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Review article

From science to technology: Orientation and mobility in blind children and adults

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ABSTRACT

The last quarter of a century has seen a dramatic rise of interest in the development of technological solutions for visually impaired people. However, despite the presence of many devices, user acceptance is low. Not only are visually impaired adults not using these devices but they are also too complex for children. The majority of these devices have been developed without considering either the brain mechanisms underlying the deficit or the natural ability of the brain to process information. Most of them use complex feedback systems and overwhelm sensory, attentional and memory capacities. Here we review the neuroscientific studies on orientation and mobility in visually impaired adults and children and present the technological devices developed so far to improve locomotion skills. We also discuss how we think these solutions could be improved. We hope that this paper may be of interest to neuroscientists and technologists and it will provide a common background to develop new science-driven technology, more accepted by visually impaired adults and suitable for children with visual disabilities.

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1. Introduction

The field of human locomotion has grown steadily over the past few decades (Andriacchi and Alexander, 2000; Bruijn et al., 2012; Glasauer et al., 2009). When we move through the environment our main goal is that of being able to find our own way, i.e. achieving good spatial navigation (Long and Giudice, 2010; VandenBos, 2013). Advances in our understanding of how the brain processes navigational skills have been attained by means of neurophysiological, psychophysical, neuropsychological, neuroimaging, and computational modeling studies. The principles that subtend human spatial navigation are now starting to become clearer. It is now evident, for example, that the human brain makes use of egocentric or allocentric coordinates to obtain different perspectives of the environment (Avraamides et al., 2004) that are comprised of amodal spatial representations of the surroundings, i.e. representations that do not necessarily maintain specific properties of the modality through which the signal is transmitted, which can therefore be used to accomplish successful spatial navigation (Loomis et al., 2013). Similarly, the development of locomotor abilities is now more clearly elucidated (Uchiyama et al., 2008). Locomotion, for example, seems to play an important role in the genesis of psychological changes (Anderson et al., 2013). One aspect which has received relatively less attention from the research community is how locomotion is processed and learned in children and adults with visual impairments. Visual information is fundamental for spatial processing and its absence directly impacts on the development of locomotion skills. Supporting this idea, various studies in visually impaired people have demonstrated that the absence of vision impacts on locomotor skills (e.g. (Nakamura, 1997; Rieser et al., 1986)). Understanding how these skills develop in individuals with visual impairments would provide significant benefits in the development of rehabilitation and sensory substitution systems. In the context of visual disability, orientation and mobility indicate different properties of human locomotion and exploration of environments. Orientation refers to the ability of understanding the spatial properties of an environment and being aware of one's position and its relationship with the surroundings; on the other hand, mobility indicates the capability of efficiently and safely moving in an environment (e.g. in a city by using public transport) unaccompanied (Giudice and Legge, 2008; Novi, 1998; Soong et al., 2001). Over the past decade, many groups have developed technological solutions to improve these skills in people with visual disabilities. However, only a small part of this technology is actually accepted and used by the visually impaired population. In this review we provide an overview of some of the most important factors of locomotor ability in children and adults, both with and without visual disabilities. We also provide a review of the most popular devices developed for improving spatial navigation in people with visual impairments. Our goal is to stress the importance of creating a link between scientific studies and the development of technology, in order to produce devices that are accepted by the users. Most of the technology developed to date, for example, does not take into consideration the needs of visually impaired people and provides information that is neither useful nor immediately understandable. In addition, these devices are usually tested only on small samples of visually impaired people and usually the efficacy is evaluated only in a qualitative manner. Moreover, differences depending on the visual impairment onset have been largely ignored. Many quantitative studies, carried out by neuroscientists, provide important information about how our brain processes sensorimotor signals for orientation and mobility. We believe that these studies could provide important information for the development and testing of new technological solutions. We hope that this review will stimulate neuroscientists and technology researchers to carefully consider the contribution that each discipline can provide to each other, with the goal of improving the quality of life of visually impaired individuals. In addition, we hope that this review will provide a stimulus for neuroscientists to start a wider investigation into the development of locomotor skills in children with visual impairments.

Firstly, we will discuss orientation and mobility skills in adults with and without disabilities. A distinction can be made between the role that multisensory and sensorimotor signals have in people with and without disabilities. For example, it is now evident that, compared to sighted people, visually impaired individuals make different use of auditory, haptic and vestibular cues to perform efficient walking. We will then present a list of the technological devices for supporting orientation and mobility in visually impaired adults. The devices are subdivided into two categories: technological canes and robots for locomotion; we will discuss the positive and negative aspects of both categories, presenting the technological features of the solutions developed so far.

Following this, we will discuss the development of locomotor skills in children with and without disabilities. We will stress how locomotion plays a crucial role in the genesis of psychological changes and how a delay in locomotion development can impact on cognitive spatial and social skills of the visually impaired child (Anderson et al., 2013; Piaget, 1952a,b; Uchiyama et al., 2008). Finally, we will present the few devices which have been developed for children so far. These can be described as pre-canes, virtual games and advanced tools. At the end of the review we will discuss the course which we believe should be followed to develop systems that may be better accepted by visually impaired adults and that are more suitable for younger users.

2. Orientation and mobility skills in adults with and without visual disability

When navigating through space, our brain takes advantage of mental representations based on sensory signals that provide information about how our movement is accomplished in relation to our surroundings (e.g. visual, auditory) or absolutely in space (e.g. vestibular and proprioceptive). The use of egocentric or allocentric coordinates gives rise to either "route" or "survey" representations. The former is based on the observer's viewpoint whereas the latter assumes a map-like perspective where the observer is aware of the spatial relationship between elements of the surroundings, thus used as references. Following this nomenclature, spatial navigation can be differentiated in either route or inferential, which respectively rely on egocentric and allocentric coordinates (Loomis et al., 1993; Schmidt et al., 2013; Thinus-Blanc and Gaunet, 1997). Route navigation is mostly well accomplished by blind people, as they can rely on kinematic strategies relative to experienced movement by using an idiothetic reference. On the other hand, research on inferential navigation in blind individuals has provided inconsistent results, showing impaired performance (Herman et al., 1983; Rieser et al., 1986; Thinus-Blanc and Gaunet, 1997; Veraart and Wanet-Defalque, 1987). In these cases, the task requires complex inferential processes (e.g. to provide spatial links between previously explored locations) and early blind individuals show more errors than late blind and sighted individuals (Rieser et al., 1986). However, comparable performance of blind subjects compared to sighted individuals has been found in similar tasks (Thinus-Blanc and Gaunet, 1997) and some studies showed better performance in survey spatial cognition tasks (Tinti et al., 2006); for recent reviews see (Long and Giudice, 2010; Schinazi et al., 2016) Moreover, although studies focusing on spatial memory (e.g. triangle completion task) did not provide consistent differences between sighted and non-sighted individuals (Klatzky et al., 1997, 1990; Loomis et al., 1993; Thinus-Blanc and Gaunet, 1997), such tasks