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Perceptual and navigational strategies for obstacle circumvention in a virtual environment

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Abstract— **The ability to accurately judge distance and time to collision is an important perceptual determinant in shaping obstacle circumvention strategies for functional locomotion. In addition, deficits in planning and execution, as well as biomechanical constraints imposed by age or neurological insult may lead to avoidance failure in this population. We have designed a closed system in sitting displaying self motion through a virtual environment to evaluate perceptual and navigational strategies for obstacle circumvention. In a pilot study involving six healthy young subjects and one older participant, all subjects perceived collision with a moving obstacle to have occurred almost a meter before the actual collision would have taken place. The older participant consistently under-estimated the distance of collision to a larger extent as compared to the young subjects. In the navigation task using a joystick, the older individual initiated medio-lateral deviations later than the younger individuals. The clearance distance was also observed to be smaller for the older participant thus increasing the risk of collision. Deficits in depth perception as well as motor planning may contribute to increased errors. However, rehabilitation interventions that use VR can be utilized to improve perceptual and planning abilities, such that efficacious avoidance strategies can be facilitated. Moreover, further testing of locomotion in environments may help devise novel interventions for promoting ambulation.**

Keywords-virtual reality, visuo-spatial perception, navigation, locomotion, rehabilitation

I. INTRODUCTION

Community ambulation involves navigating in complex and dynamic outdoor environments. This requires dealing with various environmental features while simultaneously carrying out other tasks. Shumway-Cook et al. [1] proposed eight dimensions or categories of environmental features that impact mobility in the community. These represent several external demands imposed by the environment that need to be met in order to navigate successfully in the community and comprise of distance, time, ambient conditions (light, weather etc.), terrain characteristics, physical load, attentional demands, postural transitions and traffic level. Traffic level and attentional demands are of particular interest as these situations are unavoidable when navigating in the community. Traffic level entails the number of people and objects in the path and involves navigating around them to avoid collisions while attentional demands entail performing the above mentioned tasks while paying attention to other environmental features and the goal. These complex tasks place considerable demands on the sensorimotor and cognitive systems and may require a higher functional capacity.

Older individuals and people with neurological deficits are often restricted in community ambulation [2,3]. They are also known to avoid tasks or features in the environment that may be difficult to perform or negotiate [4,5]. However, an encounter with obstacles in the path is almost unavoidable during community ambulation and is thus encountered frequently by community-dwelling older adults [4,5].

Accurate judgment of the time and distance to obstacle collision is an important perceptual determinant in avoiding collision with a moving obstacle. Impairment in such perception, as well as any deficits in planning navigation strategies along with biomechanical constraints imposed by age or a neurological insult may impact on the implementation of successful avoidance strategies. Deficits in planning and execution may manifest in subsequent collisions, falls and trauma. It is therefore necessary to investigate the perceptual and biomechanical determinants that may be influential in shaping obstacle avoidance strategies in these populations, which may then be used to devise efficacious intervention to facilitate successful obstacle circumvention strategies.

Virtual reality (VR) can be used to evaluate and train functional ambulation by manipulating moving obstacles and simulating the encounter in a precise, safe and controlled manner. We have devised a closed VR system in sitting displaying self motion through a virtual environment (VE) and encountering obstacles approaching from different directions. This system was used to evaluate visuo-perceptual parameters and navigation strategies with a joystick. Preliminary reports from six healthy and one old participant are reported in subsequent sections.

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II. METHODS

A. Participants

Participants included six healthy young subjects (age: 31.57 ± 10.07 years, gait speed: 1.27 ± 0.14 m/s) and one older individual (age: 73 years, gait speed: 1.37 m/s). All participants had normal or corrected-to-normal vision and did not report any visual field deficits. An informed consent was obtained for their participation in the experiments. Individual subject's comfortable gait speed was recorded using the 10-m walk test and was later used to program the speed of self motion through the VE.

B. Virtual Environment

The virtual environment (VE) was designed to evaluate the participants' ability to perceive the time and distance of potential collisions with the moving obstacle (experiment A) and their ability to circumvent the moving obstacles with a joystick (experiment B). The experiments utilized similar virtual environments consisting of a rich-texture room scaled to physical dimensions of the laboratory (11m x 7m). A blue-colored target was visible at eye-level on the far-end of the virtual room. Three red cylindrical obstacles with height and diameter approximating the height and shoulder width of each participant were used as obstacles. The obstacles were located at three positions (straight-ahead and 30° degrees left and right) in an arc of radius 3.5m and were visible at the initiation of each trial along with the blue target (Fig. 1). The VE was created using the CAREN (Computer Assisted REhabilitation ENvironments, Motek, BV) software and was viewed through a helmet-mounted display (HMD, NVsior, field-of-view 60° and screen resolution 1280x1084 pixels). The HMD provided stereoscopic view of the room. The VE display was optimized for each participant by adjusting the eye separation and focal point such that appropriate stereoscopic view of the HMD was provided. Both experiments A and B consisted of 7 blocks of 9 trials (in addition to a practice block) each and involved movement of the cylindrical obstacles from straight ahead (middle) and left and right approach directions. The obstacles were programmed such that they would move at a speed equal to each participant's comfortable gait speed and intersect at the center of the arc designated as the theoretical point of collision (TPC), as a collision would occur without interception.

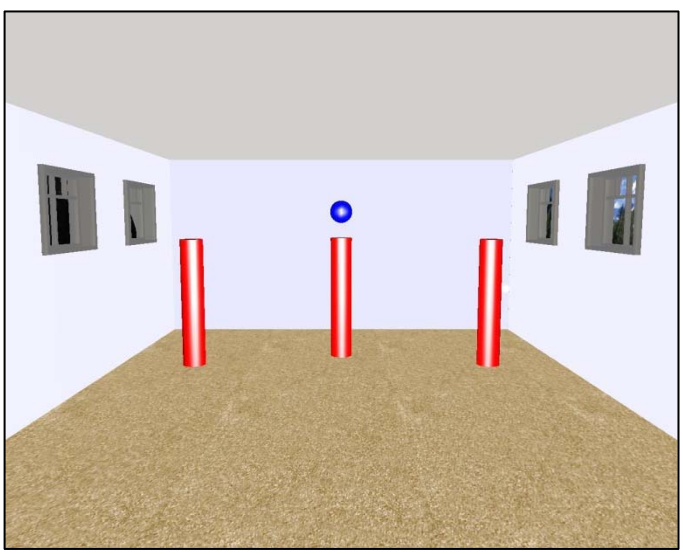

Figure 1. VE display as seen in the HMD

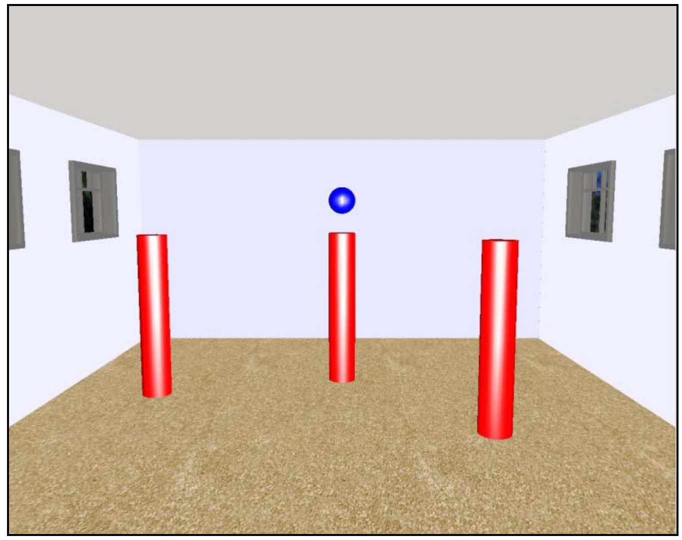

Figure 2. Example of obstacle approach (right approach direction)

C. Experiment A- estimation of point of collision

Subjects were seated placing their hands on a joystick placed on a table placed at comfortable height for the participant while wearing the HMD displaying the VE. During each trial, one of the three randomly selected obstacles approached the participant at the same speed as they virtually advanced in the VE (both speeds matched the participants' comfortable overground walking speed, Fig.2). As the moving obstacle progressed towards the pre-determined TPC, it disappeared at a distance of 2 m before the TPC while the participants continued to advance in the VE. Participants were required to click a button on the joystick when they reached the spatial point at which they perceived a potential collision with the invisible obstacle. The distance between the TPC and spatial position of the button click was used to measure any *error in distance estimation*. If the participants clicked at the TPC, the error would be zero. Any clicking occurring before or after the TPC would result in negative or positive errors, respectively.

D. Experiment B – navigation around obstacles

In experiment B, the randomly selected obstacle approached the participants as in experiment A, but they did not disappear. The participants were required to navigate around the obstacle by moving the joystick in the medio-lateral (ML) direction or forward/backward to accelerate/decelerate respectively in order to avoid a collision. The participants were allowed to use any of the above strategies and could move either to the left or to the right to avoid collision. The onset of the ML movement and subsequent ML movement were used to obtain the following outcomes -

1) Distance from TPC and time required to reach TPC at onset – the distance between the TPC and the point at which ML deviation was initiated was acquired (Fig. 3). The time required to then reach the TPC from the point of onset was also calculated.

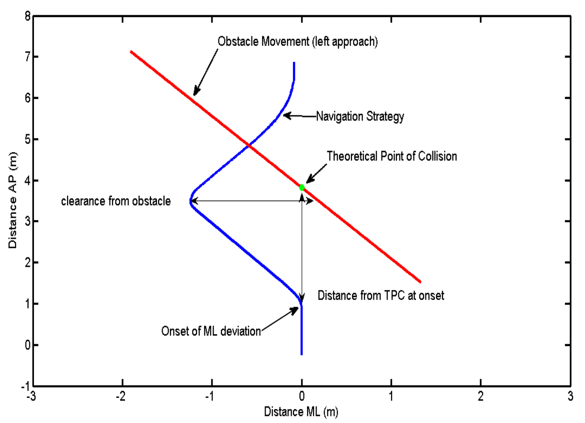

Figure 3. Example of a navigation strategy and outcome measures

2) Distance from the obstacle at the time of onset - the absolute distance of the participant in the VE from the obstacle at the point of onset of strategy was obtained.

3) Obstacle clearance – the distance from the point of maximum ML deviation relative to the TPC and the obstacle (Fig. 3) was obtained to measure obstacle clearance.

III. RESULTS AND DISCUSSION

A. Error in distance estimation

All participants under-estimated the point of potential collision in experiment A, regardless of the direction of obstacle approach (Fig. 4). Younger subjects perceived collision to have taken place almost a meter before the actual collision would have occurred (average of 0.78 ± 0.02m). However, the older subject demonstrated an average error of 1.13 ± 0.18m for all approaching directions.

B. Distance from TPC and time required to reach TPC at onset

The spatial perception of point of collision provides a judgment of a distance margin required to avoid a collision with the obstacle and would therefore be reflected in the initiation of avoidance strategies (ML deviation in this case).

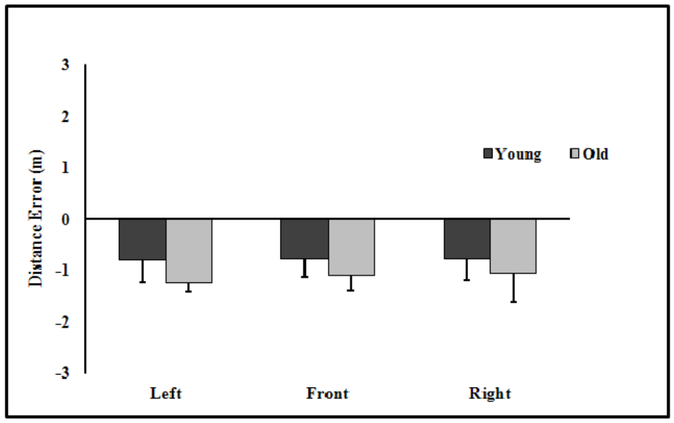

Figure 4. Error in collision point estimation

Young subjects initiated ML deviations at larger distances (2.93 ± 0.22m,2.94±0.29m and 2.94± 0.19m) to avoid colliding with obstacles approaching from the left and right and straight ahead (respectively). As in young subjects, the older subject initiated ML deviations at similar distance from TPC (Fig. 5; 2.58± 0.54m, 2.37±1.05 and 2.33± 0.56m for left, middle and right approaching obstacles respectively). However, the ML deviations in the older subjects were initiated at a smaller distance from the TPC as compared to the younger subjects. Thus, although the perceived safe distance to avoid collision may be larger in older participants, it may not translate into the action of maintaining larger margins during navigation.

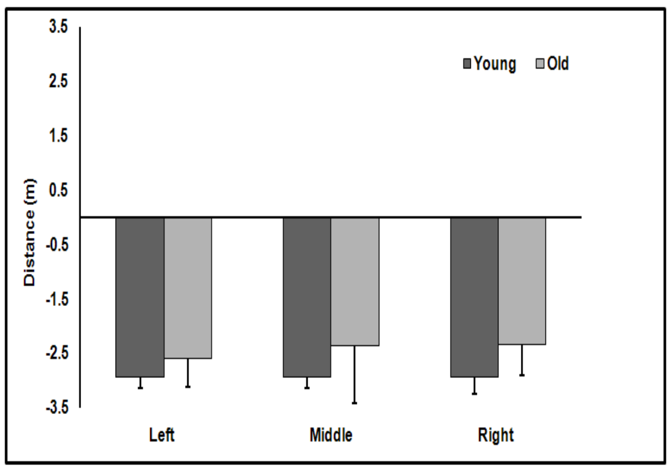

Figure 5. Distance from TPC at onset of strategy

Younger subjects also initiated ML deviations earlier than the older participant to avoid obstacle collision, regardless of approaching directions, at an average of 2.67 ± 0.99 s from TPC. The older subject not only initiated the ML deviations later but also showed preference for the approach direction. ML deviation was initiated later for the obstacle approaching from straight ahead (1.85±0.32s) or right (1.7±0.41s) as compared to the left (2.03±0.86s) (Fig. 6). This allows for lesser time to execute an avoidance strategy and thus increases the risk of collisions with obstacles.

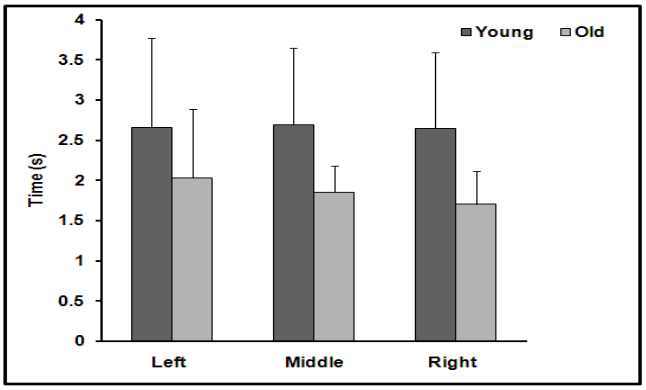

Figure 6. Time to reach TPC at onset of strategy

C. Obstacle Clearance

The clearance distance is an important spatial determinant in avoiding obstacle collision. Larger ML clearance will be required for the middle (straight-ahead) approach as compared

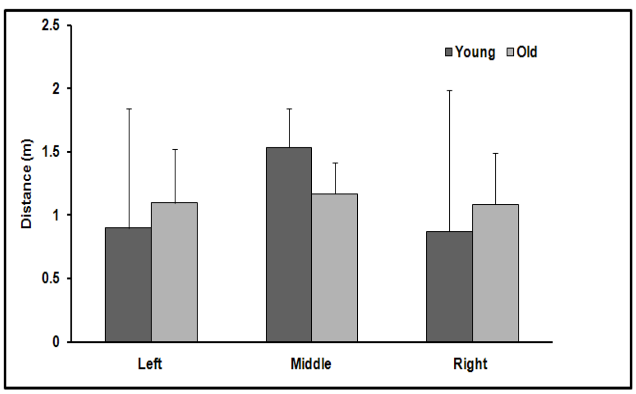

Figure 7. ML clearance from TPC

to the right and left approaches, since ML deviation alone would be needed to avoid collision with an obstacle approaching head-on. In contrast, for diagonally approaching obstacles, a change in speed may be a more appropriate strategy for avoidance. All subjects in this study used ML deviations for all approach directions. However, young subjects maintained a slightly larger clearance distance relative to the TPC to avoid the obstacle approaching straight ahead (1.53±0.31m) as compared to that approaching from the left (0.9±0.94m) and the right (0.87±1.11m). The older subject also maintained a slightly larger clearance distance straight ahead (1.17±0.24m) as compared to the left (1.09±0.42m) and the right (1.09±0.41m) obstacle approach directions. However, a larger clearance distance was maintained to avoid the obstacle approaching diagonally than straight ahead (Fig. 7), which was in contrast to the healthy subjects.

Maintenance of a sufficient clearance from the obstacle is an important requirement for avoidance of collision. Younger subjects demonstrated larger clearance distances from the obstacle as opposed to the older subject. Within approach directions, a larger clearance was maintained for the obstacles approaching from the left (1.56±0.42m) and right (1.27±0.44m) as compared to straight ahead (1.38±0.32m). In contrast, clearance distances maintained by the older subject were smaller for the left (1.2±0.38m), straight ahead (1.14±0.22m) and the right (1.27±0.44m) respectively (Fig. 8). This is in contrast to reports of larger clearance distances observed in older participants in other studies [6]. One of the reasons for the smaller clearance distances observed in the older adult might be the side to which the ML deviation was employed.

The side to which a strategy is executed (left or right) determines the extent of ML deviation required to circumvent an obstacle. For instance, if an ML deviation to the right is employed to avoid an obstacle approaching diagonally from the right, a larger ML deviation would be required to avoid a collision as opposed to a leftward deviation which would effectively place a person away from the obstacle trajectory. The older subject consistently executed ML deviations to the same side as the obstacle approach (about 90% of the trials) as compared to younger subject who largely executed ML

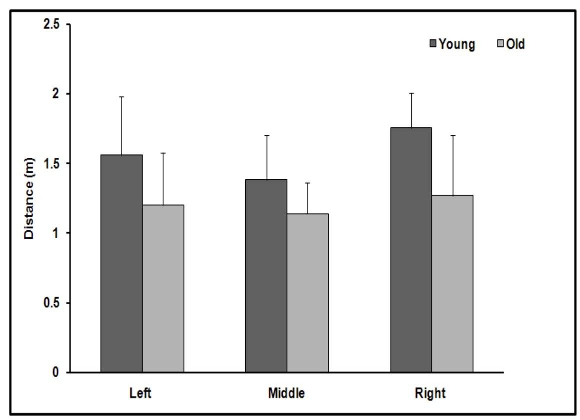

Figure 8. ML clearance from obstacle

deviations to the side opposite to the obstacle approach (in 95% of the trials).An example of the strategy employed by the older subject is shown in Fig. 9.

A larger ML deviation was thus necessary to execute a successful circumvention. In addition, these deviations needed to be executed in a shorter time given that the strategy was initiated later in the older participant. These factors increased the risk of collisions with the obstacle. In fact, the older participant encountered collision with the obstacle at least thrice during the experimental trials and more during the practice trials. Despite the presence of habituation trials, it

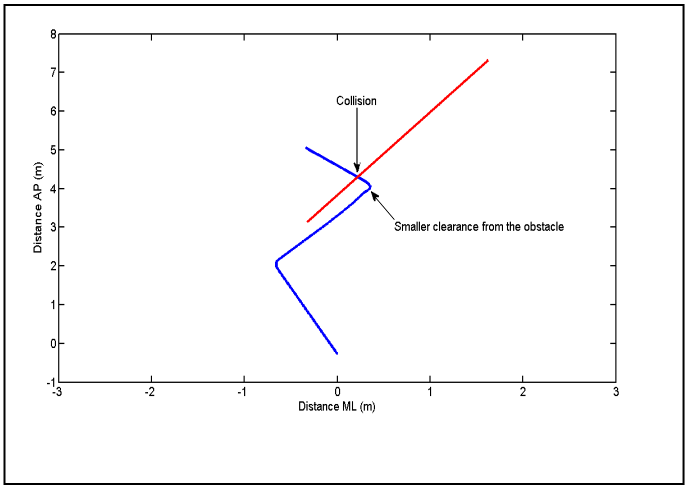

Figure 9. Obstacle circumvention strategy employed by the older subject in a collision trial

cannot be excluded that the novelty of the joystick task for the older subjects has contributed to their altered performance. Joystick navigation may have caused an increased cognitive load and thus may have increased the likelihood of collisions. This is consistent with walking studies where divided attention was shown to lead to an increased likelihood of bumping into obstacles [7,8].

The older subject thus demonstrated at-risk behavior for collisions in the navigation task as compared to the younger subjects. The older participant initiated obstacle circumvention later and maintained smaller safety margins as well as choosing to navigate in the same direction as the approaching obstacle. Whether this behavior is also seen during a walking task would be an important step in understanding the perceptual and biomechanical determinants of obstacle circumvention necessary for functional ambulation.

A learning effect was also observed in the older subject as she became more efficient in the avoidance tasks with practice. The participant learned that initiating an ML deviation in the opposite direction earned success and therefore utilized that strategy in the later trials in experiment B. This suggests that efficient avoidance strategies can be trained in populations at risk of collisions with obstacles.

Rehabilitation interventions can thus be designed to help train individuals at risk, such as older individuals and persons with stroke, to employ successful circumvention strategies and to avoid collisions during community ambulation.

IV. CONCLUSION

VR can be used to test perceptual and navigation strategies used in obstacle circumvention in young and older individuals. All participants under-estimate the potential point of collision, however older individuals may under-estimate the perceived point of collision to a larger extent. Older individuals initiate ML deviations closer to the obstacles and at a later time. Also, smaller clearances from the obstacle are maintained. Older participants thus show deficits in planning and execution of avoidance strategies during obstacle circumvention in a VE, which may reflect as an increased likelihood of collision events while walking in the community. Rehabilitation interventions need to be designed to facilitate efficient circumvention in at-risk groups such as older adults and patient with stroke.

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