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Cognitive representation of auditory space in blind football experts

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A B S T R A C T

Objectives: We compared the mental representation of sound directions in blind football players, blind non-athletes and sighted individuals.
Design: Standing blindfolded in the middle of a circle with 16 loudspeakers, participants judged whether the directions of two subsequently presented sounds were similar or not.
Method: Structure dimensional analysis (SDA) was applied to reveal mean cluster solutions for the groups.
Results: Hierarchical cluster analysis via SDA resulted in distinct representation structures of sound directions. The blind football players' mean cluster solution consisted of pairs of neighboring directions. The blind non-athletes also clustered the directions in pairs, but included non-adjacent directions. In the sighted participants' structure, frontal directions were clustered pairwise, the absolute back was singled out, and the side regions accounted for more directions.
Conclusions: Our results suggest that the mental representation of egocentric auditory space is influenced by sight and by the level of expertise in auditory-based orientation and navigation.

Blind football has become one of the most popular sports for the blind and partially sighted people worldwide. This sport is played according to the traditional football rules of the Fédération Internationale de Football Association (FIFA) with adaptations that enable blind people to participate. To help players' orient themselves, the ball is equipped with a noise-making device that allows players to locate it by sound, and verbal communication within the team makes the players aware of the locations of their colleagues and opponents. Auditory perception, as well as the adequate and rapid use of auditory information, its organization and interpretation, is therefore crucial in this sort of sport. Knowledge about the particularities of blind athletes' perception and conceptualization of space is important to support athletes and coaches in preparing adequate training sets, especially in terms of communication and orientation. Motivated by the increasing visibility of blind football in the paralympic games and by the lack of scientific studies investigating the circumstances and special expertise of blind athletes, the present study introduces a line of inquiry focusing on the mental representation (MR) of space in blind athletes as compared to blind non-athletes and sighted individuals.

In various sports disciplines, MR of movements in long-term memory (LTM) were found to provide the basis for the control of skilled movements as perceptual-cognitive reference structures (see Land, Volchenkov, Bläsing, & Schack, 2013). These studies support the idea that increased experience with particular tasks leads to the development of cognitive representation structures in LTM, which underlie movement performance. Campos, Hermann, Schack, and Bläsing (2013) used a similar methodological approach to study the cognitive representation structures of spatial features involved in spatial tasks. The authors applied Structure Dimensional Analysis (SDA; Lander & Lange, 1996; Schack, 2004, 2012) using the directions of sounds as concepts (items) to investigate MRs of auditory space in sighted individuals, and found more

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distinctive representations for directions in the frontal and rear versus the left and right regions. In accordance with studies of visual representations of space (Franklin, Henkel, & Zangas, 1995), the authors suggested that the representation of the front was more pronounced because this is where movement, manipulation, and attention were normally directed.

The relationship between MRs of auditory and visual spaces (Campos et al., 2013) and the differences in MR structures of skilled movements between experts and novices in diverse fields (see Land et al., 2013) motivated our study of expertise effects in MRs of auditory space. Using the SDA method, we compared the MR of sound directions between blind football players, blind non-athletes, and sighted participants. We expected that the sighted participants would represent the front and back regions more distinctively than the sides, corroborating Campos et al. (2013). Less differentiated representations of spatial regions were expected in the blind participants due to their lack of visual reference. Further, because regular training in blind sports provides blind athletes more varied experience in auditory-based orientation, we predicted that the blind football players' structure would be more distinctively organized than the blind non-athletes', corroborating the expertise studies across different fields (e.g. Land et al., 2013).

Method

Participants

Three groups of participants took part in the study. Group 1 consisted of nine male professional blind football players (BFP) who played in the Brazilian first league and practiced three times a week (29.7 ± 9.7 years, one left handed). One participant in this group perceived lights, the other eight were completely blind, two congenitally. Group 2 included 10 blind non-athletes (BNA; eight males, 44.4 ± 8.8 years, all right handed). All participants in this group lost their vision after age 10; one participant perceived lights, two perceived shadows and one retained 10% of his vision. All blind participants reported autonomy for daily tasks and locomotion without guides. Group 3 consisted of nine sighted control (C) subjects (two males, 28.89 ± 2.52 years, three left handed), with only recreational experience with football. Since gender has been found to not affect performance in auditory localization tasks (e.g., Maeder et al., 2001), the different blends of male and female were not expected to influence the experimental task. Participants gave their informed consent prior to the experiments, and reported being free of any known hearing deficits and/or neurological impairments. This study was conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki.

Apparatus and sound stimuli

The experiment was conducted in a room consisting of a ring (1.68 m radius, 1.8 m above ground), with 16,100 W loudspeakers (LS) attached to the ring and positioned at intervals of 22.5° pointing towards the center. The LSs were connected in a circuit linked to a computer running the programming language SuperCollider, which resynthesized the stimuli and enabled the experimenter to manually activate the LS defined by the program. For the experimenters' reference, each LS position was labeled with a number from 0 to 15 in clockwise order, but participants were not informed about this nomenclature. A rectangular carpet (50 × 30 cm) made of ethylene-vinyl acetate with borders in high relief was positioned in the center of the circle.

A single sound stimulus consisted of a series of 3 finger snap sounds with an inter-snap time difference of 500 ms, provided from Freesound.org (http://www.freesound.org/samplesViewSingle.php?id=11869). The wave file lasted roughly 25 ms. The broadband transient snap sound produced a maximum of 2753 Hz (−20 dB) corresponding to a wavelength of 16.5 samples at the used sample rate of 44,100 Hz. The intensity was adjusted manually so as to be audible to the participants.

Procedure

All participants were tested individually. Participants were asked to stand blindfolded and shoeless in the center of the ring, facing the forward direction (taking as tactile reference the high relief borders of the carpet), and were asked to keep this position throughout the experiment. The experimental splitting procedure began with the stimulus sound being played by one of the LSs (the current anchor), and subsequently by a different LS. The participant's task was to judge whether the direction of the second sound was similar or not to the direction of the anchor, by answering "yes" for similar, or "no" for dissimilar directions (note that 'similar' in this context did not refer exclusively to the same direction, but deliberately allowed the participants to base their judgments on their individual similarity criteria). In general, participants needed less than two seconds for each response, although there was no fixed inter-trial interval. Once the response was given and annotated by the experimenter, the next trial began, with the same anchor followed by another of the 14 remaining directions in a randomized order, until all of the 15 directions had been judged in relation to the current anchor; this procedure comprised one block. In the next block, a different anchor was presented in combination with all 15 LSs. The whole experiment comprised 16 blocks presented in a randomized order, each block with a different LSs as anchor. Each participant completed 240 trials in total (i.e., 6 blocks of 15 trials). After the 6th and 12th blocks, participants had a break of approximately two minutes.

Analysis

The SDA method consists of four steps: First, a splitting procedure (described in the previous sections) draws a distance scaling between the concepts from a predetermined set. In the present study, the concepts were the directions of sounds played by the 16 LSs. Second, a hierarchical cluster analysis transforms the set of concepts into a hierarchical structure. Third, a factor analysis reveals dimensions in this structured set of concepts. This step did not appear relevant to our research question as we did not expect spatial region concepts to be based on complex abstract features. The fourth step involves an intra- and inter-individual invariance analysis of the formed cluster solutions (Schack, 2012).

The first step (the splitting procedure) established 16 decision trees, one for each anchor position. The algebraic branch sums (Σ) were set on the partial quantities per decision tree, submitted to a Z-transformation for standardization, and combined into a Z-matrix. Next, the Z-matrix was transferred into a Euclidean distance matrix for a hierarchic cluster analysis, which resulted in individual cluster solutions on the 16 directions displayed as dendrograms, when determining an incidental Euclidean distance, or d_{crit}. If two directions were often judged as being similar, this was expressed as a small Euclidean distance between them, resulting in a low projection of that direction on the vertical line of the dendrogram. Only the joints formed below the incidental value d_{crit} (statistically estimated for an alpha-level of .01, as $d_{crit} = 4.59$) formed distinct clusters of directions. When two directions were repeatedly judged as dissimilar, the Euclidean distance was longer and the projection of the two directions was high in the dendrogram.

For comparison between the three group cluster solutions, a structural invariance measure λ was determined based on three