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Further Evidence That Congenitally Blind Participants React Faster to Auditory and Tactile Spatial Targets

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Congenital blindness is one of the rare human models to explore the role of experience-driven cross-modal compensation after early sensory deprivation. We re-examined spatial attention abilities in congenitally blind participants and sighted controls using a paradigm comparable to the one of our previous study (Collignon, Renier, Bruyer, Tranduy, & Veraart, 2006), except that this time the auditory and tactile stimuli were now presented in sequence. Although both groups performed the task with similar accuracy, we observed that blind participants had shorter reaction times than sighted controls for the detection of spatial targets in both sensory modalities. Moreover, this finding held true for both the selective and divided attention conditions. These results not only confirm previous reports on the superiority of the blind during auditory and tactile attention tasks, but also broaden our knowledge of the mechanisms underlying cross-modal compensation.

Keywords: blindness, sensory compensation, psychophysics, auditory, tactile

Congenitally blind (CB) individuals compensate for their lack of vision through efficient use of their remaining senses (Collignon, Voss, Lassonde, & Lepore, 2008). Indeed, their ability to sharply focus their attention on either auditory or tactile locations to quickly react to environmental changes appears to be crucial for their everyday life activities, especially for those involving mobility and navigation. In various studies, spatial attention paradigms with auditory and/or tactile stimulations were used to explore the putative neural and behavioural reorganization processes that occur after blindness. For example, Kujala et al. compared the selective (Kujala, Alho et al., 1995) and divided (Kujala, Lehtokoski, Alho, Kekoni, & Naatanen, 1997) spatial attention abilities of CB and sighted control (SC) participants, using sequences of auditory and tactile stimuli. They only found faster reaction times in blind persons during divided attention tasks. This led these authors to suggest that enhanced performance of blind compared to sighted participants in spatial attention tasks might be specific to conditions requiring the division of spatial attention between auditory and tactile targets (Kujala, Lehtokoski et al., 1997). However, in a recent study, Collignon, Renier, Bruyer, Tranduy, and Veraart (2006) observed that CB participants showed better spatial attention abilities compared to SC during both the selective and divided spatial attention tasks when auditory and tactile stimuli were presented simultaneously.

A major difference between the Collignon et al. study (2006) and those of Kujala and collaborators (Kujala & Alho, 1995; Kujala & Lehtokoski, 1997) relates to the use of either simultaneous or sequential presentations of auditory and tactile stimuli. Simultaneous paradigms produce significant interactions between senses (Calvert, Spence, & Stein, 2004) and require active sensory suppression to ignore distractors from the nonpertinent modalities to react efficiently to the target. Following a recent behavioural study that showed reduced multisensory integration and altered auditory-tactile interactions in CB (Hotting & Roder, 2004), we postulated that the superiority of CB that was observed in the previous study of Collignon et al. (2006) might, at least in part, result from a lesser distractive effect of the nonpertinent spatial information when simultaneously presented in a concurrent modality.

To gain further insight into the multisensory attentional processes in the blind, here we explored selective and divided spatial attention abilities in CB and SC using a similar paradigm as in Collignon et al.'s study ((2006), except that this time auditory and tactile stimuli were presented in sequence rather than simultaneously. Also, special attention was paid to the calibration of stimuli, given the influence of stimulus saliency on performance in attention tasks (Bonnet, 1986). When comparing attentional skills in CB and SC, it is particularly important to exclude any possible sensory confounds during the task because participants who are blind may possess sharpened sensitivity for the discrimination of basic features of auditory or tactile stimuli (Goldreich & Kanics, 2003; Lessard, Pare, Lepore, & Lassonde, 1998; Muchnik, Efrati, Nemeth, Malin, & Hildesheimer, 1991; Roder, Teder-Salejarvi, et al., 1999; Van Boven, Hamilton, Kauffman, Keenan, & Pascual-Leone, 2000). Accordingly, the selection of identical stimuli in both groups might result in a more salient perception in CB

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compared to SC, which would bias the differences in attention tasks. Therefore in the present experiment, auditory and tactile stimuli were individually calibrated to ensure the same perceptual salience in every participant. This procedure was thought to allow assessment of attention performance independently of basic sensory sensitivity. Simple reaction times were also recorded as a control condition, to explore whether any behavioural difference between the CB and SC could be attributed to changes in stimulus detection or response production.

Method

Participants

Eight participants who are blind with congenital peripheral deficits and eight sighted control (SC) participants were included in the study. Congenitally blind (CB) participants had no more than rudimentary sensitivity for brightness contrasts without any pattern vision (see Table 1 for details). The two groups were matched at an individual level for age (*M* in years ± *SD*: 34 ± 13 for the participants who are blind; 30 ± 10 for the sighted participants), gender (3 women in each group), handedness (6 right handed, 1 left handed, and 1 bimanual in each group) and educational level. Handedness was evaluated using the Edinburgh inventory (Oldfield, 1971) in SC and a modified version of this questionnaire in CB participants. The SC participants were blindfolded during the tasks. This experiment was approved by the Biomedical Ethics Committee of the School of Medicine of the Université Catholique de Louvain. All participants were without any recorded history of neurological or psychiatric problems, reported normal hearing and tactile functions and did not use psychotropic medication at the time of testing.

Materials and Stimuli

Participants were individually tested in a soundproof room (Figure 1A). Participant's head was stabilised in a straight ahead position by restraining the chin. Participants' hands lied on a table, with each hand 30 cm away from the body midline. Auditory stimuli were pure sinusoidal tones of 2 kHz with duration of 170 ms delivered through headphones. Interaural level difference, the primary cue for sound localisation in azimuth at this frequency, was manipulated to induce intracranial left or right sound location (Blauert, 1997). Tactile stimuli were trains of five short biphasic square wave pulses (30 Hz, 105 μs). Thusly, when referring to tactile stimuli in the present manuscript, we refer to electrocutaneous stimulation. These electrical stimuli were applied to the skin using disposable ring electrodes (Nicolet Biomedical, Madison, WI) placed around the proximal and distal interphalangeal joints of the middle finger of each hand. Stimuli deliverance and participant's responses recording was controlled by a custom-made software created in Labview (National Instruments, Austin, TX). Vocal responses were used to determine reaction times. To do so, we used a custom-made system which monitored the participant's voice level at all times during the experiment. When the level rose above a user-specified threshold, this was reported to the computer with an accuracy of 1 ms. The user-specified thresh-

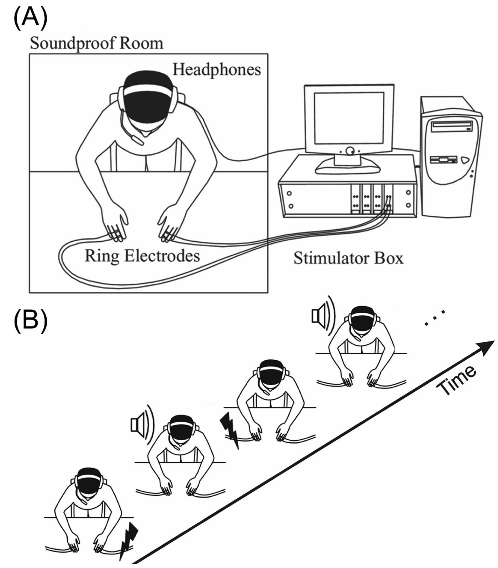

Figure 1. Experimental setup (A) and design (B). Auditory left, auditory right, tactile left, and tactile right stimuli were randomly presented in sequence to the participants. Participants were required to detect right-sided sounds in the selective auditory task and left-sided touch in the selective tactile task. They were required to detect both right-sided sounds and left-sided touch in the divided attention task. Vocal reaction times were measured for target responses.

Table 1
Characteristics of Participants Who Are Blind

Participant	Age	Educational level	Sex	Handedness	Onset of blindness	Cause of blindness
1	20	College degree	M	L	Congenital	Retinopathy of prematurity
2	21	College degree	F	R	Congenital	Cytomégalovirus
3	26	High school degree	M	R	Congenital	Genetic[a]
4	30	High school degree	F	A	Congenital	Retrolental fibroplasia
5	31	Graduate school	F	R	Congenital	Bilateral retinoblastoma
6	37	College degree	M	R	Congenital	Retinopathy of prematurity
7	52	College degree	M	R	Congenital	Bilateral retinoblastoma
8	56	College degree	M	R	Congenital	Retinopathy of prematurity

Note. M = male; L = left handed; F = female; R = right handed; A = ambidextrous.
[a] No additional details were available.

old was individually determined and set before starting the experiment.

Procedures

To ensure that the experimental stimuli had the same saliency in all participants, we proceeded to an adjustment phase before starting the tasks. The advantage of not choosing stimuli with predetermined intensities was twofold. First, the perceptual salience of the stimuli could be adjusted between the two groups. Second, given the large age range of the participants (due to the use of stringent constraints to recruit participants who are blind) and considering the age-related decline in sensory acuity (Bonnet, 1986; Goldreich & Kanics, 2003), individual adjustment allowed a selection of stimuli with the same saliency in all participants.

As an initial step, the absolute detection threshold for right auditory stimulation was determined using the method of limits (Goldstein, 2006). To double the perceived intensity sensation of this detection threshold we then used the Fechner's law ($S = k \log R$, where S refers to the subjective measurement, k is a constant multiplicative factor determined by the experimenter—two in the present experiment—log refers to the natural logarithmic function, and R is the unit of stimulus measurement). Participants were then asked to adjust the sound's loudness in the left ear until they perceived the same sound intensity as in the right ear, so that the sound was perceived as coming from the centre of the line joining the two ears when delivered binaurally at those intensities. Because Fechner's law does not apply for electrical stimulation (Goldstein, 2006), we individually calibrated the intensity of the stimuli in each hand as follows: stimulus intensity was gradually increased according to the participant's self-report of intensity. Participants were instructed to determine a level in which the stimulation was felt "strong, but comfortable and not painful". Participants then adjusted the stimulation between hands to equate the perception of intensity in the left and right sides, providing a prominent but nonetheless comfortable stimulation during the tasks.

The just-noticeable stimulus intensity differences were also determined for both intermanual and interaural intensity levels. This was achieved by using a two alternative forced choice task, in which participants had to determine whether a delivered stimulation was stronger on the left or on the right side. Decreasing the left or right intensity of the electrocutaneous stimulation induced a left/right lateralization of the tactile stimuli and the same procedure was applied to the stereo channel for sounds. This allowed us to ascertain the minimal intermanual and interaural intensity differences necessary to induce left/right lateralized sensations for each participant. Finally, because working at just-noticeable difference (JND) levels would have resulted in spatial attention tasks that would have been too complex, we increased the auditory JND value by 40% and the tactile JND value by 5%. This differential increase of JND values for auditory and electrocutaneous stimulation was justified by the differences in the perception of intensity changes between both senses, as described by Collignon et al. (2006), which demonstrated that these transformations induced comparable discrimination levels in both modalities.

The present study involved both simple and choice reaction times measurements. Donders (1967) pioneered the technique of measuring perceptual and cognitive processes by comparing simple and choice reaction times (SRT and CRT, respectively). According to Donders (1868/1969), SRT are obtained when participants are required to respond as quickly as possible to the presence of any signal. Therefore, SRT were hypothesised to reflect the time needed for (a) detecting the stimulus and (b) executing the motor response. However, CRT are measured in more complex tasks in which discrimination is required based on the stimuli characteristics. For example, in a go–no go task as in the present experimental tasks, participants are supposed to press a button only when a target is recognised. In the present study, we carried out both a SRT control condition and CRT experimental tasks to verify whether observed between-groups differences in performance would vary according to the complexity of the task.

Choice reaction time tasks. Sequences of four kinds of stimuli (auditory left, auditory right, tactile left, and tactile right; Figure 1B) were used in three spatial attention tasks: (a) an auditory selective attention task in which participants had to only react to right-sided sounds, (b) a tactile selective attention task had to react to left-sided pulses, and (c) a divided attention task in which participants had to attend and react to right-sided sounds and left-sided pulses. The order of these experimental tasks was counterbalanced across participants. Each spatial attention task comprised a sequence of 120 successive auditory and tactile stimuli delivered either to the left or the right side. Each sequence consisted of 50% targets and 50% distracting stimuli presented in pseudorandom order. To avoid anticipatory responses we varied the interstimulus intervals within a range of 1,500 to 3,000 ms (average 2,250 ms). Vocal reaction times were measured for target responses (within a window of 150 to 1,500 ms poststimulus). We used a go–no go procedure in which participants were instructed to say *oui* ("yes" in French) as quickly and as accurately as possible when a target was perceived, and to withhold their response when the stimulation was irrelevant. Prior to the attention tasks, all participants completed a sequence of 20 practise trials.

Simple reaction time task. After the choice reaction time tasks, participants also performed a simple reaction time task (SRT) to assess to the time required for sensory detection and motor production speed. For this control condition, 120 stimuli were presented to the participants (30 of each kind: auditory left/right, tactile left/right). The participants were instructed to respond *oui* as fast as possible after each stimulus, whatever its location or the modality. To decrease the attentional load of this control task aimed at evaluating sensory treatment and vocal production, each stimulus was preceded by a warning sound (500-Hz, 50-ms duration) with a delay of 500 to 1,500 ms (Bonnet, 1986). Interstimuli intervals varied to prevent anticipatory responses. Responses faster than 150 ms were considered as anticipatory responses and discarded from analysis. The interval between individual responses and the following warning signal was set at 1,000 ms.

Results

Sensory Measurement

Between-groups differences for auditory and tactile thresholds as well as for auditory and tactile JND were separately investigated with two-tailed t tests for independent samples.

Thresholds. No between-groups differences were found for auditory detection threshold expressed in an arbitrary computer intensity level, $t(14) = -1.53$; $p = .15$ (SC: $M = 69$, $SE = 12$; CB: $M = 91$, $SE = 38$). There was also no between-groups difference for tactile comfort level expressed in μA, $t(14) = 0.02$, $p = .99$; SC: $M = 4{,}750$, $SE = 959$; CB: $M = 4{,}738$, $SE = 1{,}750$.

JNDs. We did not find significant differences for auditory JND, as expressed in a percentage of the reference tones, $t(14) = 1.44$; $p = .17$ (SC: $M = 24$, $SE = 6$; CB: $M = 20$, $SE = 4$) nor in tactile JND, as expressed in a percentage of the reference electro-cutaneous stimuli, $t(14) = -0.92$; $p = .37$ (SC: $M = 10$, $SE = 4$; CB: $M = 12$, $SE = 3$).

Choice Reaction Time Tasks

Data collected in the attention tasks were analysed separately for accuracy and reaction times by means of a 2 (group: blind, sighted) × 2 (modality : auditory, tactile) × 2 (task : selective, divided) factorial design analysis of variance (ANOVA) with repeated measures on the last two factors. Accuracy scores were computed based on hits (hits rate: the proportion of targets correctly detected) and FA (false alarms rate: the proportion of stimuli erroneously identified as targets) in terms of a discrimination measure Pr (performance rating = hits – FA) according to the Two-High Threshold Model (Snodgrass & Corwin, 1988).

For accuracy scores in the CRT tasks, we only found a significant main effect of the factor modality, $F(1, 14) = 17.9$, $p = .0008$; $\eta_p^2 = 0.561$; indicating that the discrimination of auditory targets ($M = 0.94$, $SE = 0.007$) was easier than the discrimination of tactile targets ($M = 0.79$, $SE = 0.04$), both in the selective and in the divided attention tasks (see Figure 2).

The ANOVA carried out on the median latency of correct responses revealed a significant main effect of the group factor, ($F(1, 14) = 7.74$, $p = .015$, $\eta_p^2 = 0.356$. Accordingly, CB ($M = 570$, $SE = 25$) were significantly faster than SC ($M = 669$, $SE = 25$) for the discrimination of auditory and tactile spatial targets in both the selective and the divided attention tasks (see Figure 3). No other significant results were observed in the ANOVA.

We also investigated speed–accuracy trade-off effects in the tasks to verify if the faster reaction times observed in the blind group were not due to the fact that participants who are blind privileged speed over accuracy. For this purpose, we used correlation analyses aimed at investigating the relationship between speed and accuracy in the several tasks in each group. The following results were obtained: auditory-selective (blind: $r = .15$, $p = .7$; sighted: $r = -0.36$, $p = .39$), auditory-divided (blind: $r = -0.12$, $p = .77$; sighted: $r = -0.78$, $p = .02$), tactile selective (blind: $r = -0.48$, $p = .23$; sighted: $r = -0.91$, $p = .001$), tactile divided (blind: $r = -0.24$, $p = .57$; sighted: $r = -0.22$, $p = .6$). Accordingly, no speed–accuracy trade-off effect could account for CB superior performance, as shown by the absence of positive significant correlation between accuracy and latencies in the detection of auditory or tactile targets in both attention tasks for both groups. The significant negative correlations observed here reflect an inverse relationship between speed and accuracy in the sighted for the auditory-divided and the selective tactile conditions. This reflects the fact that in these conditions, the sighted people who were reacting faster (decrease in RTs) were also more accurate (increase in Pr score). This does not raise any doubts about the possibility that between-groups differences are due to the fact that they have adopted different strategies to carry out the task, especially that sighted have privileged accuracy over speed for example.

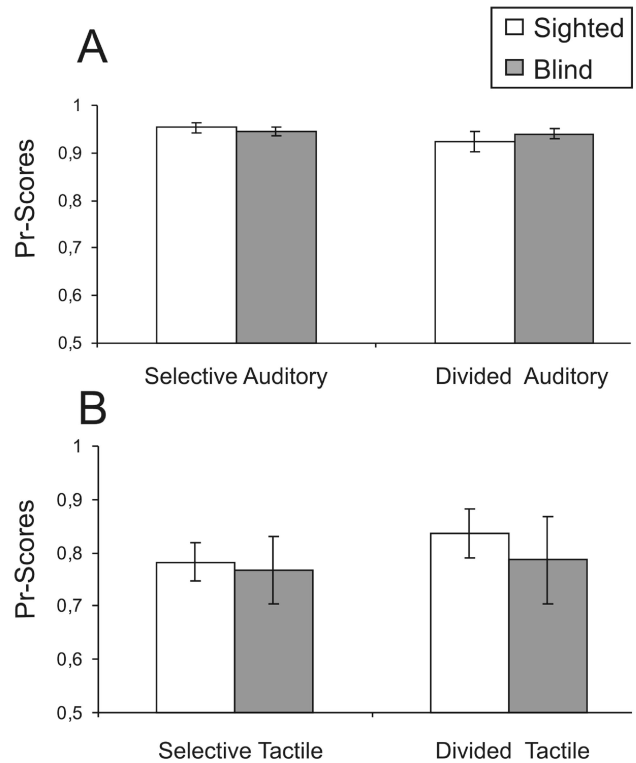

Figure 2. Accuracy in the spatial attention tasks. The Pr index (obtained by subtracting the false alarm rate from the rate of correct responses: Hit-FA) is displayed as a function of the group, the modality, and the task (means and standard errors). The Pr score vary between −1 (inverse sensitivity) over 0 (null sensitivity) to 1 (perfect sensitivity).

SRT

Reaction times collected in the SRT tasks task (see Figure 4) were analysed by means of a 2 (group: blind, sighted) × 2 (modality: auditory, tactile) factorial design ANOVA with repeated measures on the last factor.

In the SRT task, there was a significant effect of the modality factor, $F(1, 14) = 5.8$, $p = .03$; $\eta_p^2 = 0.293$; showing that participants reacted more rapidly to tactile than to auditory stimuli. However, no significant main effect of the group factor, $F(1, 14) = 2.4$, $p = .14$; $\eta_p^2 = 0.148$; and no interaction effects were found, $F(1, 14) = .1$, $p = .7$; $\eta_p^2 = 0.01$. It is noteworthy that both groups reacted faster in the SRT to tactile stimuli than to auditory stimuli but were less accurate in discriminating the tactile targets compared to the auditory targets in the CRT selective attention tasks. Accordingly, the tactile stimuli could have hypothetically induced a stronger sensation than the auditory stimuli whereas left, right discriminations were more difficult for tactile targets than for auditory ones.

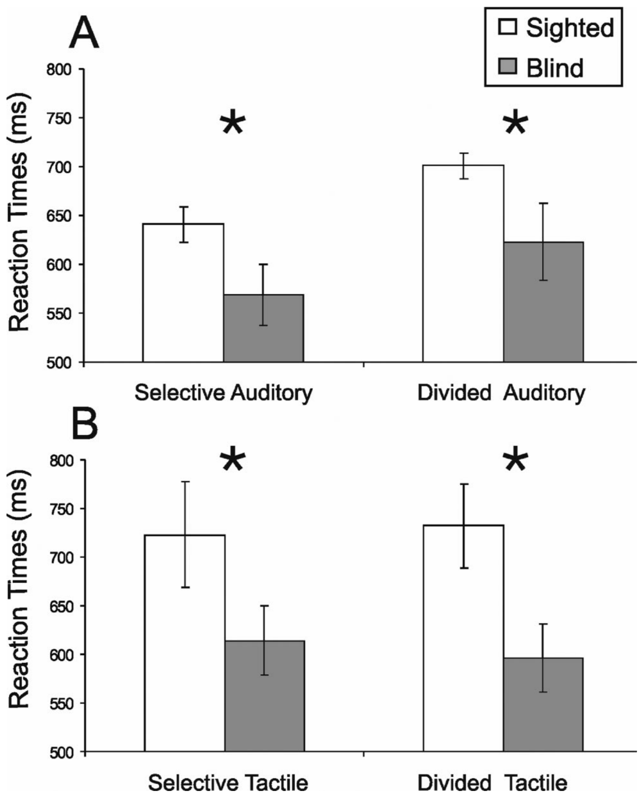

Figure 3. Reaction times in the spatial attention tasks. The latency of correct responses (means and standard errors of individual medians, in ms) is shown as a function of the group, the modality and the task. $^{*}p < .05$.

Even if not significant, one may notice that there was a trend toward faster SRTs in CB compared to SC in the simple reaction time task (see Figure 4). To further assess the relationship between SRTs and CRTs, we carried out an analysis of covariance (ANCOVA) aimed at controlling the potential effect of simple reaction times on the selective and divided attention tasks for each modality separately. In other words, we examined whether the faster CRTs observed in the blind group compared to controls were still significant when the modality-specific SRT was defined as a covariate. This analysis showed that the group effect was still significant in the auditory modality, $F(1, 13) = 5.44$, $p = .036$; $\eta_p^2 = 0.295$; as well as in the tactile modality, $F(1, 13) = 5.34$, $p = .038$; $\eta_p^2 = 0.291$. Therefore, the faster CRT reaction times in CB were not due to group differences in SRT.

Discussion

The present study provides compelling evidence for the presence of cross-modal compensation in CB by demonstrating that they reacted faster than SC to auditory and tactile spatial targets in selective and divided attention tasks. Individual adjustment of auditory and tactile stimuli insured independence of the reaction times from bottom-up sensory driven mechanisms such as differences in stimulus saliency between the two groups. Moreover, the superiority of CB was neither the product of enhanced stimulus detection nor of response production because CB did not differ from SC in a SRT task using the same events. The results of the present study thusly strongly support the notion of a more efficient top-down attentional modulation of non visual sensory events in participants who are blind.

No differences were observed between CB and SC in either the auditory detection or the tactile "comfort" threshold tasks. Moreover, we did not observe any differences between both groups in the JND tasks for interaural and intermanual intensity. This replicates the observations of Collignon et al. (2006) and suggests that supranormal abilities in participants who are blind are susceptible to manifest in higher order cognitive tasks rather than in more basic sensory threshold measurements (Niemeyer & Starlinger, 1981; Starlinger & Niemeyer, 1981).

In a previous experiment using successive presentation of auditory and tactile spatial stimuli, Kujala and collaborators did not find enhanced abilities in CB during selective attention tasks but did only during divided attention tasks (Kujala, Alho et al., 1995; Kujala, Lehtokoski et al., 1997). However, it remains possible that the use of an oddball paradigm, in which participants had to react to rare and easily discernable stimuli, might have reduced the associated arousal and processing demand of the task (Hazeltine, Teague, & Ivry, 2002). In contrast, CBs' superiority in selective attention tasks could be unveiled when using a paradigm that increased the attentional demand by individual calibration of the stimuli and a high percentage of targets such as in the present study.

Results obtained in the present experiment confirmed the previous demonstration of CB's superiority in spatial attention tasks using simultaneous presentation of auditory and tactile stimuli (Collignon et al., 2006). Here we assessed spatial attention in a paradigm using sequential presentation of nonvisual targets and observed that CB participants processed these stimuli faster than SC. This methodological difference appeared to be crucial for our understanding of the precise mechanisms underlying the compensatory abilities in CB. On the one hand, in accordance with previous studies (Hotting and Roder, 2004; Warren, 1984), the shorter reaction times we previously observed in CB during the simultaneous paradigm were thought to result from a lesser distracting effect of the nonpertinent stimuli when presented at the same time as the target and in the task-irrelevant modality. On the other hand, the present dem-

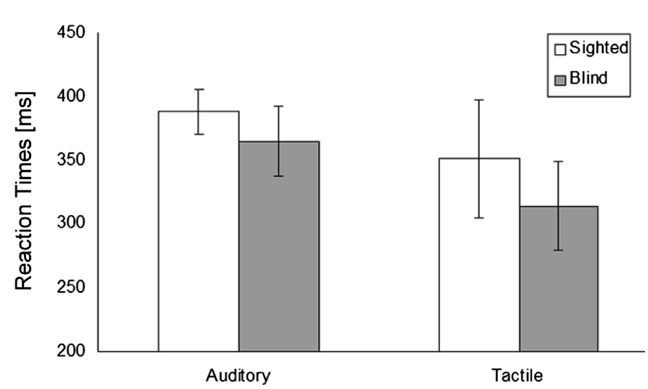

Figure 4. Reaction times in the simple reaction time task. The latency of responses (means and standard errors of individual medians, in ms) is shown as a function of the group and the modality.

onstration of enhanced performance in CB using sequential auditory and tactile spatial stimuli suggests that the superior performance of CB during bimodal attention tasks does not solely rely on altered auditory-tactile interactions. The present observations thusly provide new evidence regarding the nature of the alterations related to the deployment of spatial attention after early onset visual deprivation and indicate that efficient top-down attention mechanisms could account for the faster reaction times measured in participants who are blind during spatial tasks.

It is noteworthy that better performances previously had been observed in CB when they had to focus their attention on nonspatial attributes, such as the intensity or the tonal frequency of the stimuli (Liotti, Ryder, & Woldorff, 1998; Roder, Rosler, Hennighausen, & Nacker, 1996). Given that the aforementioned studies focused on different stimulus attributes, it is tempting to suggest that some higher order factors contributed to the improved abilities observed in the blind population, such as a more efficient top-down attention modulation of nonvisual sensory events. Accordingly, a fair number experiments have highlighted the contribution of attentional load in the total amount of neural activation within the reorganized visual brain areas of the blind (Kujala, Alho, & Naatanen, 2000; Kujala et al., 2005; Stevens, Snodgrass, Schwartz, & Weaver, 2007; Weaver & Stevens, 2007). For example, in a recent fMRI investigation (Weaver & Stevens, 2007), participants who are blind showed significant increases in BOLD signal throughout the occipital cortex only when they had to attend to auditory or tactile targets but not when the same stimuli where not attended to (distractors). Similarly, Stevens et al. (2007) showed that preparatory activity in the occipital cortex of individuals who are blind in response to an attentional cue predicted performance in an auditory discrimination task. Additional studies using event-related potentials have also demonstrated an attention-modulated enhancement of occipital brain responses to target stimuli in both the auditory (Kujala, Alho, et al., 1997, 1995; Kujala, Alho, Paavilainen, Summala, & Naatanen, 1992; Kujala, Huotilainen, et al., 1995) and the tactile (Kujala, Alho, et al., 1995) modalities. Therefore, when dealing with nonvisual stimuli, shifts of attention toward particular stimulus characteristics appear to be a prerequisite for occipital cortex activation in participants who are blind (Kujala et al., 2005).

In conclusion, the present results broaden our knowledge of the mechanisms underlying cross-modal compensation for visual loss, by demonstrating enhanced spatial attention in CB that is independent of sensory confounds and that occurs in a situation in which auditory and tactile targets are presented in sequence. Various experiments have investigated the attentional abilities within different sensory modalities (auditory or tactile), assessing different information processing tasks (dealing with intensity, pitch or spatiality), or testing different mechanisms of attention (selective or divided) with different paradigms (simultaneous or sequential). Most of them have shown enhanced performance in participants who are blind (Collignon et al., 2006; Kujala, Alho et al., 1995; Kujala, Lehtokoski et al., 1997; Liotti et al., 1998; Roder, Rosler, & Neville, 1999). The substantial differences between the stimuli used in these studies strongly suggests that a more common cognitive process, such as the control of attention, is likely responsible for the supranormal performance of CB in nonvisual information processing.

Résumé

La cécité congénitale est l"un des rares modèles humains nous permettant d′explorer le rôle de la privation sensorielle à long terme sur le développement des modalités sensorielles préservées. Dans cette étude, nous avons réexaminé les capacités d"attention spatiale chez des participants aveugles congénitaux et chez des sujets voyants contrôles aux yeux bandés. Bien que les deux groupes aient obtenu des scores d′exactitude comparables, les participants aveugles démontraient des temps de réaction plus courts que les voyants lors de la détection de cibles auditives et tactiles. Ces résultats confirment la présence de compensations sensorielles chez les personnes nonvoyantes et nous permet d′élargir notre compréhension des mécanismes sous-tendant ces habiletés supranormales.

Mots-clés : cécité, compensation sensorielle, psychophysique, auditif, tactile

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