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REHAB-1088; No. of Pages 10
ARTICLE IN PRESS
Annals of Physical and Rehabilitation Medicine xxx (2017) xxx–xxx
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Original article

Effect of visuospatial neglect on spatial navigation and heading after stroke

Gayatri Aravind [a,b,*], Anouk Lamontagne [a,b]

[a] School of Physical & Occupational Therapy, McGill University, H3G 1Y5 Montreal, QC, Canada
[b] Feil and Oberfeld Research Centre, Jewish Rehabilitation Hospital, Research site of CRIR, 3205, place Alton Goldbloom, H7V 1R Laval, QC, Canada

ARTICLE INFO

Article history:
Received 24 January 2017
Accepted 8 May 2017

Keywords:
Visual neglect
Cerebrovascular accident
Steering
Obstacle circumvention
Virtual Reality

ABSTRACT

Background: Visuospatial neglect (VSN) impairs the control of locomotor heading in post-stroke individuals, which may affect their ability to safely avoid moving objects while walking.
Objective: We aimed to compare VSN+ and VSN− stroke individuals in terms of changes in heading and head orientation in space while avoiding obstacles approaching from different directions and reorienting toward the final target.
Methods: Stroke participants with VSN (VSN +) and without VSN (VSN−) walked in a virtual environment avoiding obstacles that approached contralesionally, head-on or ipsilesionally. Measures of obstacle avoidance (onset-of-heading change, maximum mediolateral deviation) and target alignment (heading and head-rotation errors with respect to target) were compared across groups and obstacle directions.
Results: In total, 26 participants with right-hemisphere stroke participated (13 VSN+ and 13 VSN−; 24 males; mean age 60.3 years, range 48 to 72 years). A larger proportion of VSN+ (75%) than VSN− (38%) participants collided with contralesional and head-on obstacles. For VSN− participants, deviating to the same-side, as the obstacle was a safe strategy to avoid diagonal obstacles and deviating to the opposite-side led to occasional collisions. VSN+ participants deviated ipsilesionally, displaying same-side and opposite-side strategies for ipsilesional and contralesional obstacles, respectively. Overall, VSN+ participants showed greater distances at onset-of-heading change, smaller maximum mediolateral deviation and larger errors in target alignment as compared with VSN− participants.
Conclusion: The ipsilesional bias arising from VSN influences the modulation of heading in response to obstacles and, along with the adoption of the “riskier” strategies, contribute to the higher number colliders and poor goal-directed walking abilities in stroke survivors with VSN. Future research should focus on developing assessment and training tools for complex locomotor tasks such as obstacle avoidance in this population.

1. Introduction

Obstacle avoidance is an important component of independent community ambulation [1], which is a critical goal of rehabilitation among post-stroke individuals [2]. In our previous studies, we have shown that obstacle avoidance abilities are altered by the presence of stroke and to a greater extent by the presence of visuospatial neglect (VSN) [3–5]. However, what characterizes the obstacle avoidance strategies that lead to successful versus unsuccessful avoidance of a collision in these individuals remains unclear.

Studies conducted in healthy adults have shown that for successful obstacle avoidance and goal-directed walking, information regarding the heading in space and heading in relation to objects of interest (e.g., obstacles and target) are key factors in route selection and planning the locomotor trajectory [9–11]. The spatial relationships maintained with visuospatial cues such as obstacles or targets would determine the success of the locomotor activity (i.e., obstacle avoidance or target interception). Information about an obstacle or target such as its size and location, its instantaneous distance from the participant, and the speed and direction of its movement would be used to prospectively determine whether a collision is likely to occur and the time

* Corresponding author. Feil/Oberfeld/CRIR Research Centre, Jewish Rehabilitation Hospital, 3205, place Alton Goldbloom, Laval, Quebec, Canada.
E-mail addresses: gayatri.aravind@mail.mcgill.ca (G. Aravind), anouk.lamontagne@mcgill.ca (A. Lamontagne).

http://dx.doi.org/10.1016/j.rehab.2017.05.002
1877-0657/

available to safely bypass the obstacle [12,13]. As walking continues, these relationships are constantly changing, necessitating frequent monitoring and updating of this information. Such "spatial updating" is used to determine whether the current trajectory should be maintained or whether changes are needed to avoid the obstacle or reach the target. Under such dynamic conditions, the walking trajectory would heavily rely on online processes (as opposed to pre-planned), contingent on the participant's interaction with the environment [9,10]. Thus, the role of visuospatial attention in the online control of locomotor trajectory cannot be understated.

Visuospatial neglect is an attentional-perceptual disorder commonly observed in stroke survivors. It reduces the ability to uptake visuospatial information from the contralesional side of space and use this information for action [14,15]. Because the visual attention is preferentially oriented toward ipsilesionally located stimuli, contralesionally located stimuli are ignored or detected after a delay [14,15]. In the context of an obstacle avoidance task, a delay in detecting obstacles reduces the time and distance available to perform an avoidance strategy [3,16]. VSN also results in the ipsilesional shift of the subjective midline, which provides a framework for spatial orientation and goal-directed walking [17]. Consequently, individuals may incorrectly code the coordinates of visuospatial cues such as obstacles or targets, leading to incorrect subjective localizations and judgments of distances from objects [18]. Finally, previous studies have shown that the use of self-motion cues such as optic flow, used to guide locomotion, can be impaired in people with stroke with VSN (VSN+) versus without VSN (VSN−) [19]. This altered utilization of visuospatial cues in VSN+ individuals is likely to interfere with their ability to modulate locomotor heading with respect to targets and/or obstacles, but this warrants further investigation.

The main objective of this study was to compare VSN+ and VSN− stroke individuals on their changes in heading and head orientation in space while avoiding obstacles approaching from different directions and reorienting toward the final goal (i.e., target).

Secondary objectives were to evaluate the effect of direction of obstacle approach on measures of obstacle avoidance and alignment with the target and to examine the relations between locomotor outcomes related to obstacle avoidance and alignment with the target with clinical scores of VSN, cognitive function and balance confidence. We hypothesized that VSN+ participants, compared to VSN− participants, would show a preference to orient their heading and head toward the ipsilesional side in response to approaching obstacles and would display larger heading errors with respect to the final destination (target); these alterations would be more pronounced for obstacles approaching from the neglected (left) side than for obstacles approaching from the right side or from head-on. As suggested by results from our previous studies [3], we further hypothesized that the ability to avoid the obstacle and to align with the target would not be explained by clinical measures of VSN severity, cognitive status and balance confidence.

2. Methods

We included 26 participants with a first stroke with the following inclusion criteria: a right hemispheric stroke confirmed by CT/MRI; an ability to walk independently at speeds < 1.2 m/s with or without a walking aid; incomplete motor recovery (scores = 3 to 6/7 on leg and foot impairment inventory of Chedoke McMaster Stroke Assessment [CMMSA]); and right-handed dominance (Edinburgh Handedness Inventory). VSN participants had a further clinical diagnosis of VSN based on the Motor Free Visual Perceptual Test (MVPT)[20], Letter Cancellation Test [21] or Bells Test [22]. Individuals with a visual field defect, hearing loss, cognitive deficits or other co-morbid conditions (medical charts) interfering with locomotion were excluded (see Table 1). Ten VSN+ and 9 VSN− participants had an ischemic stroke, and 3 VSN+ and 4 VSN− participants had a hemorrhagic stroke. Five healthy control (CTL) participants were also recruited to understand the locomotor behaviors of individuals without stroke-related sensorimotor deficits.

2.1. Experimental set-up and procedures

This study was part of a larger project designed to evaluate the ability of post-stroke participants with and without VSN to perceive and actively avoid moving obstacles while walking and performing a simultaneous cognitive task [5]. In this paper, we present the findings related to the kinematic strategies adopted by the participants to avoid the approaching obstacle under a single-task condition.

The experiments were conducted using a virtual environment (VE) that permitted testing obstacle avoidance behavior in a safe and realistic environment. Participants wore an nVisor SX60 head-mounted display (HMD) apparatus (NVIS, USA). A 12-camera Vicon-512 motion capture system tracked the position of 3 reflective markers affixed to the HMD. This information was fed to the CAREN 3 virtual reality software (Motek BV, Amsterdam) to provide real-time updates of participants' head position and orientation in the VE. Reflective markers were also placed on specific body landmarks as specified in the full-body maker set based on the Plug-in-Gait model from Vicon, with 2 additional markers placed on the walking aid when applicable (lower panel in Fig. 1a). Data on body kinematics were recorded at 120 Hz in CAREN 3.

2.2. Locomotor obstacle avoidance task

The VE set-up for the locomotor task included a room (12 × 8 m) with a blue circular target placed on the wall at the far end (11 m) and 3 red cylinders (obstacles) positioned in front of a theoretical point of collision (TPC) in an arc at 0° (Head-on), 40° right (ipsilesional side) and 40° left (contralesional side) [5] (See Fig. 1a for a screenshot of the VE). The TPC is the point at which the participant and the obstacle paths, if left unaltered, would meet and collide together. Participants were positioned at the beginning

Table 1
Characteristics of participants in the study without and with visual spatial neglect (VSN− and VSN+).

Group		Age (yrs)	Chronicity (months)	CMMSA (/7)	MOCA (/20)	TMT-B (s)	Walking speed (m/s)	ABC (/100)	Line bisection error (mm)	Bells omission (no. of omissions)	Apples omission (no. of omissions)
VSN−	Mean±*SD*	60.8 ± 6.5	11.8 ± 5.1	–	27.1 ± 1.6	84.6 ± 26.7	0.6 ± 0.2	92.1 ± 4.5	57.6 ± 22.8	1.9 ± 1.7	1.5±1.8
	Range	51–72	20-May	5.5–6.6	24–30	40–140	0.5–0.9	85–97	5	0	0–5
VSN+	Mean±*SD*	59.8 ± 7.7	10.5 ± 4.6	–	26.1 ± 1.5	151.8 ± 117.2*	0.6 ± 0.1	76.3 ± 8.1*	103.8 ± 51.2*	6.9 ± 2.1*	5.2 ± 2.5*
	Range	48–72	20-Jan	5.4–6.6	24–28	58–438	0.5–0.8	62–89	64–216	11-May	0–8

MoCA: Montreal Cognitive Assessment; TMT-B: Trail Making Test–B; CMMSA: Chedoke McMaster Stroke Assessment; ABC: Activities-specific Balance Confidence scale.
* $P<0.05$.

Please cite this article in press as: Aravind G, Lamontagne A. Effect of visuospatial neglect on spatial navigation and heading after stroke. Ann Phys Rehabil Med (2017), http://dx.doi.org/10.1016/j.rehab.2017.05.002