Gait & Posture 41 (2015) 233–239

Contents lists available at ScienceDirect

Gait & Posture

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

Proactive gait strategies to mitigate risk of obstacle contact are more prevalent with advancing age

B.C. Muir [a,b], J.M. Haddad [a,b], M.J.H. Heijnen [a], S. Rietdyk [a,b,*]

[a] Department of Health and Kinesiology, Purdue University, West Lafayette, IN, USA
[b] Center on Aging and the Life Course, Purdue University, West Lafayette, IN, USA

ARTICLE INFO

Article history:
Received 17 April 2014
Received in revised form 28 September 2014
Accepted 6 October 2014

Keywords:
Adaptive gait
Obstacle
Advancing age
Proactive gait strategies
Older adults

ABSTRACT

The purposes of this study were to determine if healthy older adults adopt strategies to decrease the likelihood of obstacle contact, and to determine how these strategies are modified as a function of advancing age. Three age groups were examined: 20–25 yo ($N = 19$), 65–79 yo ($N = 11$), and 80–91 yo ($N = 18$). Participants stepped over a stationary, visible obstacle on a walkway. Step length and gait speed progressively decreased with advancing age; the shorter step length resulted in closer foot placement to the obstacle and an associated increased risk of obstacle contact. Lead (first limb to cross the obstacle) and trail (second) limb trajectories were examined for behavior that mitigated the risk of contact. (1) Consistent trail foot placement before the obstacle across all ages allowed space and time for the trail foot to clear the obstacle. (2) To avoid lead limb contact due to closer foot placement before and after the obstacle, the lead toe was raised more vertically after toe-off, and then the foot was extended beyond the landing position (termed lead overshoot) and retracted backwards to achieve the shortened step length. Lead overshoot progressively increased with advancing age. (3) Head angle was progressively lower with advancing age, an apparent attempt to gather more visual information during approach. Overall, a series of proactive strategies were adopted to mitigate risk of contact. However, the larger, more abrupt movements associated with a more vertical foot trajectory and lead overshoot may compromise whole body balance, indicating a possible trade-off between risk of contact and stability.

1. Introduction

The ability to safely move through varied environments is an important factor in maintaining independence and quality of life in older adults [1,2]. Thirty-four to 53% of falls in older adults occur as a result of a trip [3,4], the majority of which occur during obstacle negotiation [3]. Therefore, obstacle crossing has been examined extensively in order to understand how aging influences the likelihood of tripping.

Slower gait speed and shorter step length are consistently observed when older adults step over stationary, visible obstacles [5–7]. While these changes are typically interpreted as cautious gait strategies, the shortened step length increases the likelihood of obstacle contact [6–8]. Contact risk is likely compounded by the fact that step length progressively decreases with advancing age during both level gait [9] and obstructed gait [8]. Progressively shorter step length may partially explain why fall risk doubles in people older than 80 years compared to those aged 65–79 years [10]. It is reasonable to expect that healthy aging adults may adopt strategies that minimize the risk of obstacle contact, such as increased foot clearance. However, no consistent age-related changes in clearance have been observed across studies when crossing stationary, visible obstacles. Lead toe clearance has demonstrated an increase [11], decrease [12], and no change [6,7] with age. Therefore, it is important to examine the foot trajectory more closely for evidence of other strategies that minimize contact risk.

The purposes of this study were to characterize the foot trajectories of healthy older adults while stepping over obstacles and to determine if these foot trajectories reflect adaptive strategies that decrease the likelihood of obstacle contact. Further, we determine how these strategies are modified as a function of advancing age. Qualitative examination of the foot trajectories resulted in the development of new variables that quantify the shape of the foot trajectory with advancing age. Since more challenging tasks are more likely to delineate group differences

* Corresponding author at: 800 W. Stadium Ave., West Lafayette, IN 47907-2046, USA. Tel.: +1 765 496 6703; fax: +1 765 496 1239.
E-mail address: srietdyk@purdue.edu (S. Rietdyk).

http://dx.doi.org/10.1016/j.gaitpost.2014.10.005
0966-6362/

[13], participants stepped over stationary obstacles while wearing goggles that obstructed the lower visual field. Visual obstruction also increases the likelihood of obstacle contact [14,15]. Wearing goggles simulates daily activities with visual obstructions, such as carrying a tray. A short walkway was selected to resemble walkways in the home, since most older adult falls occur in the home [16].

2. Methods

Three age groups were examined: 20–25 year olds (yo) ($N = 19$), 65–79 yo ($N = 11$), and 80–91 yo ($N = 18$) (Table 1, participant characteristics also found in Ref. [9]). All participants were healthy, able to climb 1.5 flights of stairs, walked without a walking aid, had no neuromuscular or orthopedic disorders, and required minimal assistance to complete daily activities. All participants signed informed consent approved by the University's Institutional Review Board.

Kinematic data were collected at 60 Hz (Optotrak, NDI, Waterloo, Canada). Ten infra-red emitting diodes (IREDs) were placed bilaterally on the fifth metatarsal, posterior calcaneus, lateral malleolus, lateral femoral condyles, greater trochanter, and glenohumeral axis. Two IREDs were placed near the right temple, and one IRED was placed on the obstacle.

Participants stood still and, when instructed, walked along a 3.2 m walkway and stepped over a stationary, visible obstacle placed at 1.5 m (Fig. 1). Obstacles were 78 cm wide by 0.5 cm deep, composed of masonite, painted flat black, and designed to tip if contacted. Twenty-four trials were completed in a randomized order, six of each obstacle height (1, 10, and 20 cm) and six during unobstructed gait (described in Ref. [9]). Trials with an obstacle contact were not included in the averages.

Participants wore goggles that blocked view of the obstacle as the participant came within two steps. If needed, the participant could look down by flexing the neck. To determine the head angle required to look at the obstacle, the last trial was a foveation trial where the participant looked directly at the 10 cm obstacle as they walked up to and crossed it (Fig. 2E and F).

Gait events (foot contact and toe off) were selected visually using a custom program (Visual Basic, Microsoft, Redmond, WA). Standard gait parameters including step width, step length, horizontal toe distance, horizontal heel distance, and toe clearance were calculated with a custom MATLAB routine (The MathWorks, Inc. Natick, MA). Step width and step length were the medial-lateral and anterior–posterior distances, respectively, between the heel markers at two consecutive heel contacts. Horizontal toe distance was the anterior–posterior distance between the obstacle and toe marker during stance prior to crossing (Fig. 1). Horizontal heel distance was the anterior–posterior distance between the obstacle and heel marker during stance after crossing (Fig. 1). Gait speed was the differentiated anterior–posterior displacement of the distal temple marker, averaged over the crossing steps. Toe and heel clearances were calculated as the vertical distance between the obstacle and the toe and heel, when the toe and heel were directly above the obstacle. Minimum foot clearance was defined as the smallest value of toe and heel clearance [6,17], as either the forefoot or rearfoot may come closer to the obstacle during crossing [18]. All measures were calculated for the lead (first foot to cross obstacle) and trail (second foot) limbs. Variability of each measure was calculated as the standard deviation of the six trials for each obstacle condition.

Table 1
Participant characteristics.

	20–25 yo	65–79 yo	80–91 yo	*p*-Value
N	19	11	18	
Gender (M/F)	9/10	3/8	7/11	
Age (years)	22.1 (1.3)	73.5 (4.0)	85.1 (2.9)	**<0.01**
Mass (kg)	70.3 (15.8)	73.6 (12.6)	68.9 (14.6)	0.71
Height (cm)	168.2 (9.3)	168.4 (8.1)	164.1 (10.1)	0.33

Mean (standard deviation).
The significant *p*-values are bold.

Absolute head angle in the sagittal plane was determined relative to horizontal (Fig. 2E and F). To assess if participants looked directly at the obstacle during approach, the head angle of the foveation trial was subtracted from the head angle of each trial. Therefore, a positive head angle indicates an angle higher than the foveation trial. Minimum head angle was calculated during two walkway regions: Approach-1 – the 0.5–1 m region of the walkway, and Approach-2 – the 1–1.5 m region of the walkway (Fig. 2E and F).

We observed that older adults tended to have a more rectangular lead limb trajectory, where the foot was first lifted vertically to peak height, then moved forward to cross the obstacle (Fig. 2A). The slope of the initial toe movement was not a suitable measure due to widely varying behavior; instead we quantified the trajectory shape. The area of two shapes was calculated: A_{traj}, area under the toe trajectory calculated by integration, and A_{rect}, area of the rectangle formed by the stride length and maximum toe height (Fig. 3B). The rectangular ratio was calculated as A_{traj}/A_{rect}, where a value closer to one reflects a more rectangular trajectory. In addition, the lead foot tended to be pulled backward before landing (termed lead overshoot; Figs. 2A and 3A). Lead overshoot was the maximum anterior–posterior toe position during swing minus the anterior–posterior toe position at landing (Fig. 3A).

Statistical analyses were completed in SAS, version 9.3 (SAS Institute, Cary, NC) using a two-way, age group (3 levels; 20–25 yo, 65–79 yo, and 80–91 yo) by obstacle height (3 levels; 1 cm, 10 cm, 20 cm), linear mixed model ANOVA with participant nested within age group. Post hoc comparisons (Duncan) were conducted. Due to the large number of dependent variables, the *p*-value was set to $p \leq 0.01$.

3. Results

3.1. Obstacle contacts

Seventeen obstacle contacts were observed in 840 trials (2%). All age groups showed similar contact rates: 2.0%, 2.0%, and 1.9% for 20–25 yo, 65–79 yo, and 80–91 yo, respectively. Contact rates as a function of obstacle height were: 1.4%, 0.3%, and 4.2% for the 1 cm, 10 cm, and 20 cm obstacle, respectively. Contacts occurred for the following reasons: foot contact during crossing (9 contacts, 52.9% of all contacts), stepping on an obstacle (4 contacts, 23.5%, always with the 1 cm obstacle), walking into the obstacle (no attempt was made to lift the limb; 2 contacts, 11.8%), or contacting the obstacle at heel contact with the lead limb (the foot was pulled backward too far at the end of swing; 2 contacts, 11.8%). The percentage of contacts that occurred with the lead limb were: 0%, 67%, and 33% for 20–25 yo, 65–79 yo, and 80–91 yo, respectively.

3.2. Minimum foot clearance, toe vs heel

In successful trials, the lead heel was closer to the obstacle than the toe for 78%, 89%, and 85% of trials for 20–25 yo, 65–79 yo, and 80–91 yo, respectively. For the trail foot, the toe was closer to the obstacle than the heel for 100%, 98%, and 94% of trials for 20–25 yo, 65–79 yo, and 80–91 yo, respectively.

3.3. Interaction effects

An interaction effect of age group by obstacle height demonstrates that the three age groups accommodated the obstacle heights differently. Interaction effects were observed in gait speed for both the lead and trail crossing steps (Table 2) and lead overshoot (Fig. 3C; Table 2). The two older groups showed a greater decrease in gait speed (18%) from 1 to 10 cm than 20–50 yo (8%). Lead overshoot was larger for the older groups (Fig. 3C). In the 10 cm obstacle, all three groups were different from each other; in the 20 cm obstacle, 65–79 yo and 80–91 yo were not different from each other, but were greater than 20–25 yo.

3.4. Height effects

The majority of the gait parameters were modified as a function of obstacle height (Table 2), consistent with previous research [6]. As the purpose of this study