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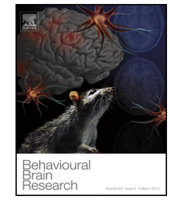

Research report

Does blindness affect egocentric and allocentric frames of reference in small and large scale spaces?

Tina Iachini*, Gennaro Ruggiero, Francesco Ruotolo

Laboratory of Cognitive Science and Immersive Virtual Reality, Department of Psychology, Second University of Naples, Italy

HIGHLIGHTS

- The impact of the scale of space on blind people's spatial memory was verified.
- Blind (early/late) and sighted people performed egocentric and allocentric tasks.
- Congenitally blind people had difficulty in the allocentric task in large space.
- Visual experience helps to develop allocentric representations of large space.
- A stable body facilitates the blinds' egocentric task in small space.

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ABSTRACT

There is evidence that early deprivation of vision prompts the use of body-based, egocentric spatial representations in congenitally blind individuals, whereas previous visual experience favors the use of object-based, allocentric representations (e.g. Pasqualotto A, Spiller MJ, Jansari AS, Proulx MJ. Visual experience facilitates allocentric spatial representation. Behav Brain Res 2013;236:175–79). Here we investigated whether the influence of the visual status on the capacity to represent egocentric and allocentric spatial relations is mediated by the scale of space explored: large-scale (where a haptic + locomotor exploration is required) and small-scale space (where haptic exploration is needed). Our results showed that congenitally blind people had more difficulty in representing spatial information allocentrically with respect to late blind and sighted individuals, but this difficulty was stronger with large-scale than small-scale space. Instead, egocentric performance was better than the allocentric one for all groups, particularly in the small scale condition. These results suggest that visual experience is necessary to develop accurate allocentric representations especially of large-scale spaces. This is probably due to its capacity to convey a large amount of spatial information simultaneously and to its role on the setting up of multisensory brain areas underlying spatial cognition. In the absence of any kind of visual experience, egocentric spatial representations are favored, especially in small-scale space, when the body offers a stable anchor point.

1. Introduction

Many human spatial abilities, such as remembering the position of objects, reaching objects or finding the way, imply that frames of reference, traditionally classified as egocentric and allocentric, are used as anchor points. Egocentric frames of reference use the organism or body parts as the center of the organization of surrounding space (e.g. *the object in front of you*), whereas allocentric frames of reference are centered on external objects or on the environment itself (e.g. *the object X on the right of object Y*) [1–6]. The impact of blindness on the use of these two kinds of reference frames is an issue still debated in the literature [7–11].

We know from the literature that without the aid of any residual visual experience, non-visual perceptual modalities (e.g., proprioceptive, tactile, kinesthetic) rely essentially on egocentric frames of reference [7,9,12–14]. Consistently, several studies have reported that tasks requiring egocentric frames of reference were performed similarly by congenitally (blind from birth) and adventitiously (late onset of blindness) blind participants in comparison with sighted controls [8,12,15–21].

Instead, tasks requiring allocentric frames of reference appear more difficult for congenitally blind than adventitiously blind or

* Corresponding author at: Laboratory of Cognitive Science and Immersive Virtual Reality, Department of Psychology, Second University of Naples, Viale Ellittico, 33, 81100, Caserta, Italy. Tel.: +39 0823 27532; fax: +39 0823 274759.
E-mail address: santa.iachini@unina2.it (T. Iachini).

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sighted people [7,10,13,22]. Therefore, apart from few exceptions [17,23–25], the majority of studies suggests that the absence of any kind of visual experience may limit the capacity to process functionally efficient allocentric representations.

This has been recently verified by Pasqualotto and colleagues [11] who have shown that people with visual experience, such as blindfolded sighted and late blind people, preferentially used allocentric frames to represent spatial information, whereas congenitally blind people tended to prefer self-based, egocentric, reference frame. The preference of congenitally blind people for egocentric rather than allocentric representations could be due do the fact they have no experience of what the vision allows, that is to convey simultaneous spatial information about different objects.

Instead, they have to rely on somatosensation to acquire new spatial information and this represents an effortful and error prone serial process [26], particularly for developing an allocentric representation of the environment [27,28].

However, some literature shows that when spatial information is acquired in small-scale space differences between sighted and blind individuals' spatial performances are reduced. For example, Hollins and Kelley [29] have shown that blind individuals performed similarly to the sighted blindfolded ones in a spatial relocation task, in both egocentric and allocentric conditions. Similar results were found by Coluccia and co-workers [30] with an object location memory task. Instead, Ruggiero, Ruotolo and Iachini [31] found out that congenitally blind participants were slower than sighted, blindfolded and late blind participants in processing metric allocentric information while no difference was found for categorical (e.g. right/left) allocentric representation. Finally, Tinti and colleagues [19] showed that blind individuals' allocentric representation of a pathway was similar to that of blindfolded sighted individuals if the acquisition of spatial information fell within a blind person's typical range of experiences.

On the other side, the data regarding large-scale space are particularly puzzling. For example, Rieser and colleagues [32,33] reported that congenitally blind participants performed worse than adventitiously blind and sighted participants in allocentric and egocentric spatial tasks regarding large scale space explored by locomotion. Similarly, Ruggiero et al. [34] in a spatial memory task based on locomotor and haptic exploration of a spatial array and requiring egocentric and allocentric frames, found a difficulty with the allocentric component in congenitally blind people as compared to blindfolded and sighted people. Instead, all groups performed similarly in the egocentric processing. In contrast, other studies found very little difference in a series of navigation tasks between participants who were normally sighted, congenitally blind or adventitiously blind [24,25,35,36].

We argue that the scale of space, among other individual and task-related variables [16,24,37–39] may affect the impact of blindness on the resulting spatial behavior and may help to interpret the discrepant data emerging from studies about blinds' spatial memory.

Siegel [40] and Acredolo [41] have proposed the distinction between small- and large-scale spaces.

Small-scale spaces do not enclose the observer and can be apprehended in a single glance. Large-scale spaces require observer's whole-body movement in order to be explored because they can only be viewed in segments. Therefore, in order to learn spatial information in small-scale spaces blind people can only use haptic exploration while the body is still and offers a stable egocentric frame; instead, in large-scale spaces they have to move with their whole body through the space and touch the objects they encounter [40–42]. These requirements may be particularly limitative for blind people. For example, Rieser and colleagues [32] asked participants to work out spatial relations between large scale positions learned through locomotion and found impairments in early blind participants, whereas in a small-scale haptic version of the task Barber and Lederman [43] did not.

In order to assess whether the scale of space affects the processing of egocentric and allocentric frames of reference in the absence of vision, congenitally (blind from birth) and adventitiously (onset of blindness at least after 13 years of age) blind people were compared to sighted people (blindfolded or not) on a spatial memory task. The task explicitly required to retrieve from memory egocentric and allocentric spatial relations of stimuli presented in small or large-scale space. Accuracy and response time measured the spatial performance. In line with the literature, the condition "small space" was characterized by configurations of objects placed on a desk whose spatial relations could be easily haptically explored by standing seated in front of them, whereas the condition "large space" presented a larger version of the same configurations of objects placed on the floor of a room whose spatial relations could be explored by walking among them and touching each object. The egocentric–allocentric task has already been used to assess spatial memory in healthy adults [44–46], brain damaged patients [3,47], blind people [31,34], children with Cerebral Palsy [48,49] and has proved its efficacy in inducing a specific involvement of spatial frames of reference.

We expect that congenitally blind people should be less accurate and slower than sighted and blindfolded sighted people in processing allocentric information. This effect should be particularly evident in large-scale space [7,10,13]. As regards adventitiously blind people, we cannot put forward precise hypotheses since the data available in the literature are less clear and show that their spatial performances are often in between those of congenitally blind and sighted people [7,8]. The four groups should perform similarly, in terms of accuracy and processing time, in the egocentric processing of small-scale spatial information. However, it is possible that the large-scale context may slow the egocentric processing time of congenitally blind people. Finally, since the literature suggests a female difficulty with the allocentric component of spatial memory and specifically in large scale environments [50,51], a related gender difference was also expected.

2. Materials and methods

2.1. Sample

A total number of 132 participants, 46 females and 86 males, took part in the experiment: 22 congenitally blind, mean age = 35.5, SD = 8.3, range = 20–53; 22 adventitiously blind, mean age = 38.4, SD = 7.2, range = 26–58; 44 blindfolded sighted, mean age = 35.5, SD = 8.5, range = 22–58; 44 sighted people, mean age = 35.3, SD = 8.3, range = 24–58. Mean education (years of schooling) within each group was: congenital = 12.0, SD = 3.3, adventitious = 12.3, SD = 2.8, blindfolded sighted = 12.8, SD = 3.2, and sighted = 13.2, SD = 3.2. Two groups of 66 participants each (11 congenitally blind, 11 adventitiously blind, 22 blindfolded sighted, 22 sighted) were assigned to two experimental conditions: learning of spatial stimuli in small-scale and in large scale spaces. Sighted and blindfolded sighted participants were matched to blind persons in terms of gender, age and educational level. Specific ANOVAs showed no difference between groups in age ($F < 1$) and education ($F < 1$). Adventitious and congenital participants were totally blind and were recruited with the assistance of the UIC, the main Association of Italian blind people in Naples, Caserta (Italy) and their provinces. Congenital participants were blind from birth. Adventitious participants became blind later in life (at least after 13 years, mean age of onset = 17.9, SD = 3.18, range = 13–25). The loss of sight was due to several aetiologies: congenital retinitis pigmentosa, optic nerve atrophy, congenital glaucoma in congenitally blind