20, *p* = .42) and fast-velocity (*r* = .14, *p* = .58) conditions. This finding indicates that the greater the caregiver's sensitivity to social touch, the greater the infant's heart rate deceleration in response to medium-velocity touch.

Discussion

In the current study, we investigated whether human infants are sensitive to pleasant touch by assessing their levels of physiological arousal and behavioral engagement while being stroked at varying velocities (slow, medium, and fast). In line with our predictions, the current results revealed that only when stroked at medium velocity, (a) infants' heart rate decelerated, which reflects increased parasympathetic activity and is indicative of a decrease in arousal, and (b) infants' behavioral engagement with the stroking object (brush) increased, which is indicative of an increased interest in the stroking object. These findings support the notion that pleasant touch plays a vital role in human social interactions by demonstrating that the sensitivity to pleasant touch emerges early in human development.

Critically, infants' selective physiological (decrease in heart rate) and behavioral (increased engagement) responses to medium-velocity brushing are in line with the response profile of a special class of nerve fibers in human adults—the CLTM afferents (which show preferential activity in response to medium-velocity brushing; see Löken et al., 2009). This suggests that the physiological and behavioral effects observed in infants might be related to CLTM afferent function. Note that a direct test of CLTM afferent function is unlikely to be carried out because of ethical and technical concerns. Therefore, the current approach can be seen as an indirect but effective way of illuminating CLTM afferent function in human infants. Furthermore, our results show that infants' physiological and behavioral responses are unlikely to be related to the discriminative touch system mediated by myelinated Aβ fibers. If our measures had been influenced by the discriminative touch system, we should have observed a linear relationship between the velocity of touch and our physiological and behavioral measures, but this was not the case. Our findings therefore provide evidence for a selective responsiveness to medium-velocity touch in 9-month-old infants. This physiological and behavioral sensitivity might serve important adaptive functions, because caregiving touch has been shown to be essential for promoting healthy social and cognitive development (Feldman et al., 2009; Field, 2010).

It is important to note that the observed decrease in heart rate in response to pleasant-touch stimuli agrees with the existing view that touch and its positive influence on mood, growth, and development rely on parasympathetic activity (Field, 2010). Generally, heart rate deceleration is thought to reflect parasympathetic activity facilitating an orienting reflex (Graham & Jackson, 1970) and has been observed in response to sedative music treatments in premature infants (Lorch, Lorch, Diefendorf, & Earl, 1994; Shenfield, Trehub, & Nakata, 2003). The observed heart rate deceleration in response to pleasant-touch stimuli may be related to findings showing that touch attenuates heart rate increases in anticipation of electrical shock (Anderson & Gantt, 1966). Clearly, more work, including a wider range of measures, is needed to elucidate the exact physiological nature of pleasant touch and its effects in infancy.

Our analysis further revealed that decreases in each infant's heart rate during the medium (but not during the slow or fast) condition were correlated with his or her parents' score on the STQ. This finding, as well as the fact that in the heart rate data, standard errors were greater than the mean changes across conditions, suggests that there is variation in the infants' responsiveness to pleasant touch. Individual differences might be attributed to differences in the primary caregiver's sensitivity to social touch. From the current data, it remains unclear whether this association exists because (a) infants experience differing levels of social touch as a function of their caregiver's sensitivity to social touch or (b) sensitivity to social touch is heritable and therefore correlated between caregivers and infants (Morrison et al., 2011).

In addition to the physiological responses, we assessed the behavioral engagement of infants during the experiment and observed greater attentional engagement with the stimulating brush during the medium-velocity condition than during the slow- and fast-velocity conditions. This shows that infants preferentially orient toward the object that produces the medium-velocity touch, and it provides behavioral evidence for infants' sensitivity to pleasant-touch stimuli. Infants show this increased engagement even though they have to look away from an attention-grabbing (distractor) video stimulus in order to engage with the brush. Given the required disengagement from the video screen, this might be seen as even stronger evidence for a behavioral preference for the pleasant-touch stimulus. The observed behavioral preference in infants may be related to adults' preference for medium-velocity stimuli, as indexed by their pleasantness ratings (Löken et al., 2009). However, it is also possible that medium-velocity stroking simply induces increased attention in the infant rather than a specific hedonic state.

It is interesting that despite the presence of the female experimenter performing the tactile stimulation, the behavioral effect was limited to the brush, as no significant effect was observed for engagement with the experimenter. This may be due to the fact that the experimenter's attention was focused on the brush and therefore cued the infants' attention toward that object (Grossmann & Farroni, 2009). Alternatively, this might be due to a heightened salience of the object causing this touch sensation. Regardless of the exact nature of this behavioral response, the current behavioral findings critically add to the heart rate results by demonstrating that infants at 9 months of age not only show a selective physiological response but also preferentially orient their attention to pleasant-touch stimuli.

In summary, through the direct assessment of physiological and behavioral responses to touch, the present study is the first to demonstrate that human infants are sensitive to medium-velocity pleasant touch. This supports the notion that the ability to perceive and sensitively respond to pleasant touch is vital from early in ontogeny because of its significance for affiliation, bonding, and biobehavioral synchrony, especially between caregivers and infants (Feldman, 2012; Feldman et al., 2009; Field, 2010). This study, by providing evidence for the existence of a functioning pleasant-touch system in human infants, lays the foundation for future work that should systematically examine this ability and its underlying physiological mechanisms, as well as its typical and atypical effects on social and cognitive development.

Author Contributions

M. T. Fairhurst, L. Löken, and T. Grossmann designed the study; M. T. Fairhurst conducted the study and analyzed the data; and M. T. Fairhurst, L. Löken, and T. Grossmann wrote, edited, and revised the manuscript.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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