Age Related Effects on Muscle Excitation During The Five Times Sit-To-Stand Test

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ABSTRACT

Each year, 28-35% of people 65 and over have at least one injurious fall, which can limit mobility and reduce quality of life. The Five Times Sit-To-Stand (5xSTS) is a clinical evaluation of muscle strength and fall risk. However, the outcome of this assessment only reflects time to completion and does not reveal muscle coordination or movement during the task. Evaluating muscle coordination is important to guide treatment and reduce fall risk. Net joint moments can provide insight to the muscle mechanical requirements for task completion, which can explain differences in muscle excitation. Thus, we evaluated lower limb muscle excitation, sagittal hip, knee and ankle joint moments, and time to completion of 5xSTS in healthy younger and older adults. Twenty-two (11 younger and 11 older) healthy adults completed a 5xSTS trial where they rose from a seat to a standing position and returned to the seat five consecutive times as quickly as possible. We compared integrated electromyography values for the leg and low back muscles as well as hip, knee, and ankle joint moments between groups with an unpaired t-test. Older adults required greater muscle excitation for the gluteus medius (p=0.025), lumbar paraspinals (p=0.014), rectus femoris (p=0.002), vastus lateralis (p=0.011), and tibialis anterior (p=0.038). Older adults took a similar amount of time to complete 5xSTS (p=0.473), indicating muscle compensations in this group. Older adults had similar or lower joint moments when compared to younger adults. Thus, older adults generated similar muscle forces as younger adults during 5xSTS but required greater muscle excitation to achieve these muscle forces. Muscle excitation changes may affect energy cost and fall risk during sit-to-stand with aging. Understanding these changes can aid in developing rehabilitation treatments and muscle strength benchmarks.

> “Understanding muscle activity across the lifespan during clinical mobility assessments, such as the five times sit to stand test, is critical for identifying fall risk and diagnosing movement deficits. This article explores muscle-level adaptations that older adults use to rise quickly and effectively.”
>
> — Dr. Anne Silverman

Introduction

The global population is trending toward a larger proportion of older adults due to long lifespans and lower birth rates [1]. Each year, 28-35% of people 65 and over have at least one injurious fall, which can limit mobility, reduce quality of life, decrease the ability to work, and cause loss of independence [2]. Mitigating fall risk is important to maintain independence in the aging population and reduce overall healthcare costs. Muscle strength is known to decline with age and a decrease in lower limb strength has been linked to a higher risk of falls [3]. Currently, fall prediction is completed with accessible clinical assessments used to evaluate gross muscle strength and to identify individuals who are at risk of an injurious fall. The Five Times Sit-to-Stand (5xSTS) is a commonly used clinical assessment, which only requires a chair and a timer. This assessment has been shown to have good to excellent test-retest reliability when measuring lower limb strength [4]. However, the main outcome of this assessment, time to completion, does not reveal muscle coordination or movement strategy. Understanding factors that limit performance or alter the movement strategy needed for older adults to complete the task may aid in making more effective rehabilitation protocols that reduce fall risk.

Standard anatomical directions and planes are used to describe motion and outcome metrics in this study (Fig. 1). To compare movement strategy between older and younger adults muscle excitation was evaluated. Muscle excitation is the signal from motor neurons that causes a muscle to contract and produce force. Lower limb and trunk muscles were the focus of this analysis, as well as several prior sit-to-stand transfer studies due to their contribution to dynamic postural control. Specifically, the lumbar paraspinals, gluteus medius, rectus femoris, biceps femoris long head, vastus lateralis, medial gastrocnemius, soleus, and tibialis anterior were explored (Fig. 2).

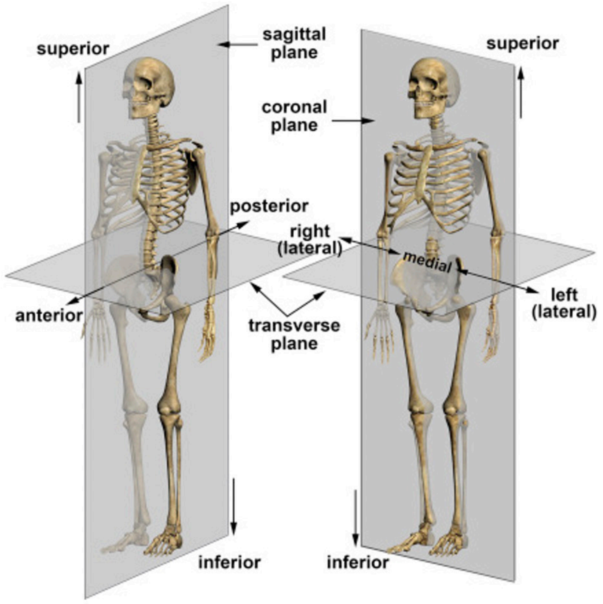

Figure 1 *Anatomical Planes of Reference and Directional Terms [5].*

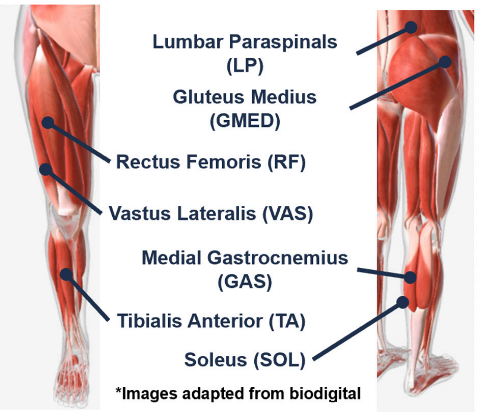

Figure 2 *Lower Limb and Trunk Muscles Evaluated.*

Previous research on the 5xSTS assessment has been limited in the quantifying muscle excitation and movement coordination for individuals across the lifespan. In a 5xSTS study of patients who underwent total knee arthroplasty (total knee replacement surgery), patients had higher coactivation of the vastus lateralis and biceps femoris long head alongside a longer time to completion compared to a healthy group [6]. The altered movement strategy was linked with lower performance in the 5xSTS assessment and a higher fall risk. Another transition assessment is the Stand-to-Sit test, which accounts for half of the motion in the 5xSTS task. One Stand-to-Sit study showed that a shorter rectus femoris burst duration observed in older adults was linked to a reduction in time of the body center of mass within the base of support [7]. Increased time outside of the base of support (area below a person including points of contact) can decrease stability during the Stand-to-Sit task. These studies have shown that differences in muscle excitation between older and younger adults might explain how older populations stabilize themselves during sit-to-stand transfer tasks. Net joint moments can provide insight to the mechanical requirements to complete a task, which can provide insight into differences in muscle excitation. Thus, we evaluated lower limb muscle excitation, sagittal hip, knee and ankle joint moments, and time to completion of 5xSTS in healthy younger and older adults.

Methods

Participants

The participants were divided into two groups: (1) healthy younger adults and (2) healthy older adults (Table 1). All participants provided their informed consent for the protocol approved by the Colorado Multiple Institutional Review Board. Participants were excluded if they had a musculoskeletal injury in the past six months, had a neurological disorder, impairment or take medications the affect balance or were part of a vulnerable population (e.g., minors, pregnant women). Hand grip strength was evaluated using a hand-held dynamometer. Each participant was instructed to hold the dynamometer with their elbow at a 90° angle and apply as much pressure with their hand as possible. Three trials were performed for both hands then the average was taken across all trials for each participant.

Table 1 *Mean ± SD of Baseline Anthropometry.*

	Younger	Older
Age (years)	23.8 ± 5.0	62.1 ± 7.8
Height (in)	68.5 ± 2.3	66.9 ± 2.3
Weight (lb)	151 ± 27.8	178 ± 47.4
Sex	5F/6M	7F/4M
Hand Grip Strength (lbs)	84.6 ± 21.2	63.5 ± 21.5

Each participant completed one 5xSTS trial. The participants started in a seated position on a stool with their hips and knees flexed at 90°, feet spaced shoulder-width apart, and with arms folded across their chest. They rose from the seat to a standing position five consecutive times as quickly as possible and returned to a resting, seated position after the fifth rise (Fig. 3).

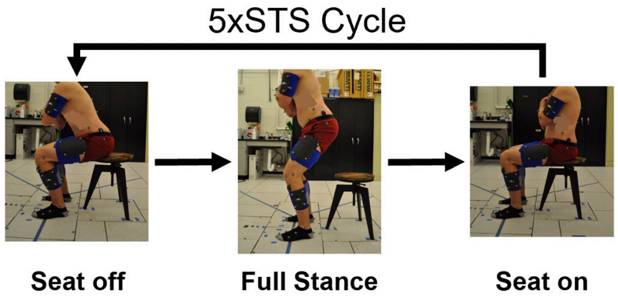

Figure 3 *5xSTS Seat Off to Seat On Cycle.*

Instrumentation

Sixteen wireless surface electromyography (EMG, Delsys, 2000 Hz) sensors were placed bilaterally on the lumbar paraspinals, gluteus medius, rectus femoris, biceps femoris long head, vastus lateralis, medial gastrocnemius, soleus, and tibialis anterior (Fig. 4). Skin was shaved and cleaned, and the sensors were placed on each muscle belly halfway between origin and insertion and oriented parallel to the fiber direction [8]. 72 retroreflective markers were placed on the lower body, trunk, arms and head.

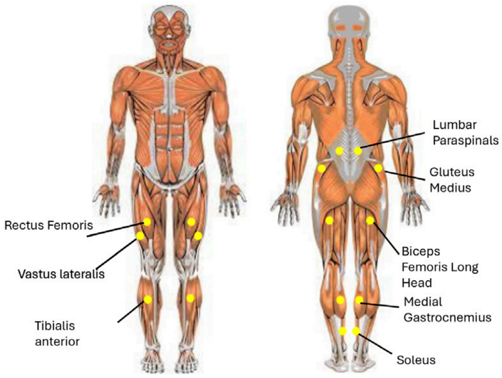

Figure 4 *EMG Sensor Bilateral Placement (Figure modified from Konrad, 2005)*

Kinematic marker trajectories were collected using seven-camera system (Qualisys, 200 Hz). EMG signals were time synchronized with optical motion capture and ground reaction forces (GRFs) collected from in-ground force plates (AMTI, 2000 Hz).

Analysis

GRFs were filtered with a 6 Hz Butterworth lowpass filter. The processed GRF underneath the stool was used to define a threshold (the weight of the stool) for the first seat off and the last seat on. Time to completion of 5xSTS was the duration from the first seat off to the final seat on. A cycle in the 5xSTS was defined as the time between one seat off and the next seat on. EMG sensors measure the electrical potential in a muscle during the task. Integrating the EMG signal over a specific period gives a single value to represent muscle excitation. EMG signals were high pass filtered (50 Hz) to remove the DC offset and full wave rectified (absolute value of the signal). The linear envelope of the EMG signal was created by filtering the rectified signal with a 4 Hz Butterworth lowpass filter. For each participant, the EMG signal for each muscle was normalized to its maximum linear envelope value during 5xSTS (Fig. 5). The normalized EMG signals were integrated over the 5xSTS time duration to calculate integrated electromyography (iEMG) values to obtain a value for overall muscle excitation during the entire 5xSTS task:

$$iEMG = \int_{t(Seat\ Off)}^{t(Seat\ On)} \frac{5xSTS\ EMG\ Signal}{Max\ 5xSTS\ EMG}\,dt$$

iEMG values for each muscle were averaged across both legs and compared between groups.

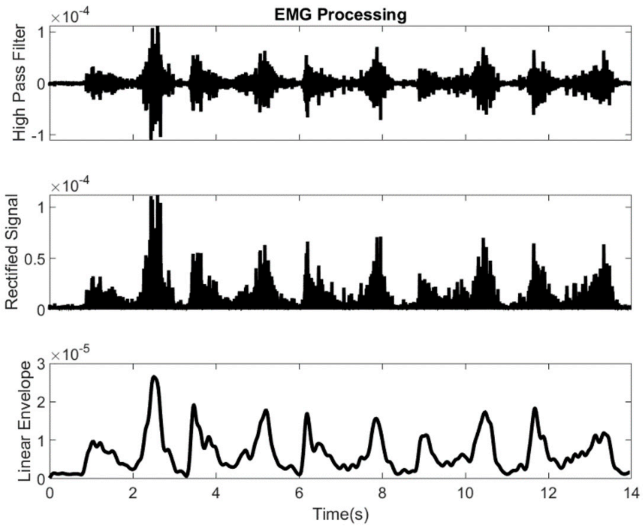

Figure 5 *Example EMG Processing Steps.*

Motion trajectories were filtered with a 6 Hz Butterworth lowpass filter. The trajectories were identified (Fig. 6, Qualisys), then used to develop a twelve-segment dynamic model in Visual3D (Fig. 7). This model was used to calculate sagittal plane hip, knee and ankle net joint moments. The joint moments were normalized to participant body mass (in kg) and extracted for the third cycle of the 5xSTS to avoid initiation and termination behavior in the first and last cycle. The moments were then averaged across both legs. Then, peak extension and flexion were extracted for each joint. We compared iEMG values for eight muscles, peak hip, knee, and ankle extension and flexion moments, as well as the time to complete the 5xSTS between younger and older participants with an unpaired t-test ($\alpha=0.05$).

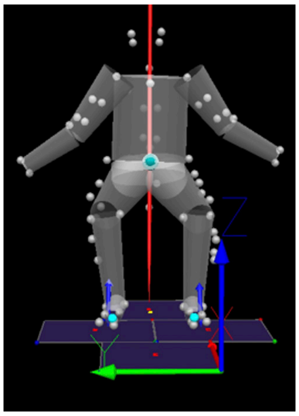

Figure 6 *Marker Identification (QTM).*

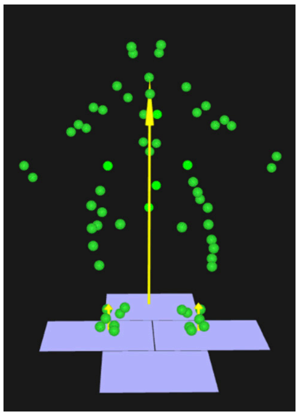

Figure 7 *Twelve-Segment Model Example (Visual3D).*

Results

The younger group's mean (± SD) time to completion was 9.96 ± 2.47 s and the older group's time to completion was 10.58 ± 1.36 s. There was not a significant age effect for time to completion ($p = 0.473$). Muscle excitation for the gluteus medius ($p = 0.025$), lumbar paraspinals ($p = 0.014$), rectus femoris ($p = 0.002$), vastus lateralis ($p = 0.011$), and tibialis anterior ($p = 0.038$) was higher in older adults compared to younger adults (Fig. 8). There was no significant difference in soleus ($p = 0.783$) or medial gastrocnemius ($p = 0.514$) iEMG between the groups. The biceps femoris long head signal had movement artifact due to contact between the leg and the stool and was removed from the analysis. In addition, one older participant was removed from the lumbar paraspinals analysis due to movement artifact.

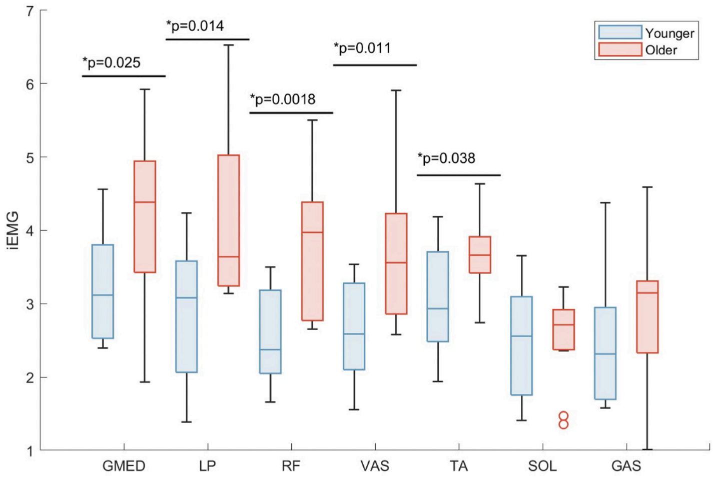

Figure 8 *Mean (±SD) iEMG in younger and older adults for gluteus medius (GMED), lumbar paraspinals (LP), rectus femoris (RF), vastus lateralis (VAS), tibialis anterior (TA), soleus (SOL), and medial gastrocnemius (GAS). *Significant difference between groups ($p < 0.05$).*

The younger adults had greater hip ($p < 0.001$) peak extension and knee ($p = 0.013$) peak flexion moments than the older adults (Fig. 9). There was not a significant age effect for ankle peak dorsiflexion ($p = 0.811$) or plantarflexion ($p = 0.598$).

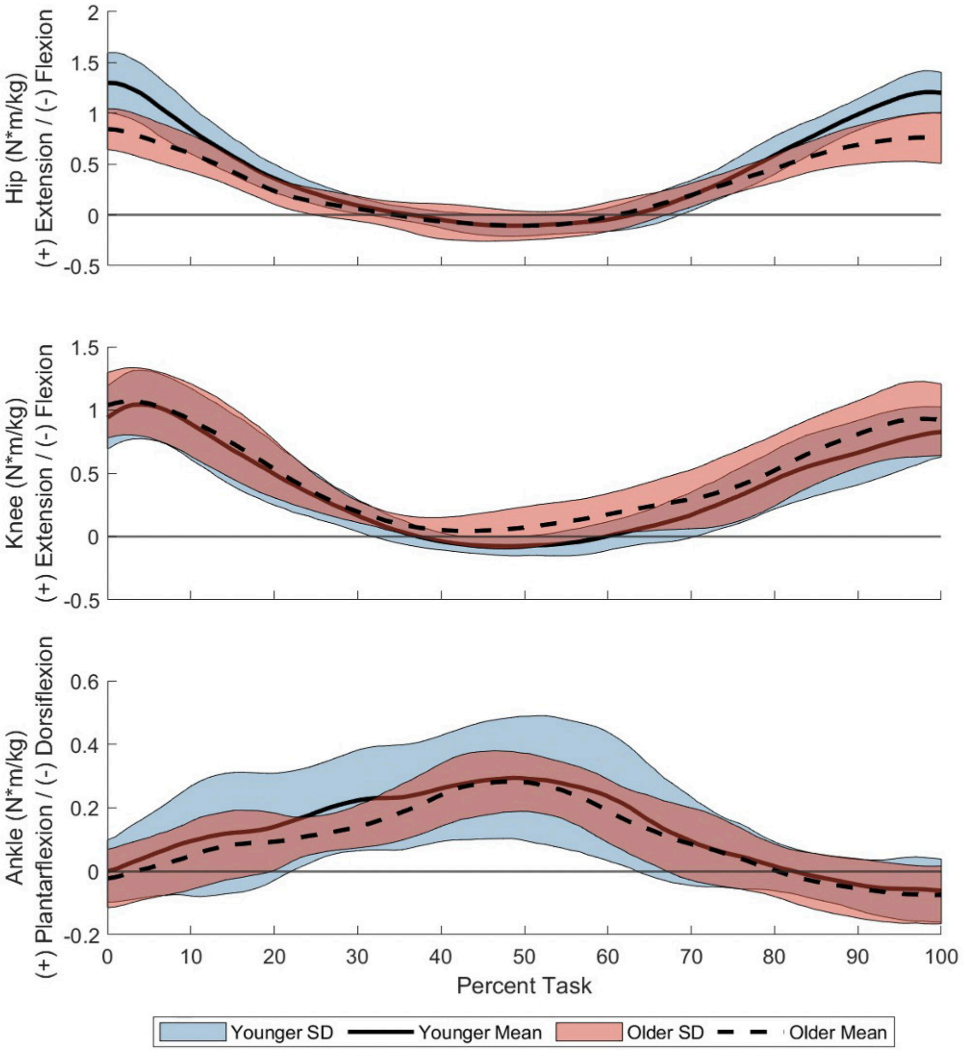

Figure 9 *Mean (±SD) average joint moment over third cycle in younger and older adults' hip, knee, and ankle.*

There was no significant difference in hip (p = 0.832) peak flexion or knee (p = 0.861) peak extension between the groups. Younger adults had a higher average hand grip strength than older adults that was almost significant (p = 0.054).

Discussion

Older adults required higher muscle excitation to complete the 5xSTS task in a similar amount of time as the younger participants. Older adults had a lower peak knee and hip extension moment and a higher iEMG in hip and knee extensor muscles. A higher peak extension moment alongside higher muscle excitation was expected in older adults. The smaller extension moments generated by the older adults indicates that higher muscle excitation was not due to force production and more likely due to excitation timing differences between the groups. Greater rectus femoris and vastus lateralis iEMG in the older group may be explained by co-contraction, as previous 5xSTS studies found higher coactivation in the vastus lateralis and biceps femoris long head in patients with total knee arthroplasty [6]. We found similar dorsiflexion moments between older and younger adults suggesting the increase in tibialis anterior excitation is due to activation timing. Higher tibialis anterior iEMG in older adults is consistent with previous studies that show the tibialis anterior is activated earlier in older adults during sit-to-stand [9]. Hip abductors and back extensors contribute to postural control, which is important in 5xSTS. Greater excitation from the gluteus medius and lumbar paraspinals in older adults may indicate a compensation for potential muscle weakness [10,11], while still effectively controlling torso motion. Hand grip strength has been linked to lower limb strength and was found to be lower in the older group [12]. This difference in hand grip strength suggests lower overall muscle strength in older adults, which is consistent with the higher gluteus medius and lumbar paraspinal iEMG to achieve similar mechanics when compared to younger adults. A non-significant difference in soleus and medial gastrocnemius excitation between age groups may be due to feet being planted during 5xSTS, requiring low ankle plantarflexor demand. This result is further supported by our finding that the plantarflexion moment between groups was not different. 5xSTS is an extension focused task so similarity in peak joint moment flexion between groups is expected. Older adults took a similar amount of time to complete the 5xSTS as younger adults, although they required greater muscle excitation which indicates different muscle strategies were used between the two groups to complete the task.

Conclusions and Future Work

Our study quantified muscle excitation in healthy younger and older adults completing the 5xSTS clinical test. Older adults generated smaller or similar peak extension joint moments compared to younger adults, and thus differences in muscle force required to complete the 5xSTS are likely not the cause of greater lower limb iEMG in older adults. Additionally, the time to complete the 5xSTS was similar between groups, so time to complete the task does not explain the difference in iEMG between groups. Time to completion is the main outcome of the 5xSTS and it does not provide insight to muscle coordination used to complete the task. Future work should examine lower limb muscle excitation timing between these participant groups during 5xSTS to build upon the iEMG results. Time of muscle activation could provide additional insight to the cause of higher muscle excitation in older adults. The cause of muscle excitation differences in older and younger adults can then be used to inform rehabilitation and strengthening exercises. Depending on the cause of muscle excitation differences, collecting additional data in a clinical assessment setting (such as joint angles or muscle excitations) during the 5xSTS could provide a better understanding of an individual's movement strategies. For individuals at risk of fall, this would aid in creating a personalized rehabilitation plan which would likely target specific muscles to guide training and reduce fall risk.

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