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INCREASING STRENGTH-TO-WEIGHT RATIO BY BODY WEIGHT UNLOADING NORMALIZES GAIT BIOMECHANICS IN OLDER ADULTS

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SUMMARY

The aim of this study was to compare the effect of incrementally increasing the strength-to-weight ratio (S:W) on gait biomechanics in older adults using a body weight unloading model. Knee extensor maximum voluntary isometric contraction torque (MVIC) was recorded. The S:W was calculated by normalizing the MVIC to body mass. An overhead, pneumatic unweighting system was utilized to reduce body weight and manipulate the S:W. Walking trials were performed at four different levels of S:W: normal S:W, S:W +0.1 $Nm.kg^{-1}$, S:W +0.2 $Nm.kg^{-1}$, and S:W +0.3 $Nm.kg^{-1}$. Vertical ground reaction forces (VGRF), stride kinematics and muscle activation were recorded for 10 seconds while the subjects walked on an instrumented treadmill at self-selected speed. Weight acceptance peak force ($p = 0.02$), push-off peak force ($p < 0.001$), push-off rate ($p = 0.009$), double limb-support time ($p = 0.002$) and gastrocnemius lateralis activation ($p = 0.07$) were lower in the +0.3 $Nm.kg^{-1}$ condition than at normal S:W. Manipulating S:W, using artificial body weight reduction, suggests that the knee extensor S:W must increase by approximately 0.3 $Nm.kg^{-1}$ to promote improved gait biomechanics in older adults.

INTRODUCTION

Aging negatively affects the lower-extremity strength-to-weight ratio (S:W) which results in difficulty walking, climbing stairs and standing [1]. Cross-sectional studies show a linear relationship between S:W and mobility in older adults but it is likely that longitudinal gains in S:W do not result in equal improvements in mobility [1]. It is possible to study the effect of an improved S:W on walking performance in a within-subjects design, not by increasing strength but by artificially reducing weight with an overhead support system. The aim of this study was to compare the effect of incrementally increasing the S:W on gait biomechanics in older adults using a body weight unloading model.

METHODS

Subjects

Data of eight older adults (5 women and 3 men) were considered for this study. The subjects had an average age of 72.1 ± 5.8 yr, body mass of 85.4 ± 27.7 kg, body mass index of 28.7 ± 6.8 kg m^{-2}, Rapid Assessment of Physical Activity (RAPA) 1 score of 5.9 ± 1.2, RAPA 2 score of 1.3 ± 1, and Short Physical Performance Battery (SPPB) score of 10.9 ± 1.4.

Procedures

Data collection was performed on three different days. On the first day, the SPPB was performed and subjects were habituated to strength assessment and treadmill walking with body weight support. On the second day, knee extensor MVIC torque was recorded and a second habituation session of treadmill walking was performed. On the third day of data collection, gait biomechanics data (VGRF and stride kinematics) and muscle activations were recorded at the four different S:W conditions while walking at preferred speed.

Strength Measurements

Subjects were positioned on the dynamometer chair with the knee flexed at 75º. Four MVIC of the knee extensors were performed for each leg, for a duration of three seconds, with 30 seconds of rest between each trial. All strength measurements were completed using a HUMAC Norm dynamometer (CSMI, Stoughton, MA, USA) integrated with a BIOPAC MP150 data acquisition system (Biopac Systems, Inc., Goleta, California, USA) that recorded joint torques from the analog output of the dynamometer at a sample rate of 1,000 Hz. Torque data were smoothed by taking the mean every 20 samples using a sliding window. The highest peak torque was taken from for trials of each leg from each leg. These two values were averaged and normalized to body mass to determine the knee extensor S:W. Then, for each subject the reduction in body mass needed to increase S:W by 0.1, 0.2 and 0.3 $Nm.kg^{-1}$ was determined according to the following equations:

$$Eq\ 1.\ Target\ S{:}W = S{:}W + 0.1\ Nm.kg^{-1}$$

$$Eq\ 2.\ Target\ Body\ Mass = \frac{Knee\ extensor\ MVIC}{Target\ S{:}W}$$

$$Eq\ 3.\ Target\ Unloading = Body\ Mass - Target\ Body\ Mass$$

Gait Biomechanics and Muscle Activation Assessment

Participants walked on a motorized, instrumented treadmill equipped with in-deck force plates (Gaitway II, Kistler Instrument Corp., Amherst, NY, USA) that recorded VGRF and kinematic gait variables for each foot over ten seconds at a sample rate of 200 Hz.

The gait biomechanics assessment protocol consisted of: a familiarization of three minutes walking on the treadmill at 0.8 $m\cdot s^{-1}$, one minute of walking on the treadmill at maximal comfortable gait speed, and one minute of walking on the treadmill at preferred gait speed for each of four different S:W conditions (normal S:W; S:W +0.1 $Nm\cdot kg^{-1}$; S:W +0.2 $Nm\cdot kg^{-1}$; and S:W +0.3 $Nm\cdot kg^{-1}$). The S:W was artificially manipulated using an overhead pneumatic body weight unloading system (PneuWeight, Pneumex, Sandpoint, ID, USA) that provided a vertical lift to reduce body weight.

Electromyography

Electromyogram (EMG) signals were recorded by telemetry (BioNomadix, Biopac Systems, Inc, Goleta, CA, USA) at a sample frequency of 1,000 Hz for vastus lateralis (VL) and gastrocnemius lateralis (GL) muscles during the four different S:W conditions [2]. The reference electrode was placed on the patella. Before placing the electrodes, the subject's skin was shaved and cleaned with alcohol to reduce impedance. The EMG signal was band-pass filtered between 20-500 Hz, full-wave rectified and the signal was integrated every 20 samples. The average peak value of six strides, at each level of S:W, was normalized to the peak EMG obtained from the maximal speed trial.

Statistical Analysis

Repeated measures analysis of variance was used to compare the VGRF (weight acceptance peak force, push off peak force, weight acceptance rate and push off rate), kinematics (stride length, double-limb support time, and single-limb support time) and VL and GL muscles activation between the four different S:W trials in a within subjects design. When a significant time (trial) effect occurred, least significant difference post-hoc analysis was used to determine which trials were different. The significance level was set at $p < 0.05$ for all tests.

RESULTS AND DISCUSSION

Significant differences between trials occurred for weight acceptance peak force ($F = 10.45$ and $p < 0.001$), push-off peak force ($F = 38.89$ and $p < 0.001$), push off rate ($F = 5.37$ and $p = 0.007$), single-limb support time ($F = 3.79$ and $p = 0.026$), double-limb support time ($F = 5.46$ and $p = 0.006$) and gastrocnemius lateralis activation ($F = 3.99$ and $p = 0.024$). Preferred gait speed was not different between conditions ($F = 0.72$, $p = 0.97$), nor was stride length ($F = 0.99$, $p = 0.41$).

Weight acceptance peak force (Newtons) in the S:W +0.3 $Nm.kg^{-1}$ condition was 7% lower than S:W ($p = 0.02$), 13% lower than S:W + 0.1 $Nm.kg^{-1}$ ($p = 0.001$), and 6% lower than S:W + 0.2 $Nm.kg^{-1}$ ($p = 0.011$). Also, the weight acceptance peak force was 13% lower at S:W +0.2 $Nm.kg^{-1}$ than at S:W ($p = 0.024$). Push-off peak force was, respectively, 6%, 12% and 22% higher at S:W than at S:W +0.1 $Nm.kg^{-1}$ ($p = 0.015$), S:W +0.2 $Nm.kg^{-1}$ ($p = 0.003$), and S:W +0.3 $Nm.kg^{-1}$ ($p < 0.001$). Also, push-off peak force was 12% higher at S:W +0.1 $Nm.kg^{-1}$ than at S:W +0.2 $Nm.kg^{-1}$ ($p = 0.031$) and 11% higher at S:W +0.2 $Nm.kg^{-1}$ than S:W +0.3 $Nm.kg^{-1}$ ($p < 0.001$). Push-off rate was, respectively, 24% and 21% lower at S:W +0.3 $Nm.kg^{-1}$ than at S:W ($p = 0.009$) and S:W +0.1 $Nm.kg^{-1}$ ($p = 0.001$).

For the conditions that a vertical lift was provided to increase the S:W, body weight was decreased which required a lower VGRF at the same walking speed. Although joint torque was not measured during walking, the lower VGRF should have resulted in lower extensor torques at the hip, knee and ankle, allowing these muscles to work at a lower percentage of their capacity. The reduction of the weight acceptance peak force may make this exercise modality useful for older adults with lower extremity weakness or osteoarthritis.

Single-limb support time was, respectively, 3% and 4% longer at S:W +0.3 $Nm.kg^{-1}$ than at S:W +0.1 $Nm.kg^{-1}$ ($p = 0.018$) and S:W +0.2 $Nm.kg^{-1}$ ($p = 0.047$). Double-limb support time was, respectively, 16%, 13% and 13% shorter at S:W +0.3 $Nm.kg^{-1}$ than S:W ($p = 0.002$), S:W +0.1 $Nm.kg^{-1}$ ($p = 0.026$), and S:W +0.2 $Nm.kg^{-1}$ ($p = 0.023$). Shorter single-limb support time and longer double-limb support time often occur in older adults with balance and strength deficits [3]. Our findings demonstrated that an increase in the S:W of +0.3 $Nm.kg^{-1}$ may be the strength threshold necessary to promote improvements in the temporal aspects of elderly gait. This finding may provide clinicians working with older adults a strength improvement goal likely to enhance mobility, although these preliminary findings should be validated in a larger sample.

GL activation was 12% and 9% lower at S:W +0.2 $Nm.kg^{-1}$ than S:W ($p = 0.02$) and S:W + 0.1 $Nm.kg^{-1}$ ($p = 0.006$). Motor unit recruitment increases concurrently as muscular force increases to maximal capacity. Thus, for the trials that increased the S:W, the muscles were working at a lower percentage of capacity which reduced activation and may have resulted in reduced reliance on high-threshold motor units that are characteristically prone to fatigue. Thus, a reduction in the required vertical force during push off, and a reduced activation of GL motor units when S:W is improved, may reduce perceived effort and the onset of fatigue during walking in older adults.

CONCLUSIONS

The artificial increase in S:W promoted a normalization of temporal gait biomechanics and reduction in muscle activation in older adults. The strength increment of 0.3 $Nm.kg^{-1}$ was the condition that promoted the most significant changes in kinetic, temporal, and muscle activation parameters. However, preferred gait speed was unaltered which suggests that an extended period of adaptation may be needed to alter customary walking speed.

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