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The perception of affective and discriminative touch in blind individuals

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ABSTRACT

Enhanced tactile acuity in blindness is among the most widely reported results of neuroplasticity following prolonged visual deprivation. However, tactile submodalities other than discriminative touch are profoundly understudied in blind individuals. Here, we examined the influence of blindness on two tactile submodalities, affective and discriminative touch, the former being vital for social functioning and emotional processing. We tested 36 blind individuals and 36 age- and sex-matched sighted volunteers. In Experiment 1, we measured the perception of affective tactile signals by asking participants to rate the pleasantness of touch delivered on the palm (nonhairy skin, sparsely innervated with C tactile [CT] fibers) or the forearm (hairy skin, densely innervated with CT fibers) in a CT-optimal versus a CT-nonoptimal manner using a paradigm grounded in studies on tactile sensory neurophysiology. In Experiment 2, we implemented a classic task assessing discriminative touch abilities, the grating orientation task. We found that blind individuals rated the touch as more pleasant when delivered on the palm than on the forearm, while the opposite pattern was observed for sighted participants, who rated stimulation on the forearm as more pleasant than stimulation on the palm. We also replicated the previous findings showing enhanced discriminative tactile acuity in blind individuals. Altogether, our results suggest that blind individuals might experience affective touch differently than sighted individuals, with relatively greater pleasantness perceived on the palm. These results provide a broader insight into somatosensory perception in blind individuals, for the first time taking into consideration the socioemotional aspect of touch.

1. Introduction

Touch is important for recognizing objects, perceiving form, shape, and texture, detecting vibrations, and identifying the direction of stimuli moving over the body. In addition to this, touch holds significant emotional and social value [50]. Tactile experiences can be perceived as pleasant, and when they are, this is often associated with the activity of C-tactile (CT) afferents [73]. These unmyelinated nerve fibers are activated by touch applied with velocities between 1 and 10 cm/s ([1,47]) and are found predominantly in hairy skin but also sparsely in glabrous skin [77]. However, the activation of CT fibers cannot be the single source of perceived pleasantness, given that the touch applied to nonhairy skin can also be pleasant [61,62]. Indeed, the stimulation of the glabrous skin of the palm, densely innervated predominantly with Aβ fibers, has been empirically shown to evoke pleasant sensations [20,23, 24]. Furthermore, the relationship between the velocity of touch and pleasantness ratings follows a similar inverted-U shape curve on the palm and the forearm [20]. Therefore, it could be the case that the intensity of perceived pleasantness of glabrous skin stimulation is influenced by other aspects of tactile experience, such as top-down factors [11] or attachment style [6], among others. Interestingly, the affective experience of touch has also been shown to be modulated by visual cues, even when the tactile stimulation itself remains consistent [28,38,65].

Numerous experiments have investigated touch in blind individuals. Several studies have shown that tactile acuity in blind individuals is superior to that in sighted individuals ([26,29,2]), similar to their vibrotactile perception abilities ([76]; for a review, see [63]). However, there are also reports showing no differences between blind and sighted individuals in tactile acuity [71] or texture discrimination [32]. Touch in blind individuals has also been studied in a multisensory context, for example, investigating audio-tactile processing [12,13,35,36,59]. Surprisingly, to the best of our knowledge, the affective aspect of touch has

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not yet been investigated in blind individuals.

The lack of investigations on affective touch perception in blind individuals is an important gap in knowledge for several reasons. First, there is a close link between the neurobiological basis of the perception of tactile pleasure and that of pain [46]. Pleasantness and pain are two forms of salient touch, providing homeostatic input that informs about the status of the body and its needs, which makes them a part of a broader interoceptive system (see [21]). In a recent study [58], we showed that cardiac interoceptive accuracy is enhanced in blind individuals. Pain has also been systematically shown to be altered in blind individuals [66–68]. Therefore, examining affective touch in blind individuals would allow us to further explore the importance of skin-mediated interoceptive signals following blindness. Another reason why affective touch perception in blind individuals needs to be investigated is related to affective touch being one of the nonvisual means of expressing emotions to other people (see [34,41]) and playing a unique role in social development (see [16,18]). It is particularly interesting given that adult blind individuals not only do not show impairments in emotion processing compared with sighted individuals [27], but exhibit improved ability to distinguish emotional information, along with

Table 1
Blind participant characteristics.

Participant	Age (years)	Sex	Cause of blindness	Age at blindness onset	Handedness	Reading hand (finger)	Age when learned Braille	Reading frequency
1	24	male	atrophy of the optic nerve	congenitally blind	right-handed	left (index finger)	6	every day
2	26	male	retinopathy of prematurity	congenitally blind	ambidextrous	left	7	every day
3	37	female	retinopathy of prematurity	congenitally blind	ambidextrous	right	7	every day
4	28	female	retinopathy of prematurity	congenitally blind	right-handed	right	8	every day
5	25	male	retinopathy of prematurity	congenitally blind	ambidextrous	left	7	rarely
6	34	male	undefined (genetic)	congenitally blind	right-handed	left	7	every day
7	32	female	retinopathy of prematurity	congenitally blind	ambidextrous	left	6	rarely
8	43	male	atrophy of the optic nerve	congenitally blind	right-handed	left (index finger)	7	rarely
9	31	male	retinopathy of prematurity	congenitally blind	right-handed	right	5	once a week
10	32	female	retinopathy of prematurity	congenitally blind	ambidextrous	right (index finger)	7	rarely
11	40	female	atrophy of the optic nerve	congenitally blind	right-handed	right (index finger)	7	every day
12	39	female	retinopathy of prematurity	congenitally blind	right-handed	left (index finger)	6	often
13	40	female	retinopathy of prematurity	congenitally blind	right-handed	left	6	none
14	30	female	atrophy of the optic nerve	congenitally blind	ambidextrous	right	4	rarely
15	30	male	optic nerve hypoplasia	congenitally blind	ambidextrous	right	7	once a week
16	39	male	retinopathy of prematurity	congenitally blind	ambidextrous	left	5	rarely
17	27	male	retinopathy of prematurity	congenitally blind	right-handed	right	7	rarely
18	45	female	retinopathy of prematurity	congenitally blind	ambidextrous	left	7	rarely
19	45	male	retinopathy of prematurity	congenitally blind	ambidextrous	left	7	rarely
20	22	male	microphthalmia	congenitally blind	ambidextrous	left	4	every day
21	45	female	retinopathy of prematurity	congenitally blind	right-handed	right (index finger)	7	every day
22	31	female	atrophy of the optic nerve	congenitally blind	ambidextrous	right (index finger)	7	often
23	31	male	retinopathy of prematurity	congenitally blind	ambidextrous	left	6	once a week
24	35	female	congenital glaucoma	congenitally blind	ambidextrous	both	7	rarely
25	23	male	atrophy of the optic nerve	congenitally blind	ambidextrous	left (index finger)	7	every day
26	22	male	retinopathy of prematurity	congenitally blind	ambidextrous	left (index finger)	6	every day
27	33	male	atrophy of the optic nerve	congenitally blind	right-handed	left (index finger)	6	rarely
28	29	male	retinopathy of prematurity	congenitally blind	right-handed	left (index finger)	7	rarely
29	36	female	undefined (genetic)	congenitally blind	ambidextrous	right (index finger)	4	often
30	42	male	toxoplasmosis	congenitally blind	right-handed	right (index finger)	8	often
31	35	female	undefined (genetic)	congenitally blind	right-handed	right (index finger)	4	rarely
32	40	male	eye injury	3	ambidextrous	right (index finger)	6	rarely
33	23	female	glaucoma	4	right-handed	left (middle finger)	4	rarely
34	26	female	retinal detachment	17	right-handed	left (index finger)	17	rarely
35	38	male	glaucoma	21	right-handed	right (index finger)	22	none
36	45	female	eye injury	23	right-handed	left (index finger)	19	often

heightened activation of the amygdala in response to emotional auditory stimuli [39,40]. Therefore, possibly, the improved emotion discrimination abilities observed in blind individuals in the verbal and auditory domains could extend to the tactile domain, leading to a higher sensitivity to affective touch.

The present study investigated the influence of visual deprivation on two dimensions of touch. In the first experiment, we measured the perceived pleasantness experienced from light, dynamic stroking touches applied to the forearm and palm using CT-afferent optimal and nonoptimal velocities (see [22]). In the second experiment, we measured the tactile spatial acuity of our participants using the grating orientation task, in which participants identify the orientation (horizontal or vertical) of a grooved surface applied to their fingertip [74]. We decided to employ these two tasks to obtain a broader picture of the tactile abilities of our participants, focusing on two key functions of touch, affective and discriminative, and to see whether there is a relationship between them (see [50]). The overarching goal of this study was to take the first step toward understanding how the absence of vision influences the affective dimension of touch and how affective touch relates to discriminative touch, which, altogether, could have important implications for advancing our understanding of the role of visual experience in social functioning of blind individuals.

2. Materials and methods

2.1. Participants

A total of 36 blind and 36 sighted individuals (age range: 22–45 years, mean age: 33.42 years in the blind group, 33.19 in the sighted group; 19 men and 17 women per group; 1 left-handed individual in the sighted group) participated in the study. For each blind participant, a sighted, sex- and age-matched participant was recruited. All participants reported that they did not have any other sensory or motor disabilities. A history of neurological or psychiatric disorders was an exclusion criterion.

For all blind participants, blindness was attributed to a peripheral origin. The requirements for participation were complete blindness or having only minimal light sensitivity but without ability to functionally use this sensation and without having any pattern vision. Thirty-one participants were congenitally blind, two early blind (early blindness defined here as acquired in childhood, 0–2 years after birth, as in [31, 70]), and three late blind. The results following the post hoc exclusion of late blind participants and the matched control volunteers are described in Supplementary material for purely descriptive purposes. Blind participants' characteristics are presented in Table 1. Handedness was assessed using the Edinburgh Handedness Inventory [53] in the sighted group and its modified version in the blind group [4].

The same participants also took part in two other behavioral experiments that will be reported separately ([58] and Radziun et al., in preparation).

The study was approved by the Jagiellonian University Ethics Committee. All participants provided written informed consent before the study and were compensated for their time; blind participants' travel expenses were reimbursed. The documents were read to blind participants by the experimenter, who then used a tactile marker to indicate the location for signatures.

2.2. Experimental tasks and procedures

First, the participants were informed about the experimental setup and received a short description of the procedure. Each participant was seated on a chair in a comfortable position. The participants were asked to remove their jewelry and roll up their sleeves so that the entirety of their forearm and palm was within the reach of the experimenter. Sighted participants were blindfolded while performing the tasks. The affective touch task was conducted on the left palm and forearm and the grating orientation task was conducted on the right index finger.

2.2.1. Affective touch task

Before the start of the task, the experimenter marked two identical 9 × 4 cm areas on the left forearm and palm using a washable marker, following the same procedure used in previous studies (e.g., [17]). Making sure that the stimulation was applied only inside the marked shape allowed the experimenter to control the extent of the stimulated area and the pressure applied during the touch, as too much pressure would lead to a wider spreading of the brush. The stimulated areas were alternated to counteract the fatigue of the CT fibers (see [49]). The touches were administered using a soft brush (Precision Cheek Brush, Article No. 89650729, Åhléns, Stockholm, Sweden) at seven velocities: 0.3, 1, 3, 6, 9, 18 and 27 cm/s. The direction of movement was always proximal to distal concerning the participant. Two velocities of 3 and 6 cm/s (here defined as 'CT optimal' [47]) are typically perceived as more pleasant than 1 and 9 cm/s (here defined as 'borderline') and 0.3, 18, and 27 cm/s (here defined as 'CT nonoptimal'; [47]). The touch was delivered manually by a trained female experimenter (DR) in all participants (see [28] and [64] for investigations on the effect of the sex of the experimenter on the perception of touch pleasantness). The participant's task was to verbally rate the pleasantness of the touch using a rating scale ranging from 0 (not at all pleasant) to 100 (extremely pleasant). Each velocity was repeated three times, for a total of 21 trials per skin site presented in three blocks, in random order. Immediately after reporting the experienced pleasantness of touch, participants were asked to rate their confidence in the assessment (as in [22]). This judgment was made using a scale from 0 (not confident at all) to 10 (extremely confident).

In order to assess an additional aspect of metacognitive reflection, specifically the participants' prior and post-task beliefs about their performance, they were asked to evaluate their performance in the task for all trials before and after completing it. This was done after they received instructions for the task and had a chance to ask any clarifying questions (as in [22]). Therefore, before starting the task, the participants were given the following instruction: *Now that I have explained the task to you, how well are you going to perform in the task of judging the pleasantness of the touch on a scale ranging from 0 (not so well/total guess) to 100 (very well/very accurate)?* Upon finishing the task, the participants were asked to evaluate their performance in all trials. They were given the following instruction: *Now that you have done the task, how well did you perform in the task of judging the pleasantness of the touch on a scale ranging from 0 (not so well/total guess) to 100 (very well/very accurate)?* These data were analyzed independently from the confidence judgments made after each trial.

2.2.2. Grating orientation task (discriminative touch task)

In this procedure, eight hemispheric plastic domes with parallel bars and grooves of equal width were used as stimuli (JVP [Johnson-Van Boven-Phillips] Spatial Discrimination Domes, Stoelting, Inc. Wood Dale, IL). The widths were of the following sizes: 0.35, 0.5, 0.75, 1, 1.2, 1.5, 2, and 3 mm. The grating orientation task [74] was performed following the standard procedure outlined by Van Boven et al. [75]. The participant's right index finger was fixated palm-up on a table while a trained experimenter applied the gratings to the right finger's distal pad with moderate force for approximately 1.5 s. The experimenter avoided any movement of the participant's finger caused by contact with the grating. The orientation of the grating was either horizontal or vertical relative to the finger's long axis. The participants were asked to identify the orientation of the grating, i.e., whether it was horizontal or vertical (two-alternative forced-choice paradigm). The task comprised eight blocks, with one for each grating width. Each block consisted of 20 randomized trials, 10 horizontal and 10 vertical. The order of blocks was fixed and corresponded to the decreasing width of the gratings. No feedback was given to the participants regarding the accuracy of their responses. Immediately after identifying the grating orientation, the participants were asked to rate their confidence in the accuracy of their responses. This confidence judgment was made using a scale from 0 (total guess) to 10 (complete confidence).

To examine prior and posterior beliefs about one's performance (see above), after the participants received the instructions for the task and had a chance to clarify any questions they had, they were asked to evaluate their overall performance on the task in relation to all trials. Therefore, before the task, they were provided with the following instruction: *Now that I have explained the task to you, how well are you going to perform in the task on a scale ranging from 0 (not so well/total guess) to 100 (very well/very accurate)?* Upon completing the task, the participants were asked to reflect on their performance across all trials. They were provided with the following instruction: *Now that you have done the task, how well did you perform in the task on a scale ranging from 0 (not so well/total guess) to 100 (very well/very accurate)?* The data was analyzed independently from the confidence assessments given after each trial.

2.3. Data analysis

2.3.1. Affective touch task

We calculated the scores for tactile pleasantness for the CT-optimal, borderline, and CT-nonoptimal velocities by averaging the scores in each category. Then, we investigated the main effects of velocity and skin site on pleasantness employing a repeated-measures ANOVA.

The second variable of interest was the so-called 'affective touch sensitivity' (see [42]; Kirsch et al., [43]; [22]), which refers to the individual's ability to differentiate between the levels of pleasantness of affective and neutral touch, without taking into account the overall perceived pleasantness. To this end, we used the averaged pleasantness scores for CT-optimal and CT-nonoptimal velocities and calculated the difference between these two categories, for the forearm and the palm separately.

2.3.2. Grating orientation task (discriminative touch task)

The grating orientation threshold was calculated by linear interpolation between grating widths spanning 75 % correct responses (as in [51,74,79]). Eight participants from the blind and 12 from the sighted groups were excluded from the data analysis of this particular task because they could not perform beyond the expected standard psychophysical level of 75 % accuracy.

2.3.3. Belief of performance accuracy and confidence

Belief of performance accuracy data collected prior to and after tasks completion was compared between the groups. The averaged confidence ratings over trials involving forearm and palm stimulation were correlated with affective touch sensitivity for the forearm and palm, respectively. Similarly, associated confidence ratings averaged across all trials were correlated with the grating orientation threshold.

2.4. Plan of statistical analysis

The data were tested for normality using the Shapiro—Wilk test. The affective touch rating data were found to be nonnormally distributed ($p < 0.05$). However, we decided to use parametric tests for all analyses because of their utility in ANOVAs and factorial designs, such as in the current study (see [57] for a similar approach). Nonparametric tests yielded the same results as the use of parametric approach, unless specified otherwise. Bonferroni correction was used to follow up on significant effects and interactions. When used, the uncorrected p-value is accompanied by a corrected alpha level (α). All p values are two-tailed. Data exclusion criteria were established before data analysis.

For the Bayesian analyses, the default Cauchy prior was used. BF_{01} denotes support for the null hypothesis over the alternative hypothesis, while the BF_{10} indicates support for the alternative hypothesis over the null hypothesis (e.g., BF_{01} of 7 suggests seven times stronger support for the null hypothesis, whereas BF_{10} of 7 indicates seven times stronger support for the alternative hypothesis). BF values ranging from 0.333 to 3 are typically deemed inconclusive [37,45].

The data were analyzed and visualized with RStudio software, version 1.4.1717, and the BayesFactor software package, version 0.9.12–4.2. The data are available at https://osf.io/4dybv/. For data visualization, the raincloud plots were used [3].

3. Results

3.1. Affective touch

As expected, there was a main effect of velocity on touch pleasantness ($F(2, 142) = 33.86$, $p < 0.001$). A follow-up Bonferroni-corrected ($\alpha = 0.017$) analysis revealed that across both groups, slow, CT-optimal touch was rated as more pleasant ($M = 73.58$; $SD = 17.63$) than fast, CT-nonoptimal touch ($M = 62.94$; $SD = 20.24$; $t(71) = 6.86$; $p_{uncorrected} < 0.001$, CI95% = 7.55–13.73) and touch delivered at borderline velocities ($M = 69.32$; $SD = 18.26$; $t(71) = 6.07$; $p_{uncorrected} < 0.001$, CI95% = 2.86–5.66). There was also a significant difference between borderline and CT-nonoptimal touch ($t(71) = 4.30$; $p_{uncorrected} < 0.001$, CI95% = 3.42–9.34). There was no significant main effect of skin site ($F(1, 71) = 0.10$, $p = 0.758$). We did not observe a main effect of group ($F(1, 71) = 0.06$, $p = 0.806$).

There was no significant interaction between velocity and skin site ($F(2, 142) = 0.38$, $p = 0.682$) or between velocity and group ($F(2, 142) = 1.25$, $p = 0.290$). Importantly, however, there was a significant interaction of skin site and group ($F(1, 71) = 13.45$, $p < 0.001$), with touch being rated overall as more pleasant on the forearm ($M_{Sighted} = 70.09$; $SD_{Sighted} = 17.45$) than on the palm ($M_{Sighted} = 66.11$; $SD_{Sighted} = 17.80$; $\alpha = 0.025$; $t(35) = 3.01$, $p_{uncorrected} = 0.005$, CI95% = 1.29– 6.66) in the sighted group, consistent with previous findings (e.g., [22]; Fig. 1). Interestingly, in the blind group, touch was rated overall as more pleasant on the palm ($M_{Blind} = 70.81$; $SD_{Blind} = 17.42$) than on the forearm ($M_{Blind} = 67.45$; $SD_{Blind} = 20.13$), but the difference did not reach statistical significance after Bonferroni correction ($\alpha = 0.025$; $t(35) = 2.24$, $p_{uncorrected} = 0.032$, CI95% = 0.31–6.41), nor was it significant using the nonparametric approach ($V = 403.5$, $p_{uncorrected} = 0.070$, CI95% = −0.14 to 5.65). There was no significant difference between the groups in the overall perception of affective touch delivered on the forearm ($t(70) = -0.59$, $p_{uncorrected} = 0.554$, CI95% = −11.50 to 6.22) or on the palm ($t(70) = 1.13$, $p_{uncorrected} = 0.262$, CI95% = −3.58 to 12.98).

Furthermore, we found a significant interaction between the group and velocity and skin site ($F(2, 142) = 3.60$; $p = 0.030$; Fig. 2), suggesting that the pleasantness ratings differ between the groups when contrasting the skin sites and velocities. In the sighted group, a follow-up Bonferroni-corrected ($\alpha = 0.017$) post hoc analysis revealed a significant difference between the forearm and palm in the perception of slow, CT-optimal touch ($M_{Sighted} = 74.32$, $SD_{Sighted} = 17.98$ and $M_{Sighted} = 69.88$, $SD_{Sighted} = 17.49$, respectively; $t(35) = 2.53$; $p_{uncorrected} = 0.016$, CI95% = 0.88–8.00; note that the p-value did not reach statistical significance using nonparametric approach: $V = 449.5$, $p_{uncorrected} = 0.028$, CI95% = 0.75–7.50) and the perception of borderline touch ($M_{Sighted} = 71.09$, $SD_{Sighted} = 17.35$ and $M_{Sighted} = 66.29$, $SD_{Sighted} = 18.46$, respectively; $t(35) = 2.77$; $p_{uncorrected} = 0.009$, CI95% = 1.28–8.32), but not in the perception of CT-nonoptimal touch ($M_{Sighted} = 64.85$, $SD_{Sighted} = 19.46$ and $M_{Sighted} = 62.16$, $SD_{Sighted} = 20.01$, respectively; $t(35) = 1.76$; $p_{uncorrected} = 0.088$, CI95% = −0.42 to 5.81), showing a preference for the stimulation of the forearm. The pattern was the opposite among the blind group. There was a difference between the forearm and the palm in the perception of slow, CT-optimal touch ($M_{Blind} = 72.87$, $SD_{Blind} = 21.49$ and $M_{Blind} = 77.25$, $SD_{Blind} = 17.20$, respectively), but it did not reach statistical significance after Bonferroni correction ($\alpha = 0.017$; $t(35) = -2.08$; $p_{uncorrected} = 0.045$, CI95% = −8.65–− 0.11) or when using the nonparametric approach ($V = 159.5$, $p_{uncorrected} = 0.083$, CI95% = −9.17 to 0.42). Furthermore,

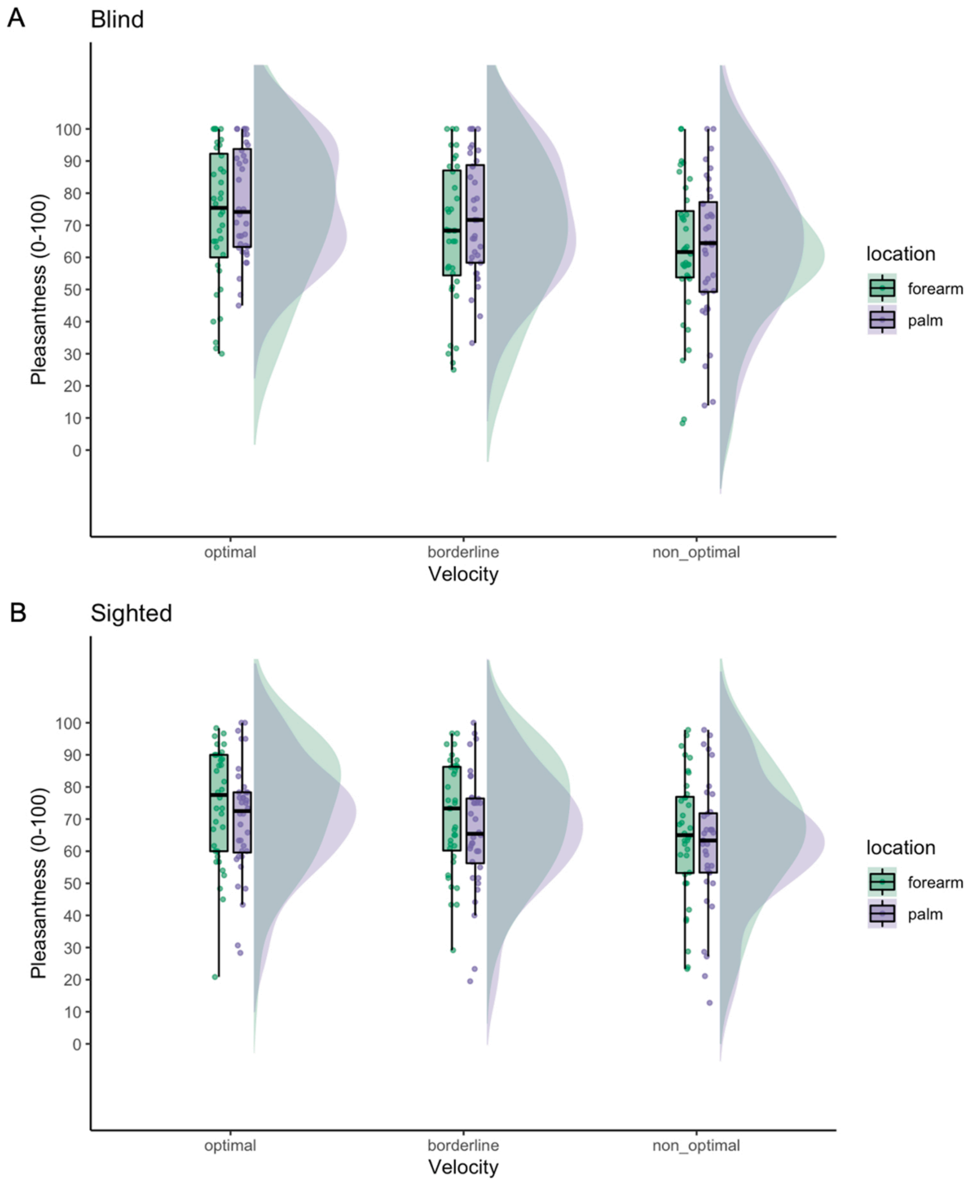

Fig. 1. Tactile pleasantness perception in the blind (A) and sighted (B) groups according to the velocity of touch (CT-optimal, borderline, and nonoptimal). The boxplots depict the data based on their median (thick black line) and quartiles (upper and lower ends of boxes). The vertical lines, i.e., the whiskers, indicate the minimum or maximum values within 1.5x the interquartile range above and below the upper and lower quartiles. The datapoints outside the vertical lines are the outlier observations, the furthest being the minimum or maximum values in the data. The following figures are formatted in the same fashion.

there was a significant difference in the perception of borderline touch (M_{Blind} = 67.50, SD_{Blind} = 21.76 and M_{Blind} = 72.39, SD_{Blind} = 18.50, respectively; $t(35) = -2.84$; $p_{uncorrected} = 0.007$, CI95% = −8.37–– 1.40) but not in the perception of CT-nonoptimal touch (M_{Blind} = 61.97, SD_{Blind} = 21.99 and M_{Blind} = 62.78, SD_{Blind} = 21.99, respectively; $t(35) = -0.53$; $p_{uncorrected} = 0.602$, CI95% = −3.96 to 2.33), overall showing a preference for the stimulation of the palm. There was no significant difference between the groups in the perception of affective touch delivered on the forearm at CT-optimal ($t(70) = 0.31$, $p_{uncorrected} = 0.757$, CI95% = −7.86 to 10.76), borderline ($t(70) = 0.77$, $p_{uncorrected} = 0.443$, CI95% = −5.67 to 12.84), and nonoptimal velocities ($t(70) = 0.59$, $p_{uncorrected} = 0.557$, CI95% = −6.87 to 12.65). Similarly, there was no significant difference between the groups in the perception of affective touch delivered on the palm at CT-optimal ($t(70) = -1.80$, $p_{uncorrected} = 0.076$, CI95% = −15.52 to 0.78), borderline ($t(70) = -1.40$, $p_{uncorrected} = 0.166$, CI95% = −14.79 to 2.59), and nonoptimal velocities ($t(70) = -0.13$, $p_{uncorrected} = 0.901$, CI95% = −10.50 to 9.26).

Regarding affective touch sensitivity, we did not find a preference for forearm or palm stimulation either in the sighted ($M_{Sighted}$ = 9.47, $SD_{Sighted}$ = 11.28, $M_{Sighted}$ = 7.72, $SD_{Sighted}$ = 11.77, respectively; $t(35) = 0.88$, $p = 0.387$) or in the blind group (M_{Blind} = 10.90, SD_{Blind} = 16.55, M_{Blind} = 14.47, SD_{Blind} = 17.40, respectively; $t(35) = -1.64$, $p = 0.111$, CI95% = −7.99 to 0.86).

No significant effect of sex on any of the touch pleasantness scores was found (all p values > 0.05).

3.2. *Discriminative touch*

We predicted that in the grating orientation task, the blind group would perform significantly better (exhibit higher acuity) than the sighted group. Indeed, there was a significant difference between the blind and sighted groups (M_{Blind} = 1.15, SD_{Blind} = 0.32, $M_{Sighted}$ = 1.60, $SD_{Sighted}$ = 0.48; $t(50) = -3.99$, $p < 0.001$; Fig. 3).

The performance of the sighted group in the task was comparable to the results found in other studies that used the same paradigm [9,51,80], indicating that the task was successfully implemented in the current study.

3.3. *Relationship between affective and discriminative touch*

In the sighted group, we did not find a significant correlation

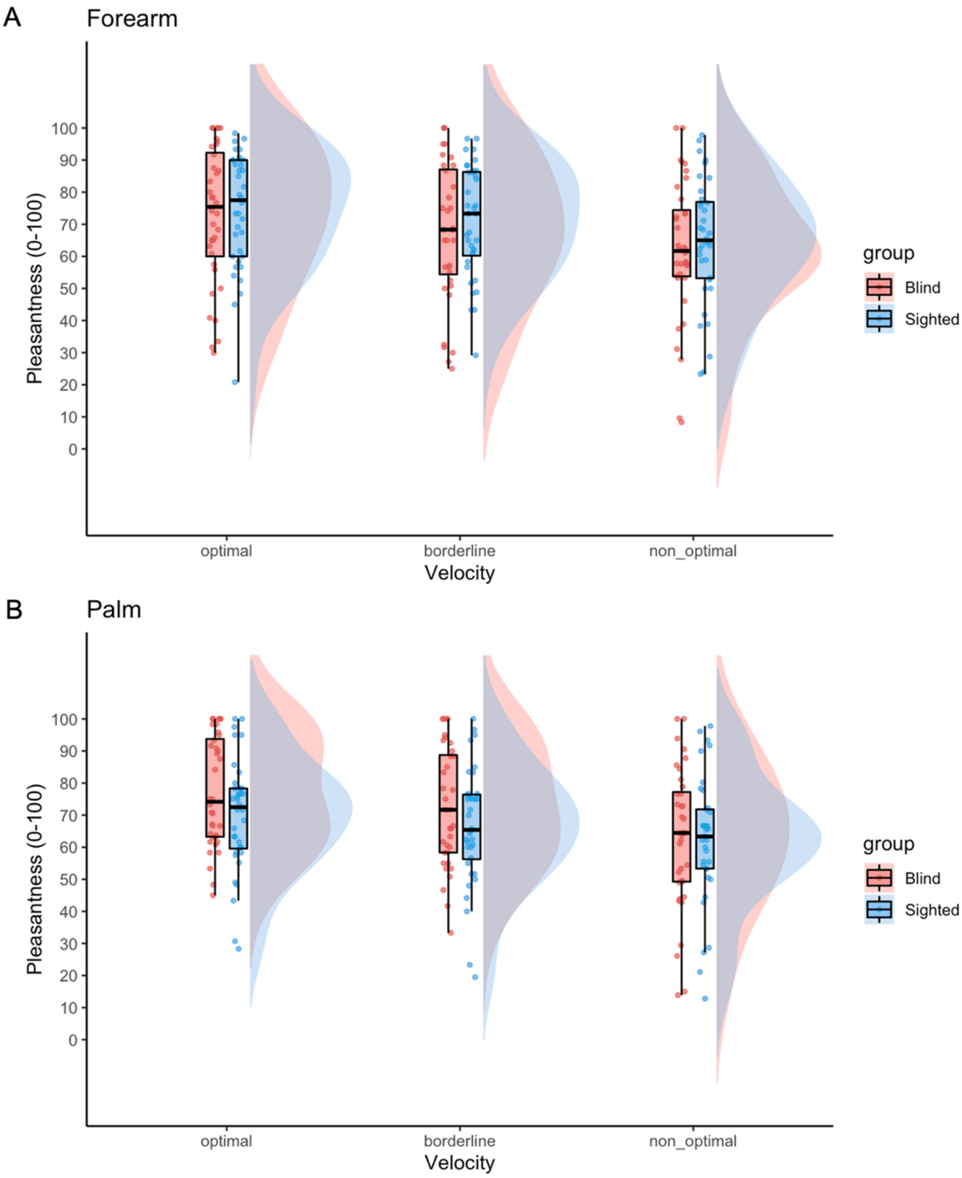

Fig. 2. Tactile pleasantness perception as perceived on the forearm (A) and palm (B) across the groups.

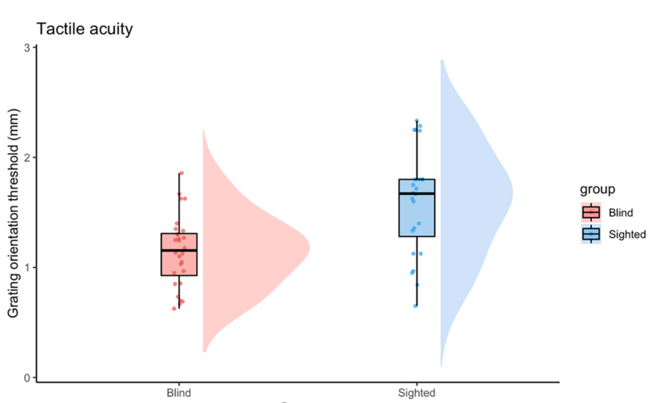

Fig. 3. Discriminative tactile acuity in the blind and sighted groups.

between affective touch sensitivity on the forearm or the palm and the grating detection threshold, although the Bayesian analysis suggests that this result is inconclusive ($r = 0.017$, $p = 0.939$, CI95% = −0.39 to 0.42, $BF_{01} = 2.266$; $r = 0.117$, $p = 0.585$, CI95% = −0.30 to 0.50, $BF_{01} = 2.010$, respectively). Similarly, no such significant correlations were found in the blind group, and the Bayes factors were inconclusive ($r = -0.143$, $p = 0.467$, CI95% = −0.49 to 0.24, $BF_{01} = 1.943$; $r = -0.098$, $p = 0.619$, CI95% = −0.45 to 0.29, $BF_{01} = 2.187$, respectively).

3.4. Belief of performance accuracy and confidence

In the affective touch task, we found no difference between the blind and sighted groups regarding their belief in the accuracy of their performance either before the completion of the task ($M_{Blind} = 72.75$, $SD_{Blind} = 20.30$, $M_{Sighted} = 67.85$, $SD_{Sighted} = 17.52$; $t(70) = 1.01$, $p = 0.316$, CI95% = −4.79 to 14.59) or after the completion of the task ($M_{Blind} = 77.06$, $SD_{Blind} = 19.92$, $M_{Sighted} = 71.88$, $SD_{Sighted} = 13.93$; $t(70) = 1.23$, $p = 0.223$, CI95% = −3.23 to 13.59). Similarly, in the grating orientation task, we found no difference between the blind and sighted groups regarding their belief in the accuracy of their performance either before the completion of the task ($M_{Blind} = 67.25$, $SD_{Blind} = 24.45$, $M_{Sighted} = 73.71$, $SD_{Sighted} = 16.86$; $t(50) = -1.09$, $p = 0.281$, CI95% = −18.36 to 5.44) or after the completion of the task ($M_{Blind} =$

49.11, $SD_{Blind} = 20.41$, $M_{Sighted} = 44.83$, $SD_{Sighted} = 19.46$; $t(50) = 0.77$, $p = 0.446$).

In the sighted group, we did not find a significant correlation between affective touch sensitivity on the forearm or the palm and corresponding confidence ratings ($r = 0.083$, $p = 0.629$, CI95% = −0.25 to 0.40; $r = 0.040$, $p = 0.819$, CI95% = −0.29 to 0.36, respectively), nor did we find these correlations in the blind group ($r = 0.105$, $p = 0.541$, CI95% = −0.23 to 0.42; $r = -0.013$, $p = 0.939$, CI95% = −0.34 to 0.32, respectively). Similarly, in the sighted group, we did not find a significant correlation between the grating orientation threshold and the averaged confidence ratings across the task ($r = -0.079$, $p = 0.712$, CI95% = −0.47 to 0.33), nor did we find these correlations in the blind group ($r = -0.148$, $p = 0.453$, CI95% = −0.49 to 0.24).

4. Discussion

We found that blind individuals rated touch as more pleasant on the palm than on the forearm. In contrast, the opposite pattern was observed for matched sighted participants, who preferred the stimulation of the forearm to the stimulation of the palm. We also replicated the previous findings showing enhanced discriminative tactile acuity in blind individuals. Thus, our results suggest differences in discriminative and affective tactile stimuli processing following blindness.

Healthy-sighted individuals frequently exhibit a preference for affective stimulation delivered on hairy skin ([5,22,30]; but see also the opposite evidence: [52]). This preference was also observed in our study. Affective touch typically takes the form of slow-moving and light tactile stimuli, which are also the kind of stimuli that optimally activate CT afferents in the skin. Thus, CT signals are considered to play an important role in affective touch sensations [47]. Alterations in responses to CT-optimal touch have been observed, among others, in anorexia nervosa (e.g., [17]), autism (e.g., [10,56]), and fibromyalgia (e.g., [8]), showing reduced perception of affective touch, accompanied by pain hypersensitivity [8,25,44], an observation that has also been made concerning pain in several consecutive investigations in blind individuals [66–69]. Why do blind individuals not show a difference in the overall intensity of perceived pleasantness of affective touch but display an unusual preference for the palm, in contrast to the sighted group? It has been shown that the experience of affective touch can be modulated by the context in which it is embedded, meaning that social-cognitive factors also play a role in determining the pleasantness of the tactile experience [48,60,62]. It could be the case that for blind individuals, who extensively use their palms daily, the context of being touched on this body part is different than for sighted individuals, as palms are one of the primary sources of their knowledge about the environment, including the affective dimension. Notably, the glabrous surface of the palm has been described as an active, touch-seeking body part that enables and facilitates social interaction [54,55]. From this perspective, the glabrous part of the palm would be a tissue that can both communicate and receive tactile affectivity, perhaps creating a particularly important channel of social expression in blind individuals. Indeed, sighted individuals experience social, affective pleasure through both somatosensory and visual signals. It could be hypothesized that blind individuals rely more on their palms to perceive and generate social-affective pleasure in everyday situations due to their lack of vision. Nevertheless, in our data, we observed a main effect of velocity but no interaction between velocity and group, which suggests that the perceived pleasantness is modulated by not only social but also physiological factors in both groups, as pleasantness ratings across hairy and glabrous skin sites are typically influenced by stroking velocity due the firing properties of the conducting mechanoreceptive afferent fibers (see [20]). Therefore, taking into consideration the patterns of results demonstrated by the sighted and blind groups, our findings would be in line with the coexistence of contextual and physiological factors in the modulation of the affective touch experience. Future studies should determine exactly which factors contribute to different perceptions of tactile affective signals in blind individuals.

In a recent study [58], we showed that cardiac interoceptive accuracy is enhanced in blind individuals. Skin-mediated signals such as pain, thermosensation, and affective touch are also considered interoceptive in some theoretical proposals because such signals reach the posterior insular cortex (an important target of visceral inputs) through a special anatomical pathway that is distinct from that of discriminative touch and may contribute to the monitoring of the physiological condition of the body and homeostasis ([21]; see also [7,14,15]). In one of the previous studies examining pain in blind individuals, congenitally blind participants were shown to have lower heat pain thresholds, higher sensitivity to cold pain stimuli, and higher ratings of pain experienced in response to suprathreshold laser stimuli [66]. In another study, blind participants were also shown to discriminate innocuous heat better than sighted individuals [68]. However, despite their preference for the palm, blind individuals in our experiment did not exhibit a higher sensitivity to affective touch than the sighted group. This indicates that affective touch is not impacted by visual deprivation in the same way as other interoceptive submodalities, such as cardiac interoception, pain, and thermosensation. Further research is needed to clarify the reason for this difference, whether it results from plasticity within the CT system, top-down modulation, or a combination of those. Previous studies on the somatosensory abilities of blind individuals have focused on the discriminative aspect of touch, such as tactile acuity, vibrotactile perception, and texture discrimination (as noted in the 1 section). Given this, we believe that further investigation into the affective dimension of touch is an important new area for blindness research.

This study replicates previous findings showing enhanced tactile acuity following blindness ([29,75,2]). However, to the best of our knowledge, this is the first time discriminative tactile abilities have been compared with the affective perception of touch in blind individuals. We did not find a significant correlation between grating detection threshold and affective touch sensitivity on the forearm and the palm, respectively, in the blind or sighted groups. These findings suggest a dissociation between these two dimensions of somatosensation in both groups, consistent with previous theoretical proposals (see [50]). However, it should be pointed out that pleasant touch was tested on the left arm and palm, in line with previous studies (e.g., [22]), whereas the grating detection threshold was tested on the right index finger (pad) as is a typical protocol (e.g., [74]). Thus, we cannot exclude that differences in somatosensory processing between the two hands (and between the palm and the index finger) might contribute to such finding. Enhanced discriminative tactile acuity following blindness is typically explained as a result of adaptive cortical plasticity [75]. Such plasticity has been shown to lead to the engagement of the visual cortex in the processing of touch [71] and increased connectivity of these regions with the primary somatosensory cortex [33,78]. However, there are studies showing that this sensory enhancement is a result of perceptual learning due to Braille reading experience ([32]). Thus, the findings we report in this study suggest that these neuroplasticity-related enhancements observed within discriminative touch can be independent of the changes that presumably underlie the differences observed in affective touch.

The present study has some additional limitations. First, tactile stimulation was performed by a trained experimenter instead of a robot. Although the experimenter had undergone extensive training, the precision of delivered touches could have been more controllable if a machine had been used. However, we decided to use manual touch delivery instead of a robot to increase the ecological validity of the study, given that we were predominantly interested in the social aspect of the affective touch experience. Manual delivery makes the stimulation more natural and embedded in a comfortable context; manual stroking is often used in affective touch studies (e.g., [20]) and provides a tactile experience comparable to that delivered by a robot [72]. Second, the number of repetitions for each touch velocity was relatively low, although similar to previous studies (e.g., [19]). However, a recent study showed that the number of repetitions does not influence the pattern of tactile pleasantness [20]. Nevertheless, future research should address this issue with an experimental design focused solely on affective touch perception in blind individuals, as the existence of group differences has been introduced to the literature in this inaugural study. Finally, although there are reports of differences between congenitally and non-congenitally blind individuals on pain perception [67], investigating the effect of blindness onset was outside of the scope of the present study, as we do not have the tools to address this point with the data that we collected. Therefore, future studies should consider the potential effect of the onset of blindness on the perception of affective touch.

In conclusion, we conducted the first study on affective touch perception in blind individuals. We found that blind individuals, compared to sighted individuals, tend to prefer affective, social touch when delivered on the glabrous skin of the palm compared to the hairy skin of the forearm. Our results have the potential to inform future studies on emotional processing, physical social interactions, and the contribution of bodily signals to the conscious experience of the self in blind individuals.

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CRediT authorship contribution statement

Dominika Radziun – Conceptualization, Data curation, Formal analysis, Investigation, Project administration, Visualization, Writing – original draft, **Laura Crucianelli** – Conceptualization, Methodology, Supervision, Writing - review & editing, **Maksymilian Korczyk** – Data curation, Project administration, Writing - review & editing, **Marcin Szwed** – Funding acquisition, Resources, Writing - review & editing, **H. Henrik Ehrsson** – Funding acquisition, Resources, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare no competing interests.

Data availability

The data are available at https://osf.io/4dybv/.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.bbr.2023.114361.

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