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Short communication

Visual experience facilitates allocentric spatial representation

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HIGHLIGHTS

- Previous studies showed that regular sets of objects are allocentrically represented.
- We tested congenital and late blind, and blindfolded sighted participants.
- Visual experience determined the reference frame for spatial representation.
- by affecting the multisensory brain areas involved in spatial cognition.

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ABSTRACT

Representing the position of the objects independently from our own position is a fundamental cognitive ability. Here we investigated whether this ability depends on visual experience. Congenitally blind, late blind and blindfolded sighted participants haptically learnt a room-sized regularly shaped array of objects, and their spatial memory was tested to determine which spatial reference frame was used. Crucially, the use of an object-based reference frame requires representing the regular structure of the array. We found that blindfolded sighted and late blind participants, that is those with visual experience, showed a preferential use of the object-based or 'allocentric' reference frame. On the contrary, congenitally blind participants preferred a self-based, or egocentric, reference frame. This suggests that, due to its developmental effect on the multisensory brain areas involved in spatial cognition, visual experience is necessary to develop a preference for an object-based, allocentric reference frame.

1. Introduction

McNamara and colleagues [1] reported the counterintuitive result that the representation of a regular array of objects was based on the intrinsic structure of the array (i.e. object-based, or allocentric, rows-and-columns grid pattern), rather than on the egocentric viewing position (see also [2] for equivalent results within the peripersonal space in arm's reach). More precisely, from a given viewing position, participants viewed a set of objects disposed on the room's floor and then their spatial memory was tested in a Judgement of Relative Direction task (JRD) where they imagined being close to a given object within the array, being oriented toward a second object and pointing in the direction of a third one (i.e. heading). For example, "Imagine that you are at the clock, facing the shoe, point to the jar"). Surprisingly, results showed that participants were more accurate for headings aligned with the intrinsic structure of the array than with the familiar viewpoint. This suggests that participants could extract the grid pattern of the array and use it to store the position of the objects in their spatial memory and, consequently, they performed the JRD task better when the tested headings matched the grid pattern. Here we adapted the method by McNamara and colleagues [1] and tested congenitally blind, late blind, and blindfolded sighted participants to investigate whether the ability using an allocentric reference frame is subject to visual experience or whether it is innate.

Additionally, the current study can shed a light on the role of a critical period for developmental vision on spatial cognition and brain organisation [3]. In fact, although it is an established opinion that blindness sharpens the remaining modalities [4,5], discordant results have been reported by studies investigating spatial cognition in blind individuals. Thus, some researchers found

Abbreviations: CB, congenitally blind; LB, late blind; S, sighted.

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results suggesting that congenital blindness prejudices the complete development of spatial cognition [6,7]. On the contrary, other authors reported data suggesting that visually impaired people can perform spatial tasks at the same level as sighted [8,9]. Yet, a few studies comparing the use of spatial reference frames across blind participants may suggest that visual experience is crucial for spatial tasks requiring the use of allocentric spatial representation, while egocentric spatial abilities should be preserved [10,11].

Along these lines, we created a somatosensory task (i.e. based on haptics, proprioception and vestibular cues) where two groups of blind and one group of blindfolded sighted participants were led by the experimenter to explore objects arranged in a regular array and then they underwent a JRD task. If visual experience is crucial for developing allocentric spatial representation, and thus for the ability of perceiving the grid-pattern of the array, we would find that participants without visual experience (congenitally blind) are less precise in JRD involving headings parallel to the grid-pattern (i.e. that the allocentric reference frame is not exploited). Yet, they will be more accurate in JRD involving headings parallel to the routes walked during the array exploration, that is, to the participants' egocentric representation of the array. On the other hand, participants possessing visual experience (late blind and blindfolded sighted) are expected to exhibit the opposite results: more accurate performance for allocentric headings, and poorer for egocentric.

2. Method

2.1. Participants

We tested 20 blind participants recruited through local blind institutions. Ten were congenitally blind (CB), five males and five females, with a mean age of 43 (16.23 SD). Ten were late blind (LB), five males and five females, with a mean age of 43 (12.18). Finally, we tested a group of ten matching blindfolded sighted individuals (S), five males and five females, with a mean age of 43.4 (9.05) (see Table 1 for details). None reported any motor impairment. All participants signed a consent form approved by the local Research Ethics Committee. Participants received £10 for their participation.

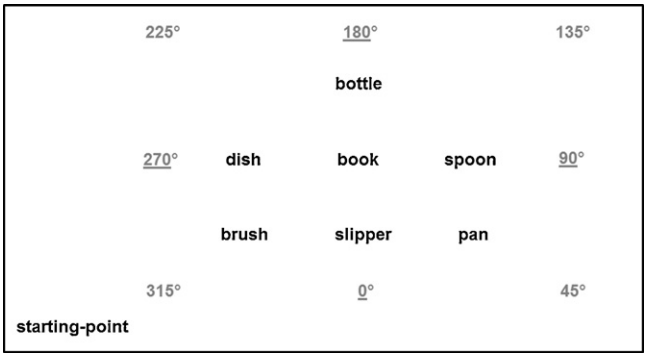

Fig. 1. A depiction of the experimental setup with the eight headings. The underlined headings are the allocentric (0°, 270°, 180° and 90°) while the remaining are the egocentric (315°, 225°, 135° and 45°).

2.2. Apparatus

Common objects were arranged inside a roughly rectangular room about 12.5 m × 9 m (see Fig. 1). Each object was placed on a 90 cm tall stool to facilitate haptic exploration. Between each stool there was a distance of about 1.5 m. A chair placed about 2 m from the closest object (brush) was the starting-point of each exploration.

During the JRD task, participant used a LogiTech™ 3DPro joystick connected to a Dell™ Latitude E5510 laptop running a MatLab™ program that recorded pointing angles and reaction times. The pointing task took place in a nearby room sized 3 m × 2 m. Sighted participants were blindfolded throughout the experiment by a MindFold™. As no blind participant had more than light/darkness sensitivity none of them wore the blindfold.

2.3. Procedure

The experiment consisted of two phases, learning and testing. Sighted participants were blindfolded. Then participants were guided into the 'learning' room where they familiarised with the use of the joystick. Led by the experimenter, participants began the exploration of the array. Objects were explored one-by-one, with participants being led along straight routes back-and-forth

Table 1
Details of the participants; 'Educ.' indicates the level of education (University or Secondary). 'Y' means 'yes' and 'N' means 'no', while 'L/D' means 'light/darkness' sensitivity and, if relevant, in which eye (left of right). Etiology abbreviations: RoP, retinopathy of prematurity; Retinobl, retinoblastoma; Cong, congenital; Cat, cataracts; Gla, glaucoma; RP, retinitis pigmentosa; Ret deg, retinal degeneration.

	Sex	Age	Hand	Educ.	Onset	Etiology	Braille reading	Visual imagery	Residual vision
CB1	M	59	Rx	Uni.	Birth	RoP	Y	N	N
CB2	M	58	Rx	Uni.	Birth	Retinobl	Y	N	N
CB3	F	26	Rx	Sec.	Birth	Genetic retinal dysplasia	Y	N	N
CB4	F	27	Rx	Uni.	Birth	Optic nerve did not develop	Y	N	L/D
CB5	F	27	Rx	Sec.	Birth	Cong Cat + Gla	Y	N	L/D
CB6	M	63	Rx	Sec.	Birth	RoP	Y	N	N
CB7	F	27	Lx	Uni.	Birth	Cong gla + Cat	Y	N	N
CB8	F	35	Rx	Uni.	Birth	Cong gla	Y	N	L/D
CB9	M	46	Rx	Sec.	Birth	RoP	Y	N	N
CB10	M	62	Rx	Sec.	Birth	RoP	Y	N	N
LB1	F	38	Rx	Uni.	21	Optic nerve atrophy	Y	Y	L/D
LB2	M	22	Rx	Uni.	12	Gla	Y	Y	L/D
LB3	M	55	Rx	Sec.	2	Measles	Y	Y	N
LB4	M	58	Rx	Sec.	50	RP	N	Y	N
LB5	M	44	Rx	Uni.	32	Retinal degeneration	Y	Y	L/D
LB6	F	44	Lx	Sec.	21	Diabetic retinopathy	N	Y	N
LB7	F	54	Lx	Uni.	2	Retinobl	Y	Y	N
LB8	M	24	Rx	Sec.	3	Optic nerve atrophy	Y	Y	L/D (Lx)
LB9	F	44	Rx	Sec.	25	RP + retinal dystrophy	Y	Y	L/D (Lx)
LB10	F	47	Rx	Sec.	11	Retinal degeneration	Y	Y	N