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Dynamic clearance measure to evaluate locomotor and perceptuo-motor strategies used for obstacle circumvention in a virtual environment

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ABSTRACT

Circumvention around an obstacle entails a dynamic interaction with the obstacle to maintain a safe clearance. We used a novel mathematical interpolation method based on the modified Shepard's method of Inverse Distance Weighting to compute dynamic clearance that reflected this interaction as well as minimal clearance. This proof-of-principle study included seven young healthy, four post-stroke and four healthy age-matched individuals. A virtual environment designed to assess obstacle circumvention was used to administer a locomotor (walking) and a perceptuo-motor (navigation with a joystick) task. In both tasks, participants were asked to navigate towards a target while avoiding collision with a moving obstacle that approached from either head-on, or 30° left or right. Among young individuals, dynamic clearance did not differ significantly between obstacle approach directions in both tasks. Post-stroke individuals maintained larger and smaller dynamic clearance during the locomotor and the perceptuo-motor task respectively as compared to age-matched controls. Dynamic clearance was larger than minimal distance from the obstacle irrespective of the group, task and obstacle approach direction. Also, in contrast to minimal distance, dynamic clearance can respond

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differently to different avoidance behaviors. Such a measure can be beneficial in contrasting obstacle avoidance behaviors in different populations with mobility problems.

1. Introduction

Community ambulation entails dealing regularly with dynamic obstacles (people, small vehicles, etc.) (Musselmen et al., 2007; Shumway-Cook et al., 2010). Safe navigation around these can be achieved by making speed and/or directional changes while walking. Adequate sensory, motor and cognitive abilities are required to judge obstacle motion and impending collision (if any) and to plan, execute and modify avoidance strategies. Deficits in one or all of these capabilities, as often seen in people with stroke, may result in increased risk of collisions and consequent falls and injuries. Although the safety implications with regard to obstacles are very important for community ambulation post stroke, there is little research investigating obstacle circumvention in post-stroke individuals, particularly those without visuospatial neglect.

The dynamic interaction between the obstacle and the participant arises from the participants' attempts to escape collision by maintaining a safe clearance distance from the obstacle. The smallest instantaneous clearance distance from the obstacle, used in some studies (Cinelli & Patla, 2007; Fait, McFadyen, Swaine, & Cantin, 2009; Gerin-Lajoie, Richards, & McFadyen, 2005; Hackney, van Ruymbeke, Bryden, & Cinelli, 2014; Vallis & McFadyen, 2003) as an outcome measure, provides some information about this safe clearance. However, it provides a glimpse of the clearance maintained at one critical event (that of passing the obstacle) and not the clearance distance maintained throughout the strategy, which is of particular interest to us. Alternatively, clearance throughout the strategy can be obtained by simply averaging the instantaneous distances between obstacle and the individual or by using measures such as personal space (Gérin-Lajoie et al., 2005) that define the contours of an avoidance strategy, expressed as an elliptical area centered on the individual. However, these measures do not take into account the minimum clearance from the obstacle. It was thus necessary to use a measure that reflected minimal clearance while simultaneously taking into account the entire avoidance strategy. To that end, we have utilized a novel outcome based on the modified form of Shepard's method of Inverse Distance Weighting (IDW) (Franke & Nielson, 1980; Renka, 1988; Shepard, 1968) to quantify clearance over the entire circumvention strategy that is centered on the minimum clearance.

In rehabilitation, virtual reality (VR) technology can be used to evaluate and train obstacle circumvention by manipulating moving obstacles and simulating the encounter in a precise, safe and controlled manner. We have devised a virtual environment (VE) to evaluate obstacle circumvention that can be examined during walking or with joystick navigation in the sitting position (previously described in Darekar, Aravind, Lamontagne, & Fung, 2011). The VE corresponds to or simulates self-motion through the virtual scene while encountering moving obstacles approaching from different directions. The joystick navigation task was added to help reveal the underlying perceptuo-motor strategies involved in obstacle circumvention by minimizing the effect of biomechanical constraints imposed by walking. This is particularly relevant for the post-stroke population where biomechanical constraints imposed on the paretic hemi-body could influence circumvention to a greater extent. Addition of the sitting joystick navigation task may help gauge the relative contribution of cognitive-perceptual deficits in shaping obstacle avoidance strategies. We have thus, in this study, used a VE to assess two moving obstacle circumvention tasks – a locomotor task and a perceptuo-motor (navigation with a joystick) task, with the primary intent to evaluate the use of modified IDW to quantify dynamic clearance.

The primary objectives of this study were: (1) to evaluate the use of a novel mathematical interpolation method to calculate dynamic clearance on a group of young healthy participants; and (2) to