Gait & Posture 50 (2016) 131–136

Contents lists available at ScienceDirect

Gait & Posture

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

Full length article

Effects of age and physical activity status on redistribution of joint work during walking

Harsh H. Buddhadev[a,b,*], Philip E. Martin[b]

[a] Department of Health and Human Development, Western Washington University, Bellingham, WA 98225, United States
[b] Department of Kinesiology, Iowa State University, Ames, IA 50011, United States

ARTICLE INFO

Article history:
Received 9 March 2016
Received in revised form 14 August 2016
Accepted 31 August 2016

Keywords:
Plantarflexors
Speed
Isokinetic
Strength

ABSTRACT

During walking older adults rely less on ankle and more on hip work than young adults. Disproportionate declines in plantarflexor strength may be a mechanism underlying this proximal work redistribution. We tested the hypothesis that proximal redistribution is more apparent in older compared to young adults and in sedentary compared to active individuals over multiple walking speeds. We recruited 18 young (18–35 yrs) and 17 older (65–80 yrs) physically active and sedentary adults. Participants completed five trials at four walking speeds as marker positions and ground reaction forces were collected. Sagittal plane net joint moments were computed using inverse dynamics. Instantaneous joint powers for the ankle, knee, and hip were computed as products of net joint moments and joint angular velocities. Positive joint work was computed by integrating hip, knee, and ankle joint powers over time in early, mid, and late stance, respectively. Relative joint work was expressed as a percentage of total work. Isokinetic strength of lower limb flexor and extensor muscles was measured. Older adults had lower relative ankle ($p = 0.005$) and higher relative hip ($p = 0.007$) work than young adults for multiple speeds. Non-significant trends ($p < 0.10$) indicating sedentary participants had lower relative ankle ($p = 0.068$) and higher relative hip work ($p = 0.087$) than active adults were observed. Age-related differences in plantarflexor strength were not disproportionate compared to strength differences in knee and hip musculature. Age influenced proximal work redistribution over multiple walking speeds. Physical activity status showed a similar trend for proximal work redistribution, but failed to reach statistical significance.

1. Introduction

Because walking is essential for most activities of daily living, maintaining walking abilities in older adults is critical [1]. Biomechanical gait analysis is one way to systematically and quantitatively assess age-related gait adaptations. Kinetic variables such as net joint moments, power, and work elucidate mechanisms underlying a chosen walking pattern. Changes in gait kinetics with age provide insights into neuromuscular factors underlying these adaptations.

During walking, positive work performed by lower extremity extensor muscles account for 90% of the total mechanical energy generated during a full gait cycle [2]. This energy generation is inferred from the magnitude of positive work done during early, mid, and late stance, respectively. During early stance, positive work generated by hip extensors corresponds to the H1 power phase. Similarly, the K2 power phase during mid-stance is produced by knee extensors performing positive work. During late stance, the plantarflexors produce a vigorous push-off action, producing positive work that defines the A2 power phase [2–4].

When walking at identical speed, older adults generate lower power and do less work about the ankle while generating higher power and work about the hip than young adults [5–9]. DeVita and Hortobágyi [6] characterized this age-related redistribution of joint work as a distal-to-proximal shift in control strategy. They suggested disproportionately high declines in plantarflexor strength compared to declines about the knee and hip contribute to this distal-to-proximal shift in older adults [6]. Compared to hip and knee musculature, multiple studies have shown the plantarflexors make the highest contribution to energy generation during walking [5–8,10–12]. Consequently declines in plantarflexor strength and power generating capacity likely necessitate compensation by proximal muscle groups, regardless of whether the decline in plantarflexor strength is disproportionally high.

* Corresponding author at: AH 454, MS 9067, 516 High Street, Bellingham, WA 98225, United States.
E-mail addresses: harsh.buddhadev@wwu.edu (H.H. Buddhadev), pemartin@iastate.edu (P.E. Martin).

http://dx.doi.org/10.1016/j.gaitpost.2016.08.034
0966-6362/

Whether age-related gait adaptations originate from disproportionate strength reductions of more distal muscles or more simply from comparable declines in strength, sedentary individuals, both older and young, are also likely to demonstrate gait adaptations similar to those shown by healthy older adults. For example, Graf et al. [9] showed that frail older adults generated lower ankle and higher hip joint peak power compared to healthy older adults when walking at comfortable speed. Similarly, Savelberg et al. [7] recruited active and inactive young and older adults to assess the effects of age and physical activity (PA) status on distribution of joint work at a single speed of walking. Older adults performed 23% less ankle work and 97% more hip work than young adults. No significant differences between active and inactive adults were observed in ankle and hip work. They concluded that age affected distribution of joint work about lower limb joints whereas PA status did not.

In general, older adults have lower preferred walking speeds than young adults. With increases in walking speed, average positive ankle, knee, and hip joint work increase [5,8]. Two recent studies [8,13] suggest proximal redistribution of joint work becomes more apparent in older adults at higher walking speeds. It is plausible that proximal redistribution of joint work in sedentary compared to active individuals may also become apparent at higher walking speeds as demands on the musculature increase. This question, however, has received limited attention. Therefore, there is a need to re-address the effect of age and PA status on redistribution of joint work more systematically over a large range of speeds.

Therefore, our purpose was to investigate the effect of age and PA status on distribution of joint work about the ankle, knee, and hip joints at multiple walking speeds. We hypothesized that: 1) older adults rely more on hip musculature and less reliance on ankle musculature as reflected by relative work contributions compared to young adults; 2) sedentary individuals have higher relative hip work and lower relative ankle work than physically active individuals; and 3) as walking speed increases, relative joint work performed at the ankle decreases while that performed at the hip increases.

2. Methods

2.1. Participants

Eighteen young (18–35 years old; 9 active, 9 sedentary) and 17 older (65–80 years old; 9 active, 8 sedentary) healthy, community dwelling adults were recruited for the study. GPower 3.1 was used to calculate sample size from ankle and hip work data for walking reported by DeVita and Hortobágyi [6]. To achieve a statistical power of 0.8 for age group contrasts at an alpha level of 0.05, a sample size of 24 (12 participants per age group) was needed.

Exclusion criteria included use of assistive devices for walking and any muscular, orthopedic, neurologic, and/or cardiovascular disorders that limited normal walking ability. All participants completed a health history and PA survey. The criterion for being categorized as physically active, which was the same for both older and young participants, was at least 30 min of moderate intensity PA performed at least twice per week in the previous year. This is less than the recommendation of 150 min of moderate intensity PA per week in the *2008 Physical Activity Guidelines for Americans* [14]. A recent national survey showed only 11% of older adults meet these guidelines [15]. Our PA inclusion criterion was intentionally reduced to facilitate participant recruitment. Nevertheless, vigorous recruiting successfully produced age and PA groups that did not differ significantly on mass and height but were substantially different on PA per week and lower extremity strength (Table 1). Approximately 80% of our active participants met or exceeded the 2008 PA guidelines. The University Institutional Review Board approved the study, and all participants gave written informed consent before participating.

2.2. Data collection

In the first of two testing sessions, peak isokinetic strength and anthropometric data were collected. Kinematic and kinetic data were collected in session 2 as participants walked under four speed conditions.

2.2.1. Session 1

Participants completed maximal isokinetic strength tests at $60^\circ\,s^{-1}$ for ankle, knee, and hip flexors and extensors using a Biodex isokinetic dynamometer (Shirley, NY, USA). Strength testing was conducted on the dominant leg, defined as the leg preferred for kicking a ball. Participants completed a 10-min warm up and familiarization process prior to isokinetic testing. Participants then completed two sets of six repetitions at maximal effort for each joint in the following order: ankle, hip, and knee, as investigators provided verbal encouragement. A 5-min rest interval separated individual joint assessments. Next, participant body weight, height, and anthropometric characteristics of the right leg were measured to predict lower extremity inertial properties using methods by Vaughan et al. [16].

2.2.2. Session 2

The second session was completed within 7–14 days of session 1. Reflective markers (n = 21) were attached on participants' right shoe, lower extremity, and trunk. Using an 8-camera Vicon system

Table 1
Description of participants by group, including peak isokinetic torques ($N\,m\,kg^{-1}$) measured at $60^\circ\,s^{-1}$. Peak torque produced by all muscle groups was significantly lower for older compared to young adults. Active participants generated greater torque for knee flexion compared to sedentary participants.

	Older Sedentary	Older Active	Young Sedentary	Young Active
Sample size	8	9	9	9
Sex	5F, 3M	5F, 4M	5F, 4M	5F, 4M
Age (years)	72.0 ± 6.6	69.0 ± 4.5	20.8 ± 2.6	22.4 ± 3.6
Mass (kg)	73.8 ± 16.5	75.8 ± 16.3	70.8 ± 9.9	63.4 ± 10.3
Height (cm)	167.4 ± 10.2	169.9 ± 9.1	171.5 ± 8.9	174.3 ± 8.2
Moderate intensity PA (min/week) ‡	22.5 ± 44.6	221.1 ± 109.1	16.7 ± 50.0	271.1 ± 225.1
Peak plantarflexor torque *	0.93 ± 0.35	0.97 ± 0.44	1.13 ± 0.35	1.33 ± 0.24
Peak dorsiflexor torque *	0.46 ± 0.12	0.51 ± 0.22	0.55 ± 0.09	0.67 ± 0.21
Peak knee extensor torque *	2.00 ± 0.63	2.54 ± 1.58	2.84 ± 0.60	3.40 ± 0.85
Peak knee flexor torque *, ‡	0.98 ± 0.30	1.16 ± 0.54	1.41 ± 0.35	1.79 ± 0.41
Peak hip extensor torque *	1.64 ± 1.16	2.25 ± 1.09	3.26 ± 0.64	4.07 ± 0.36
Peak hip flexor torque *	1.44 ± 0.70	1.69 ± 0.62	2.08 ± 0.76	2.12 ± 0.62

Note: Numbers represent mean ± one standard deviation (SD). Statistically significant ($p < 0.05$) age main effect (*) and PA status main effect (‡).