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Effect of bed height and use of hands on trunk angular velocity during the sit-to-stand transfer

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The ability to rise from a chair or bed is critical to an individual's quality of life because it determines functional independence. This study was to investigate the effect of bed height and use of hands on trunk angular velocity and trunk angles during the sit-to-stand (STS) performance. Twenty-four older persons (median age 74 years) were equipped with a body-fixed gyroscopic sensor and stood up from a bed adjusted to different heights, with and without the use of hands at each height. Peak angular velocity and trunk range of motion decreased with increasing bed height (all $p \leq 0.038$) and were lower using hands during STS transfer indicating less effort. In conclusion, gyroscopic sensor data of the STS transfer of older persons show differences as an effect of bed height and use of hands. These results provide the rationale for recommending a relatively high bed height for most of the older persons.

Practitioner Summary: To minimise the effort during sit-to-stand transfer performance from bed, it is necessary to understand the effect of bed height and use of hands. It is concluded that a relatively high bed height and the use of hands is helpful for most of the older persons during sit-to-stand transfer.

Keywords: bed height; inertial sensor; older persons; sit-to-stand; use of hands

1. Introduction

The sit-to-stand (STS) transfer is a prerequisite for any kind of mobility, which in older persons is associated with health and well-being (LaCroix et al. 1993; Manini et al. 2006). Starting from a sitting position with a three-point contact (buttocks, left foot and right foot) on a stable surface, the transfer to standing is characterised by the loss of the buttock contact during a complex movement. As a consequence, falls occur when the performance of this movement is inappropriate. In a cohort of nursing home residents, 41% of all falls were associated with the STS transfer (Rapp et al. 2011). In this context, it is obvious that the use of hands during STS transfer has a supporting effect (Arborelius, Wretenberg, and Lindberg 1992) and that the height of the seat may affect the risk involved. Schenkman, Riley and Pieper (1996) showed that trunk angular velocities reflect differences in effort to perform the STS transfer due to differences in chair height. Here, angular velocity was the outcome parameter to describe trunk orientation during the STS transfer.

The STS transfer from bed is worth further investigation, since the nightly bed STS transfer related to nocturia is a potential falls risk factor (Stewart et al. 1992). Furthermore, beds in a clinic are usually height adjustable, which has an effect on movement strategies (Schenkman, Riley, and Pieper 1996), but the effect of bed height so far has been investigated only in the context of muscular activity and exertion during standard nursing tasks (Caboor et al. 2000) where higher bed heights are desirable from the nurses' health perspective. In contrast, lower bed heights are desirable with respect to falling out of bed and resulting injuries (Bowers et al. 2008; Hanger, Ball, and Wood 1999).

Assessment of STS transfer kinematics is commonly done using instruments, such as force plates and opto-electronic devices (Lindemann et al. 2003; Schenkman, Riley, and Pieper 1996). These are generally accepted and precise techniques. However, they lack clinical applicability because they are expensive, locally tied and time consuming. In a clinical environment, more suitable methods are desirable to assess STS performance. Inertial sensors are eligible for this purpose because they are small, cheap and relatively easy to use (Zijlstra and Aminian 2007). They can detect body sway (Lindemann et al. 2012), power (Zijlstra et al. 2010) and other parameters relevant to assess STS performance, such as angular velocity (Boonstra et al. 2006; Wentink et al. 2014).

The aim of this study was to determine the effect of bed height and use of hands on trunk angular velocity and trunk angles measured with an inertial sensor during STS performance. It was hypothesised that angular velocity decreases with increasing bed height and with the use of hands during the STS transfer.

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2. Methods

2.1 Subjects and design

For this cross-sectional experimental study, a mixed sample of 24 older persons (median age 74 years, 50% women) was recruited from a German geriatric rehabilitation clinic and from the community. The participants had to be above 60 years of age. Exclusion criteria were inability to stand up from a bed, orthopaedic and neurologic problems affecting the STS transfer (e.g. hip fracture, knee replacement, stroke) and cognitive problems affecting understanding of the protocol or informed consent. The study was approved by the ethical committee of the local university. All participants gave written informed consent.

2.2 Data acquisition of outcome parameters and descriptive variables

Data acquisition was performed in all subjects using a DynaPort® Hybrid (McRoberts B.V., The Hague, the Netherlands) data logger (87 × 45 × 14 mm). The DynaPort® Hybrid makes use of a tri-axial seismic acceleration sensor (LIS3LV02DQ, STMicroelectronics, Agrate Brianza, Italy) and three orthogonally placed gyroscopic sensors (XV-3500CB, Epson, San Jose, CA, USA). The gyroscopic sensors had a range of ± 100 deg/s, a resolution of ± 7 mdeg/s, were sampled at a rate of 100 samples per second and low-pass filtered (zero-phase) with a cut-off frequency of 5 Hz. Data were stored for offline analysis on a microSD card. Outcome variables' peak angular velocity of flexion and extension (deg/s) was calculated as the mean of the maximum values of two trials. Furthermore, range of movement of flexion and extension of the trunk (deg) was calculated by numerical integration of the angular velocity data using the function 'cumtrapz' in MATLAB (The MathWorks, Inc., version 7.13) and averaged over two trials.

The sensor was fixed in a belt worn at the lower back, so that the axes of the sensor were aligned with the anatomical axis of the lower trunk. In addition, knee angles and foot angles were measured manually by a goniometer at all bed heights.

Habitual gait speed was measured over a distance of 4 m by stopwatch, as a descriptive parameter. The older participants were screened for co-morbidities by questionnaire (Groll et al. 2005). The participants are described in detail in Table 1.

2.3 Assessment protocol

After measurement of body height, knee height was measured as the distance from knee joint space to the ground and leg length as the distance from trochanter major to the ground. Then falls, co-morbidities and gait speed were assessed. Finally, the participant was seated on a height adjustable bed with his/her feet comfortably apart. The Hybrid sensor was fixed around the waist. The 100% bed height was defined according to the method of Schenkman, Riley and Pieper (1996) with the bed adjusted so that the thighs of the participant were horizontal, feet flat on the ground and knee angle and ankle angle were self-chosen, prepared to stand up. The bed height was measured with a yardstick excluding the 13-cm-thick mattress, which was compressed individually by the participants. STS performance was assessed from 80%, 100% and 120% bed height in a random order. Participants were instructed to stand up with their habitual speed at each bed height, twice with their arms folded in front of the trunk (see Figure 1) and twice with using hands to push off from the mattress. Each STS transfer started with the instruction to stand up and ended with the instruction to stand still for about 10 s. Rehearsal trials were allowed if needed. Knee angles and foot angles were measured in the sitting position after standing up with folded arms.

Table 1. Description of the 24 older participants.

	Median	1st–3rd quartile	Min–Max
Age (years)	74.0	69.0–78.8	64–91
Body mass (kg)	71.5	60.8–81.0	41–139
Body height (cm)	166	161.0–174.0	152–191
Knee height (cm)	51.0	49.0–53.5	45–61
Leg length (cm)	85.5	83.0–91.8	79–105
100% bed height (cm)	37.5	36.5–39.4	31–45
Habitual gait speed (m/s)	1.11	0.79–1.26	0.42–1.48
Co-morbidities (number)	3.0	2.0–4.0	0–5

Note: An individually compressed mattress of 13-cm thickness was lying on top of the 100% bed height.

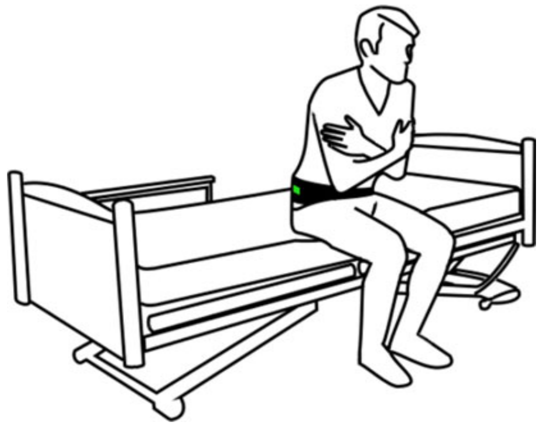

Figure 1. Participant standing up from bed with arms folded in front of the trunk and sensor fixed in a belt worn at the lower back.

After completion of all trials the participants were asked whether using hands or not during the STS transfer was more challenging, and which one of the positions (low, middle, high) was the most challenging and which one was the least challenging position.

2.4 Statistics

With regard to the small sample size, non-parametric statistics were applied. Friedman and Wilcoxon tests were used to show differences, and Spearman's coefficient of correlation was used to show associations. The significance level was set to an uncorrected $\alpha = 5\%$ (two-sided). All analyses were conducted using SPSS version 16 software (SPSS Inc., Chicago, IL, USA).

3. Results

Ninety-two per cent of the participants reported that in general the use of hands during STS transfer made the performance less challenging. All participants reported that the lowest position (80% bed height) was the most challenging position to perform the task and six persons were not able to get up from this position without using hands. Eighty-three per cent reported that the highest position (120% bed height) was the easiest position to get up.

Peak angular velocity decreased with increasing bed height for flexion without ($p = 0.007$) and with ($p < 0.0001$) use of hands. For extension the same decrease with increasing bed height was documented without ($p = 0.02$) and with ($p = 0.001$) use of hands. Trunk flexion range of motion also decreased with increasing bed height without ($p = 0.001$) and with ($p < 0.0001$) use of hands. For trunk extension range of motion, the same decrease with increasing bed height was documented without ($p = 0.038$) and with ($p = 0.001$) use of hands. Results of peak angular velocity and trunk range of motion are presented in detail in Table 2.

All peak trunk angular velocities of flexion and extension were higher at all bed heights without using hands to stand up from bed (see Table 2) with p-values of 0.012 or less indicating statistical differences, with only flexion at 100% bed height

Table 2. Peak trunk angular velocity and trunk range of motion of all 24 participants during STS transfer from 80%, 100% and 120% bed height.

	Peak angular velocity		Trunk range of movement	
Bed height, use of hands	Flexion (deg/s)	Extension (deg/s)	Flexion (°)	Extension (°)
80%, without	86.5 (81.4–95.0)	54.5 (39.6–65.4)	42.3 (35.4–51.0)	30.0 (18.9–37.3)
80%, with	78.3 (60.1–82.8)	42.0 (29.1–60.5)	39.8 (32.8–48.1)	28.3 (12.0–33.0)
100%, without	77.5 (70.0–81.5)	49.0 (37.5–60.0)	38.0 (31.5–43.5)	26.5 (20,0–33.5)
100%, with	74.0 (58.6–85.5)	43.8 (28.5–51.8)	34.3 (30.0–42.5)	25.0 (16.5–33.3)
120%, without	73.8 (66.8–86.4)	45.3 (37.0–55.9)	37.5 (28.6–43.5)	26.0 (17.9–32.9)
120%, with	65.5 (42.8–74.1)	36.8 (25.6–53.3)	28.8 (22.9–38.1)	24.0 (11.6–29.6)

Note: Results are presented as median (1st–3rd quartile).

being not statistically significant. Trunk range of motion of flexion and extension was higher at all bed heights without using hands with p-values all 0.014 or less, with only flexion at 80% and 100% bed height being not statistically significant.

The 100% (thighs horizontal) bed height was associated with body height ($r = 0.773$) rather than with knee height ($r = 0.667$) or leg length ($r = 0.662$). Median knee angles increased from low (74.0°) to middle (82.5°) to high (90.0°) bed height significantly (all $p < 0.0001$) whereas there were no relevant differences in foot angles for different bed heights (see Table 3). Knee angles and foot angles of all bed heights were not associated with body height, knee height or with leg length (all $r < 0.402$).

4. Discussion

The results of this study confirmed our hypothesis that angular velocity decreases with increasing bed height and with the use of hands during the STS transfer, and that this can be measured by gyroscopic body-fixed sensors. Moreover, body-fixed sensors are the only solution for practical use in the clinical routine, when the movements of interest are complex, such as getting up from a lying position in bed, when markers of an opto-electronic system are covered and force plates are not applicable (Bagala et al. 2012). Thus, different movements can be quantified by gyroscopic body-fixed sensors in research and in the clinical routine.

With regard to bed height and angular velocity, our results are in line with the results of Schenkman, Riley and Pieper (1996), where angular velocities were measured by an opto-electronic system. In our study, the maximum angular velocity during flexion was lower at the low bed height compared to the study of Schenkman, Riley and Pieper (1996). Higher angular velocities in their study may be explained by their younger cohort. Our results mirror the perception of the participants that standing up was perceived to be harder from lower starting positions. During the phase in which peak angular velocity is reached, the person has to create a forward momentum, which reaches its maximum during seat-off (Hirschfeld, Thorsteinsdottir, and Olsson 1999; Lindemann et al. 2003). The results of our study and the study of Schenkman, Riley and Pieper (1996) show that subjects increase trunk flexion angular velocity to overcome mechanical difficulties of decreasing bed/chair height. Although we cannot conclude an optimum bed height from our study, results suggest that a bed height higher than sitting with thighs horizontal reduces the effort required to stand up from the bed. Furthermore, the study indicates that there is not one bed height for all persons. In order to confirm this, controlled studies would be required. A low bed height is likely to decrease fall impact on those persons who are unable to transfer (Bowers et al. 2008; Hanger, Ball, and Wood 1999), for example severely demented persons with motor disability. In contrast, our results show that persons with borderline motor function and adequate executive function could be supported with an elevated bed height to maintain or increase autonomy.

Differences between using hands or not to push off from the bed are in line with a previous study (Arborelius, Wretenberg, and Lindberg 1992) and indicate that pushing off with hands is an alternative solution to overcome mechanical difficulties of decreasing bed height. These differences occur as differences in angular velocity and differences in range of motion. Again, in our study, these differences are mirrored by the participants' perception. These results concerning the use of hands and bed height provide the rationale to standardise test conditions of STS performance measurements at least for repeated measurements.

Our results indicate that body-fixed inertial sensors can be used to determine differences in effort to perform an STS transfer related to environmental constraints (seat height) and movement strategy (use of hands). The discriminative value of gyroscopic body-fixed sensor data to characterise STS performance is corroborated by other studies showing differences in STS performance of different groups (Millor et al. 2013; Schenkman, Riley, and Pieper 1996; van Lummel et al. 2012).

Decreasing knee angles with increasing bed height indicate that the participants attempted to position their feet close to their body before standing up. This keeps the forward momentum, necessary to bring the centre of mass over the base of support, at a minimum. In contrast, a foot angle of 81°–84° seems to be an optimum for the starting position of the STS transfer irrespective of bed height because there was no relevant variance related to different bed heights and different knee angles.

Table 3. Knee angles and foot angles of all ($n = 24$) participants related to different bed heights.

	80% bed height Median (1st–3rd q)	100% bed height Median (1st–3rd q)	120% bed height Median (1st–3rd q)
Knee angle (°)	74.0 (67.0–76.8)*	82.5 (78.0–87.0)*	90.0 (85.3–94.5)*
Foot angle (°)	83.0 (79.0–88.8)	84.0 (78.5–86.0)	81.0 (76.3–84.8)

Note: q = quartile.
*Significant difference between bed heights all $p < 0.0001$.

One limitation of our study is that our results cannot be generalised to younger cohorts, but the STS transfer performance is more relevant in older persons than in younger persons.

In conclusion, gyroscopic sensor data of the STS transfer of older persons show differences as an effect of bed height and use of hands to push off. With regard to the STS transfer, these results provide the rationale for a bed height for most of the older persons higher than sitting with thighs horizontal. Furthermore, the results provide the rationale to standardise test conditions of STS performance measurements in older persons.

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