ELECTROMECHANICAL DELAY AND LEG –SPRING STIFFNESS IN YOUNG AND OLDER MEN

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This study compared leg-spring stiffness and electromechanical delay times in muscles of older and younger adult males. Vertical leg-spring stiffness measures were obtained from 10 older males and 12 younger males who completed drop jumps on a force-sledge apparatus from a drop height of 30 cm. Electromechanical delay times were also obtained on the ankle plantar flexors while performing a simple heel raise activity. The results indicated that younger males produced 24% longer EMD times and 58% higher leg-spring stiffness scores compared with older males ($p < 0.001$). These results suggest that younger males jumped using a stiffer overall leg-spring but older males have a stiffer tendon contribution to overall leg–spring stiffness.

KEY WORDS: muscle-tendon stiffness, running, ageing, jumping.

INTRODUCTION: The role of muscle stiffness in controlling performance in running and jumping has been described using linear spring-mass models and there is strong evidence that leg-spring stiffness is related to cadence and running speed, (McMahon and Cheng, 1990). Leg spring-mass models assume the numerous musculoskeletal springs combine so the entire musculoskeletal system can act as a single linear spring (McMahon and Cheng, 1990; Kerdok et al, 2002). The stiffness of this spring-mass system is thought to have two distinct components, namely vertical stiffness ($\mathbf{k}_{\mathbf{vert}}$) and overall leg-spring stiffness ($\mathbf{k}_{\mathbf{leg}}$). Vertical stiffness provides the mechanism by which the downward velocity of the body is reversed during ground contact and can be calculated from the ratio of the peak vertical force (Fy_{peak}) to the vertical displacement of the centre of mass (Δy) during contact. McMahon and Cheng (1990) and Farley and Gonzalez (1996) have shown that Fy_{peak} and Δy occur simultaneously during running and hopping. Although $\mathbf{k}_{\mathbf{vert}}$ does not correspond to any physical spring in the model, it is important in determining how long the spring-mass system remains in contact with the ground. Furthermore, in activities where the leg-spring acts vertically, such as hopping or running on the spot, $\mathbf{k}_{\mathbf{vert}} = \mathbf{k}_{\mathbf{leg}}$. Such models do not isolate the structural spring mechanisms such as the tendon from the contractile elements, therefore the contribution of structural elements to leg-spring stiffness remains unknown. The electromechanical delay (EMD) during muscle contraction gives an indication of the musculotendinous stiffness, which is one of many aspects that contribute to leg stiffness. “In general the passive joint stiffness, the intrinsic muscle stiffness and stretch reflexes each contribute significantly to the net joint stiffness” Arampatzis, (1999). Winter and Brookes (1991) have shown that the compliance or stiffness of the musculotendinous structures can be effectively estimated by determining electromechanical delay (EMD). Furthermore, Winter and Brookes (1992) proposed the EMD can be subdivided into two periods, one representing the delay between muscle activation and force registration, force development time (FDT) and the second period representing Elastic Charge Time (ECT) which describes the delay between the first registration of force and movement. It is proposed that ECT is affected by the compliance of the musculotendinous structures. To date, the influence of the ageing process on leg-spring stiffness control remains unclear.

The purpose of this study was to compare the leg-spring stiffness and EMD times in older and younger adult males and in doing so, examine how age influences the relative contributions of structural (tendon) and contractile components of leg-spring stiffness control in jumping activities.

METHOD: Twenty-two adult males participated in this study. The participants were separated into two groups: younger adults consisting 12 adults aged 19 to 23 years and older adults consisted of 10 adults aged 47 to 60 years. The study had obtained ethical approval from the University Research Ethics Committee and written informed consent was obtained from all subjects prior to their participation in the study.

Table 1: Physical characteristics of the subjects

Group		Age (years)	Height (cm)	Weight (N)
Younger	Mean (±SD)	21.75 (±1.42)	179.5 (±5.25)	770 (±78)
Older	Mean (±SD)	54.00 (±4.30)	176 (±4.76)	756 (±81)

All participants completed a simple heel raising activity to obtain measures of EMD as described by Winter & Brookes (1991). In this procedure, participants sat on a plastic chair with the knee joint at a 90° angle. The ball of the foot was placed on a force plate and the remainder of the foot on the floor. A foot switch was placed under the heel and EMG electrodes were attached to the calf muscle detect changes in electrical activity from the triceps surae muscle group. On the command, 'Go' participants were required to raise their heel as fast as possible. EMG analysis was performed using a BioPac/ Powerlab 2/20 system (Biopac Systems, Inc, Goleta, CA, USA). The change in activation of the muscle was determined by inspection of the EMG records. Following previous work (Clegg and Harrison 2005), a change of ±0.015 mV in the EMG signal was used to indicate increased muscle activation. The instant of foot plantar flexion force was detected from the force platform records and the heel movement was detected by the foot-switch. EMD was defined as the time period between muscle activation and heel movement. ECT was defined as the time interval between the registration of force on the force platform and movement of the heel. FDT was defined as the time interval from the muscle activation to the registration of increased force and was calculated by subtracting the ECT from the EMD time, (Winter and Brookes, 1991). All participants completed 10 trials with approximately 30 to 60 seconds between trials.
All participants also completed three two-legged drop jumps from a 30 cm drop height. All jumps were performed on a force-sledge apparatus. This consisted of a sledge with attached chair sliding on a fixed track inclined at 30° to the horizontal. A winch with a quick-release mechanism was located at the top of the track. This was attached to the sledge and used to hoist subjects to desired height for dropping. A force plate was positioned at right angles to the base of the track. Participants were instructed to jump maximally and to minimise their ground contact time. Participants were secured in the chair with a harness and straps at the waist and shoulders to prevent any upper body movement during the jumps. Ground reaction force measurements were obtained for each jump using an AMTI (Watertown, MA, USA) force plate which sampled at 1000 Hz. A reflective marker was attached to the sledge and SVHS (50 Hz.) video recordings were obtained of the motion of the sledge during the jumps. Ground reaction force measurements were synchronised with the video data using a Peak event and video control unit, (Peak Performance Technologies, Colorado, USA). The video records were digitised using Peak Motus® and the displacement of the sledge from was calculated from the video records using a GCV quintic spline algorithm. The vertical leg spring stiffness was defined as the ratio of the peak force in the spring to the displacement of the spring at the instant of maximal compression (i.e. bottom of the crouch) and was obtained using the following equation:

$$\mathbf{k}_{\mathbf{vert}} = \frac{Fy_{crouch}}{D_{sledge}}$$

where Fy_{crouch}= maximum force at the bottom of the crouch.
D_{sledge}= maximum displacement of sledge at the bottom of the crouch

Overall jumping performance was measured by calculating the flight time of the jump from force platform record.

Statistical Analyses: All statistical analysis of the data was carried out in SPSS © (Release 12.0.1). An independent Student t-test was used to determine significant differences in electromechanical delay times, flight time and $\mathbf{k_{vert}}$ scores between the older and younger adult groups. Effect sizes were estimated using Cohen's **d** which is given by the equation:

$$\mathbf{d} = \frac{M_{young} - M_{old}}{SD_{pooled}}$$

where $M_{young} - M_{old}$ is the difference between the two group means
SD_{pooled} is the standard deviation of all measures

RESULTS AND DISCUSSION: Figure 1 presents the results of the EMD analysis on younger and older adult males. Winter and Brooks (1991) proposed that FDT is an indication of the conduction of the action potential along the T tubule and the subsequent release of calcium by the sarcoplasmic reticulum, and ECT is the time between the development of tension and actual movement.

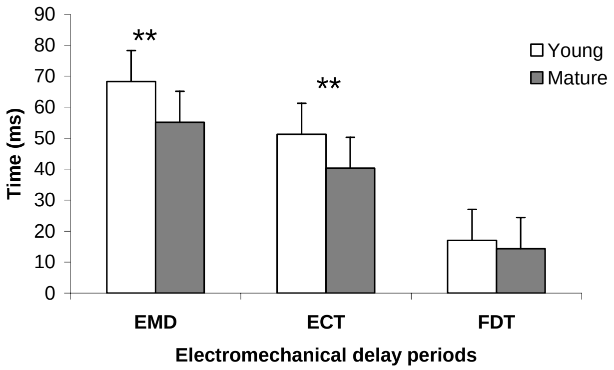

Figure 1 Mean EMD, FDT and ECT scores with 95% Confidence intervals for younger and older adult groups. (**indicates a significant difference between groups; $p<0.001$).

The results of this experiment showed no age related difference in FDT but there were significant differences ($p< 0.001$) for EMD and ECT (Levene's test of equal variance was not significant in all cases, $p > 0.05$). The shorter EMD and ECT times are indicative of greater musculotendinous stiffness in older adults compared to younger males. The effect sizes (Cohen's **d**) for EMD and ECT were 2.95 and 2.61 respectively. These results indicate very large effect sizes between the two age groups and this suggests that ageing causes a significant increase in tendon stiffness. This could be explained by the relatively higher ratio of tendon to contractile tissue in older muscle. This finding is contrary to that of Maganaris (2001) who found greater tendon compliance in subjects aged 70 to 80 years. The mean overall jumping performance (flight time) of younger adults was 0.330 s (±0.057) compared with 0.309 s (±0.042) for older adults. The difference in means was not statistically significant.

Figure 2 presents the results of the leg-spring stiffness test and the results indicate that younger adult males generated significantly higher $\mathbf{k_{vert}}$ scores compared with the older adult group. Cohen's **d** for $\mathbf{k_{vert}}$ was 2.65 suggesting a very large age related effect size for leg-spring stiffness. Leg-spring stiffness is an overall measure of how the spring-mass model of the leg behaves in running or hopping and the stiffness score will be influenced a combination of various components such as joint, tendon and muscle contraction force. Taken together, the results of this experiment indicate that overall leg-spring stiffness is higher in younger adults whereas tendon stiffness appears to be higher in older adults. Since overall leg stiffness is reduced in older adults this suggests that with ageing, the muscle contraction component of leg stiffness will be reduced.

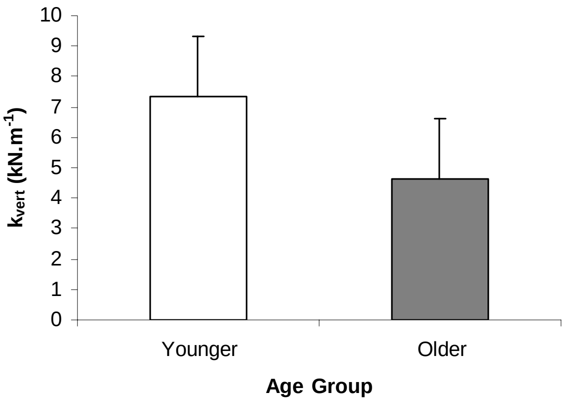

Figure 2: Mean Leg spring stiffness scores with 95% Confidence intervals for older and younger adult groups while performing drop jumps at 30 cm. (** indicates a significant difference between groups; $p<0.001$).

The contribution that increased tendon stiffness makes to overall leg-spring stiffness in older males is far exceeded by the increased muscle force contribution to stiffness in the younger adult group. The results suggest that older adults appear to utilise a different strategy in their jumping performance which results in lower overall leg-spring stiffness and reduced contribution from muscle contraction force. The results of the EMD analysis indicate that in addition to the important role that muscle plays in controlling the leg-spring stiffness in jumping, the structural elements of the muscle and tendon also have a significant contribution to stiffness control in running and jumping especially in older adults.

CONCLUSION: This study shows that younger adults generate significantly higher leg-spring stiffness and longer EMD times compared with older adults. This suggests that older adults may use a different jumping strategy to control stiffness while jumping.

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