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Effects of Age and Physical Activity Status on Redistribution of Joint Work During Walking

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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.

Keywords

Isokinetic, Plantarflexors, Speed, Strength

Disciplines

Exercise Physiology | Exercise Science | Kinesiology | Motor Control

Comments

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

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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 it failed to reach statistical significance.

Keywords: Plantarflexors, speed, isokinetic, strength

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.

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 and colleagues [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.

METHODS

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 minutes of moderate intensity PA performed at least twice per week in the previous year. This is less than the recommendation of 150 minutes 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.

****Insert Table 1 about here****

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.

Session 1

Participants completed maximal isokinetic strength tests at 60 $deg \cdot s^{-1}$ 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-minute 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-minute 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].

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 (Centennial, CO, USA) and an AMTI force plate (Newton, MA, USA), three-dimensional marker positions and ground reaction forces were sampled synchronously at 100 Hz and 500 Hz, respectively.

Data were captured for the four experimental walking speed conditions (1.1, 1.3, 1.5, and 1.7 $m \cdot s^{-1}$), which were randomly ordered. A marker on the low back was used to monitor average speed through the measurement zone. Participants initially practiced walking at the targeted speeds and then completed five acceptable trials for each speed while marker position and ground reaction force data were collected. Acceptable trials were ones in which average speed was within 3% of the target speed and there were no visible indications of adjusting the stride to impact the force platform.

Data Analysis

Ground reaction forces and marker position data for walking trials were filtered using a low pass fourth order Butterworth filter at 20 Hz and 6 Hz, respectively. Data for one stride were identified starting with right heel strike on the force plate to the next right heel strike. The first heel strike was identified when the vertical component of the ground reaction force exceeded 20 N. The second heel strike, which was not on a force platform, was predicted based on the horizontal distance between heel and sacral markers [17]. Ground reaction forces were down-sampled to 100 Hz to match the sampling frequency of motion capture. Segment and joint linear and angular velocities and accelerations were computed using first central difference approximations. A sagittal plane inverse dynamics model was used to estimate net joint forces and moments at the ankle, knee, and hip [3]. Instantaneous net joint powers for all three joints were then computed as products of net joint moments and joint angular velocities [2, 3, 18]. Average positive work performed in the sagittal plane during H1, K2, and A2 power phases [2, 4, 6] were computed by integrating joint powers in early, mid, and late stance, respectively. Based on total work performed (i.e., sum of A2, K2, and H1 positive work), relative work performed during each power phase was expressed as a percentage of total work.

Statistical Analysis

Three-way mixed model ANOVAs with repeated measures on speed were used to assess the effects of age, PA status, and speed on stride length, total average work, and average and relative positive joint work performed at the ankle, knee, and hip. The effects of age and PA status on body mass, height, and maximal isokinetic strength measures were assessed using two-way ANOVAs. Alpha was set at 0.05. Statistical power and effect sizes (Cohen's f) are reported for primary dependent variables. Small, medium, and large effect sizes correspond to f-values of 0.10, 0.25, and 0.40, respectively [19]. All statistical procedures were performed using SPSS (Version 19).

RESULTS

Older adults showed lower peak isokinetic strength for ankle, knee, and hip flexor and extensor muscle groups than young adults (table 1). Age-related differences in plantarflexor strength were not disproportionately higher than differences for knee and hip extensors. Ankle, knee, and hip flexor and extensor isokinetic strength measures were not affected by PA status, except for knee flexion. Sedentary adults had 18% lower knee flexor strength than active individuals (p=0.05).

Stride lengths for both young and older adults increased linearly with increases in walking speed (figure 1). On average, older adults took 6% shorter strides than young adults (p=0.015). Differences in stride length between older and young participants were accentuated at higher walking speeds (age x speed, p<0.001). PA status did not affect participants' stride lengths at any speed.

****Insert Figure 1 about here****

Total positive work was not different for older and young adults, but the way in which total work was generated differed between age groups (figure 2, upper panels). Work done about the hip was 9% higher for older compared to young adults (p=0.043), and this difference was reasonably consistent across walking speeds. In contrast, older adults generated less ankle work, although this difference was only apparent at faster speeds (age x speed, p<0.001). The knee made the smallest contribution to total work; knee work was nearly identical for older and young participants across speeds. PA status did not significantly affect total lower extremity work or individual joint contributions to total work (figure 2, lower panels). As walking speed increased, all groups (older, young, sedentary, and active individuals) showed higher total average positive work and average ankle and knee positive work ($p<0.001$); hip work was not affected by speed.

****Insert Figure 2 about here****

Work contributions by the ankle, knee, and hip expressed as percentages of total work (figure 3) supported the anticipated age effect on walking mechanics. Older participants generated higher relative work at the hip ($p=0.007$, statistical power=0.805, f=0.523) and lower relative work at the ankle ($p=0.005$, statistical power=0.830, f=0.540). Relative work contributions were also consistent with the hypothesized influence of PA status, although these trends did not reach statistical significance. Sedentary individuals showed a trend for higher relative work at the hip ($p=0.087$, statistical power=0.403, f=0.318) and lower relative work at the ankle ($p=0.068$, statistical power=0.449, f=0.339). Relative work results for the knee were not affected significantly by either age or PA status.

****Insert Figure 3 about here****

As speed increased from 1.1 to 1.7 $m \cdot s^{-1}$, relative work at the hip decreased by 9% ($p<0.001$), relative work at the knee increased by 7% ($p<0.001$), and relative ankle work did not change (figure 4, upper and lower panels).

****Insert Figure 4 about here****

DISCUSSION

Consistent with our first hypothesis, older adults showed greater reliance on hip work and less reliance on ankle work during walking than young adults. These results for age-associated redistribution of relative joint work are in agreement with those reported previously [5, 6, 20]. DeVita and Hortobágyi [6] indicated higher relative contributions from hip extensors compensates for lower output of ankle plantarflexors in older adults. They suggested a disproportionate decline in plantarflexor strength compared to more proximal musculature may be a mechanism underlying distal-to-proximal redistributions of joint work shown by older adults [6]. Although we also observed a proximal redistribution of joint work during walking, our results for isokinetic strength about the ankle, knee, and hip did not show a disproportionate decline in plantarflexor strength (table 1). Our isokinetic strength trends are comparable with those reported previously for young and older adults [8, 21, 22]. As expected, both flexor and extensor strength was significantly lower for older participants at all three joints. Focusing specifically on extensors, strength measures for older adults were 23%, 27%, and 45% lower than those for young participants at the ankle (p=0.024; f=0.427), knee (p=0.018; f=0.448), and hip (p<0.001; f=0.699), respectively. Thus, our results show substantially greater age-related strength differences about the hip than the ankle and knee, and yet a proximal redistribution of joint work was still observed for our older participants.

Despite lack of support for a disproportionate decline in plantarflexor strength, reduced capacity to generate a strong push-off about the ankle in late stance still necessitated compensation by proximal muscles. We conclude that age-associated redistribution in relative joint work reflects an interplay between the high demands on plantarflexors during walking and strength declines of plantarflexor muscles with age.

Based on the expectation that sedentary individuals have lower strength normalized to body size than physically active individuals, we hypothesized that sedentary participants show a distal-to-proximal redistribution of work during walking compared to physically active individuals. Although not statistically significant, isokinetic extensor strengths about the ankle, knee, and hip of sedentary participants were 10%, 18%, and 22% lower, respectively, than those for active participants (table 1). These differences are comparable with published research [23, 24]. Trends for relative joint work indicated sedentary individuals had lower relative ankle work and higher relative hip work than physically active individuals. These non-significant statistical trends for relative work were meaningful owing to their moderate to large effect sizes. Chances of type II errors in the light of inadequate statistical power may have been the reason for not finding significant differences for these PA status contrasts.

Considering the relative effects of age and PA status in our experimental design, our results for both isokinetic strength and relative work during walking indicate age had a stronger and more reliable influence on strength and gait outcomes than PA status. The effect of PA status, if statistically significant, would have been similar to the effect of age on these outcomes suggesting a common mechanism may underlie age- and PA status-associated adaptations. We expected strength differences between participant groups to be associated with gait adaptations, and suggest age and PA status influences may be additive. Strength capacity for all muscle groups showed a similar pattern: older sedentary < older active < young sedentary < young active (table 1). Consistent with these strength trends, older sedentary participants displayed the lowest relative ankle work and highest relative hip work, whereas young physically active participants displayed the highest relative ankle work and lowest relative hip work (figure 3). These findings are consistent with those of Graf et al., [9], who reported that frail older adults generated lower peak ankle and higher peak hip power than healthy older adults when walking at a comfortable speed.

Higher walking speeds place greater demands on lower extremity musculature as reflected by joint moments, work, and power [5, 8, 12, 13, 25]. Based on our assumption that plantarflexor strength and power generating capacity can be limiting during walking, we hypothesized that a distal-to-proximal redistribution would be more apparent as walking speed increased. Our net joint work results (figure 2) showed ankle work systematically increased as speed increased from 1.1 to 1.7 $m \cdot s^{-1}$. An age-speed interaction indicated work differences between older and young adults were greater at higher speeds. Net knee joint work also systematically increased with speed for both young and older participants. Net hip work was higher in older compared to young adults across speeds but was unaffected by speed probably due to reduction in duration of stance phase with speed. Thus, when expressed as a percentage of total work, relative ankle work did not change, knee work increased by 7%, and hip work decreased by 9% with the increase in speed (figure 4). Peak and average net ankle, knee, and hip joint powers of our participants increased linearly with walking speed ($p<0.001$). Cumulatively, our joint power and work data partially support our speed hypothesis. Our results indicate that despite the age-related decline in strength of plantarflexors, ankle power and work increased to meet at least some of the increased mechanical demand of fast walking speeds. Regardless of walking speed, older adults relied on greater hip power and work. These data are consistent with Graf et al.[9] who showed that frail older adults increased peak ankle, knee, and hip powers to accomplish a fast walking speed.

In summary, redistribution of energy generation associated with age is robust across speeds. PA status did not significantly influence redistribution of energy generation, despite medium to large effect sizes for ankle and hip relative work. Our isokinetic strength data refute the suggestion that disproportionate declines in plantarflexor strength are responsible for proximal redistribution of joint work. Instead, we suggest that interplay between high demands on plantarflexor muscles during walking and a reduction in maximal plantarflexor strength capacity with age necessitate greater contributions from more proximal musculature. Regardless of whether older adults show disproportionately high declines in plantarflexor strength, maintaining strength of plantarflexor muscles is critical since these muscles are especially important to power generation during walking.

CONFLICT OF INTEREST

The authors have no conflict of interest.

References

[1] Simonsick EM, Guralnik JM, Volpato S, Balfour J, Fried LP. Just get out the door! Importance of walking outside the home for maintaining mobility: findings from the women's health and aging study. J Am Geriatr Soc. 2005;53:198-203.
[2] Winter DA. Biomechanics and motor control of human gait: normal, elderly and pathological. Waterloo, Ontario: University of Waterloo Press; 1991.
[3] Winter DA. Biomechanics and motor control of human movement. Fourth ed. Hoboken, New Jersey: John Wiley & Sons; 2009.
[4] Eng JJ, Winter DA. Kinetic analysis of the lower limbs during walking: what information can be gained from a three-dimensional model? J Biomech. 1995;28:753-8.
[5] Cofré LE, Lythgo N, Morgan D, Galea MP. Aging modifies joint power and work when gait speeds are matched. Gait Posture. 2011;33:484-9.
[6] DeVita P, Hortobagyi T. Age causes a redistribution of joint torques and powers during gait. J Appl Physiol. 2000;88:1804-11.
[7] Savelberg HH, Verdijk LB, Willems PJ, Meijer K. The robustness of age-related gait adaptations: can running counterbalance the consequences of ageing? Gait Posture. 2007;25:259-66.
[8] Silder A, Heiderscheit B, Thelen DG. Active and passive contributions to joint kinetics during walking in older adults. J Biomech. 2008;41:1520-7.
[9] Graf A, Judge JO, Ounpuu S, Thelen DG. The effect of walking speed on lower-extremity joint powers among elderly adults who exhibit low physical performance. Arch Phys Med Rehabil. 2005;86:2177-83.
[10] Judge JO, Davis RB, Õunpuu S. Step length reductions in advanced age: the role of ankle and hip kinetics. J Gerontol Ser A Biol Sci Med Sci. 1996;51:M303-12.
[11] Winter DA, Patla AE, Frank JS, Walt SE. Biomechanical walking pattern changes in fit and healthy elderly. Phys Ther. 1990;70:340-7.
[12] Monaco V, Rinaldi LA, Macri G, Micera S. During walking elders increase efforts at proximal joints and keep low kinetics at the ankle. Clin Biomech. 2009;24:493-8.
[13] Anderson DE, Madigan ML. Healthy older adults have insufficient hip range of motion and plantar flexor strength to walk like healthy young adults. J Biomech. 2014;47:1104-9.
[14] 2008 Physical Activity Guidelines for Americans. Washington, DC: U.S. Department of Health and Human Services; 2008.
[15] National interview survery. Atlanta, GA: Centers for Disease Control and Prevention, US Department of Health and Human Services; 2013.
[16] Vaughan CL, Davis BL, O'connor JC. Dynamics of human gait. Champaign, Illinois: Human Kinetics Publishers; 1992.
[17] Zeni JA, Jr., Richards JG, Higginson JS. Two simple methods for determining gait events during treadmill and overground walking using kinematic data. Gait Posture. 2008;27:710-4.
[18] Robertson DG, Winter DA. Mechanical energy generation, absorption and transfer amongst segments during walking. J Biomech. 1980;13:845-54.
[19] Cohen J. Statistical power analysis for the behavioral sciences. Hillsdale, New Jersey: Lawrence Erlbaum Associates; 1988.
[20] McGibbon CA, Krebs DE. Effects of age and functional limitations on leg joint power and work during stance phase of gait. J Rehabil Res Dev. 1999;36:173-82.
[21] Harbo T, Brincks J, Andersen H. Maximal isokinetic and isometric muscle strength of major muscle groups related to age, body mass, height, and sex in 178 healthy subjects. Eur J Appl Physiol. 2012;112:267-75.

[22] Reeves ND, Spanjaard M, Mohagheghi AA, Baltzopoulos V, Maganaris CN. Older adults employ alternative strategies to operate within their maximum capabilities when ascending stairs. J Electromyogr Kinesiol. 2009;19:e57-68.
[23] Soot T, Jurimae T, Jurimae J, Gapeyeva H, Paasuke M. Relationship between leg bone mineral values and muscle strength in women with different physical activity. J Bone Miner Metab. 2005;23:401-6.
[24] Horstmann T, Maschmann J, Mayer F, Heitkamp HC, Handel M, Dickhuth H. The influence of age on isokinetic torque of the upper and lower leg musculature in sedentary man. Int J Sports Med. 1999;20:362-7.
[25] Teixeira-Salmela LF, Nadeau S, Milot MH, Gravel D, Requiao LF. Effects of cadence on energy generation and absorption at lower extremity joints during gait. Clin Biomech. 2008;23:769-78.

Table 1: Description of participants by group, including peak isokinetic torques (N·m·kg^{-1}) measured at 60 deg·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 (‡).

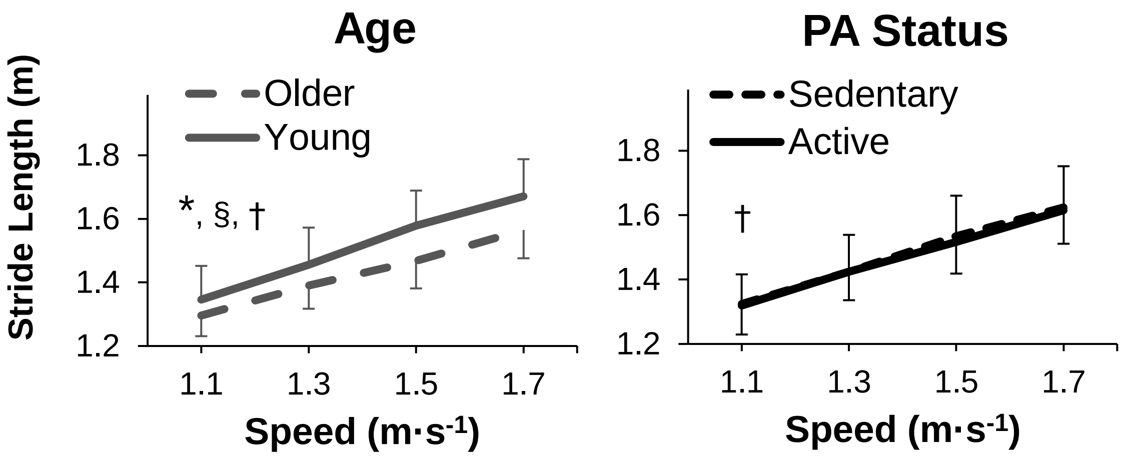

Figure 1: Stride length increased for both older and young adults and active and sedentary individuals with increasing walking speed (left and right panels; $p<0.001$). Left panel shows older adults had shorter stride lengths than young adults (age x speed interaction, $p<0.001$), but these differences were significantly different only at 1.5 $m \cdot s^{-1}$ ($p=0.003$) and 1.7 $m \cdot s^{-1}$ ($p=0.006$). When collapsed on age, sedentary and active individuals displayed nearly identical responses to walking speed increases (right panel). Data are presented as mean ± 1 SD. Statistically significant ($p<0.05$) age main effect (*), age x speed interaction (§), and speed main effect (†).

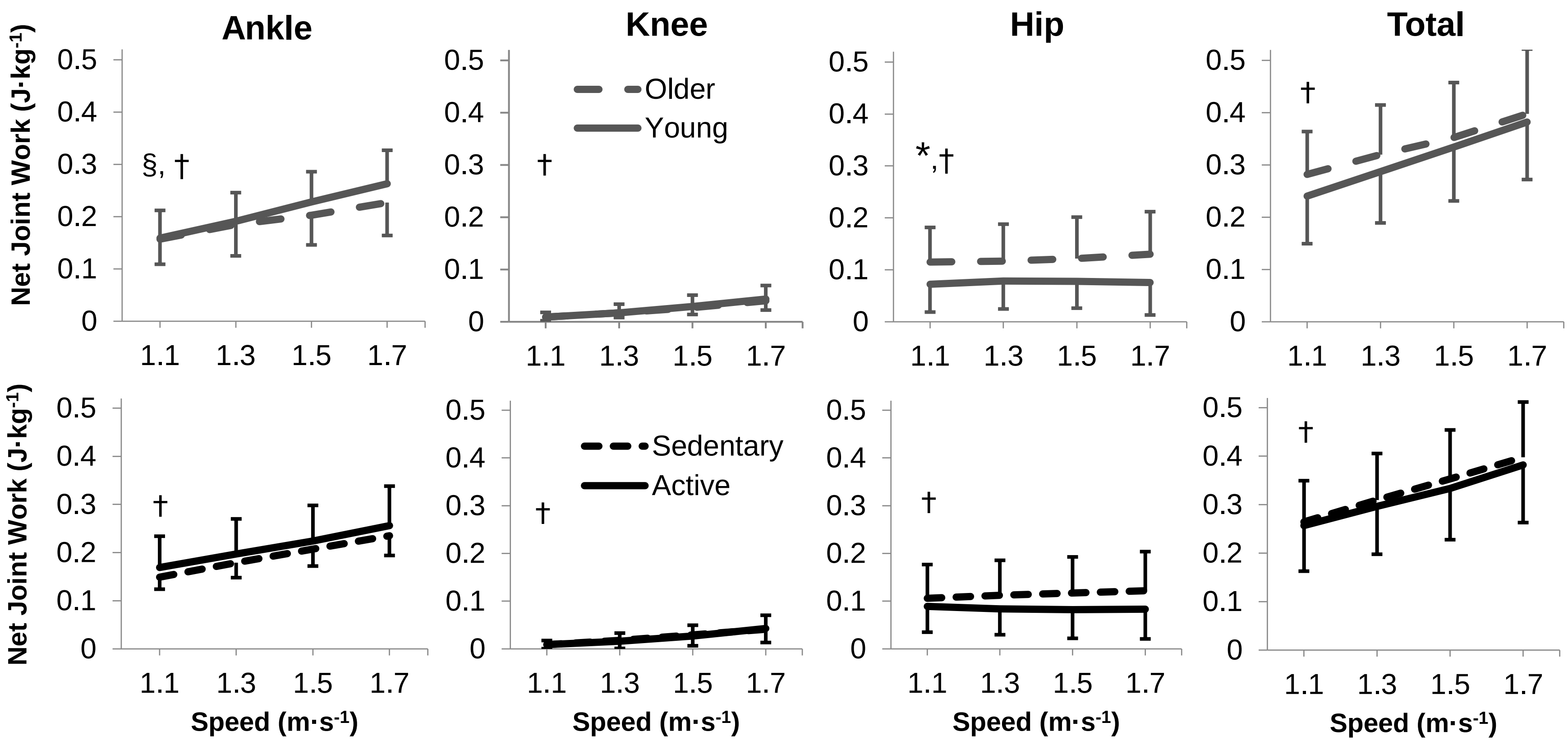

Figure 2: For older vs. young participants (upper panels), older adults performed more average positive work (p=0.043) at the hip compared to young participants. In addition, as speed increased the differences between young and older participants increased for average ankle work (age x speed interaction, p<0.001) and tended to decrease for total work (age x speed interaction, p=0.065). When collapsed on age, no differences were observed in total average work and average ankle, knee, and hip work performed by active and sedentary individuals (lower panels). As speed increased, total average positive work (p<0.001) and average positive

work performed at the ankle ($p<0.001$) and knee increased ($p<0.001$) for both young and older adults and active and sedentary individuals. Data are presented as mean ± 1 SD. Statistically significant ($p<0.05$) age main effect (*), age x speed interaction (§), and speed main effect (†).

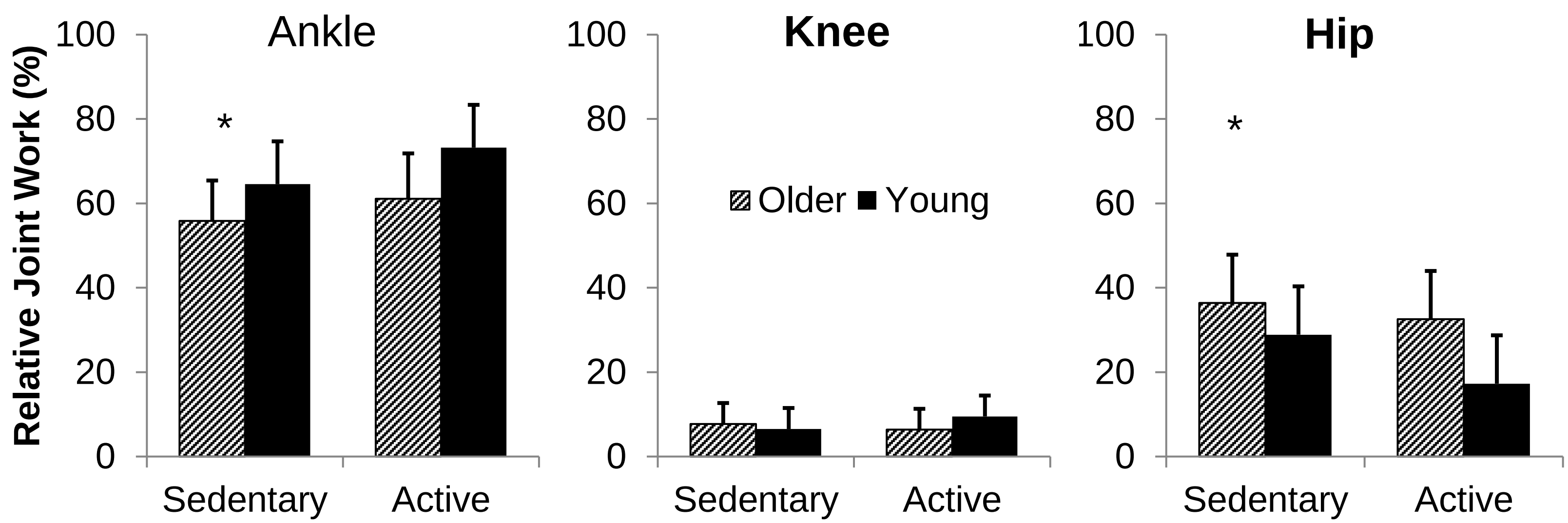

Figure 3: Relative ankle work was lower (p=0.005) and relative hip work was greater (p=0.007) in older compared to young adults. Sedentary participants showed a trend of having lower relative ankle work (p=0.068) and greater relative hip work (p=0.087) than active participants. Relative knee work was not influenced by either age or PA status. Data are presented as mean ± 1 SD. * statistically significant age effect at p<0.05.

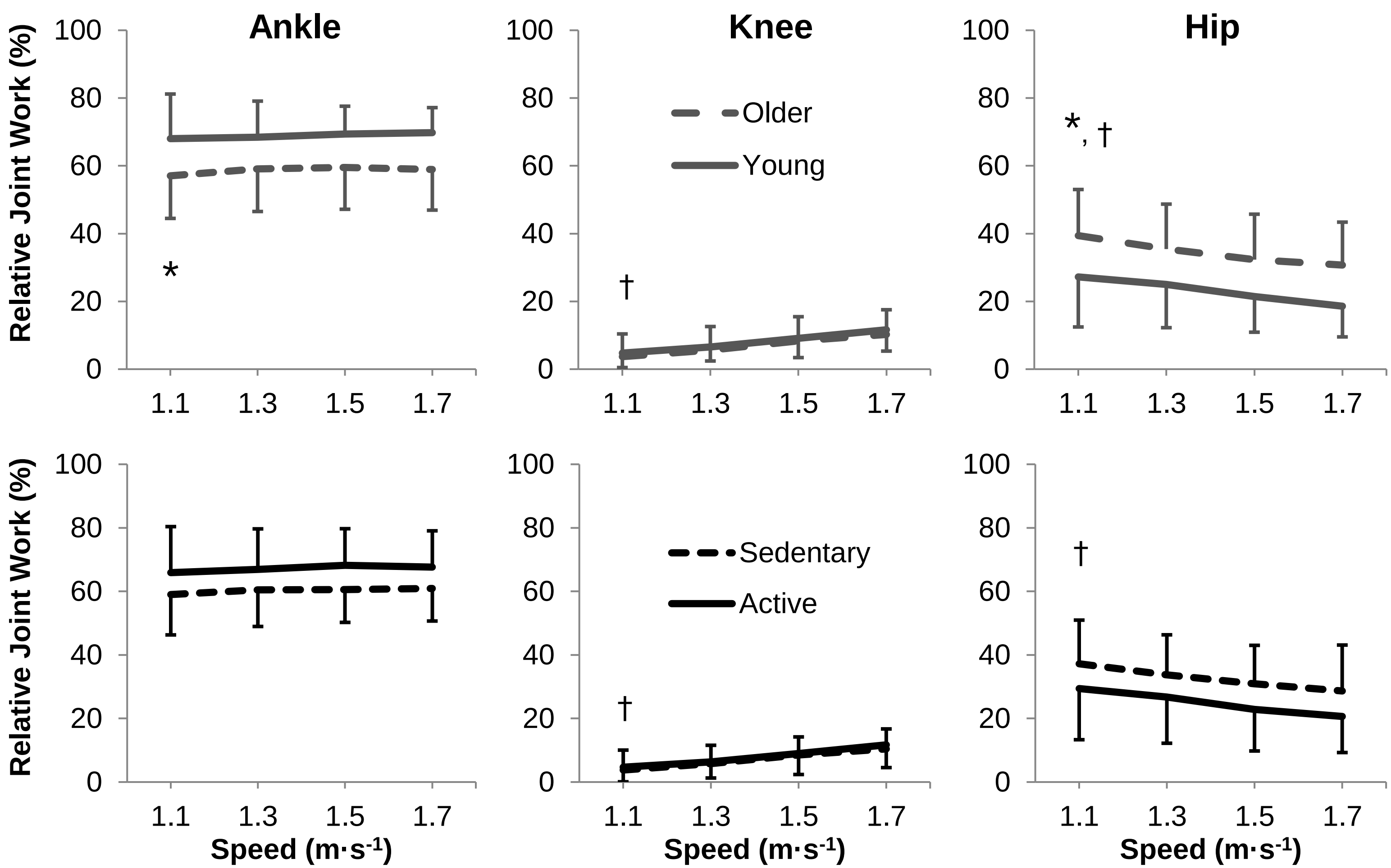

Figure 4: Relative work contributions were lower at the ankle (*p*=0.005) and higher at the hip (p=0.007) for older participants compared to young participants (upper panels). Relative work contributions of sedentary individuals tended to be lower at the ankle and higher at the hip compared to physically active individuals (lower panels; ankle, *p*=0.068; hip, *p*=0.087). As speed increased,

relative knee work increased ($p<0.001$) and relative hip work decreased ($p<0.001$). Data are presented as mean ± 1 SD. Statistically significant ($p<0.05$) age main effect (*) and speed main effect (†).

Highlights

- Older compared to young adults had lower strength across the ankle, knee, and hip.
- Older compared to young adults did lower ankle and higher hip work when walking.
- Sedentary compared to active adults tended to show lower ankle and higher hip work.