Gait & Posture 41 (2015) 153–158

Contents lists available at ScienceDirect

Gait & Posture

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

Age-related differences when walking downhill on different sloped terrains

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ARTICLE INFO

Article history:
Received 10 April 2014
Received in revised form 22 September 2014
Accepted 24 September 2014

Keywords:
Downhill gait
Sloped terrains
Accelerometers
Attenuation
Older adults

ABSTRACT

Despite the common situation of walking on different sloped terrains, previous work on gait has focused on level terrain. This study aims to assess whether any age-related differences exist in spatiotemporal and stability parameters when walking downhill on three different sloped walkways. Two tri-axial accelerometers were used at the levels of head and pelvis to investigate spatiotemporal parameters, magnitude (root mean square, RMS), harmonic content of accelerations (harmonic ratios, HR) and attenuation between body levels (ATT) in 35 older adults (OA, 69 $\pm$ 4.5 y.o.) and 22 young adults (YA, 22.1 $\pm$ 1.9 y.o.). Older adults walked at the same speed and cadence as young adults in flat terrain (FL, 0%) and moderate hill (MH, 8%). In the highest slope (PH, 20%), older adults reduced speed and step length and both groups increased cadence. Age had no effect on attenuation and RMS profiles. RMS increased with slope in all directions at both head and pelvis, except, for medio-lateral direction (ML), with similar head RMS in all slopes. There is an important shift in ATT from anteroposterior direction (AP) to ML at the highest slope, resulting in smaller antero-posterior attenuation and greater medio-lateral attenuation. Age differences appeared in the smoothness (HR) at the flat terrain, with increased vertical and antero-posterior values for young adults. As slope increased, group differences disappeared and HR decreased for all directions of motion. In general, spatiotemporal adaptations to increased slope seem to be part of a mechanism to improve ML attenuation, in both young and old adults.

1. Introduction

The maintenance of equilibrium during human walking is a particularly challenging task for the postural control system [1]. This is especially important for the understanding of stability and falls in older people, since more than 60% of falls occur during locomotion [2].

Neuromuscular capacity declines with age [3], commonly affecting the control of balance and posture. Normally, older adults with a low falling risk adopt more conservative gait patterns, decreasing speed and step length [3–5], especially when facing challenging conditions such as irregular surfaces [6]. Very healthy active elderly have been reported to walk at the same preferred speed as younger adults while presenting greater variability of spatiotemporal measures, lower extremity joint angles, and trunk motions [7]. Moreover, the ability to attenuate accelerations from pelvis to head levels in older adults is less effective during level walking when compared to young counterparts in the antero-posterior (AP) and medio-lateral (ML) directions [6,8].

Multi-surface level [4] and irregular level surfaces [6,9] have also been used to study gait, however, few studies have reported data collected in different sloped terrains. During daily life, it is very common to face different inclinations, i.e. ramps accessing buildings (6-9% inclination) or more abrupt hills (up to 20–25%). Both uphill and downhill walking represent a greater physical challenge. However, in terms of fall risk, the latter warrants greater attention. Walking downhill increases momentum due to gravity producing accelerations that may perturb posture and disrupt gaze; affecting gait control. Little is known about gait adaptations occurring at different sloped terrains. Tulchin et al. [10] studied foot mechanics, McIntosh et al. [11] and Kuster et al. [12] studied young adults leg mechanics on sloped terrains, indicating several changes in joint kinematics and kinetics when compared to level

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http://dx.doi.org/10.1016/j.gaitpost.2014.09.022
0966-6362/

walking. Hong et al. [13] and Franz and Kram [14] reported a shift to a greater knee loading and knee extensors muscle activation when young adults walked downhill. Franz and Kram [15] found no differences in braking GRFs or negative work rates between old and young adults when walking downhill. Hunter et al. [16] reported that young adults do not take optimal advantage of the propulsion provided by gravity to decrease energetic cost, but instead prefer a more stable and costly gait pattern. No study has looked at age-related gait adaptations when walking downhill.

1.1. Purpose

To study the effect of downhill walking at three different-sloped terrains on spatiotemporal and accelerometer-related stability parameters in a group of young and older adults.

2. Methods

2.1. Participants

Thirty-five older adults (OA) and 22 young adults (YA) were recruited (Table 1). All subjects wore their own footwear in order to recreate daily life conditions (generally flexible rubber sole or sports shoes). Additionally, participants were physically active, had no known visual, vestibular, musculoskeletal or neurologic impairment and provided written informed consent before completing testing sessions. Prior approval was obtained from our institution's Bioethics Committee.

Participants were instructed to walk at a self-selected pace in random order on flat (FL, 0%), moderate downhill (MH, 8%) and pronounced downhill (PH, 20% slope) outdoor walkways. Distance traveled on each walkway was 15 m, with the middle 10 m marked for step counting. Walkways slope was obtained by a certified topographer.

2.2. Data collection and analysis

Accelerometry has been widely used to obtain gait spatiotemporal and stability parameters [6,8,9,17,18]. Inertial measurement units (Technaid SL, ±5 g), were used to collect three-dimensional linear accelerations from pelvis and head levels, sampled at 50 Hz, stored and later processed with a custom-written algorithm (Matlab, Mathworks Inc.). Three trials were performed for each condition, steps were counted (rounded to the nearest half step) every trial to obtain step length and further combined with average step time (from accelerometer data) to calculate speed. Five strides were chosen from the raw data for each trial. Data was then filtered with a low-pass 4th order Butterworth filter (cut-off frequency of 20 Hz) [17]. Heel strikes were identified using the positive peaks of antero-posterior pelvis accelerations [17] and later used to segment every step. Sensors were fixed in the pelvis area and at the posterior part of the head with tight elastic bands [9]. To correct mean raw vertical acceleration due to accelerometer tilt in the sagittal and horizontal planes, tilt angle was obtained for each device in each trial and then used to adjust the pertinent components to a global coordinate system [9,18].

The following variables were calculated:

(1) *Walking velocity* (m/s): 10 m/(average step time × # of steps).
(2) *Cadence* (steps/min): CAD = 60/(average step time).
(3) *Average step length* (cm): distance/number of steps.
Gait data was scaled to body size, using leg length (LL), according to Hof [19]. "Corrected" step length is step length divided by LL; "corrected" velocity is velocity divided by the square root of (g*LL). "Corrected" cadence was cadence value divided by the square root of (g/LL).
(4) *Step timing variability*: standard deviation for the step time of the 10 chosen steps of each trial was obtained, and averaged for the three trials of each condition, according to [9].
(5) *Acceleration root mean square* (*RMS*): accelerations were transformed to give a mean equal to zero by subtracting the mean value, expressed as "g" values (divided by "g") and then the standard deviation was the RMS. Accelerations increase with higher walking speeds [9,18,20,21], thus RMS values were normalized (i.e. divided) to walking speed for each trial for further comparisons, according to [4]. RMS was calculated for each trial, from the chosen interval, and then averaged. RMS is an indicator of the magnitude of accelerations in each direction.
(6) *Attenuation*: a coefficient of attenuation (ATT) [8] was calculated to study the ability to dissipate accelerations from pelvis (P) to head (H):
$$\mathrm{ATT}(\%) = (1 - \mathrm{RMS_H}/\mathrm{RMS_P}) \times 100$$
(7) *Harmonic ratio* (*HR*): indication of gait pattern smoothness [9] and step-to-step symmetry within a stride [22], calculated according to Menz et al. [9]. Greater HR represents a smoother gait. HR was obtained for every stride, 5 values per trial, then the average of three trials (15 strides) was calculated.

2.3. Statistical analysis

Two-way mixed (2 × 3) ANOVAs (Age group × Slope) with Bonferroni corrections were used to determine the effect of age (OA, YA) and slope (FL, MH, PH) (repeated-measures factor) on spatiotemporal parameters (walking velocity, step length, step timing variability) and attenuation on each direction (V, ML and AP).

Three-way mixed ANOVAs (2 × 3 × 2) (Age group × Slo- Slope × Level) with Bonferroni corrections were used to determine the effect of age, slope and accelerometer location (head vs. pelvis) on RMS and HR for every direction of motion (V, ML and AP).

Table 1
Participant characteristics.

Characteristics[a]	Older adults (OA) (N = 35; women: 24, men: 11)	Young adults (YA) (N = 22; women: 4, men: 18)
Age (years)	69.6 ± 4.5	22.1 ± 1.9*
Body mass (kg)	64.8 ± 11.7	70.5 ± 12.6*
Height (cm)	159.1 ± 10.8	173.2 ± 9.8*
BMI	25.5 ± 2.8	23.4 ± 3.2*
Leg length (LL)[b]	75.4 ± 5.8	82.4 ± 6.7*

[a] Data are mean ± SD.
[b] Leg length is defined as the distance from the greater trochanter to lateral malleolus.
* $p < 0.05$, difference between OA and YA.

3. Results

Analysis for velocity showed a significant Slope × Group interaction (F(2,110) = 5.13, p = 0.007). Further analysis showed young adults walking faster than older adults in PH. Cadence presented a main effect for slope (F(2,110) = 38.68, $p < 0.001$). Both groups increased cadence in PH compared to FL and MH. Step length (SL) presented a Slope × Group interaction (F(2,110) = 8.5, $p < 0.001$). Older adults reduced step length at PH compared to FL and MH. Older adults walked with shorter steps than young adults in all slopes. Corrected data for LL showed that "corrected step length" was shorter for older adults only in the PH. Corrections for body size had no effect on velocity and cadence. Group and slope had no effect on step timing variability. See Fig 1 and supplementary materials.

3.1. RMS and attenuation

Table 2 shows RMS and attenuation (ATT) values. Three way ANOVAs for V, ML and AP RMS showed that group factor was not involved in any significant