Gait & Posture 54 (2017) 106–111

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

Effects of visual deprivation on stability among young and older adults during treadmill walking

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ARTICLE INFO

Article history:
Received 21 May 2016
Received in revised form 27 February 2017
Accepted 1 March 2017

Keywords:
Variability
Visual deprivation
Step length
Step width
Foot landing angle

ABSTRACT

The purposes of this study were 1) to investigate the effect of visual deprivation on stability during treadmill walking in older and young adults, and 2) to examine if such an effect differs between age groups. Under the protection of a safety harness, 10 young (23.20 ± 2.44 years) and six older adults (67.83 ± 2.48 years) participants performed two 90-s walking trials (one with eyes open or EO and the other with eyes closed or EC) at their self-selected treadmill walking speeds determined during EO walking. The step length, step width, foot landing angle, the duration of stance phase, and cadence were calculated from the foot kinematics collected for each participant. The variability (i.e., the standard deviation) of step length, step width, foot landing angle, and the duration of stance phase was also calculated to quantify the stability during walking. Our results revealed that both young and older adults took a cautious gait pattern during EC walking, as evidenced by the shorter step length, smaller foot landing angle and shortened stance phase compared to EO walking. Under both visual conditions, older adults exhibited shorter step length and smaller foot landing angle than their young counterparts. No age-related differences were observed for the measurements of variability (i.e., the quantification of stability) while the variability measurement of all four variables was higher during EC walking than during EO walking for both age groups. Findings from this study could provide insights into the mechanisms of how visual information affects stability during gait.

1. Introduction

The visual system provides essential sensory information to maintain dynamic stability during human locomotion [1–4]. Visual impairment significantly impacts stability and has been identified as a fall risk factor among elderly [5–7]. Dynamic stability has also been closely related to falls among adults [8,9]. Thus, a thorough understanding of how the visual impairment influences human gait stability could provide guidance for developing fall prevention paradigms targeting people with visual impairments.

A few studies examining the potential effects of visual deprivation on gait stability have concluded that low vision reduces dynamic stability and increases the dependency on the somatosensory and vestibular systems to control gait stability in humans [10–13,5]. However, subjects in previous studies walked over ground at their self-selected speed under both conditions (i.e., eyes open or EO vs. eyes closed or EC). Adults attempt to walk more slowly when the visual input is disturbed than when the visual input is intact [14]. Consequently, a same subject could walk at different speeds under the two conditions. Studies have discovered that gait speed influences stability [14]. The unmatched gait speed between the two walking conditions thus becomes a confounder. It is nearly impossible to separate the contribution of visual deprivation to the observed changes in dynamic stability from the one contributed by the altered gait speed when the speed is not controlled. It therefore remains unknown how visual loss alone affects dynamic stability during human gait. It is highly desirable to investigate the impact of visual deprivation on human dynamic stability within an environment in which the gait speed can be controlled precisely between visual conditions. A treadmill provides an ideal platform to fulfill this goal given its capability of accurately controlling the gait speed [15,16].

Previous studies suggested that the gait spatiotemporal parameter variability could reflect stability in healthy adults [17–20,13]. For instance, the increased gait step width variability has been associated with falls in older adults [21]. Moreover, low or high step-to-step variability provides a reliable indication of automated and rhythmic walking patterns linked to the control of

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http://dx.doi.org/10.1016/j.gaitpost.2017.03.001
0966-6362/

dynamic stability [17]. Therefore, step-to-step variability could be a useful measurement to examine the effect of visual deprivation on walking stability.

Although some studies inspected how age influences the effects of visual condition on gait kinematics, research concerning how age modifies the effects of visual input on dynamic stability is highly sparse. Whether the effects of visual impairment on dynamic stability differ between age groups still remains unexplored. This is a nontrivial issue given that older population is a growing demographic worldwide, that age-related decline in vision is a fall risk factor [11–13,22], and that fall prevention is becoming a pressing issue for this population [17].

Therefore, the primary purpose of this study was to investigate the effect of visual deprivation on dynamic stability in both young and older adults while walking on a treadmill at an identical speed. The specific aims were to 1) determine to what extent the visual deprivation affects dynamic stability when the walking speed is controlled under both visual conditions (i.e., EO vs. EC); and 2) to examine whether such an effect is dependent on age. We hypothesized that participants, regardless of the age, would be less stable when walking with visual input blocked than when walking with intact visual input. We further hypothesized that the effects of visual deprivation on stability would be more pronounced in elderly than in their young counterparts.

2. Materials & methods

2.1. Participants

Twenty young and 17 older adults with no neurological, musculoskeletal or known gait impairments were initially recruited for this study. Prior to the experiment, all participants provided written informed consent approved by the Institutional Review Board. Only six older and 10 young adults could complete the EC walking trials (Section 2.2) and their data were included in the final analysis (Table 1), leading to a 43% successful participation rate.

2.2. Experimental protocol

Participants were first positioned on a standard treadmill to determine their preferred speed under the EO walking condition [23]. Then, all participants were transferred to an ActiveStep treadmill (base dimension: 36.5″ width × 80″ length) (Simbex, NH). A harness connected to an overhead arch was applied to protect participants. All participants walked on the ActiveStep treadmill approximately 5 min to acclimate to it. Afterwards, each participant performed two 90-s trials (one EO and one EC) in a random order at the pre-determined self-selected speed (young: 1.21 ± 0.08 m/s, older: 0.95 ± 0.23 m/s). Participants were instructed to walk as normally as possible and look ahead upon the EO trial. During the EC walking, the eyes were covered by an eye mask. The feet kinematics were recorded at 120 Hz using a motion capture system (Vicon, UK) from six markers attached on both feet. Ten young and 11 older adults could not complete the EC trials due to either stepping outside the treadmill belt ($n = 16$) or self-requested termination ($n = 5$). Their data were excluded from the final analysis.

2.3. Data reduction

To eliminate possible acceleration and deceleration effects at both ends, only the middle 70-s period was used for each trial. The collected positions of all markers were low-pass filtered using a fourth, zero-lag Butterworth filter [24]. Five spatiotemporal parameters were calculated from the filtered marker paths: the step length, step width, foot landing angle, the duration of the stance phase and the cadence. Timing of touchdown and liftoff of each step was determined by the foot kinematics. Step length was calculated as the anteroposterior distance between two heels at their touchdowns (Fig. 1a). Step width was the mediolateral separation of the heels at their touchdowns (Fig. 1a). Both step length and step width were normalized to the body height (*bh*). Foot landing angle (in deg or °) was defined as the angle formed between the foot sole and the walking surface at touchdown (Fig. 1b), where a flat foot represented zero degree with toe up being positive. The stance phase duration (s) was the time elapsed between touchdown and liftoff of the same foot. The cadence was determined as the reciprocal of the duration from touchdown to the following touchdown at the contralateral limb and expressed over one minute. These five variables were calculated for all steps within the 70-s period for each subject. The average value over all steps was computed and used to represent each subject's gait spatiotemporal parameters for the step length, step width, foot landing angle, and the stance phase duration. Stability, quantified by the variability of the step length, step width, foot landing angle, and the stance phase was calculated as the standard deviation of all steps.

2.4. Statistical analyses

All analyses were performed in SPSS 21.0 (IBM, NY). The dependent variables included the five gait parameters and the variability of the four parameters. A repeated measures analyses of

Table 1
Individual and group demographic parameters in mean (standard deviation) for both young and older participant groups.

	Young (n = 10)				Older (n = 6)			
Number	Age (years)	Gender	Height (m)	Mass (kg)	Age (years)	Gender	Height (m)	Mass (kg)
1	22	F	1.58	70.8	72	M	1.89	110.8
2	22	M	1.75	98.5	67	F	1.55	54.0
3	23	M	1.59	83.0	69	F	1.55	83.8
4	28	M	1.70	99.2	66	F	1.52	67.2
5	25	F	1.62	84.2	68	M	1.75	115.2
6	20	F	1.53	46.8	65	F	1.49	59.9
7	26	F	1.58	48.9				
8	21	F	1.60	82.7				
9	23	M	1.93	114.8				
10	22	M	1.73	67.2				
Group	23.2 (2.4)	5F (5M)	1.66 (0.13)	79.6 (21.8)	67.8 (2.5)	4F (2M)	1.63 (0.16)	81.9 (26.2)
p-value*	<0.001	0.515#	0.354	0.673				

F: female; M: male.
* vs. older.
# Chi-squared test used.