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Psychological Science published online 1 December 2010

DOI: 10.1177/0956797610391099

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Psychological Science OnlineFirst, published on December 1, 2010 as doi:10.1177/0956797610391099

Research Report

ASSOCIATION FOR PSYCHOLOGICAL SCIENCE

Psychological Science
XX(X) 1–7
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DOI: 10.1177/0956797610391099
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Early- and Late-Onset Blindness Both Curb Audiotactile Integration on the Parchment-Skin Illusion

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Abstract

It has been shown that congenital blindness can lead to anomalies in the integration of auditory and tactile information, at least under certain conditions. In the present study, we used the parchment-skin illusion, a robust illustration of sound-biased perception of touch based on changes in frequency, to investigate the specificities of audiotactile interactions in early- and late-onset blind individuals. Blind individuals in both groups did not experience any illusory change in tactile perception when the frequency of the auditory signal was modified, whereas sighted individuals consistently experienced the illusion. This demonstration that blind individuals had reduced susceptibility to an auditory-tactile illusion suggests either that vision is necessary for the establishment of audiotactile interactions or that auditory and tactile information can be processed more independently in blind individuals than in sighted individuals. In addition, the results obtained in late-onset blind participants suggest that visual input may play a role in the maintenance of audiotactile integration.

Keywords

audiotactile interaction, multisensory integration, blindness, parchment-skin illusion

Received 4/7/10; Revision accepted 8/16/10

For centuries, the senses that allow humans to perceive the world, such as vision, audition, and touch, have been studied independently. Indeed, as late as the 1960s, little was known about how individual senses influence each other, and even less was known about how they become integrated to provide a unified picture of what people perceive as reality. Although a few early studies examined bisensory interactions (e.g., Stratton, 1897), it is arguably through illusory percepts, such as the McGurk effect (McGurk & MacDonald, 1976), that multisensory phenomena became the focus of intense and sustained investigation (for a review, see Calvert, Spence, & Stein, 2004). Of particular importance to the present study is the demonstrated influence of auditory signals on tactile perception (e.g., Soto-Faraco & Deco, 2009) and the well-established fact that deprivation in one modality (e.g., vision) can modify the development of the remaining modalities, in terms of both unisensory processing and multisensory integrative processes (for a review, see Hötting & Röder, 2009; Merabet & Pascual-Leone, 2010).

It is well known that presenting a single somatosensory stimulus simultaneously with two successive sounds can lead to the perception of two distinct tactile sensations (Bresciani et al., 2005; Hötting, Friedrich, & Röder, 2009; Hötting & Röder, 2004). This illusory audiotactile phenomenon is related to the classic audiovisual illusory-flash effect (Shams, Kamitani, & Shimojo, 2000), and the similarity of results between the audiovisual and the audiotactile versions of this illusion points to similar cross-modal relationships, at least in the temporal domain. Audiotactile effects have also been shown in the frequency domain. Jousmäki and Hari (1998) reported that increasing or reducing the high-frequency content of the sound generated by rubbing the hands together resulted in a modulation of the experienced dryness or moistness of the palms. This sound-induced alteration of touch perception, known as the parchment-skin illusion, appears to be a robust case of cross-modal fusion (see also Guest, Catmur, Lloyd, & Spence, 2002).

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It is interesting that an enhanced ability to ignore irrelevant auditory or tactile stimuli while processing an auditory or tactile task has been demonstrated by congenitally blind individuals (Hötting & Röder, 2004; Hötting, Rösler, & Röder, 2004). Atypical audiotactile processing by blind subjects has also been recently supported by Occelli, Spence, and Zampini's (2008) study, which showed that blind participants had shorter just-noticeable differences in an auditory-tactile temporal-order task than did sighted participants, but only when stimuli were presented from different spatial positions. These studies, however, focused on temporal or spatial effects, and the question remains as to whether such research could be extended to the frequency domain.

Another unresolved question is whether the age of onset of visual deprivation affects integration of the auditory and tactile modalities. Visual input from birth may be crucial for the development and maintenance of audiotactile integration processes. Indeed, studies in animals have shown that the capacity to integrate input from different modalities is acquired during the first months after birth (Lewkowicz & Lickliter, 1994), although of course these processes also increase in complexity during the first years of life (Wallace, 2004). Numerous reports have revealed discrepancies in unisensory processing, as well as neuroanatomical differences, between early- and late-onset blind individuals (e.g., Burton, McLaren, & Sinclair, 2006; Jiang et al., 2009; Stevens & Weaver, 2009); specifically, extensive brain reorganization seems more prevalent in congenitally blind individuals. Assuming that multisensory processes develop gradually with experience, we suggest that visual deprivation in early life and visual deprivation in later life should alter multisensory interactions in different ways. In their study involving spatial elements, however, Occelli et al. (2008) reported that blind participants, no matter the age of onset of the blindness, performed more accurately than sighted participants. The question remains, again, whether such performance differences could be extended to the frequency domain.

The objective of our study was to further investigate the role of vision in the development and maintenance of normal interactions between audition and touch. In particular, the use of the parchment-skin illusion was intended to determine whether blindness alters audiotactile integration in the frequency domain. Furthermore, by comparing percepts of both early- and late-blind individuals with percepts of sighted control subjects, we aimed to disambiguate whether early visual input is sufficient to permanently establish normal audiotactile integration or whether continuous visual input is necessary for the maintenance of such integration.

Method

Participants

One group of sighted individuals and two groups of blind individuals (early blind and late blind) participated in the study. The sighted control group was composed of 9 adults (5 females and 4 males) ranging from 26 to 60 years of age (*M* = 41 years). The early-onset blind group was composed of 10 subjects (4 females and 6 males) ranging from 26 to 60 years of age (*M* = 41 years). None of the early-blind subjects had ever had functional vision that allowed pattern recognition or visually guided behavior. The late-onset blind group was composed of 8 subjects (3 females and 5 males) ranging from 28 to 60 years of age (*M* = 44 years). Before losing their sight, participants in the late-blind group had functional vision that allowed them to recognize visual shapes and to read printed letters. The mean age of blindness onset in the late-blind group was 19 years (range = 14–27 years), and the mean duration of blindness before taking part in the study was 25 years (range = 13–46 years).

At the time of testing, participants in the two blind groups either were totally blind or had only rudimentary sensitivity to brightness differences and no pattern vision at all. In both groups, blindness was caused by peripheral deficits with no additional neurological impairments. For all subjects, pure-tone-detection thresholds at octave frequencies ranging from 250 to 8000 kHz were within normal limits in both ears. All subjects reported normal tactile perception. The research ethics boards of the Center for Interdisciplinary Research in Rehabilitation of Greater Montreal and of the Université de Montréal approved the study, and all participants gave informed consent.

Procedure, stimuli, and design

Participants sat in a comfortable chair in a sound-attenuated booth. The participants in the sighted control group were blindfolded. On each trial, participants in all groups were asked to rub the palms of their hands together back and forth four times at approximately 2 cycles per second in front of a microphone (see Fig. 1a). In accordance with the methods of Jousmäki and Hari (1998), we had participants listen to the sounds they produced in real time through foam insert earplugs (Etymotic Research, Elk Grove Village, IL) at a self-adjusted comfortable hearing level (approximately 50 dB for all participants).

Sounds were played back to participants in three different auditory conditions (see Fig. 1b). In the first condition, the audio stimulus was the original sound. In the other two conditions, the sounds were modified with an equalizer (Realistic 31-2018A; Sci-Coustics, Inc., Barrie, Ontario, Canada) and a mixer (MG10/2 mixing console; Yamaha, Buena Park, CA). In the second (accentuated) condition, the audio feedback was increased by 20 dB, and frequencies higher than 2 kHz were augmented by an additional 12 dB. In the third (attenuated) condition, audio feedback was reduced by 20 dB, and frequencies higher than 2 kHz were attenuated by an additional 12 dB. According to Jousmäki and Hari (1998), the accentuated and attenuated conditions would induce the perception of drier and of moister palmar skin, respectively.

Before the start of the experiment, participants were asked to rub their palms together for 1 min and to remember the

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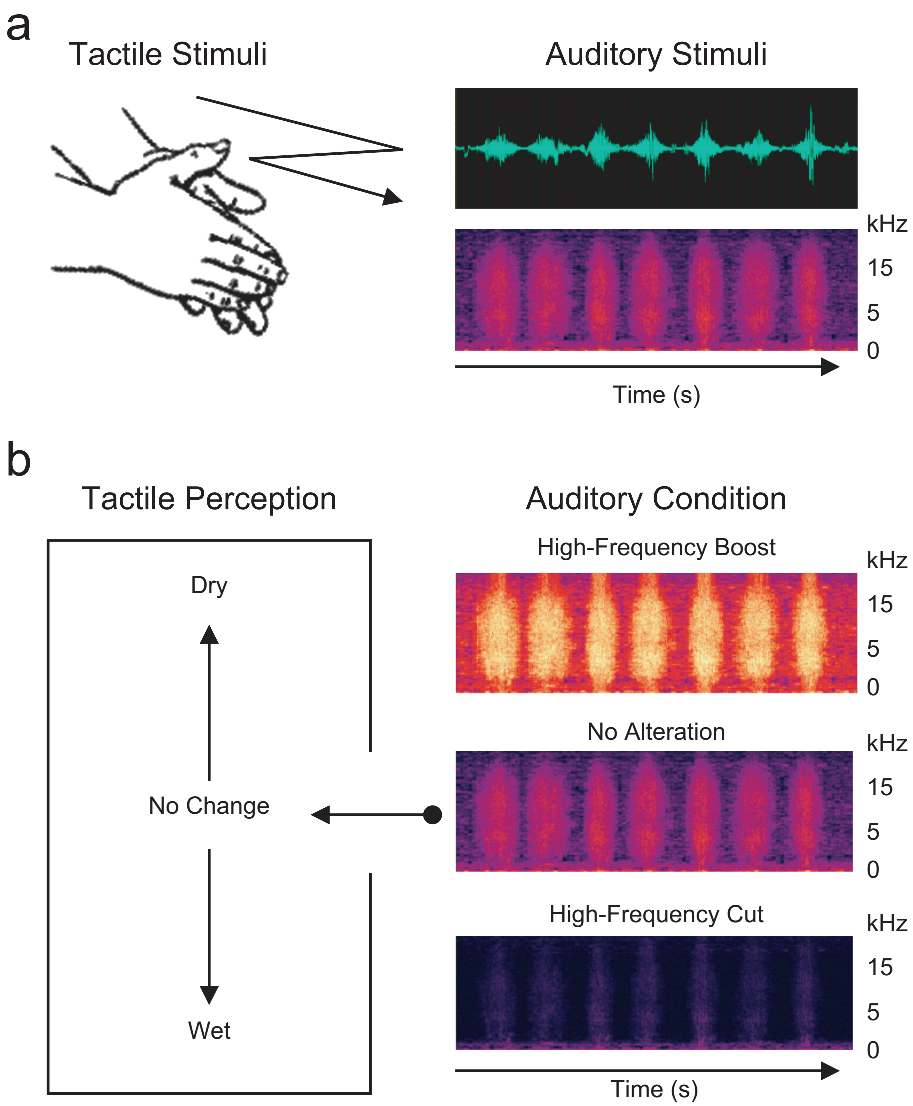

Fig. 1. Illustration of the parchment-skin illusion. Each participant rubbed his or her hands together (a; left). The spectrogram and oscilloscope readout (right) depict the acoustic parameters of the sound produced by 1 participant in terms of amplitude, timing, and frequency. Participants heard the sound of the rubbing in three auditory conditions (b). In the first condition (normal palmar skin perception), the audio feedback was unaltered. In the second and third conditions, the sound was modified so that the high frequencies were accentuated or reduced, respectively. These alterations induced a change in tactile perception, resulting in perception of the palmar skin as drier or moister, respectively.

feeling as "a normal palmar skin perception" (i.e., 0 on our scale). During the experiment, participants were instructed to focus on tactile perception and to report any changes in palmar skin consistency on a scale ranging from –5 (*moist*) to +5 (*dry*). They were specifically instructed to report a change in tactile sensation, not in auditory perception. Participants reported their responses verbally to the experimenter.

In their experiment with the parchment-skin illusion, Jousmäki and Hari (1998) used a scale similar to ours to rate perception from *dry* to *moist*, except that their scale was part of a two-dimensional grid with a second dimension of *rough* to *smooth*. However, a multidimensional scale, such as theirs, may generate confusion in the response (Guest et al., 2002). In addition, the rough-smooth scale has been evaluated independently and has proved to be more difficult to interpret than the dry-moist scale (Guest et al., 2002). Therefore, we used a unidimensional scale (dry-moist) to minimize any potential ambiguities in qualifying palmar skin changes. The three experimental conditions were each repeated 10 times in a pseudorandom order.

Results

All participants were able to accurately identify normal palmar skin perception. The reported perception of the skin in this condition was continuously very close to 0, with only small

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variations in the responses (see Fig. 2a). Figures 2b and 2c show the average performance for all groups in the accentuated and attenuated conditions, respectively. The results show that a parchment-skin illusion was clearly perceived by the control group. Indeed, all control individuals consistently reported a clear change in palmar skin perception whenever the high frequencies were increased (Fig. 2b) or decreased (Fig. 2c). As expected, palmar skin was reported to be drier than normal in the accentuated condition and moister than normal in the attenuated condition.

Five out of 10 subjects in the early-onset blind group and 4 out of 8 subjects in the late-onset blind group were unable to perceive any change in tactile perception regardless of whether high frequencies were increased or decreased. In addition, 1 early-onset blind individual showed only negligible changes in tactile sensation in the accentuated condition, and 1 early-onset blind individual showed negligible changes in the attenuated condition (a reverse pattern of responses from the control group). We performed a Kruskal-Wallis analysis of variance between groups in the accentuated and attenuated conditions. There was a significant difference between the groups in the changes in tactile sensation, both when high frequencies were amplified (Kruskal-Wallis = 19.03; $p < .001$) and when they were attenuated (Kruskal-Wallis = 18.99; $p < .001$).

Post hoc Mann-Whitney tests revealed that control subjects' perceived changes in palmar skin texture were significantly different from the perceived changes of early- and late-onset blind individuals. Significant differences were found between control subjects and early-onset blind individuals whether high frequencies were amplified ($p < .001$) or reduced ($p < .001$). The same difference was observed between control subjects and late-onset blind individuals. There was also a significant difference in palmar skin perception between early- and late-onset blind individuals, but only when the high frequencies were attenuated ($p < .007$). In addition, when compared with the control group, the early-onset blind group showed a tendency toward the perception of drier palmar skin in the attenuated condition. There were no other significant differences between groups.

Discussion

The results of our investigation confirm the robustness of the parchment-skin illusory percept in sighted individuals. The patterns of results observed in the blind individuals, however, were very different. Exactly half of the blind participants were unable to perceive any changes in tactile perception, whether higher frequencies were increased or attenuated, and 2 other early-onset blind individuals showed only negligible changes. Thus, only 3 out of 10 early-onset blind individuals and 4 out of 8 late-onset blind individuals showed a pattern of results that was similar to the pattern of results in sighted individuals. These findings are consistent with previous data that suggest the presence of atypical interactions between the auditory and the somatosensory systems following visual deprivation (Hötting & Röder, 2004; Hötting et al., 2004; Occelli et al., 2008).

In order to better ascertain whether the differences observed between the percepts of control subjects and the percepts of

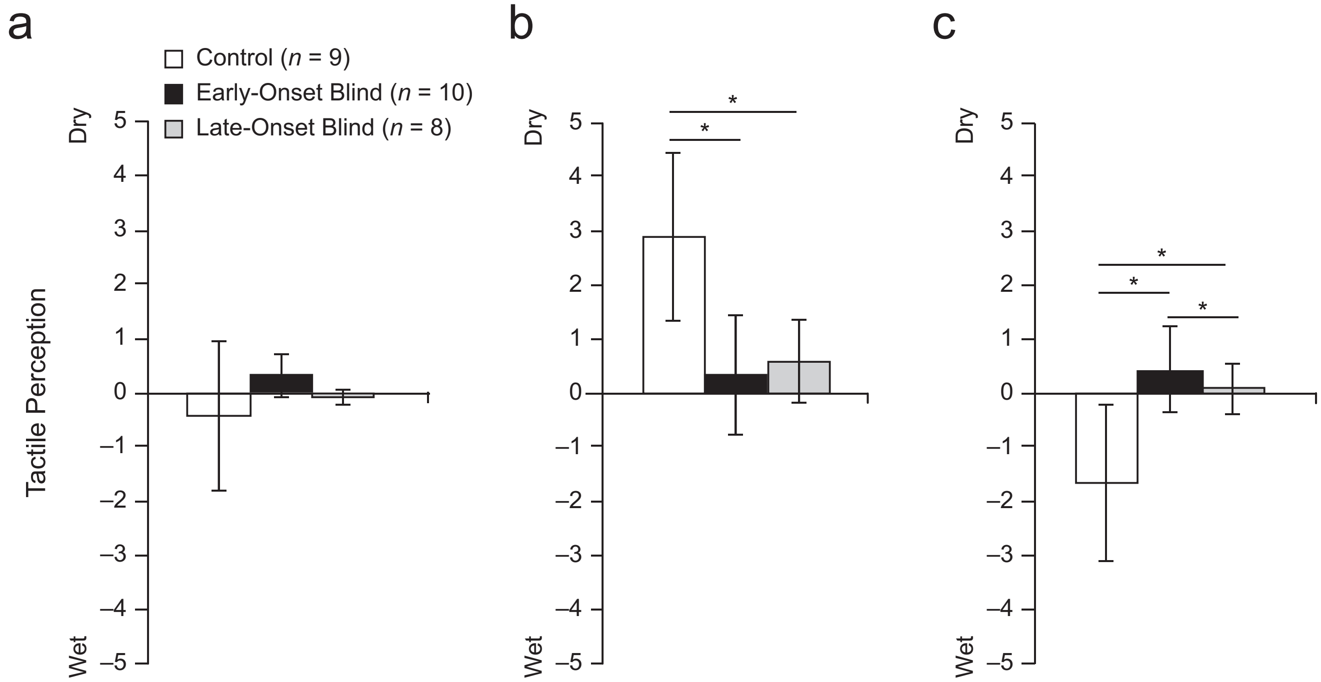

Fig. 2. Mean changes in palmar skin perception of the three subject groups during the parchment-skin illusion task. Results are shown for the three conditions of the study: (a) without modification of the auditory signal, (b) with the high frequencies of the signal accentuated, and (c) with the high frequencies attenuated. Error bars indicate standard deviations. An asterisk indicates a significant difference between groups ($p < .01$).

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blind individuals reflected a robust effect, we investigated a posteriori the blind individuals who were resistant to the parchment-skin illusion. They were explicitly asked to qualify any tactile change (e.g., roughness, smoothness, dryness, wetness) they might have felt during the various experimental manipulations, and the audiotactile effect they were expected to have felt was described to them in detail. They were then asked to perform at least five repetitions of the three experimental conditions, and they were asked to report any change, even if the change was very subtle. They remained fully resistant to the audiotactile effect. On the basis of this complete resistance to the illusion, we believe that group biases due to attention or motivation are very unlikely to account for the pattern of results in the main study.

Recent studies have suggested that visual input from birth may be essential for the emergence of multisensory functions in humans. For example, Putzar, Goerendt, Lange, Rösler, and Röder (2007) reported that audiovisual interactions were reduced or absent in patients who temporarily had cataracts at an early age. Similar results in an audiovisual fusion task have been reported in congenitally deaf individuals following cochlear implantation (Schorr, Fox, van Wassenhove, & Knudsen, 2005). Taken together, these results suggest that interactions between the senses are not necessarily innate, but rather are acquired early in development through everyday experiences.

The role of vision in the emergence of audiotactile integration

Because congenitally blind individuals perform differently from sighted control subjects on audiotactile tasks (Hötting & Röder, 2004; Hötting et al., 2004; Occelli et al., 2008), it has been suggested that vision is important for the establishment of normal audiotactile interaction processes. Hötting et al. (2004) suggested that the enhanced unisensory processing that has been repeatedly observed in blind individuals (e.g., Lessard, Pare, Lepore, & Lassonde 1998; Goldreich & Kanics, 2006; Van Boven, Hamilton, Kauffman, Keenan, & Pascual-Leone, 2000) may lead to more accurate performance in the tactile or the auditory domain. Indeed, the availability of more salient auditory and tactile information in blind subjects may attenuate the need for integration between these senses. Our results in an audiotactile-illusion task involving nontemporal, frequency elements (i.e., the parchment-skin illusion), like the results of Hötting and Röder (2004) in a task involving temporal elements (i.e., the audiotactile illusory-flash effect), tend to confirm this hypothesis.

The importance of visual input as infants come to know the world around them may explain why even the multisensory interactions that do not directly include vision would still be at least in part vision-based. The performance of the early-onset blind individuals in the parchment-skin illusion task is consistent with the notion that visual input from birth is essential for the establishment of normal audiotactile interactions and that extensive cross-modal changes occur following visual deprivation. Indeed, it has been suggested that multisensory functions develop gradually and that they are greatly influenced by early sensory experiences (e.g., Wallace, Carriere, Perrault, Vaughan, & Stein, 2006; Wallace & Stein, 2007).

Because of this maturational course, the influence of early sensory deprivation on multisensory interaction has received considerable attention, notably in the visual domain. Extracellular recordings carried out in animals suggest that early visual deprivation can modify auditory and somatosensory coding in some multisensory structures, namely, the anterior ectosylvian sulcus and the superior colliculus (Carriere et al., 2007; Wallace, Perrault, Hairston, & Stein, 2004), as well as in a structure originally believed to exclusively process auditory functions, namely, the central nucleus of the inferior colliculus (Pageau et al., 2008). Several studies conducted with human subjects also suggest that various brain structures reorganize extensively following visual deprivation in order to process tactile or auditory information (for a review, see Hötting & Röder, 2009). The performance of the blind participants in our study could consequently be due to extensive plastic changes.

The role of vision in the maintenance of audiotactile processing

The question remains as to whether vision plays a role in audiotactile processing throughout the lifespan. The extent of cross-modal changes has been shown to be related to the age of onset of visual deprivation (e.g., Jiang et al., 2009; Stevens & Weaver, 2009). This suggests that visual input might play a substantial role in refining multisensory, as well as unisensory, responses in the remaining modalities (Porter, Metzger, & Groh, 2007). In the present study, we also attempted to assess whether such developmental aspects of visual deprivation could have an influence on not only the emergence but also the maintenance of normal audiotactile interactions in sighted individuals. The pattern of responses observed in late-onset blind individuals in our study suggests that visual input may be essential for the maintenance of normal audiotactile integration.

The fact that early- and late-onset blind individuals showed different patterns of response in at least one of the experimental conditions, however, suggests that the audiotactile interactions may be differentially influenced by early and late loss of vision. Indeed, whereas both groups were resistant to the parchment-skin illusion, they differed significantly in one of the experimental conditions. This finding is rather difficult to interpret, especially as this effect was seen only when the auditory feedback was reduced. Therefore, exactly how early and late visual deprivation differ in their influence on audiotactile integration remains to be clarified. As discussed, it is possible that our participants, perhaps specifically the blind participants, paid varying degrees of attention to the auditory changes because of the nature of the experimental procedure. This

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variation might at least in part explain these discrepancies in response (e.g., some participants perceived an effect in at least one experimental condition, whereas others did not show effects at all). It might also explain the unreliable direction of the effect in the nonresistant blind participants (e.g., in a given condition, some participants perceived a change in one direction, whereas others perceived a change in the other direction). Further studies using an age range broad enough to map the developmental courses of audiotactile effects across childhood and adulthood, possibly in conjunction with neurophysiological recordings, will be needed in order to further clarify this important issue.

Atypical audiotactile interactions in response to the parchment-skin illusion were observed in both early- and late-onset blind individuals. Our results both confirm that visual input plays an important role in the establishment of normal audiotactile integration and extend findings about such integration to the frequency domain. In addition, the present study shows that visual input may be necessary for the maintenance of normal audiotactile integration, as both early- and late-onset blind individuals showed patterns of response that were very dissimilar from the response patterns of sighted control subjects.

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.

Funding

This research was supported in part by the Canada Research Chair Program, the Canadian Institutes of Health Research, the Natural Sciences and Engineering Research Council, and the Belgian National Fund for Scientific Research.

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