Between-day reliability of trunk orientation measured with smartphone sensors during sit-to-stand in asymptomatic individuals

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DOI:
10.1016/j.msksp.2022.102713

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ABSTRACT:

Background. Trunk kinematics during sit-to-stand is often impaired in individuals with musculoskeletal disorders. Trunk kinematics is commonly assessed in laboratories using motion capture; however, this equipment is often not available outside research centers. Smartphones are widely available and may be a suitable alternative to assess trunk orientation during sit-to-stand remotely.

Objectives. We investigated whether trunk orientation in the sagittal plane during sit-to-stand can be measured reliably between days when collected remotely using smartphones.

Design. Cross-sectional study.

Method. Forty-three asymptomatic participants performed 15 sit-to-stand movements in two separate sessions remotely over videoconferencing. Trunk orientation was measured using each participant's smartphone. Absolute peak trunk orientation in the sagittal plane was extracted during standing, sitting, stand up and sit down. Relative trunk orientation was calculated as the difference between sitting and stand up, or sitting and sit down. Reliability was assessed using Intraclass Correlation Coefficient ($ICC_{2,k}$), Standard Error of Measurement (SEM) and Minimal Detectable change (MDC). Between day bias and between-gender differences were assessed using T tests.

Results. All measures showed good reliability ($ICC_{2,k}$>0.80; SEM<5.6 degrees; MDC<13.6 degrees) and no between-day bias (p>0.31). Relative measures were more consistent ($ICC_{2,k}$>0.88; SEM<3.6 degrees; MDC<9.9 degrees). No between-gender differences were observed for relative orientation (p>0.75).

Conclusions. Sagittal trunk orientation during sitting, standing, and sit-to-stand can be measured reliably when asymptomatic individuals use their own smartphones supervised over videoconferencing. These findings support the use of smartphone sensors for assessing how trunk orientation changes over time, which may assist physiotherapists assess movement patterns of individuals with musculoskeletal disorders remotely.

Keywords: Smartphone, trunk, kinematics, sit-to-stand, reliability.

INTRODUCTION:

Sit-to-stand is a daily living activity commonly impaired in individuals with musculoskeletal symptoms (Baldwin et al., 2017; Yenişehir et al., 2020). Forward transition of the center of mass is obtained by flexion of the trunk, which has been shown to be impaired in individuals with low back pain (Sedrez et al., 2019), knee osteoarthritis (Sonoo et al., 2019), and in the elderly (Dubost et al., 2005; Jeon et al., 2021). Strategies with excessive or insufficient trunk flexion have been described in the elderly (van der Kruk et al., 2021), and the inability to move the center of mass forward has been linked to unsuccessful sit-to-stand performance (Kerr et al., 2019). Objective measures of trunk orientation during sit-to-stand may assist clinicians in assessing motor impairments and to monitor the effectiveness of physiotherapy interventions.

Trunk kinematics, which includes trunk orientation (e.g.: angle between the trunk and the vertical) and thoraco-lumbar flexion (i.e.: angle between the thoracic and the lumbar spine), is usually assessed using motion capture (Christe et al., 2022; Kerr et al., 2019; Sedrez et al., 2019) and inertial measurement sensors (Roldán-Jiménez et al., 2019). These technologies are often not available outside research laboratories. Smartphone sensors, instead, are widely available to the general population and have been shown to provide valid (Elgueta-Cancino et al., 2022; Keogh et al., 2019; Sedrez et al., 2020) and reliable (Elgueta-Cancino et al., 2022; Keogh et al., 2019; Sedrez et al., 2020) measures of body segment orientation, especially in static tasks. While several acceleration parameters were shown to be reliable when measured with a smartphone during a dynamic task such as sit-to-stand (Cerrito et al., 2015), it is currently unknown if trunk orientation measures obtained with smartphone sensors are also reliable. In addition, the vast majority of studies using smartphone sensors to measure kinematics has been performed in a laboratory, where the same smartphone was placed on the participant by an experienced researcher (Elgueta-Cancino et al., 2022; Keogh et al., 2019; Sedrez et al., 2020). It is currently unknown whether reliable trunk orientation measures can be obtained in a more ecological setting, when individuals measure their kinematics using their own smartphone remotely.

In this study we investigated whether trunk orientation in the sagittal plane during sitting, standing, and sit-to-stand can be measured remotely using smartphone sensors, and whether the measures are reliable between days.

METHODS:

Forty-three adults (29 women; age: 26.7±12.3; height: 171.3±8.4 cm; weight: 72.4±17.9 kg) who reported no current pain, injury, or known motor impairment participated in two sessions at least a week apart. Participants were recruited from the student population of the XXX and from the community, and individuals who reported previous injury or pain but were currently asymptomatic were allowed to participate. This study was approved by the ethics committee of the XXX, and participants signed an informed consent before participating in the study.

Participants performed 3 sets of 5 sit-to-stand movements at a self-selected pace, wearing the same shoes and using the same chair in the two sessions, under supervision of a researcher via videoconferencing. The participants were free to choose where to perform the experimental session, for instance in their residence or elsewhere, and there were no restrictions with respect to the height of the chair. The number of repetitions was conservatively chosen as the largest number of trials reported in a recent systematic review (Pourahmadi et al., 2019). Each participant collected trunk orientation data using the Matlab Mobile app (MathWorks, Natick, US) installed in their own smartphone. We asked the participants to hold their smartphone on their upper chest using both hands during the task. Participants were instructed to stand up and sit down at their own pace, and to ensure that their back would touch the chair backseat every time they sat down. The smartphone position was standardized (landscape orientation, screen facing forward, camera on the left) so that changes in trunk orientation in the sagittal plane would be recorded as changes in Roll angle (Orientation sensor). Since 0 degrees corresponded to a vertical orientation of the smartphone, value of -20 degrees would indicate that the front of the participant chest was tilted 20 degrees from the vertical towards extension (Figure 1). The data was digitized 100 Hz and shared with the researchers through Matlab Drive (MathWorks, Natick, US).

The data was exported in csv format using a custom-made script in Matlab Online (MathWorks, Natick, US) to be analyzed in Microsoft Excel (Microsoft corporation, Redmond, US). For each repetition, we visually identified the following phases of the sit-to-stand movement: i) Sitting, before the start of the movement; ii) Stand up, first peak of trunk flexion; iii) Standing, trough between the two flexion peaks; iv) Sit down, second peak of trunk flexion. Maximum and Minimum functions were used to extract the exact value in each visually-identified phase. These absolute orientation values were averaged across 15 repetitions, separately for day 1 and day 2. As an estimate of relative orientation, Stand up range of motion (ROM) and Sit down ROM were calculated as the difference between Sitting and Stand up, or Sitting and Sit down, respectively. Since the changes in angle between sternum and thoracic spine are expected to be minimal during sit-to-stand, sensors placed on the sternum or on the thoracic spine will provide similar relative orientation estimates (although absolute measures will have a subject-specific bias equal to the angle between sternum and thoracic spine).

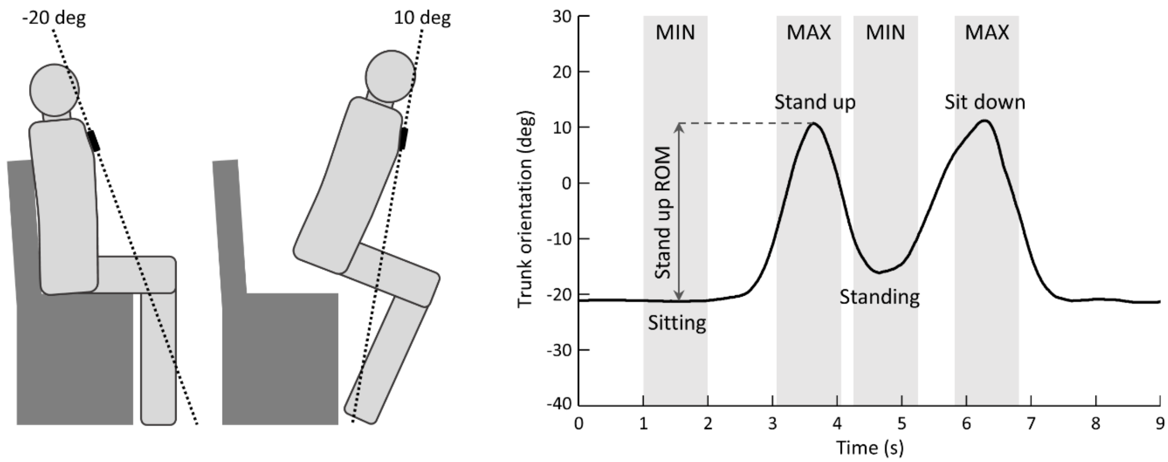

Figure 1: Left: Protocol and smartphone position. Right: Example of trunk orientation of one participant. Shaded areas depict where the maximum (Stand up, Sit down) and minimum (Sitting, Standing) values were identified to quantify kinematics during sit-to-stand.

Using SPSS (IBM, Armonk, version 28), we assessed the between-day reliability as: i) two-way random effect Intraclass Correlation Coefficient for absolute agreement and average measures ($ICC_{2,k}$); ii) standard error of measurement (SEM); iii) minimal detectable change (MDC) (de Vet et al., 2011). We estimated the between-day bias using paired T-tests. To understand whether gender influenced our estimates, we compared the absolute and relative trunk orientation between males and females using independent T-tests on the data from day 1. Significance was set at alpha = 0.05, and all data is reported as mean and standard deviation.

RESULTS:

Thirty-four participants used an Apple iPhone and 9 participants used an Android-based smartphone. Data was normally distributed (Shapiro-Wilk test). Values, reliability statistics and comparison by gender results are summarized in table 1, and Bland-Altman plots are shown in Figure 2.

While all measures showed good reliability ($ICC_{2,k}$>0.80), relative orientation measures showed larger ICC with narrower confidence intervals, lower SEM and MDC. No between-day bias was observed (Stand up: p=0.31; Sit down: p=0.42; Standing: p=0.52; Sitting: p=0.36; Stand up ROM: p=0.82; Sit down ROM: p=0.84). When comparing orientation estimates between genders, trunk flexion was approximately 10 degrees larger in males in the absolute (Stand up: p=0.012; Sit down: p=0.017; Standing: p=0.004; Sitting: p=0.001), but not in relative (Stand up ROM: p=0.756; Sit down ROM: p=0.751) orientation measures.

*Table 1: Between day reliability, bias, and gender difference in sagittal trunk orientation and range of motion during sit-to-stand. * $p<0.05$*

Phase	Value (deg)	ICC [CI]	SEM (deg)	MDC (deg)	Between-day bias (deg)	Between-gender difference (deg)
Absolute reliability measures						
Standing	-24.1±10.6	0.80 [0.64-0.89]	4.7	13.1	-1.0±9.6	9.8 *
Sitting	-31.0±10.7	0.82 [0.66-0.90]	4.6	12.7	1.3±9.2	10.9 *
Stand up	10.7±13.4	0.83 [0.68-0.91]	5.6	15.4	1.5±9.8	9.7 *
Sit down	10.8±13.0	0.86 [0.74-0.92]	4.9	13.6	1.1±8.9	9.9 *
Relative reliability measures						
Stand up ROM	41.7±11.4	0.89 [0.79-0.93]	3.6	9.9	0.2±6.9	-1.2
Sit down ROM	41.8±9.7	0.88 [0.77-0.93]	3.3	9.1	-0.2±6.3	-1.0

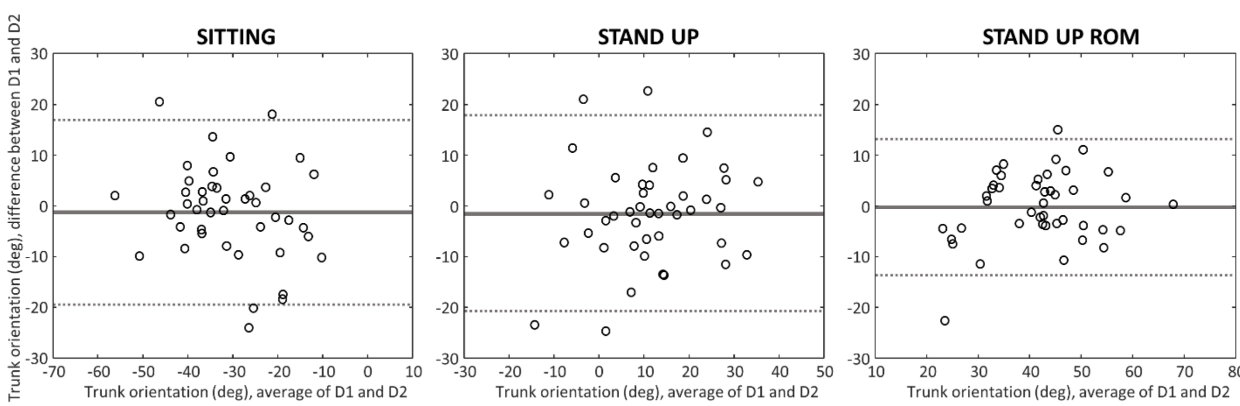

Figure 2: Between-day reliability for sitting, stand up, and stand up range of motion. In the Bland-Altman plots, each circle represents the average of (X axis) and difference between (Y axis) estimates of trunk orientation for each participant. The thick gray line represents the average difference between days, and the dashed lines depict the 95% limits of agreement. D1and D2 identify day 1 and day 2.

DISCUSSION:

Our findings show good between-reliability of trunk orientation measured remotely using smartphone sensors during sit-to-stand, especially when relative measures of range of motion is considered. The good between-day reliability is consistent with other smartphone-derived measures obtained in the laboratory (Cerrito et al., 2015; Elgueta-Cancino et al., 2022; Keogh et al., 2019; Sedrez et al., 2020), with measures of lumbar motion obtained using motion capture in individuals with and without low back pain (Pourahmadi et al., 2018), and with trunk motion measured by different raters using commercially available inertial measurement units (Hamersma et al., 2020). Although the current protocol did not allow to test whether the measure is valid, the relative trunk orientation values close to 40 degrees observed here are similar to those measured in the laboratory using IMUs (Roldán-Jiménez et al., 2019) and motion capture (Dubost et al., 2005). The inter-individual variability in relative trunk orientation of 10-11 degrees is similar to the 12-13 degrees reported when using IMUs in the laboratory (Roldán-Jiménez et al., 2019), whereas the lower variability of approximately 5 degrees reported by others (Dubost et al., 2005) may be due to differences in the protocol.

While all measures demonstrated good reliability, absolute measures were consistently biased toward posterior tilt (trunk extension) in females. This gender difference may be explained by anatomical factors, such as chest anatomy. In females, breast may have increased the distance between the bottom of the smartphone and the sternum, resulting in increased posterior tilt when absolute measures are considered. The absence of between-gender differences when relative measures (standardized to the orientation measured in sitting) are used further supports the possibility that this bias may be due to anatomical factors, therefore constant throughout the task, although gender differences in trunk orientation cannot be excluded from the current study. This gender-difference also highlights the need to investigate the validity of absolute measures in a separate investigation in a laboratory setting. Absolute measures were also less reliable than relative measures. This may be due to small differences in smartphone position between days, since recent research shows that participant-placed sensor positioning is less reliable than researcher-placed sensor positioning (Ruder et al., 2022). However, similarly to what was discussed for the gender differences, the bias due to difference in smartphone position would be removed by computing the relative orientation.

A strength of the current investigation lies in the simplicity of the experimental setup, which is a critical factor for the potential implementation of smartphone measures in the clinic and for remote assessment. Participants used their own smartphone, which implies that no specialized equipment had to be bought or provided by the clinic. The app used in the current study can currently be used for free, and the software used for data analysis is widely available. The choice of holding the smartphone on the chest, while it may be difficult to implement in certain populations (see limitations below), removed the need find a harness or other ways to secure the smartphone to the participant. Overall, this data suggest that smartphone sensors are low-cost, widely available technology can be used to objectively monitor how trunk orientation changes over time. Given the current emphasis on the use of wearables in the assessment and treatment of individuals with low back pain (Hodges and van den Hoorn, 2022), and recent evidence that patients may benefit from interventions addressing specific motor impairments (Kent et al., 2015; van Dieën et al., 2018; van Dillen et al., 2021), future studies should investigate whether smartphone sensors-based assessments may result in improved clinical outcomes.

This study also highlights some limitations of the technique that need to be addressed before it is implemented in practice. First, validity of this measure compared to laboratory equipment, the smallest number of trials that result in valid and reliable estimates, and whether there are differences between smartphone brands and operating systems needs to be established. Second, this method allows only to measure the orientation of the trunk in space, without differentiating motion at different spinal levels or contribution of other joints, such as the hip. Whether it is possible to obtain kinematic measures representative of lumbar motion, which has been reported to be impaired in individuals with low back pain (Devecchi et al., 2021; Hooker et al., 2021; Laird et al., 2014), will need to be established in future studies. Third, we could only assess the reliability of kinematics in the sagittal plane because asymptomatic individuals have limited trunk motion in the frontal and transversal plane during sit-to-stand, therefore the between-subject variance is too low to assess the reliability (de Vet et al., 2011). A simpler app that shows the data directly on the screen and automatizes data analysis may also be easier to implement in clinical practice. Finally, reliability may be lower when individuals have limited upper limb function (e.g.: due to shoulder or hand injuries) or need to use the armrests to raise from the chair.

Our findings show that it is feasible to use smartphone sensors to measure sagittal trunk orientation during sit-to-stand remotely in asymptomatic participants, and that these measures are reliable between days. These measures may assist physiotherapists monitor remotely how trunk kinematics changes over time in individuals with musculoskeletal disorders, and whether physiotherapy interventions are effective interventions to modify trunk kinematics during sit-to-stand.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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