Coordination of Strength Exertion During the Chair-Rise Movement in Very Old People

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Background. Changes in performance of standing up from a chair have been related to measures of strength or power. However, the sit-to-stand (STS) transfer requires that the individual exerts forces with appropriate magnitude and timing. These coordinative aspects have received less attention. This study aims to analyze differences in STS performance in older people based on measures that are derived from ground reaction forces (GRFs) during STS transfer.

Methods. One hundred thirty-five participants (84.5% women; mean age 82.5 years) stood up from a chair as fast as possible. Time of stabilization after reaching an upright position, power, maximum vertical GRF, increase of vertical GRF, overshoot of vertical GRF over body weight, and left–right difference of GRF were measured by a force plate under each foot. To explain variance of total time to stand up, these variables were used as independent variables in a linear regression model.

Results. Eighty-one percent of variance of total time to stand up was explained by the independent variables. The strongest predictor of total time was time of stabilization ($F = 459.4$). Another model of linear regression explained 37% of variance of time to reach an upright position, with increase of GRF as the strongest predictor ($F = 38.3$). Influence of maximum vertical GRF was weak in both models.

Conclusions. Variables related to coordination of strength, measured during STS transfer, were able to explain a high proportion of variance of time to rise from a chair. Stabilization after reaching an upright position seems to be a parameter worth further investigation.

Rising from a seated to a standing position is a basic requirement for mobility in daily life and a prerequisite for physical independence, especially for elderly persons. The sit-to-stand (STS) transfer requires that the individual is able to exert enough force to rise the body’s center of mass. Thus, leg muscles must be able to produce an adequate strength and power. However, the center of mass must be transferred safely from a seated position to a stable end position during standing. The phase of stabilization is the time between reaching an upright position and reaching this end position safely. Related to ground reaction force (GRF), the end position can be defined as stable when vertical GRF oscillates in a defined corridor (1). To achieve a stable end position above the base of support, it is crucial that forces are exerted with appropriate magnitude and timing. This aspect of coordinative exertion of strength during STS has received less attention, and it can be questioned whether strength, power, or the timing of forces is the major factor in explaining differences in performance of STS. Answering this question can possibly help in defining strategies to improve performance in older persons who suffer from a deterioration of functional performance of the STS transfer.

The relative importance of strength, speed, and balance for the STS transfer has been demonstrated (2–4). Regression models in these studies were able to explain 47% or less of the variance in STS time. Coordination of strength and velocity results in task-specific power, which was shown to be relevant for STS transfer (5–7).

One characteristic of all previous studies was that changes in the duration of STS were related to measures of strength or power as obtained by additional assessments that were unrelated to performance of the STS transfer. In contrast, there are characteristics of strength and its exertion related to time, which can be measured during the STS transfer. Strength can be measured by the GRF as a result of the vertically directed downward push to rise the body upwards (8). The amplitude of GRF higher than body weight (overshoot) and the left–right distribution of GRF are markers of coordinated application of vertical force. In power (strength $\times$ velocity) and the maximum increase of GRF, the demand to coordinate force and time is obvious by their units ($W = \text{Nm/s}$, N/s). Another marker of coordination is the duration of the stabilization phase after rising from a chair, when the momentum of vertical and horizontal movement has to be controlled and stabilized in the upright body position (9). Those aspects of strength and coordinative strength exertion can be measured during a single STS transfer by a method described by Lindemann and
The basis for deriving those parameters is a force measurement related to time by force plates connected to a computer.

This study analyzes the relative importance of strength and strength exertion related to time, as assessed during only one simple measurement, in explaining the total duration of the STS transfer.

**METHODS**

**Participants and Design**

The study was a cross-sectional investigation. All included individuals were participants of an intervention study to prevent falls in community-dwelling elderly persons. The inclusion criteria were age 65 years or older and subjective rating of falls risk by ambulant care givers. The study was approved by the ethical committee of the local university. Participants had to give written informed consent. Data on 135 participants were analyzed. From 270 participants of the fall prevention study, 28 had to be excluded because they were not able to come to the laboratory to participate in the measurement because of severe functional impairment. Furthermore, 104 persons were excluded because they were not able to rise from a chair without using armrests or other assistance. Three women withdrew their consent. The mean age of the 135 included participants (84.5% women) was 82.5 years (standard deviation 5.3 years). To describe the study sample, participants reported on history of falls and comorbidity. Cognition was assessed by using the short Orientation-Memory-Concentration test (10), and habitual gait speed was assessed during a standardized 2-minute walk (11). Balance was tested while standing in different positions (open stance, closed stance, semitandem stance, tandem stance) without any hold for a maximum of 15 seconds in each position. If a participant was able to keep a position for 15 seconds, the next more challenging position was tested. The characteristics of the participants are listed in Table 1.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>82.5</td>
<td>5.3</td>
<td>67–95</td>
</tr>
<tr>
<td>Height, cm</td>
<td>158.5</td>
<td>7</td>
<td>143–183</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>67.3</td>
<td>12</td>
<td>40.3–103.5</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>26.8</td>
<td>4.3</td>
<td>17.1–40.7</td>
</tr>
<tr>
<td>Habitual gait speed, m/s</td>
<td>0.82</td>
<td>0.2</td>
<td>0.22–1.39</td>
</tr>
<tr>
<td>Balance, standing, s¹</td>
<td>47.3</td>
<td>10.2</td>
<td>15.9–60</td>
</tr>
<tr>
<td>Cognition (SOMC)¹</td>
<td>4.3</td>
<td>6.6</td>
<td>0–28</td>
</tr>
<tr>
<td>No walking aid (%)</td>
<td></td>
<td></td>
<td>51.5</td>
</tr>
<tr>
<td>Cane (%)</td>
<td></td>
<td></td>
<td>31.3</td>
</tr>
<tr>
<td>Wheeled walker (%)</td>
<td></td>
<td></td>
<td>17.2</td>
</tr>
<tr>
<td>History of fall (last 12 mo) (%)</td>
<td></td>
<td></td>
<td>63.4</td>
</tr>
<tr>
<td>Stroke (%)</td>
<td></td>
<td></td>
<td>23.9</td>
</tr>
<tr>
<td>Parkinson’s disease (%)</td>
<td></td>
<td></td>
<td>5.2</td>
</tr>
<tr>
<td>Rheumatoid arthritis (%)</td>
<td></td>
<td></td>
<td>10.4</td>
</tr>
</tbody>
</table>

Notes: *Habitual gait speed = distance walked in 2 min/120.

¹Balance (standing) = a maximum of 60 seconds was calculated by adding 15 seconds or less for each position (open stance, closed stance, semitandem stance, tandem stance).

¹Cognition = SOMC scoring 0 (best) to 28 (worst).

SD = standard deviation; SOMC = Short Orientation-Memory-Concentration test.

**Measurement**

Participants were asked to stand up from a chair of standard height (46 cm) as fast as possible without using armrests with each foot standing on a separate force plate. Time to stand up, power, maximum vertical GRF, increase of vertical GRF, and overshoot of vertical GRF over body weight were measured by a method described elsewhere in detail (1). Force plates provided a curve of vertical GRF as a function of time. From this curve the time to stand up was calculated. For data analysis, two phases of the whole movement were defined. The preparation/rising phase starts with a first decrease of vertical force by > 2.5% of resting weight (~ feet + shank). The value of 2.5% was derived empirically. This phase ends when vertical force reaches body weight after decreasing and increasing again after peak force. During the following stabilization phase, vertical GRF oscillates around body weight. It starts with the end of the preparation/rising phase and ends at the point when vertical force oscillates inside a corridor of 2.5% of body weight. A typical curve of vertical force as function of time during an STS transfer is shown in Figure 1. Participants who were not able to rise from a chair without using armrests or other assistance showed different force–time curves, so the phases of rising could not clearly be separated by the described method. These participants had to be excluded.

Power (W) was calculated from the measured time to rise body weight from a seated to a standing position. Rising starts with seat-off, when vertical force reaches peak force (12) and ends with the end of the preparation/rising phase (8). Thus, power in our method is not a maximum or mean value, but is derived from the constants body weight, body height standing – body height sitting, and the measured time.
of rising, and is simply named “power” in the following text. Power was calculated from the following equation:

\[ P = \frac{F \times s}{t} \]

where \( F \) and \( s \) represent the constant factors of vertical GRF of body weight and the difference between body height standing and body height sitting, respectively. \( t \) represents the duration of the rising phase.

Increase in the rate of vertical force (N/s) was defined as increase from 20% to 90% of maximum force divided by elapsed time in between. Overshoot (N) was defined as maximum vertical force minus GRF of body weight, regardless of time of maximum force. Power, increase, and overshoot were derived from the sum curve of the left and right force plates. In addition, the difference between the maximum force (N), generated on the left and right force plate adjusted to BMI.

### Results

Descriptive data of all independent and dependent variables as well as nonadjusted values are shown in Table 2. Poor to fair correlation could be shown between the predefined independent variables. Fair coefficients of correlation could be documented for the association between adjusted overshoot/adjusted maximum GRF, adjusted overshoot/adjusted increase, and adjusted maximum GRF/adjusted power. Correlation coefficients are shown in detail in Table 3.

Regression analysis including power, maximum vertical GRF, increase of GRF (each adjusted to BMI), and time of stabilization as independent variables explained 81% of the variance of the total time to stand up. By far strongest predictor of total time was time of stabilization (F = 459.4). Overshoot and left–right difference of GRF, each adjusted to BMI, were excluded in a stepwise elimination because of nonsignificance (p values were 0.471 and 0.977, respectively).

Regression analysis including power, maximum vertical GRF, and increase of GRF (each adjusted to BMI) as independent variables explained 37% of the variance of time to reach an upright position. Here, the strongest predictor of time to reach an upright position was increase of GRF adjusted to BMI (F = 38.3). Overshoot and left–right difference of GRF, each adjusted to BMI, and time of stabilization were excluded in a stepwise elimination because of nonsignificance (p values were 0.481, 0.977, and 0.703). Results of the regression analysis are shown in detail in Tables 4 and 5.
Table 4. Regression Analysis of the Total Time to Stand Up
From a Chair (Intercept = 1.5907, \( r^2 = 0.8087 \))

<table>
<thead>
<tr>
<th>Regression Coefficient</th>
<th>Standard Error</th>
<th>F Statistic</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pow/BMI</td>
<td>0.02278</td>
<td>0.00518</td>
<td>19.34</td>
</tr>
<tr>
<td>GRF/BMI</td>
<td>0.0250</td>
<td>0.00661</td>
<td>11.59</td>
</tr>
<tr>
<td>Incr/BMI</td>
<td>-0.00260</td>
<td>0.00043</td>
<td>36.82</td>
</tr>
<tr>
<td>T-stab</td>
<td>1.01647</td>
<td>0.04742</td>
<td>459.41</td>
</tr>
</tbody>
</table>

Note: Pow/BMI = power adjusted to body mass index; GRF/BMI = maximum vertical ground reaction forces (GRF) adjusted to BMI; Incr/BMI = increase of vertical GRF adjusted to BMI; T-stab = time of stabilization phase.

Table 5. Regression Analysis of the Time to Reach an Upright Position (Intercept = 1.5904, \( r^2 = 0.3721 \))

<table>
<thead>
<tr>
<th>Regression Coefficient</th>
<th>Standard Error</th>
<th>F statistic</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pow/BMI</td>
<td>-0.02246</td>
<td>0.00508</td>
<td>19.54</td>
</tr>
<tr>
<td>GRF/BMI</td>
<td>0.02265</td>
<td>0.00657</td>
<td>11.87</td>
</tr>
<tr>
<td>Incr/BMI</td>
<td>-0.00261</td>
<td>0.00042</td>
<td>38.26</td>
</tr>
</tbody>
</table>

Note: Pow/BMI = power adjusted to body mass index; GRF/BMI = maximum vertical ground reaction forces adjusted to BMI; Incr/BMI = increase of vertical GRF adjusted to BMI.

**DISCUSSION**

The main focus of the study was to examine the relative importance of strength and coordination of strength exertion related to time during the STS transfer. We analyzed independent variables, which were directly derived from the outcome performance, to avoid over- or underestimation of the variables. Although there is an obvious association between different variables measured during one movement, poor to fair coefficients of correlation indicate a relative independence of the included variables.

A large proportion of variance of the total time to stand up from a chair could be explained by the introduced models. The higher percentage of explained variance in STS transfer in our study, compared to studies of McCarthy and colleagues (4) (43% and 33%), Lord and coworkers (3) (34.9%), and Schenkman and colleagues (2) (47%), is mainly caused by measuring a stabilization phase in our investigation and including this time of stabilization as an independent variable. It is apparent that a stabilization phase, included in total time, is relevant for measurement of total time to rise from a chair. Thus, the results could be expected to be better than in previous studies. The relative importance of the stabilization phase is expressed by the result of the F statistic.

One limitation of the study is that the unit to measure the stabilization phase and the unit to measure total time were the same, but as there was much variation and a wide range in performance of stabilization phase (mean duration 0.38 s, standard deviation 0.42 s, range 0–3.15 s) the individual value could have a major or minor influence on the total time of STS transfer. We included stabilization phase to quantify postural stability in this crucial phase of the movement. Furthermore, it is important to mention that there was no ceiling effect in strength-related parameters. Values for a younger cohort with a mean age 67.8 years (1) were better in power (41.5%), maximum GRF (38.4%), overshoot (221.4%), and increase of GRF (132.6%). Thus, these strength-related parameters could have been potential factors in the regression analysis. In contrast, it seems that this old cohort had adequate strength to complete the STS transfer. Better values of power, maximum GRF, overshoot, and increase of GRF might be related to a faster rise time. Furthermore, this contrived test situation (i.e., to rise as fast as possible) might not be representative of habitual performance.

As problems during STS transfer might occur in a phase prior to the stabilization phase, we also calculated the regression model for the time to reach an upright position. Here, explanation of the variance of time to reach an upright position was comparable to the aforementioned studies. Thus, basic factors influencing time of stabilization seem to be less effective in the preparation/rising phase. Nevertheless, the stabilization phase seems to be an important factor for total STS transfer and is worth further investigation. During this phase of movement, the upward and forward directed movement of the center of mass has to be slowed down. Additional measurements, such as electromyogram signals of calf muscles or measurement of horizontal forces, may help to analyze STS transfer. To have more information about this crucial phase of rising seems to be important against the background that motor strategies differ between older and younger persons during STS transfer (14,15).

In this study the importance of power, besides an increase of GRF, as a major determinant of time to rise from a chair confirms the previous results of Miszko and colleagues (16), who demonstrated that an intervention of power exercises is able to improve physical function.

The influence of vertically directed strength was remarkably low in both models. This finding indicates that explanation of variance by isokinetic (meaning constant speed of movement during the measurement) strength measurement solely (4) might overestimate the given association. Strength is a dynamic variable during STS transfer (8,10,13), and the speed of body parts, which can be measured by goniometric or optoelectronic systems, is not constant during STS transfer (8,13). Against this background measurement of isometric (meaning no movement during the measurement) strength (2,3) also has to be seen critically in this context. Thus measurement of strength, especially when not assessed during functional performance, can not be seen as a correlate of performance, although there is an association. This hypothesis is corroborated by studies that were designed to improve functional performance by strength training solely, but could show only minimal or no improvement in functional performance, whereas strength improvements were considerably high (17,18).

The nonsignificant association and therefore exclusion from the model of left–right difference of vertical GRF is remarkable because studies of Lomaglio and Eng (19) indicate a clear association. This association might be explained by the facts that: (i) they included only hemiplegic individuals, whereas the proportion of hemiplegic participants in our study was small; and (ii) they measured GRF at liftoff and not maximum GRF of left and right leg.

Providing that variables such as increase of GRF, power, and time of stabilization represent coordinative aspects, our investigation shows that STS transfer is not only influenced...
by strength, but also by coordination of strength exertion. Here, the influence of power was superior to that of maximum vertical GRF, a finding which is in agreement with those of Bean and colleagues (20).

The fact that we measured relatively rapid rises with high importance of momentum control might be caused by the functional status of the cohort, i.e., the ability to rise without the use of hands. For participants unable to rise without the use of hands the predictive parameters for the STS transfer might be others than in this study.

It is important to consider that coordination aspects in functional tasks might differ according to baseline status. A functional test like the STS must be a challenging maneuver for the selected cohort, to avoid ceiling effects. Considering that up to half of the falls in frail older adults occur during STS transfer, it seems also ecologically appropriate to study coordination of strength exertion under this condition. The tested cohort with a mean age above 80 years, reduced mobility status, a positive fall history of > 60%, and multiple other functional deficiencies seemed therefore appropriate to study this research question.

Conclusion

Our study can explain a high proportion of variance of time to rise from a chair by including variables which represent coordinative aspects of strength. In contrast to previous studies, all variables were measured during the STS transfer. Thus, over- or underestimation of their influence is unlikely. Stabilization after reaching an upright position seems to be a parameter worth further investigation. More research is needed to show whether these results can also be applied to people who are not able to rise from a chair without the use of arms.

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References


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