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Exploring the Impact of Congenital Visual Impairment on the Development of Absolute Pitch Using a New Online Assessment Tool: A Preliminary Study

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A high incidence of absolute pitch has been reported among individuals with visual impairment (VI), while recent behavioral and imaging evidence has indicated that enhanced abilities in the auditory domain result from the cross-modal takeover of the visually deafferented occipital areas. In this study, we tested the identification of musical pitch associated with verbal labels in children with congenital VI, together with a group of fully sighted children who acted as a comparison group, using a novel online assessment tool. The results indicated superior naming of musical pitch in the group with VI compared with the control group. Moreover, a bimodal distribution was found in the VI group in terms of the number of accurate pitch identifications. These preliminary findings suggest that enhanced pitch-naming ability in individuals with severe VI may be due to early differences in neural development brought about by loss of sight.

Keywords: congenital visual impairment, absolute pitch, paired associative learning

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It is widely believed that individuals with severe visual impairment (VI) show heightened auditory abilities (Voss, Collingon, Lassonde & Lepore, 2010). For example, to navigate around their environment, people with blindness show an increased sensitivity to physical sounds (Ockelford, Pring, Welch & Treffert, 2006). Indeed, numerous studies have indicated that visually impaired individuals outperform the sighted in several auditory tasks, such as pitch discrimination (Gougoux, Zatorre, Lassonde, Voss & Lepore, 2005; Voss & Zatorre, 2012; Wan, Wood, Reutens & Wilson, 2010), auditory spatial tasks (Gougoux et al., 2005; Voss, Gougoux, Zatorre, Lassonde & Lepore, 2008), voice processing (Gougoux et al., 2009), and speech perception (Rokem & Ahissar, 2009). Pring (2008) suggested this was likely to be the case because of increased attention to the acoustic input.

It has also been suggested that early blindness can lead to high levels of musical ability (Gougoux et al., 2004; Rauschecker, 2001; Treffert, 1989). Furthermore, it has been proposed that there is a greater incidence of absolute pitch (AP) in musicians with early blindness, compared with sighted musicians (Hamilton, Pascual-Leone & Schlaug, 2004). After extensive studies of several hundred children with a varying range of the degree of VI, Ockelford (1988), and Ockelford and Matawa (2009) noted that AP exists in approximately 40% of children with congenital blindness, and that this ability typically first manifests itself around the age of 24 months.

AP is the ability to identify a specific tone, or conversely to produce a designated musical pitch, without reference to any other (Ward, 1999). In contrast to the blind population, AP is possessed by a very small portion of the general population, a typical estimate being approximately 1 in 10,000 among Western populations (Bachem, 1955; Takeuchi & Hulse, 1993). However, it should be noted that AP is not an all-or-none phenomenon and can be referred to in various ways such as "pseudo AP," "limited AP," "genuine AP," or "universal AP," depending on the level of the recognition accuracy or the pitch range (Révész, 2001). Moreover, there are different theories that account for the acquisition and development of AP in the general population, such as genetic predisposition (Baharloo, Johnston, Service, Gitschier & Freimer, 1998; Baharloo, Service, Risch, Gitschier & Freimer, 2000), a differential biological substrate (Athos et al., 2007), and the effect

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of early musical training during a critical age period (Takeuchi & Hulse, 1993).

To assess the AP ability independent of formal musical knowledge, we designed a tool based on paired associative learning that has been used by previous studies (Heaton, 2003; Heaton, Davis & Happé, 2008; Heaton, Hermelin & Pring, 1998; Heaton, Pring & Hermelin, 2001; Pring, Woolf & Tadic, 2008). Beyond exploring the use of a new AP assessment tool, which is accessible to both blind and sighted participants, we also set out to make a preliminary comparison between congenitally blind and sighted children to test the hypothesis that congenitally blind children and young people may show enhanced pitch-naming ability compared with sighted chronological age–matched control individuals. Hence, a new paradigm that does not rely on visual memory was devised. Given that the two groups were matched on chronological age, it is likely that the blind children would be less advanced cognitively, and would have more limited memory capacity compared with their sighted counterparts (Pring, 2008); hence, any explanation of a potential superiority in pitch naming is unlikely to be explicable by these factors. More specific matching than this—for example, on musical experience or education, or in terms of global memory tests—was not carried out at this stage.

Method

Participants

The study involved 12 congenitally and totally blind[1] (seven female, five male, M age = 12.5 years, SE = 0.73, age range: 6.7–15.7 years) (see Tables 1 and 2 accordingly for demographics and test scores and 15 sighted (5 female, 10 male, M age = 10.3 years, SE = 0.82, age range: 6.9–16.2 years) children and young people). The fully sighted children were matched on chronological age as closely as it was practicable, providing a comparison group. An independent samples t-test showed no significant difference in chronological age between the two groups ($t(23) = 2.02$, $p >$ .467). None of the participants with VI reported having any auditory deficits or learning difficulties.

Materials and Procedure

Screening questionnaires, as used by previous studies (Ockelford & Matawa, 2009; Ockelford et al., 2006), were collected. Participants' parents answered a series of questions referring to their children's age, gender, medical diagnosis, musical interest, musical education, musical activity, or other special interests in the auditory environment, as well as to the occurrence of AP possessors in the family. Memory for pitch was assessed using an online test that was presented in a storytelling format.[2] A sequence of four different pitches, well within the vocal range of children (e.g., D4, E4, F4, and Gb4) and separated by semitones in the Western musical scale, was presented in two stories. Because there are reports that performance on accuracy is better when pitch recognition is associated with white piano keys (Ward, 1999), we used musical pitches the frequencies of which correspond to both white and black keys to increase the difficulty level. In addition, whereas previous studies have used musical sequences comprising whole-tone intervals in similar tasks (Heaton, Davis & Happé, 2008), the current study aimed to test musical memory using a smaller range of tones separated by a semitone, raising the degree of difficulty. Because note-naming ability is enhanced by music lessons on the piano or other fixed-pitch instruments (Vanzella & Scellenberg, 2010), the pitches we used were complex tones, sharing the same spectrum envelope and comprising a culturally neutral timbre that was nonetheless rich in harmonics and not identical to any musical instrument. In this way, the aim was to avoid any familiarization effects caused by experience on a particular musical instrument or exposure to a specific timbre.

Procedure

The participants were asked to listen to the first story once a day for a week. Each of the four characters that was presented in the story had a specific name and was specifically associated with one of the four testing tones (D4, E4, F4, and Gb4); each of them was presented in six blocks (i.e., 4 tones × 6 blocks). To avoid contiguous repetition, the sounds were presented in a pseudorandomized manner. This phase was used to ensure participants' familiarization with the associations between the sounds and the specific verbal labels. A record of the number of times that each participant listened to the story was kept online. Independent samples t-test indicated no significant difference on the recorded listening time between the two groups ($t(25) = 0.672$, *ns*).

The participants were asked to proceed to the testing phase (second story) shortly after the completion of the training phase (first story). Testing comprised 24 trials (4 tones × 6 blocks) that were generated in a pseudorandomized manner. When a tone was presented, the participants were asked to identify the name of the character of the story corresponding to that tone. Participants did not receive any feedback for individual trials. In addition, to minimize any short-term memory effects, a sequence of 12 randomly generated tones, ranging from B3 to A3, was presented before every trial. To extract a high interference effect, the intervening tones had the same timbre as the testing pitches (Starr & Pitt, 1997).

Results

In terms of the auditory task performance, our primary aim was to explore whether the innovative online methodology would be successful and, second, to test for a potential advantage of the participants with VI over their sighted comparison group. The maximum number of correct responses was 24. A Mann–Whitney U test showed that the blind group performed significantly higher than the sighted group in the extent of their total number of accurate identifications (sighted mean ranks = 11.27, mean total score = 8.27 [SD = 3.7], blind mean ranks = 17.42, mean total score = 16.58 [SD = 9.4]; $U = 49$, $Z = -2.028$, $p < .05$[3]). Additionally, analysis was carried out between the older (>11 years) and younger participants (<11 years), and a Mann–Whitney

[1] All the children were totally blind, although four had some light perception, and one a limited degree of movement perception—as is commonly reported.

[2] It is likely that the blind participants had screen-reading software installed; however, the webpage was designed so that this should not have interfered with the playback of the two stories.

[3] t-test confirmed these results ($t = 2.89$, $p > .012$, equal variances not assumed).

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Table 1
Blind Participant Characteristics

Gender	Age	Medical diagnosis	Functional vision	Musical practice (hr/d)	Musical interest	Musical training	AP in the family	Score (% correct)
M	15.7	ROP	Some light perception	2–3	A lot	Yes	No	100
M	12	ROP	Some light perception	1–2	A lot	Yes	Unknown	100
F	15.1	ROP	No vision	1–2	A lot	Yes	No	100
F	13.4	ROP	Some light perception	0–1	A lot	Yes	Yes	100
M	13.4	ROP	Some light perception	0–1	A lot	Yes	Yes	100
F	6.7	ROP	No vision	0–1	A lot	Yes	No	37.5
F	15.7	SOP	No vision	0–1	Not at all	Yes	Yes	16.7
F	13	Leber amaurosis	No vision	1–2	A lot	Yes	Unknown	100
M	14.1	Optic atrophy	Some movement perception	1.54	2.64	1.00	1.8	25
M	10.6	Optic nerve microphthalmia	No vision	0–1	A lot	Yes	No	100
F	10.3	Retinoblastoma	No vision	0–1	A lot	Yes	Unknown	41.7
F	11.3	Detached retinas	No vision	1–2	A lot	Yes	Yes	8.3

Note. For sex, M = male; F = female.
ROP = retinopathy of prematurity; SOP = septo-optic dysplasia.

U test indicated no significant effect of age on the total number of accurate identifications (older children mean ranks = 16.09, younger children mean ranks = 10.95, $U = 54.5$, $Z = -1.676$, *ns*). Inspection of the distribution of scores indicated that the children with VI either scored 100% or their performance fluctuated between 8% and 42%; in terms of diagnosis, five of seven of the blind participants who scored at 100% accuracy were diagnosed with retinopathy of prematurity (ROP). In the sighted group, performance fluctuated between 12.5% and 46% except for one child, who was reported by parents to possess AP and who scored 75% (Figure 1). It is also worth noting that in the sighted group, the highest score was achieved on the highest pitch of the sequence (Gb).

Screening Questionnaires

In relation to the self-report questionnaire, attention was concentrated on the exploration of differences between the two groups and within the blind group, and of the effect that specific factors would have on performance. On exploring the parents' accounts of their children's interests and musical ability, consistent reports of a distinct interest in music were revealed for those in the blind group who performed with 100% accuracy on the task, although comparisons between the blind and sighted group in terms of musical interest failed to show a significant difference, $t(22) = 0.583$, $p > .05$. In addition, all the participants with VI were reported to have received instrumental and voice lessons. However, music practice was not significantly correlated with blind children's pitch identification performance, $r = .264$, $p = .216$.

Discussion

The results indicated an advantage in pitch memory of individuals with VI, as compared with their sighted control counterparts. Interestingly, a bimodal distribution emerged in the blind group, showing that they either identified all the pitch/character associations correctly or their performance was rather poor. This might suggest the occurrence of "universal AP" in the subgroup of blind children to which Ockelford (2008) has previously referred. In contrast, it could be assumed that the sighted group's pitch perception may have been based on the relations between the heights of the pitches because their performance seemed to be more

Table 2
Sighted Participant Characteristics

Gender	Age	Musical practice (hr/d)	Musical interest	Playing instrument	Musical training	AP in the family	Score (% correct)
F	9	0–1	A little	No	No	Yes	33.3
M	12.4	1–2	A lot	Yes	Yes	Yes	79.16
M	10.7	0–1	A little	No	No	Yes	37.5
F	6.9	0–1	A lot	No	No	No	25
M	9.4	0–1	A little	No	No	No	25
M	7.5	0–1	Not at all	No	No	No	33.3
M	9.2	0–1	A lot	Yes	No	No	25
M	7	1–2	A lot	Yes	No	Unknown	12.5
M	12.4	0–1	A little	No	No	Yes	41.66
M	11.4	0–1	A lot	Yes	Yes	No	20.83
M	16.2	0–1	A lot	Yes	No	Unknown	41.66
M	14.3	0–1	A little	No	No	No	41.66
F	7.1	0–1	A lot	No	No	Unknown	25
F	10.3	1.15	2.46	Yes	Yes	1.923	45.83
F	10.3	1.15	2.46	1.57	1.78	1.923	29.16

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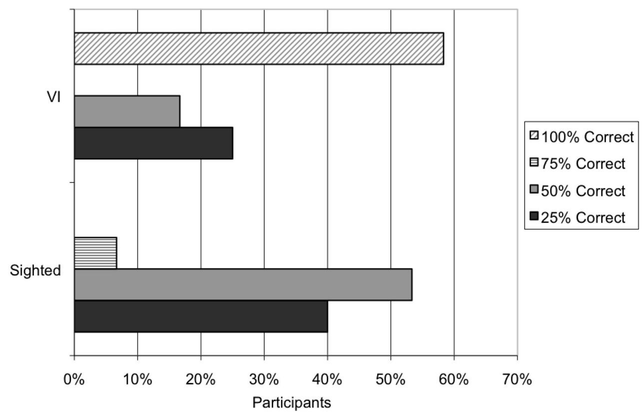

Figure 1. Distribution of the correct pitch identifications across the two experimental groups.

accurate on the highest tone. As such, it is possible that for the blind group, the lack of vision resulted in an increased interest in sound—including music—during the early years of life, which potentially leads to the development of AP, presumably, independently of any formal education. However, all the participants with VI in the current study were reported as being engaged in music education, so it is not possible to say, on the basis of the present evidence, whether this ability would have also been evident had the individuals in the blind group been lacking in musical training. A replication of the study controlling for factors such as formal music education and timing of music education onset would therefore be beneficial; however, there is a suggestion in the literature that advanced pitch identification accuracy in the blind is not a result of extended musical experience, but it rather depends on the lack of vision itself (Ockelford et al., 2006). If this were true, we could propose that the ability of AP in a subgroup of congenitally blind children is gained implicitly and effortlessly, and once it is acquired, it remains active. Accordingly, it could be claimed that music practice is not an essential factor for pitch memory in this subgroup of blind children, as the data of the current study showed that the majority of the participants who scored at the ceiling level reported spending no more than 2 hours playing instruments daily.

It is interesting to note that those participants who scored highly in the test were not especially likely to have first-degree relatives with AP—only two of the seven children who scored at 100% accuracy had reports referring to AP in the family. This is of interest because the ability of AP in the general population implicates one or more heritable genes (Athos et al., 2007). Certainly, children with severe and profound VI develop differently applying both compensatory strategies in a variety of cognitive processes, including long-term memory functions (Röder & Rösler, 2003) as well as different neural activation patterns (Kujala et al., 1997). In addition, a noteworthy observation is that five of seven children who had the diagnosis of ROP scored 100% accurately (whereas none of the fully sighted children scored 100%). These ROP children reported an intensive interest in music, and this accords with previous reports of an early obsessive interest in music may contribute to the exceptional musicality of the children with ROP (Ockelford & Matawa, 2009).[4]

In conclusion, this study was able to explore AP via a game, which can potentially be used as a tool for learning a shared "communication code" to promote development and assist the children with VI to learn and reach their potential. The results indicated superior memory for pitch when compared with age-matched sighted counterparts, and highlighted a subgroup of children with VI with special AP abilities.

[4] Previous evidence based on children and young people with ROP suggests that AP is likely to develop as a result of their medical diagnosis (Ockelford & Matawa, 2009).

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