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Early Vision Impairs Tactile Perception in the Blind

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Summary

Researchers have known for more than a century that crossing the hands can impair both tactile perception [1] and the execution of appropriate finger movements [2]. Sighted people find it more difficult to judge the temporal order when two tactile stimuli, one applied to either hand, are presented and their hands are crossed over the midline as compared to when they adopt a more typical uncrossed-hands posture [3, 4]. It has been argued that because of the dominant role of vision in motor planning and execution [5], tactile stimuli are remapped into externally defined coordinates (predominantly determined by visual inputs) that takes longer to achieve when external and body-centered codes (determined primarily by somatosensory/proprioceptive inputs) are in conflict [4, 6] and that involves both multisensory parietal [7] and visual cortex [8]. Here, we show that the performance of late, but not of congenitally, blind people was impaired by crossing the hands. Moreover, we provide the first empirical evidence for superior temporal order judgments (TOJs) for tactile stimuli in the congenitally blind. These findings suggest a critical role of childhood vision in modulating the perception of touch that may arise from the emergence of specific crossmodal links during development.

Results and Discussion

Crossing the hands led to a significant decrement in performance in sighted controls regardless of whether they were blindfolded (Figure 1, $F[1,12] = 33.82$, $p < 0.001$) or could see their arms ($F[1,11] = 13.4$, $p = 0.004$) consistent with recent findings [3, 4]. For both groups, crossing the hands more than doubled the just noticeable difference (JND; the minimum interval between the two tactile stimuli required for participants to judge their temporal order accurately on 75% of trials). A direct comparison of the sighted-blindfolded (see Figure 1B and sighted-seeing JND [uncrossed] = 57 ms, JND [crossed] = 192 ms) revealed neither a significant group effect ($p = 0.3475$) nor a significant interaction between group and posture ($p = 0.9567$). By contrast, the congenitally blind group (Table 1) was completely unaffected by the crossing of their hands (Figure 1, $p = 0.756$). Interestingly, the performance of the late-blind group (Table 1) was indistinguishable from that of sighted participants (Figure 1; posture effect for the late blind, $F[1,4] = 12.16$, $p = 0.025$; group by posture interaction, $p = 0.387$). One late-blind participant, who had been totally blind for more than 40 years, still showed a marked performance decrement when his hands were crossed (JND [crossed] = 139 ms, JND [uncrossed] = 276 ms).

We also found better temporal resolution in the congenitally blind both when compared to the sighted ($F[1,21] = 14.92$, $p < 0.001$; $F[1,21] = 6.06$, $p = 0.027$, for the uncrossed posture and $F[1,21] = 22.72$, $p < 0.001$, for the crossed posture) and when compared to the late blind ($F[1,13] = 7.11$, $p = 0.019$; uncrossed posture, $p = 0.168$; crossed posture, $F[1,13] = 12.70$, $p = 0.004$). The lack of an effect of posture change in the congenitally blind cannot, however, be attributed simply to their overall better temporal resolution ability. As when matched for performance in the normal uncrossed condition, a subgroup of seven sighted participants still showed a significant performance decrement due to adopting the crossed-hands posture ($F[1,6] = 14.50$, $p = 0.009$), whereas the seven matched congenitally blind participants, once again, did not ($p = 0.384$ (Figure 1B, right); group by posture interaction, $F[1,12] = 6.67$, $p = 0.024$).

Kitazawa [9] has recently suggested that the external spatial location of a tactile stimulus is always computed whenever we have a conscious sensation of touch and, moreover, that the temporal order of two touches is determined after the stimuli have been localized. If external and body-centered coordinates are in conflict, then the localization of cutaneous stimuli will take longer, resulting in an impairment of the ability to temporally order two touches when the second is presented while the external coordinates of the first are still being computed [4]. The present study tested the hypothesis that visual input during development may lead to an impairment of temporal order judgments for tactile stimuli when unusual postures, such as crossing the hands, are adopted in adulthood. Confirming this hypothesis, we demonstrate the dramatic and long-term effects of early visual experience on the ability of sighted and late-blind people to judge the temporal order of two touches presented one to either hand and therefore indirectly to localize touch when they adopt an unusual posture (no matter how long ago blindness occurred). By contrast, the present study shows that blind people who had never had any visual experience are unaffected by

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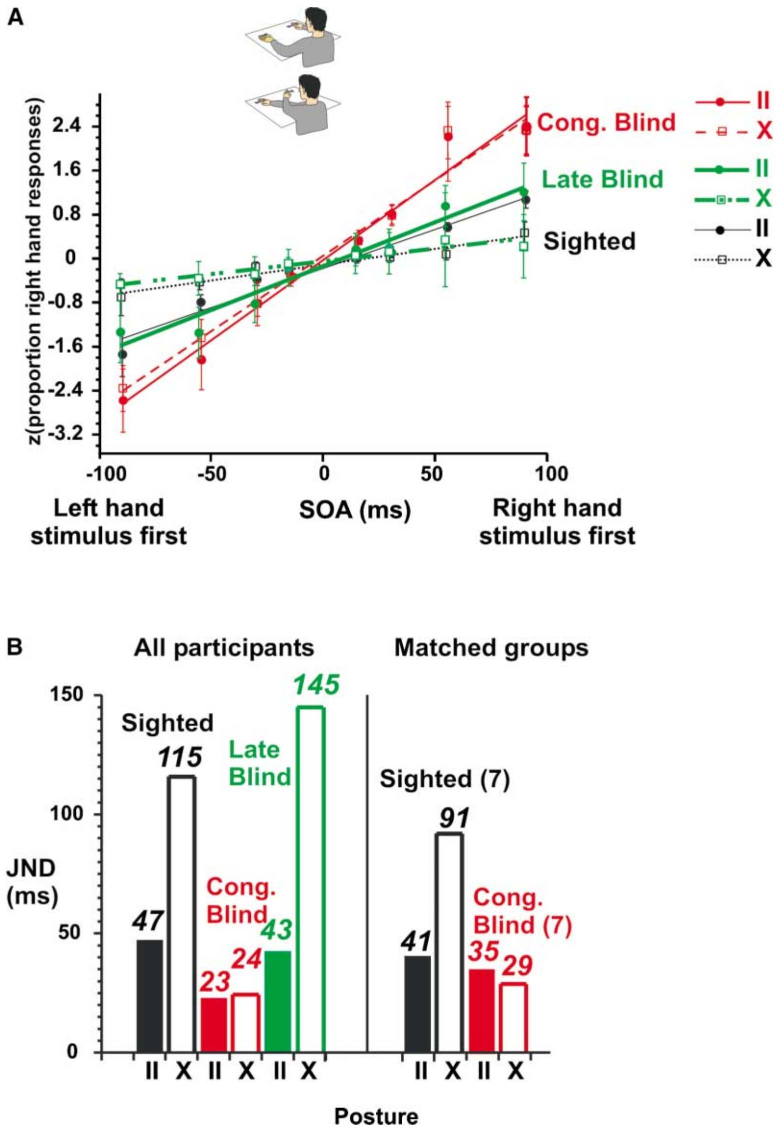

Figure 1. Performance in the Temporal Order Judgement Task

(A) Standardized z score equivalents of the mean proportions of right-hand responses (indicating right-hand stimulus perceived first) and best-fitting linear regression lines for the uncrossed (II = uncrossed posture; continuous lines) and crossed (X = crossed posture; dotted lines) hand conditions for sighted-blindfolded controls (black), congenitally blind (red), and late-blind participants (green).

(B) Just noticeable differences (JND in ms given in exact numbers above the bars) calculated on the basis of mean slopes of the linear regression lines (see [3] for methodological details) shown in (A). All participants (left panel) and for seven sighted and seven congenitally blind participants approximately matched by their performance in the uncrossed hand condition (right).

changes in hand posture, suggesting that the possibly default localization of touch in external space is dependent upon visual experience though independent of the instantaneously availability of sight. The finding that late-blind adults experience the same crossed-hands effect suggests that once established, the existence of a visual frame of reference may stay with us for life. This visual frame of reference may then impair our ability to localize touch [10–12] when externally defined coordinates, modulated primarily by visual inputs, and a body-centered reference frame, which primarily depends on somatosensory/proprioceptive inputs, come into conflict as when we adopt a crossed-hands posture [3, 4, 6].

Previous evidence has documented a switch from proprioceptively to visually dominated spatial perception during development [13]. Since the onset of blindness was at age 12 years or later in all the late-blind participants tested in the present study, future research should examine when exactly this switch occurs during development. Developmental studies in animals have shown that though neurons with multisensory response properties are present from birth onward, specific, spatially organized connections that lead, for example, to supra-additive response rates if two stimuli of different modalities are presented at the same location, emerge (in monkeys) only during the first year of life [14]. It could be hypothesized that the establishment of specific visual-tactile connections involves both selective (pruning of connections; e.g., [15]) and constructive mechanisms (growth of connections; [16]), resulting in an irreversible biasing of tactile localization by visual reference frames even when vision in lost later in life.

Finally, the present study demonstrates for the first time higher sensitivity in processing the temporal order of tactile stimuli in the congenitally blind than in the sighted or the late blind. This result extends recent findings on compensatory developmental plasticity due to the absence of one sense from birth [17, 18]. It could be speculated that if not necessary as in the present study, the congenitally blind do not activate a process that transforms, by using proprioceptive feedback information, somatotopic organized coordinates into an ex-

Table 1. Description of Participants

Congenitally Blind Participants

Nr	Age	Gender	Handedness	Visual Perception	Age of Onset	Cause of Blindness
1	31	female	right	none	birth	retina degeneration
2	24	male	right	none	birth	retrolental fibroplasia
3	24	male	neither	none	birth	optical nerve atrophy
4	27	male	right	diffuse light	birth	unknown peripheral defect
5	23	female	right	none	birth	retrolental fibroplasia
6	18	female	right	diffuse light	birth	optical nerve atrophy
7	20	female	neither	none	birth	toxication
8	20	male	right	none	birth	Norrie syndrome
9	19	male	left	none	birth	eyeballs did not develop
10	17	female	right	diffuse light	birth	toxication

Late-Blind Participants[a]

Nr	Age	Gender	Handedness	Visual Perception	Age of Onset	Duration	Cause of Blindness
1	29	male	right	diffuse light	23	6	retinitis pigmentosa
2	23	female	right	diffuse light	18	5	glaucoma
3	23	male	right	none	13	10	glaucoma
4	25	female	right	diffuse light	20	5	Morbus Bechet
5	31	male	right	none	19	12	accident
6	54	male	right	none	12	42	retinitis pigmentosa
7	45	male	right	diffuse light	35	10	retinitis pigmentosa

[a] Late-blind adults (1–5) whose total blindness persisted for at least 5 years and who were younger than 32 years. In order to have an approximately age-matched late-blind group, late-blind participants 6 and 7 were not included in the group comparisons. The JNDs of late-blind participant 6, who had been blind for more than 40 years, are, however, reported in the Results section.

ternal reference system. If the temporal order of two touches is determined only after their external position had been defined in sighted people but can be computed more immediately by congenitally blind people, it follows that the latter should show a lower overall JND, which is indeed what was found (Figure 1B).

Conclusion

Visual experience during development irreversibly influences the subsequent perception of tactile stimuli. The present data demonstrate how specific experience during development triggers and irreversibly shapes the emergence of brain functions.

Experimental Procedures

Participants

Ten congenitally blind (mean age, 22 years; range, 17–31 years) and five late-blind (mean age, 26 years; range, 23–31 years) participants took part in this study (see Table 1 for details). They were all professional Braille readers. Thirteen students with normal or corrected-to-normal vision (mean age, 22 years; range, 20–26 years; 10 females, 1 left handed) were blindfolded and served as controls (sighted blindfolded). An additional control group of 12 sighted students (mean age, 22 years; range, 19–26; 9 females, 1 left handed) was run; their hands were covered, but they could nevertheless see their arms. The experiment was performed in accordance with the ethical standards laid down in the Declaration of Helsinki.

Stimuli and Procedure

Tactile stimuli consisted of metallic pins with a diameter of 0.8 mm, which were lifted by 0.35 mm from their resting position. They were presented for 10 ms to the distal phalanxes of the left and right middle fingers at stimulus onset asynchronies (SOAs) of −200, −90, −55, −30, −15, 15, 30, 55, 90, or 200 ms (negative values indicate that the first stimulus was presented to the participant's left hand). Participants gave an unspeeded spatially compatible response by lifting the index finger of the hand that they perceived to have been stimulated first out of a light key. An auditory feedback tone (74 dB [A]) was presented from a loudspeaker cone located close to the responding hand irrespective of the correctness of the participant's response. There were 32 trials for each of the ten SOAs and two hand postures (uncrossed versus crossed), giving rise to 640 trials in total, which were presented in blocks of 80 trials. In addition, two practice blocks of 80 trials were also completed at the start of the experimental session. The tactile stimulators for the left and right hands were separated by 56 cm and were positioned 40 cm in front of the participant, whose head was immobilized by means of a chin rest. White noise was presented at 60 dB (A) through headphones to mask any slight noise (40 dB [A]) made by the operation of the tactile stimulators themselves.

Data Analyses

The mean percentages of right first responses were calculated for each participant, SOA, and posture. These values were transformed into standardized z score equivalents. Best-fitting linear regression lines were then calculated for each participant including the SOAs in the range −90 ms to 90 ms (see [3] for details). The slopes of these linear regression lines served as dependent variables in the analyses of variance (see the Results section). The just noticeable difference (JND) was calculated from the mean slopes.

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