Maximum Trunk Flexion Angle During the Sit to Stand Is Not Determined by Knee or Trunk-Hip Extension Strength in Healthy Older Adults

Thomas M. Lundin, Dennis W. Jahnigen, and Mark D. Grabiner

When rising from a chair, older adults have been reported to use a strategy in which the trunk is flexed to a greater extent than young adults, a strategy attributed by some to concerns with the postural stability demands of the task. This study determined the extent to which maximum trunk flexion angle during a self-paced sit-to-stand from a standardized initial position was influenced by the maximum isometric strength of the knee and trunk/hip extensor muscles in older adults. The hypothesis was that the larger maximum trunk flexion angle attained by older adults when rising from a chair is related to the maximum isometric strength of the knee and trunk-hip extensor muscles. To test this hypothesis, maximum voluntary isometric strength of the trunk extensor and knee extensor muscles of 28 older men and women were measured. Trunk motion during the sit-to-stand by these adults was then assessed using motion analysis. Multiple regression was used to characterize the relationship between the maximum trunk flexion angle and maximum isometric knee extensor and trunk extensor muscle strength. The derived relationship was neither statistically significant nor biomechanically meaningful. This result suggests that the trunk flexion angle attained by healthy older adults when rising from a chair from a standardized initial position is not influenced by knee extension and trunk-hip extension strength as measured in the present study.

Key Words: activities of daily living, aging, sit-to-stand, strength

There are significant questions to which solutions are sought that relate to age-related changes in variables such as muscle strength and balance, and the influences of these changes on the ability of older adults to perform motor skills that are considered fundamental to an independent lifestyle. These solutions are prerequisite to effective interventions intended to improve motor function. Although rising from and sitting into

T.M. Lundin and M.D. Grabiner are with the Department of Biomedical Engineering at The Cleveland Clinic Foundation, Cleveland, OH 44195. D.W. Jahnigen is with the University of Colorado Health Sciences Center, Denver, Colorado 80262.
a chair are among the most important motor skills indicative of physical function (Hughes, Myers, & Schenkman, 1996), there has been limited within-subject investigation of the influence of muscle strength and balance on the ability to rise from a chair. Older adults have been reported to flex the trunk to a greater extent than young adults when rising from a chair (e.g., Kerr, White, Barr, & Mollan, 1997; Schultz, Alexander, & Ashton-Miller, 1992; Wheeler et al., 1985).

This has been attributed to two requirements of rising from a chair (Alexander, Schultz, & Warwick, 1991). The first requirement is the need to maintain multidirectional postural stability. The second is the need to generate the minimum lower extremity joint moments required to rise from the chair. Schultz and colleagues (1992) related the larger trunk flexion by older adults to the postural stability requirement. Those authors reasoned that larger trunk flexion angle creates a more posturally desirable position of the body’s center of gravity over the base of support. Based upon comparison of the computed joint moments during the sit-to-stand to published values of strength in older adults (their Table 7), Schultz and colleagues (1992) suggested that joint moment requirements are not a limiting factor, except possibly for very frail older adults or older adults with lower extremity joint pain. The latter point was partially supported by Hughes and colleagues (1996) who reported that isometric knee joint extensor strength was a limiting factor in the ability of functionally impaired adults to rise from a chair.

The minimum strength requirements of a task can represent disparate between-individual percentages of the maximum available strength. If reducing the perceived total effort during a task is somehow considered in the selection of a motor strategy, then the larger trunk flexion angle of older adults during the sit-to-stand may reflect a strategy seeking a compromise between required knee and trunk-hip extension moments. From a purely static perspective, increased trunk flexion during the rise from a chair decreases the required knee extension moment, although the required trunk-hip extension moment is increased. However, although the required trunk-hip extension moment is increased, the larger trunk flexion angle also increases the length of the trunk and hip extensor muscles. This increase in muscle length subsequently increases the force generating potential of these muscles. The present investigation was conducted to determine the extent to which maximum trunk flexion angle during a self-paced sit-to-stand motion performed from a standardized initial position would be influenced by the strength of the knee and trunk/hip extensor muscles in healthy older adults. It was hypothesized that the larger maximum trunk flexion angle attained by older adults when rising from a chair would be related to the strength of the knee and trunk-hip extensor muscles.

**Methods**

Twenty-eight older adults volunteered to participate in this study and provided written informed consent. There were 11 men (mean ± standard deviation: age: 74.0 ± 2.8 years; height: 1.70 ± 0.06 m; weight: 752.4 ± 82.1 N) and 17 women (mean ± standard deviation: age: 73.1 ± 5.7 years; height: 1.57 ± 0.08 m; weight: 644.6 ± 106.5 N). All were healthy, physically active, living independently, and without presentation of gross neuromuscular or musculoskeletal impairment.

The experiment consisted of three data collections: (1) video recording of the sit-to-stand (Lundin, Grabiner, & Jahnigen, 1995), (2) measurement of maximum voluntary isometric trunk/hip extension strength, and (3) measurement of maximum voluntary knee extension strength. During the sit-to-stand protocol, 3-cm diameter reflective hemispherical markers were used to model the body as an eight link system consisting of the
bilateral feet, shanks, thighs, pelvis, and the trunk. The motions of the reflective markers were recorded using four video cameras operating at 60 Hz and a motion capture system (Motion Analysis, Santa Rosa, CA).

Each subject performed 10 trials of the sit-to-stand from a custom designed adjustable chair. The chair was positioned on a strain gauge force plate (AMTI, Newton, MA) that allowed determination of the instant the subject left the chair during the sit-to-stand motion. The chair height was adjusted so that the thigh segments were approximately parallel with the ground. The knees were flexed approximately 110°, and the feet were placed shoulder width apart and slightly adducted. The front edge of the seat was midway between the greater trochanter and lateral femoral condyle markers. The arms were placed across chest, and the use of the upper extremities to assist in execution of the task was not allowed (Alexander et al., 1991; Fleckenstein, Kirby, & MacLoed, 1988; Weiner, Long, Hughes, Chandler, & Sttudenski, 1993). Subjects were not allowed to reposition their feet during the task. Following a verbal signal to proceed, the subject rose from the chair at a self-selected speed.

Maximum voluntary isometric trunk/hip extension strength was measured using a Kin-Com dynamometer (Chattanooga Corporation, Chattanooga, TN). Subjects were secured to the Kin-Com chair with the trunk positioned vertically relative to the room and the hips flexed approximately 75°. The knees were flexed approximately 90° and were supported by a padded knee rest. The feet were not in contact with a supporting surface. A rigid, padded waist band at the L5-S1 level secured the subject in the chair, and the arms were folded across the chest.

Three trials of isometric trunk/hip extension were performed at an angle of 25° flexion from the initial vertical position. The subjects were instructed to generate their maximum trunk/hip extension moment gradually, over a period of approximately 3 s and indicate when their maximum moment had been achieved, at which time the data collection was initiated. The force signal from the dynamometer were digitized for 1000 ms at 100 Hz (Data Translation 2801A) and stored for off-line processing. An audio tone marked the completion of the data collection, at which time the subjects were allowed to relax the contraction.

Maximum voluntary isometric knee extension strength was also measured on the Kin-Com dynamometer. The subjects, secured with Velcro straps, were seated in an upright position with their hips and knees flexed approximately 90°. The knee joint centers were aligned with the center of rotation of the dynamometer. Subjects further stabilized themselves with custom designed hand grips for the dynamometer. The Kin-Com was modified to allow simultaneous and independent collection of bilateral knee extension moments using two strain gauge load cells positioned approximately 15–20 cm distal to the patella of the left and right legs (Owings & Grabiner, in press). The subjects were instructed to generate their maximum knee extension moment over a period of 3 s and to give a verbal indication when they had reached their maximum effort. The force signals from each load cell were collected for 1000 ms and digitized at 100 Hz.

Fifteen subjects were tested using the identical protocol 5 weeks after the initial test. The purpose of this session was to establish the consistency of the measures of knee and trunk strength and the maximum trunk angle during the sit-to-stand.

For the sit-to-stand, the instant of liftoff from the chair was identified from the vertical ground reaction force signal of the force plate located beneath the chair. The beginning of each trial was established two video frames (0.03 s) prior to liftoff. The video data was tracked, and the position data of the calculated marker centroids were smoothed using a recursive Butterworth filter at a cutoff frequency of 6 Hz. Trunk angle
Table 1  Means and Standard Deviations of the Maximum Trunk Flexion Angle, Peak Trunk-Hip Extension Force (Normalized) and Moment (Absolute), and Peak Knee Extension Force (Normalized) and Moment (Absolute) During the Sit-to-Stand

<table>
<thead>
<tr>
<th>Variable</th>
<th>Men (n = 11)</th>
<th>Women (n = 17)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk flexion angle (degrees)</td>
<td>38.3 ± 7.7</td>
<td>39.1 ± 6.2</td>
</tr>
<tr>
<td>Maximum trunk-hip extension force (% body weight)</td>
<td>35.5 ± 9.2</td>
<td>26.0 ± 9.5</td>
</tr>
<tr>
<td>Maximum trunk-hip extension moment (N · m)</td>
<td>268.2 ± 75.9</td>
<td>164.4 ± 59.1</td>
</tr>
<tr>
<td>Maximum knee extension force (% body weight)</td>
<td>26.8 ± 6.8</td>
<td>20.0 ± 7.7</td>
</tr>
<tr>
<td>Maximum knee extension moment (N · m)</td>
<td>199.2 ± 43.0</td>
<td>125.6 ± 48.2</td>
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</tbody>
</table>

was computed from the time-displacement data of the marker centroids and the maximum trunk flexion angle extracted for analysis.

The largest value of maximum isometric knee and trunk-hip extension moments observed during the three trials was used as representative for each subject. An allometric scaling method was used to determine the validity of expressing maximum knee and trunk-hip extension moments as a function of body weight (Foley et al., 1999; Vandenburgh & Katch, 1996a, 1996b; Vandenburgh et al., 1995). Multiple linear regression analysis was used to characterize the relationship between the maximum trunk flexion angle and the scaled maximum isometric trunk-hip and knee extension forces. All statistics were conducted using SPSS V. 7.0 (SPSS, Chicago, IL).

Results

The allometric scaling analysis revealed that normalizing the absolute measures of muscle strength by body weight was appropriate for the men and women in this study. The scaling coefficients were calculated to be 1.0 for the men and zero for the women. A scaling factor of 1.0 indicates that a simple ratio scaling (i.e., strength · body weight\(^{-1}\)) is appropriate and will not induce an unintended bias in the data. A scaling factor of zero indicates that there is no relationship between the scaling and outcome variables. Thus, although no analytic benefit is derived by scaling when the coefficient is zero, there is also no bias imposed on the data by the normalization process. It was considered advantageous to have the strength data for the men and women expressed in the same units, and therefore, the maximum isometric knee and trunk-hip extension strength for the men and the women were expressed as a percentage of their body weight.

Not unexpectedly, the men had significantly larger normalized maximum isometric knee extension \((p = .022)\) and trunk-hip extension \((p = .015)\) than the women (Table 1). However, the gender-related difference with regard to the maximum trunk angle during the sit-to-stand was not significant \((p = .778, \text{Table 1})\). The normalized maximum isometric trunk-hip extension and normalized maximum isometric knee extension strength values were significantly correlated \((r = 0.78, p = .01)\). Table 1 also includes the maximum trunk and knee extension moments expressed in N · m. Multiple linear regression revealed that the maximum trunk flexion angle achieved during the sit-to-stand was not influenced by normalized maximum isometric knee extension strength or normalized maximum isometric trunk-hip extension strength. For the men, the regression equation

\[
\theta_{\text{trunk}} = 42.88 + (10.1 \cdot \text{trunk-hip}_{\text{iso}}) - (30.4 \cdot \text{knee}_{\text{iso}})
\]
Figure 1 — Relationship between the maximum voluntary isometric trunk-hip extension moment of older men and women (n = 28) and the maximum trunk flexion angle attained during a self-paced sit-to-stand. The Pearson product moment correlation, r = 0.02, was not significant.

Predicting maximum trunk flexion angle ($\theta_{\text{trunk}}$) using the normalized maximum isometric trunk-hip and knee strength values (trunk_{iso} and knee_{iso}, respectively) accounted for effectively zero variance (adjusted $R^2 = -0.19$, $p = .81$) and had a standard error of estimate of 8.4.

For the women, the regression equation

$$\theta_{\text{trunk}} = 36.8 - (3.0 \cdot \text{trunk-hip}_{\text{iso}}) + (15.4 \cdot \text{knee}_{\text{iso}})$$

also accounted for effectively zero variance (adjusted $R^2 = -0.12$, $p = .84$) and had a standard error of estimate of 6.5.

A regression analysis conducted without distinguishing between men and women generated similar results. This is consistent with the failure of either normalized maximum isometric trunk-hip extension or normalized maximum isometric knee extension strength to demonstrate any relationship to the maximum trunk flexion angle during the sit-to-stand (Figures 1 and 2).

For the subjects and methods used in this study, the values for the normalized maximum isometric knee extension strength, normalized maximum isometric trunk-hip extension strength, and maximum trunk flexion angle during the sit-to-stand were stable over a period of 5 weeks. For the 15 subjects that were re-tested after 5 weeks, the initial test and re-test values were significantly correlated, and the differences between the values were not significant (Table 2). Table 2 also includes the maximum trunk and knee extension moments expressed in N·m.
Figure 2 — Relationship between the maximum voluntary isometric knee extension moment of older men and women ($n = 28$) and the maximum trunk flexion angle attained during a self-paced sit-to-stand. The Pearson product moment correlation, $r = -0.02$, was not significant.

Discussion

The present investigation was conducted to determine the extent to which maximum trunk flexion angle during a self-paced sit-to-stand from a standardized initial position would be influenced by the strength of the knee and trunk/hip extensor muscles in older adults. It was hypothesized that the maximum trunk flexion angle attained by older adults when rising from a chair would be related to the strength of the knee and trunk/hip extensor muscles. Specifically, it was anticipated that muscularly weaker subjects would perform the sit-to-stand task using a larger maximum trunk flexion angle. For the older adults who participated in this study, the maximum trunk flexion angle, which

<table>
<thead>
<tr>
<th>Variable</th>
<th>First test ($n = 15$)</th>
<th>Second test ($n = 15$)</th>
<th>$r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk flexion angle (degrees)</td>
<td>38.9 ± 7.5</td>
<td>40.6 ± 11.2</td>
<td>0.73*</td>
</tr>
<tr>
<td>Maximum trunk-hip extension force (% body weight)</td>
<td>30.0 ± 11.8</td>
<td>31.1 ± 11.3</td>
<td>0.67*</td>
</tr>
<tr>
<td>Maximum trunk-hip extension moment (N · m)</td>
<td>210.4 ± 89.1</td>
<td>214.5 ± 80.0</td>
<td></td>
</tr>
<tr>
<td>Maximum knee extension force (% body weight)</td>
<td>23.5 ± 8.7</td>
<td>23.5 ± 8.5</td>
<td>0.71*</td>
</tr>
<tr>
<td>Maximum knee extension moment (N · m)</td>
<td>162.1 ± 60.9</td>
<td>162.5 ± 62.6</td>
<td></td>
</tr>
</tbody>
</table>

*p = .01.
ranged from 24° to 49°, was not related to the maximum isometric strength of the trunk extensor muscles or the maximum isometric strength of the knee extensor muscles. Indeed, although the men were significantly stronger than the women for trunk-hip extension and knee extension, the women had similar maximum trunk flexion angles during the sit-to-stand. On average, for trunk-hip and knee extension strength, the men were 36 and 34% stronger than the women, respectively.

The maximum trunk flexion angle attained by the older adults in this study, approximately 38°, was similar to values previously reported. Using similar methods, Alexander and colleagues (1991) and Schultz and colleagues (1992) reported maximum trunk flexion angle values of 42.9 ± 10.0° for a sample of 23 older adults. In the study by Schultz and colleagues, the computed joint moments represented only a small fraction of the estimated available strength of the older adults. In conjunction with a more anteriorly placed ground reaction, Schultz and colleagues subsequently concluded that during a sit-to-stand, the larger maximum trunk flexion angles of older adults, compared to young adults, reflects greater concern by older adults on postural stability than on reducing the necessary joint moments. The present study, by analyzing muscle strength and maximum trunk flexion angle during the sit-to-stand for the same subjects allowed a direct, albeit partial test of this suggestion. The failure of the trunk-hip extensor and knee extensor strength to influence the maximum trunk flexion angle during the sit-to-stand in the present study seems to support the conclusions of Schultz and colleagues.

The failure of the strength of the trunk-hip and knee extensor muscles to influence the maximum trunk flexion angle during the sit-to-stand could reflect that muscle strength simply does not influence the strategy used to perform the task, the strength measures themselves were inadequate, or both. With regard to the first factor, using a standardized initial position that was similar to those of the present study, Schultz and colleagues (1992) suggested that excluding the very frail or those whose performance is restricted by joint pain, the joint torque requirements for rising from a chair do not normally limit the ability to rise from a chair. However, as the difficulty of rising from a chair is increased by lowering the seat and increasing the knee flexion angle, others have reported, or intimated an increased dependence of successful performance on strength (Hughes, Weiner, Schenkenman, Long, & Studenski, 1996; Rodosky, Andriacchi, & Anderson, 1989; Shepard & Gentile, 1994). It may be possible that the maximum available strength in the healthy older adults in this study was such that the strength requirements of the specific task in this study were too small to elicit the expected relationships between trunk flexion angle and strength.

With regard to the second factor, it is unlikely that we were able to elicit a truly maximum voluntary effort from the older adults. We accept the likelihood that the measures of maximum voluntary strength of the older adults in this study were probably underestimated. Given the generally accepted convention that it is difficult to elicit a maximum contraction even in healthy, young, motivated subjects, one must conclude that to do so in older adults must be at least as difficult. The results from the 15 subjects who performed the testing and re-testing protocol indicate that the measures of knee extensor and trunk-hip extensor strength were stable over a period of 4 weeks. However, it is not possible to estimate the extent to which the measures of maximum voluntary strength underestimated the actual individual-specic maximum strength.

This is the first study that has related the maximum trunk flexion angle during the sit-to-stand to measures of both trunk-hip extensor and knee extensor strength in the same older subjects. The hypothesis of the study was generated in response to published literature that has directly or indirectly linked, but not measured, these variables.
Although muscle strength was not found to be related to the maximum trunk flexion angle, perhaps strength is related to other variables that have been used to characterize the task of rising from a chair. Examples of previously reported variables that are clearly open for study relative to muscle strength include momentum (Hughes et al., 1994; Pai & Rogers, 1990, 1991; Schenckman, Berger, Riley, Mann, & Hodge, 1990) and trunk flexion angular velocity achieved during the sit-to-stand (Schenckman, Riley, & Pieper, 1996). It is possible that there is a functional interaction between muscular strength and the ability to develop momentum during the sit-to-stand. The initial position used in the present study mandated that momentum of the trunk be generated and controlled to achieve the task requirements. It may be possible to characterize the relationship between muscle strength and motor strategy in general, and maximum trunk flexion angle in particular, by a more complex experimental design that systematically manipulates the momentum requirements. At present, however, the results of the present study appear to provide an unambiguous answer to the original hypothesis but one that must be restricted to a sample of healthy older men and women performing a constrained sit-to-stand task.

In summary, we have measured in a group of healthy older adults the maximum trunk flexion angle attained while rising from a chair, and in these same adults, we have obtained measures of maximum isometric trunk-hip extensor and knee extensor strength. There was no relationship between the measures of strength and the maximum trunk flexion angle during the sit-to-stand. Within the limitations imposed by the experimental design, this further suggests that this particular motor strategy used by healthy older adults to rise from a chair at a self-selected speed is not influenced by the maximum isometric muscle strength of the trunk-hip and knee extension muscles.

References


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