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Interaction between allocentric and egocentric reference frames in deaf and hearing populations

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ABSTRACT

Spatial position of an object can be represented in the human brain based on two types of reference frames: allocentric and egocentric. The perception/action hypothesis of the ventral/dorsal visual stream proposed that allocentric reference frame codes object positions relative to another object/background subserving conscious perception of the external world while egocentric reference frame codes object positions relative to the observer's body/body parts subserving goal-directed actions towards the objects. In three experiments of the present study, by asking congenitally deaf participants and hearing controls to perform allocentric and egocentric judgment tasks on the same stimulus set and by using the spatial congruency effect between allocentric and egocentric positions of the same target object to indicate the extent of influences between the two frames, we aimed to investigate whether the two frames and the potential interaction between them are altered after early deafness. Our results suggested that deaf participants' responses were significantly slower in the egocentric tasks as compared to hearing controls while the two groups showed comparable task performance in the allocentric tasks, indicating that egocentric reference frame was impaired after early deafness. Moreover, the pattern of interaction between the two frames was different between deaf and hearing groups: irrelevant egocentric positions caused more interference to allocentric processing than vice versa in the hearing group while the two frames caused equivalent interference to each other in the deaf group. Further control experiments suggested that the above effects were *not* caused by the impaired sense of balance in the congenitally deaf participants (via open-loop pointing test), and was independent of whether the speed of allocentric and egocentric processing was equivalent or not in the hearing group.

1. Introduction

Spatial location of an object can be represented in two spatial reference frames: an egocentric and an allocentric one. In the egocentric reference frame, the position of an object is represented relative to the observer's body (or parts thereof). In the allocentric reference frame, the position of an object is represented relative to another object or a background independent of the observer. The neural mechanisms supporting egocentric representations, with regard to current gaze axis (retinotopic), head orientation, or body/trunk orientation, can be found in the dorsal visual stream subserving goal-directed actions (Andersen & Buneo, 2002; Andersen, Snyder, Bradley, & Xing, 1997; Cohen & Andersen, 2002; Goodale & Milner, 1992; Milner & Goodale, 1995). In contrast, the neural processes underpinning allocentric representations can be found mainly along the ventral visual stream subserving the conscious perception of objects or spatial memory functions (Andersen & Buneo, 2002; Goodale & Milner, 1992; Milner & Goodale, 1995; Rolls & Xiang, 2006). Please note here, although both vision (Goodale & Milner, 1992; Milner & Goodale, 1995) and audition (Rauschecker, 2011; Rauschecker & Tian, 2000) have dorsal and ventral streams, we specifically refer to the dorsal vs. ventral stream of vision.

The egocentric and allocentric manifestations of visuospatial neglect may occur either together or in isolation (Bisiach, Capitani, & Porta, 1985; Driver & Halligan, 1991; Marshall & Halligan, 1993; Walker, 1995), suggesting that egocentric and allocentric reference frames may have both shared and specific neural correlates in the brain. Consistent with such lesion data, functional imaging studies revealed that the egocentric and allocentric reference frames not only share neural mechanisms in the frontal and parietal lobes, but also have task specific mechanisms in the temporal and occipital cortices, and the hippocampus (Committeri et al., 2004; Fink, Dolan, Halligan, Marshall, & Frith, 1997; Galati et al., 2000; Zaehle et al., 2007). Due to the shared neural correlates of allocentric and egocentric representations and the co-existence of visuospatial neglect based on the two reference frames, it seems that allocentric and egocentric reference frames are two interacting, rather than completely independent,

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spatial reference systems. Accordingly, both behavioural and neural evidence has been revealed to support the potential interaction between the two spatial reference frames with regard to both perceptual judgments and hand movements (Neggers, Scholvinck, van der Lubbe, & Postma, 2005; Neggers, Van der Lubbe, Ramsey, & Postma, 2006; Thaler & Goodale, 2011; Thaler & Todd, 2010).

In the present study, by orthogonally crossing the allocentric and egocentric positions of the same behavioural target, we aimed at providing more direct evidence on the potential interaction between the two reference frames in normal hearing populations. More importantly, by comparing task performance between the congenitally deaf group and the normal hearing control group, we aimed to investigate whether the allocentric and egocentric reference frames and the potential interaction between them are altered after early deafness. Recent studies on visual perception in congenitally deaf human populations suggest that peripheral vision to motion stimuli is enhanced after early deafness particularly during demanding tasks. For example, deaf human individuals respond faster and more accurate than hearing controls to peripheral motion stimuli when the spatial or temporal feature of behavioral targets is uncertain (Stevens & Neville, 2006) or when the target has to be selected from among distractors (Neville & Lawson, 1987), while deaf and hearing individuals show comparable performance for central targets (see Bavelier, Dye, & Hauser, 2006 for a review). Moreover, the motion-selective area (MT-MST) in the dorsal visual stream was activated more significantly by attention to peripheral than central motion in the early deaf human individuals while the hearing populations displayed the opposite pattern, i.e., more MT-MST activation under attention to central than peripheral motion (Bavelier et al., 2001). Since neural evidence indicates that both motion processing (Beauchamp, Cox, & DeYoe, 1997; O'Craven, Rosen, Kwong, Treisman, & Savoy, 1997) and peripheral vision (Clavagnier, Prado, Kennedy, & Perenin, 2007; Prado et al., 2005) are more frequently mediated by the dorsal than by the ventral visual stream, the above results indicate that visual functions in the dorsal stream seem to be more susceptible to plastic changes induced by early deafness than visual functions in the ventral stream (Bavelier et al., 2001; Bavelier & Neville, 2002; but see Lomber, Meredith, & Kral, 2010 in non-human subjects). And, selective attention may enhance the likelihood to observe the modifications in the dorsal visual functions. It remains unknown, however, whether selective attention is a driving factor or simply a consequence of the neural plasticity (Bavelier & Neville, 2002). As we introduced above, since allocentric processing involves the ventral visual stream while egocentric processing involves the dorsal visual stream, we intended to explore, in the present study, whether allocentric or egocentric reference frame is more easily altered by early deafness, as compared to normal hearing individuals. Moreover, we also aimed to investigate whether the pattern of mutual influences between the two reference frames is altered after early deafness.

In order to investigate the potential interaction between the two spatial reference frames, we orthogonally manipulated the egocentric and the allocentric positions of an object (Fig. 1, see Methods of Experiment 1), and asked participants to perform either egocentric or allocentric judgments on the same stimulus set. Thus, target positions with regard to one of the spatial reference frames (either egocentric or allocentric) were task-relevant while target positions with regard to the other reference frame were task-irrelevant. We used the spatial congruency effect between the allocentric and egocentric positions to indicate whether an object is simultaneously coded relative to both the egocentric and the allocentric reference frames, and whether the allocentric and egocentric representations interact with each other. Specifically speaking, in trials when participants were instructed to judge the egocentric position of an object, if the task-irrelevant allocentric position of the object was also processed in the brain

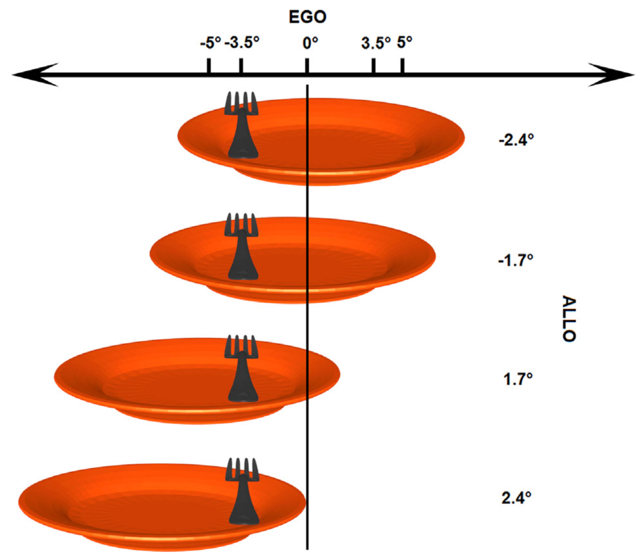

Fig. 1. Stimuli used in the study. In Experiment 1, the visual stimuli consisted of a fork intersecting an orange plate. Participants were asked to judge the position of the fork with reference either to the plate or to their midsagittal plane. The fork could appear at one of four egocentric positions. For each of the four egocentric locations of the fork (-5°, -3.5°, 3.5°, 5°), the location of the plate was varied independently around the fork, forming 4 possible allocentric positions (-2.4°, -1.7°, 1.7°, 2.4°). The vertical black line indicates the invisible midsagittal line. In Experiment 3a, the same target stimuli were presented, but the visual angles of the allocentric and egocentric positions were changed (see Methods of Experiment 3).

and interacted with the egocentric judgment, a significant facilitation/interference effect from the irrelevant allocentric representations should be observed, depending on whether the irrelevant allocentric position was congruent (both left or both right) or incongruent (one left and one right) with the task-relevant egocentric position. On the other hand, in trials when participants were asked to judge the allocentric position of an object, if the task-irrelevant egocentric position of the object was also coded in the brain and interacted with the allocentric judgment, a significant facilitation/interference effect from the irrelevant egocentric representation should be observed, again depending on whether the task-irrelevant egocentric position was congruent or incongruent with the task-relevant allocentric position. Furthermore, if allocentric and egocentric representations influence each other in a different way, differential effect sizes of the spatial congruency effect should be observed between egocentric and allocentric tasks.

Thereby, in the present experiment, performance of hearing and deaf participants was compared under either egocentric or allocentric conditions, with the allocentric and egocentric position of the target being either congruent or incongruent. By adopting this design, we could investigate the following three questions: (1) in the normal hearing brain, whether the allocentric and egocentric reference frames are two dissociable systems in parallel or two interacting systems; (2) whether the allocentric and egocentric reference frames are altered after early deafness; (3) whether the potential interaction between the two reference frames is also altered after early deafness.

2. Experiment 1

2.1. Method

2.1.1. Participants

Twenty normal hearing participants (14 female and 6 male, 21 ± 2.5 years old) and seventeen congenitally and genetically deaf participants (11 male and 6 female, 20 ± 1.5 years) from School for the Deaf, Guangzhou, China, participated in the present study. All the deaf participants had a binaural hearing loss of >90 dB, and they were exposed to and acquired Chinese sign language as a first language from