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AGE-RELATED EFFECTS OF LEG MUSCLE FATIGUE ON WALKING

[1,2]Fabio A. Barbieri, [1]Paulo C. R. Santos, [1]Lucas Simieli, [1]Diego Orcioli-Silva, [2]Jaap H. van Dieën and [1]Lilian T. B. Gobbi

[1]UNESP – Universidade Estadual Paulista– LEPLO – Rio Claro – Brazil
[2]MOVE Research Institute Amsterdam, Faculty of Human Movement Sciences, VU University Amsterdam, the Netherlands; email: barbieri_rc@hotmail.com

SUMMARY

Older adults walk more cautiously than young adults. Fatigue affects gait in young adults in a similar way. However, whether age and fatigue interact and from which age on is unknown. The aim of this study, therefore, was to analyze the age-related effects of leg muscle fatigue on walking. One hundred and twenty men, distributed over six age groups, participated. Participants performed the following sequence of the tasks: a) maximum voluntary contraction protocol; b) walking trials; c) muscle fatigue protocol; d) walking trials; e) maximum voluntary contraction protocol. Spatial-temporal and kinetic walking parameters were analyzed, and compared by two-way ANOVA (group and fatigue). The results showed age-related effects of leg muscles fatigue on walking. From 40 years old, participants modulated spatial-temporal parameters and vertical impulses more in response to fatigue than younger participants, apparently to improve balance and safety.

INTRODUCTION

Older adults walk more cautiously than young adults, with increased cadence and double support time, and decreased walking speed and stride length [1-2], probably in response to a decrease in functional capacity [3] and declined information processing [4]. Fatigue affects gait in young adults in a similar way [your review paper]. However, whether age and fatigue interact and from which age on is unknown. The aim of this study, therefore, was to analyze the age-related effects of leg muscle fatigue on walking.

METHODS

One hundred and twenty men were distributed over six groups of 20 participants: G20 - from 20 to 29 years; G30 - from 30 to 39 years; G40 - from 40 to 49 years; G50 - from 50 to 59 years; G60 - from 60 to 69 years; G70 - above 70 years. The study was approved by the local Ethics Committee (#2055/2008). The sequence of the experiment was: a) maximum voluntary contraction protocol; b) walking trials; c) muscle fatigue protocol; d) walking trials; e) maximum voluntary contraction protocol.

Maximum voluntary isometric contractions were performed in a leg press device. A load cell with a precision of 0.98 N was used in combination with a signal amplifier (EMG System do Brasil Ltda.). The participant performed the test with both legs, with the instruction to produce maximum force as fast as possible. Total contraction duration was 5 s. Two attempts were made with 2 min rest between attempts before and after muscle fatigue.

Participants performed three walking trials. The instruction given to the participant was to walk over an 8 m pathway, at self-selected speed. Ground reaction forces were measured using one force plate (AccuWalking, Advanced Mechanical Technologies), positioned across the central area of the pathway. Gait kinematics were recorded with a three-dimensional optoelectronic system (OPTOTRAK Certus), tracking four infrared emitters placed over: the lateral face of calcaneus and head of the fifth metatarsus of the right limb, and medial face of calcaneus and head of the first metatarsus of the left limb. The data acquisition systems were synchronized.

To induce fatigue, participants performed a repeated sit-to-stand task from a chair with arms across the chest [6]. The rate was imposed by a metronome (0.5Hz). The instruction was: stand up to an upright position with your knees fully extended, then sit back down and repeat this at the beat of the metronome until you can no longer perform the task. The fatigue protocol was stopped when the participant indicated that he was unable to continue, when the movement frequency fell below and remained below 0.5Hz after encouragement, or after 30 min.

For the stride in the middle of the path, we determined stride length, duration, and speed, step width, braking and propulsive impulses of the vertical forces (normalized to body weight). The dependent variables of interest were analyzed with SPSS 15.0 for Windows® ($\alpha<0.05$). The maximum voluntary contraction was compared before and after fatigue for each group by Student's t-tests to confirm leg muscle fatigue. The spatial-temporal and kinetic variables were compared using a two-way ANOVA, with group and fatigue, with repeated measures over the last factor. Tukey univariate tests were used as post-hoc tests.

RESULTS AND DISCUSSION

The fatigue protocol did induce fatigue in all groups as demonstrated by the lower values of maximum voluntary forces ($p<0.05$) (Table 1).

Univariate analyses of gait parameters indicated main effects of group and fatigue (Table 1). Moreover, there were group*fatigue interactions for stride length ($p<0.001$), stride duration ($p<0.001$), stride velocity ($p<0.001$), braking ($p<0.01$) and propulsive ($p<0.01$) vertical impulse.

Regarding the group*fatigue interactions, the Tukey univariate test indicated that the older groups (G40, G50, G60 and G70) increased stride length significantly with leg muscle fatigue, while the younger groups (G20 and G30) did not show an effect of muscle fatigue. All groups reduced stride duration with muscle fatigue, but the oldest group (G70) decreased the stride duration significantly more in comparison to the G20, G30 and G40 groups. Moreover, all groups increased stride speed with muscle fatigue, but the older (G50, G60 and G70) groups showed a larger increase of stride speed in comparison to the youngest groups. Furthermore, the G70 group showed decreased the braking vertical impulse with leg muscle fatigue more than the G20 and G40 groups. The propulsive vertical impulse decreased with muscle fatigue in the G20, G40 and G70 groups thus not revealing a clear age-related pattern.

Stride length increased with fatigue and more so among the older groups. This is unlikely to be a direct effect of fatigue, since more muscle force is required to take bigger strides. Stride length could be increased to enhance balance control in the sagittal plane. In walking, the anterior margin of safety is negative, implying that a next step is needed to maintain balance. Increasing step length will decrease the magnitude of the negative margin making it easier to come to a stop in a single step and in principle making it easier to avoid a forward fall [8].

Stride duration decreased with fatigue and again more so among the older groups. Again this is unlikely to be a direct fatigue effect. A decrease in stride time has been observed under external perturbations of balance [9] and facilitates balance control in the medio-lateral direction as well as in the fore-aft direction [8].

The increase stride length and decreased stride duration caused an increase in speed, which, as the changes in the underlying variables, was more pronounced in the older groups. It is often assumed that increased walking speed is associated with an increased risk of falls [7] but it appears that changes in stride length and duration are more important in terms of balance control then the resulting speed [9]. Moreover, the low propulsive impulse was resulted of lower plantar flexor activity after knee muscles fatigue [6], which is coincident with walking speed approaches [10] and seems be an effect of muscle fatigue.

CONCLUSIONS

In conclusion, gait is affected by an interaction of age and fatigue of the leg muscles. In general, the participants appeared to make spatial-temporal and kinetics adjustments to improve balance and safety after muscle fatigue. These adjustments were more pronounced in groups over 40 years old.

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Table 1: Means and standard deviations of spatial-temporal and kinetic variables on walking by group before and after leg muscle fatigue. For each variable, the first line is before leg muscle fatigue and the second line is after leg muscle fatigue.

Variables	G20	G30	G40	G50	G60	G70
spatial-temporal						
stride length (cm)	135.67±11.71	134.25±10.19	131.00±8.20	137.07±13.93	135.35±13.10	124.18±13.49
	136.15±12.05	134.62±12.25	133.97±7.70	138.97±14.57	139.55±12.70	128.62±15.41
step width (cm)	11.48±2.70	11.42±2.42	12.85±3.59	11.80±2.87	9.97±2.60	10.22±2.50
	12.73±3.06	12.78±2.69	14.06±2.99	13.01±3.30	10.96±2.71	11.10±2.67
stride duration (s)	1.09±0.10	1.11±0.24	1.10±0.09	1.07±0.07	1.10±0.08	1.08±0.11
	1.07±0.08	1.09±0.25	1.06±0.09	1.05±0.08	1.06±0.07	1.04±0.11
stride velocity (cm/s)	125.73±17.32	125.28±21.12	120.12±13.66	128.95±18.25	124.00±17.34	116.79±19.63
	128.70±17.68	128.88±24.25	127.38±14.66	136.62±19.66	133.30±18.06	126.2±5.29
kinetic						
braking vertical impulse (BWs)	0.29±0.04	0.28±0.03	0.31±0.04	0.30±0.04	0.29±0.04	0.28±0.04
	0.30±0.06	0.28±0.04	0.31±0.04	0.29±0.04	0.29±0.04	0.27±0.04
propulsive vertical impulse (BWs)	0.26±0.04	0.24±0.03	0.26±0.04	0.24±0.04	0.27±0.04	0.26±0.04
	0.24±0.04	0.24±0.03	0.24±0.04	0.24±0.04	0.25±0.04	0.25±0.04