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Manipulation of visual information does not change the accuracy of distance estimation during a blindfolded walking task

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While humans rely on vision during navigation, they are also competent at navigating non-visually. However, non-visual navigation over large distances is not very accurate and can accumulate error. Currently, it is unclear whether this accumulation of error is due to the visual estimate of the distance or to the locomotor production of the distance. In a series of experiments, using a blindfolded walking test, we examine whether enhancing the visual estimate of the distance to a previously seen target, through environmental enrichment, visual imagery, or repeated exposure would improve the accuracy of blindfold navigation across different distances. We also attempt to decrease the visual estimate in order to see if the opposite effect would occur. Our results would indicate that manipulation of the static visual distance estimate did not change the navigation accuracy to any great extent. The only condition that improved accuracy was repeated exposure to the environment through practice. These results suggest that error observed during blindfold navigation may be due to the locomotor production of the distance, rather than the visual process.

1. Introduction

Humans are constantly on the move, finding their way to specific locations in the environment. To reach a target both visual and non-visual sources of information can potentially be used. Visual

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information consists of static and dynamic cues (Sun, Campos, Young, Chan, & Ellard, 2004). Static visual cues can include retinal image size, texture, gradient and binocular disparity (Foley, 1980). Dynamic cues include retinal information generated by the observer's self-motion (optic flow) (Gibson, 1950; Lee, 1980; Sun, Carey, & Goodale, 1992; Warren & Hannon, 1990), as well as the motion of objects in the environment (Regan & Hamstra, 1993; Sun & Frost, 1998). Humans are also quite competent at navigating to a target without visual input. Non-visual inputs are internally generated as a result of one's body movements (Chance, Gaunet, Beall, & Loomis, 1998; Mittelstaedt & Mittelstaedt, 2001). This source of information, often referred to as 'idiothetic information' is provided by muscles and joints, motor efferent signals and vestibular information generated as a result of changes in linear or rotational movement velocities (Tversky, 2000).

Having the ability to update one's current position along a tract (path Integration) is essential for an organism to estimate how far it has travelled and how far it has to go. While a number of studies have demonstrated that visual information (via optic flow) can be used to accurately estimate and reproduce traversed distances (Bremmer & Lappe, 1999; Redlick, Jenkin, & Harris, 2001), a number of studies comparing blind, blindfolded and/or sighted participants have shown that spatial competence does not necessarily depend on prior visual experience (e.g., Loomis et al., 1993). Indeed, there have been a number of studies that have shown that idiothetic information alone is quite effective at monitoring distances (see Bigel & Ellard, 2000).

One of the first studies to demonstrate that distance estimation depends on idiothetic information was conducted by Thomson in 1983 by using the blind walking task. This task required participants to view a target briefly in the distance, typically from between 3 and 22 m away, close their eyes and walk without vision to where they felt the target was located. He found that 'equally impressive is the extent to which excluding vision does not interfere with performance, especially over the earlier parts of an act' (Thomson, 1983, p. 427). His findings suggested that participants were accurate whether vision was available to them or not. His findings also suggested that precision broke down in the region of 9–12 m, which he attributed to a fading of internalized information about the target's position (occurring after a certain time period $\sim$8 s) rather than inadequate distance information.

While many studies have shown, similar to Thomson, that blindfolded humans are able to navigate relatively successfully towards a target, his suggestion of a time limiting component has not been replicated (Fukusima, Loomis, & Da Silva, 1997; Rieser, Ashmead, Talor, & Youngquist, 1990), with many authors finding that participants become less accurate in their estimation if the distance is increased (Corlett, Patla, & Williams, 1985; Fukusima et al., 1997; Glasauer, Amorim, Vitte, & Berthoz, 1994; Loomis, Da Silva, Fujita, & Fukusima, 1992; Mittelstaedt & Mittelstaedt, 2001; Rieser et al., 1990; Steenhuis & Goodale, 1988). Indeed, there is good evidence to suggest that other factors apart from time can contribute to successful non-visual distance estimation. Such factors include step frequency (Durgin, Akagi, Gallistel, & Haiken, 2009; Durgin & Gigone, 2007), walking velocity (Mittelstaedt & Mittelstaedt, 2001) and stored velocity profiles (Berthoz, Israël, Georges-François, Grasso, & Tsuzuku, 1995). As well as locomotor information, different cognitive factors, including task demands (Ellard & Shaughnessy, 2003) and confidence (Philbeck, Woods, Arthur, & Todd, 2008) may also play a role.

If we accept the idea that people, when navigating non-visually, become less accurate as they walk greater distances, then this suggests that there is a gradual breakdown in the representation of distance. One possibility that might offer an explanation for this is the leaky integrator model (Lappe, Jenkin, & Harris, 2007). According to this model, as the distance increases in proportion to movement, there is a decay in the integrated distance value over the length of movement. In the model there is a 'gain' component that determines how much a specific movement adds to the integrated distance value (Lappe & Frenz, 2009) and a 'leak rate' which determines how much the integrated distance value decays over distance length. The nice thing about this model is that it allows for the possibility of different gains. For example, there may be separate gains for visual, vestibular and proprioceptive inputs (Lappe & Frenz, 2009). It may be possible that manipulation of the gain on any of these inputs may change the accuracy of performance. Sun et al. (2004), for example, have shown that distance estimation varied depending on the cues available and the combination of cues (e.g., vision vs vision + locomotion vs blindfold walking) suggesting that different gains may correspond to different sensory cues. While the Lappe et al. model refers to a dynamic visual gain, that is, visual gain obtained during sighted walking (especially optic flow), we ask whether the visual representation of distance,