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# RELIABILITY AND MINIMAL DETECTABLE CHANGE OF SIT-TO-STAND KINEMATICS AND KINETICS IN TYPICAL CHILDREN



original paper
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ABSTRACT

**Purpose.** The study aimed to determine the within- and between-session reliabilities as well as the minimal detectable change (MDC) of generally used temporal, kinematic, and kinetic parameters during the sit-to-stand (STS) task in typical children.
**Methods.** The study involved 10 typical children (9.8 ± 1.6 years old). Motion analysis and force plate systems were used to collect markers for 3-dimensional trajectories in space and measure the ground reaction force. The total of 29 reflective markers were placed on each participant's body in accordance with the Helen Hays marker set model by 1 rater on 2 separate days within the span of 1 week. Each subject was asked to perform an STS task 3 times from a height-adjustable chair. Intraclass correlation coefficient (ICC), standard error of measurement (SEM), and MDC for temporal, kinematic, and kinetic parameters were calculated within and between sessions.
**Results.** The results indicated that the temporal parameters achieved excellent (ICC > 0.75), the kinematic parameters presented poor to excellent (0.232 < ICC < 0.997), and the kinetic parameters showed fair to excellent (0.635 < ICC < 0.977) reliabilities in both within- and between-session analyses. The SEM of most kinematic parameters was less than 2° both within and between sessions. In addition, the MDC values for between sessions ranged 1.25–12.64°.
**Conclusions.** The findings support the reliability of using 3-dimensional motion analysis and force plate systems for measuring temporal, kinematic, and kinetic parameters for STS tasks in typical children.
**Key words:** reliability, minimal detectable change, children, sit-to-stand, kinematics, kinetics

## Introduction

Laboratory-based 3-dimensional (3D) motion capture and force measurement systems have been widely used to investigate human movements. They provide objective information concerning movement patterns, especially multi-planar, and dimensional joint kinematics and kinetics during movement [1]. Currently, these systems are applied not only in gait analysis, but also in other movement analysis, including sit-to-stand (STS) tasks [2, 3]. The STS task has been reported as the most common functional activity in daily life, especially in the child population [4]. The ability to perform this task is a pre-requisite for other activities of daily living, such as walking [5]. When quantifying movement with 3D motion capture and force measurement systems, two aspects of the data should be of concern. First, the value of data should show enough consistency or reliability for clinical decisions within one or across several sessions. Second, these data should be able to represent clinical change over time [6, 7].

In previous studies, the reliability of data obtained from within or between testing sessions conducted by the same assessor was often determined with the intraclass correlation coefficient (ICC) [8, 9]. This value could reflect both degrees of correspondence and agreement among trials and sessions. In addition, the minimal detectable change (MDC) was the most widely calculated value used to detect the change of values due to actual change in performance [10]. In 2008, Gilleard et al. [11] conducted a study to investigate within- and between-session reliabilities of kinematic and kinetic parameters in the frontal and transverse planes during STS in healthy adults. They concluded that

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both within- and between-session reliabilities were poor to good in the frontal plane, and good to excellent in the transverse plane, for measuring ranges of movement in lower limb joints. In addition, the reliability of the peak ground reaction force components was fair to excellent, whereas the lower limb joint moments were poor to excellent [11]. However, to apply 3D motion capture and force measurement systems in the child population, the reliability of measurements should be reinvestigated. Children acquire the ability to perform the STS task normally at approximately 1 year of age [12], and it continues to develop as they age [13]. Even though the sequence of joint movements and proportional duration of the segmental motion in typical 6–7-year-old children did not differ from adults, children showed twice as much intra-individual variability across trials [14]. This variability may influence the reliability of the STS task.

To date, there has been lack of evidence showing the reliability and MDC of laboratory-based 3D motion capture and force measurement systems for analysing the STS task in typical children. Therefore, the objective of this study was to determine within- and between-session reliabilities, as well as the MDC of generally used temporal, kinematic, and kinetic parameters for STS tasks in typical children.

## Material and methods

### Participants

A convenience sample of 10 children (8 girls and 2 boys) with typical development, aged 7–12 years, were recruited from the local schools. The mean age, body weight, and body height of the participants were 9.8 ± 1.6 years, 35.1 ± 11.6 kg, and 138.9 ± 14.0 cm, respectively. Subjects were excluded if they had a known neuromuscular disease according to their teachers' or guardians' reports. The size of the sample used in the study was based on the median of the sample size in a reliability study [15].

### Procedure

A prospective study was carried out to investigate the within- and between-session reliabilities of the 3D motion capture and force measurement systems. Eight cameras (Raptor-E, Motion Analysis Corporation, Santa Rosa, CA) with the sample rate of 120 Hz and 2 force platforms (Bertec Corp., Columbus, OH) with the sample rate of 1200 Hz were used to collect 3D marker trajectories and the ground reaction force. Prior to data collection, the participants were required to put on a tank top, shorts, and a swim cap for reducing the movement of markers during data collection. Then, 29 (12.5 mm) passive reflective markers were placed on the anatomical landmarks of each participant in accordance with a modified Helen Hays marker set model [16]. The anatomical landmarks were the following: top, front, and back of the head, bilateral tips of the acromion process, bilateral lateral epicondyles of the humerus, bilateral centre between the styloid process of the radius and ulna, bilateral anterior superior iliac spines, superior aspect at the L5 sacral interface, bilateral thighs, bilateral lateral femoral condyles, bilateral shanks, bilateral lateral malleoli, bilateral posterior calcaneus, bilateral centre of the feet between 2$^{nd}$ and 3$^{rd}$ metatarsals, bilateral median malleoli, bilateral medial femoral condyles, and the offset at right scapula.

The participants were instructed to perform an STS task at their self-selected speed from an adjustable chair. The height of the chair was set at 100% of the lower leg length for each child. In the starting position, the subjects sat with arms across the chest, facing forward. Both feet were completely flat on the force platforms. The ankle joint lay in a plane slightly posterior to the knee joint, in accordance with each participant's preferred position. The seat depth was set at 30% of the thigh length [17]. In the first session, the children were asked to participate in 2 practice trials prior to data collection. They also decided what their preferred feet positions were at the starting sitting position. Then, the starting position was set. The researcher marked the position of the participants' feet and the location of their buttocks to ensure that each subject sat in the same position at each trial. The same sitting position was applied in the second session. Each participant could practice 2 times prior to data collection. In each session, the children completed 3 trials, from which data were collected. Two sessions were conducted on separate days within 1 week by the same assessor, who had at least 1 year of laboratory experience in motion analysis. The distance between the 2 sessions was 3.0 ± 1.4 days.

### Data processing

Data processing was performed after all participants completed the 2 test sessions in order to minimize assessor bias. KinTools RT (version 2.0, Motion Analysis Corporation, Santa Rosa, CA) and MATLAB (version 7.0, MathWorks, Inc., Natick, MA) were used to calculate the kinematics and kinetics during the STS tasks. The trajectories of markers and the force plate data were filtered with a low-pass fourth-order Butterworth filter at a cut-off frequency of 6 Hz. In the present study, the STS tasks were divided into 2 phases: pre-extension and extension [18]. First, the pre-extension phase began with the initiation point of trunk movement and ended with seat-off, which was defined as the point of peak vertical ground reaction force. Second, the extension phase began with seat-off and ended with the end of movement. The kinematic parameters included the joint angles of the trunk, pelvis, hip, knee, and ankle joints in the frontal, sagittal, and transverse planes at seat-off, and were used for further analysis. For the kinetic parameters, only the peak moments of hip and knee extension, ankle plantar flexion after seat-off, and the peak vertical ground reaction force at seat-off were calculated. The kinetic data were normalized by the body weight of each participant. Both kinematic and kinetic parameters were obtained from the dominant limb of the subject. The values of all parameters that were achieved from each trial of the first session allowed to determine the within-session reliability. In addition, the average values of the 3 trials in both the first and the second sessions were used to indicate the between-session reliability.

### Data analysis

Statistical analyses were conducted with the use of SPSS version 22 (SPSS Inc., Chicago) for Windows. The ICC and standard error of measurement (SEM) were applied to examine the within-session (ICC (3, 1)) and between-session (ICC (3, k)) reliability of each parameter. ICC reliability values were interpreted as follows: > 0.75 was excellent, 0.4–0.75 was fair to good, and < 0.4 was poor [19]. The 95% confidence intervals (CI) were calculated for ICC. The SEM was determined with the following formula:

$$\mathrm{SEM} = SD \times \sqrt{(1 - \mathrm{ICC})}$$

The standard deviation (*SD*) was the pooled variance of the parameters in the test and retest measurements. In addition, the MDC was also calculated from between-session reliability as SEM × 1.96 ×  based on the 95% CI. Both SEM and MDC were reported in the measurement unit of each parameter.

### Ethical approval

The research related to human use has been complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the authors' University Ethics Review Committee for Research Involving Human Projects.

### Informed consent

Informed consent has been obtained from all individuals included in this study and their legal guardians.

## Results

### Temporal parameters

The ICC values within and between sessions for all temporal parameters, including total movement time and movement time in each phase, ranged from 0.752 to 0.824, indicating excellent reliability. The ranges of SEM values within and between sessions were 0.043–0.138 s and 0.051–0.135 s, respectively. MDC values less than 1 s between sessions were found in all temporal parameters (Table 1).

### Kinematic parameters

Within and between sessions, the ICC values for kinematic parameters in all movement planes were, on average, 0.807 ± 0.179 and 0.782 ± 0.25, respectively (Table 2). Within sessions, 10 out of 15 kinematic parameters showed excellent reliability (ICC > 0.75). The other 5 parameters presented fair to good reliability (ICC: 0.517–0.733), including the pelvic angle

Table 1. Intraclass correlation coefficient (ICC), standard error of measurement (SEM), and minimal detectable change (MDC) values for within and between sessions of all temporal parameters

| Parameters | Within session | | Between session | | |
|---|---|---|---|---|---|
| | ICC (95% CI) | SEM | ICC (95% CI) | SEM | MDC |
| Total movement time (s) | 0.824 (0.579–0.948) | 0.138 | 0.802 (0.204–0.951) | 0.153 | 0.343 |
| Movement time in pre-extension phase (s) | 0.752 (0.384–0.909) | 0.043 | 0.789 (0.151–0.948) | 0.051 | 0.113 |
| Movement time in extension phase (s) | 0.773 (0.458–0.931) | 0.112 | 0.794 (0.170–0.949) | 0.103 | 0.231 |

CI – confidence interval; MDC is based on 95% CI in the sagittal plane and the trunk and hip angle in the frontal and transverse planes.

Between sessions, the ICC values of most parameters showed excellent reliability (ICC > 0.75), except for the trunk and ankle angle in the frontal and transverse planes. The trunk angle in the frontal plane was characterized by fair to good reliability (ICC = 0.740), whereas the trunk angle in the transverse plane and the ankle angle in the frontal and transverse planes presented poor reliability (ICC: 0.232–0.382). The SEM values for within sessions ranged from 0.258° to 2.817°. In addition, the ranges of the SEM and MDC values between sessions were 0.559–5.651° and 1.252–12.641°, respectively (Table 2).

Kinetic parameters

Both within and between sessions, ICC values for kinetic parameters demonstrated excellent reliability (ICC > 0.75); only the peak vertical ground reaction force within sessions showed fair to good reliability (ICC = 0.635). For the peak ground reaction force, the SEM values within and between sessions were 0.327 N/kg and 0.228 N/kg, respectively. In addition, the SEM values of the peak moment within and between sessions ranged from 0.017 to 0.087 Nm/kg. The range of the MDC values of the peak moment was 0.038–0.090 Nm/kg (Table 3).

Table 2. Intraclass correlation coefficient (ICC), standard error of measurement (SEM), and minimal detectable change (MDC) values for within and between sessions of all kinematic parameters

| Parameters | Within session | | Between session | | |
|---|---|---|---|---|---|
| | ICC (95% CI) | SEM | ICC (95% CI) | SEM | MDC |
| Sagittal plane | | | | | |
| Trunk (°) | 0.987 (0.963–0.996) | 1.029 | 0.966 (0.863–0.992) | 1.465 | 3.277 |
| Pelvis (°) | 0.610 (0.239–0.870) | 0.788 | 0.779 (0.111–0.945) | 0.832 | 1.861 |
| Hip (°) | 0.781 (0.499–0.934) | 0.918 | 0.914 (0.652–0.979) | 0.957 | 2.141 |
| Knee (°) | 0.963 (0.896–0.990) | 0.634 | 0.978 (0.910–0.994) | 0.559 | 1.252 |
| Ankle (°) | 0.978 (0.937–0.994) | 0.603 | 0.924 (0.695–0.981) | 0.902 | 2.019 |
| Frontal plane | | | | | |
| Trunk (°) | 0.517 (0.127–0.829) | 1.543 | 0.740 (0.046–0.935) | 1.222 | 2.735 |
| Pelvis (°) | 0.790 (0.516–0.937) | 1.141 | 0.789 (0.152–0.948) | 2.165 | 4.842 |
| Hip (°) | 0.525 (0.137–0.833) | 2.785 | 0.897 (0.586–0.974) | 1.913 | 4.279 |
| Knee (°) | 0.952 (0.867–0.987) | 0.258 | 0.997 (0.986–0.999) | 0.709 | 1.586 |
| Ankle (°) | 0.982 (0.948–0.995) | 0.577 | 0.382 (from –1.408 to 0.851) | 3.202 | 7.163 |
| Transverse plane | | | | | |
| Trunk (°) | 0.568 (0.187–0.852) | 2.817 | 0.371 (from –1.532 to 0.844) | 3.159 | 7.066 |
| Pelvic (°) | 0.831 (0.592–0.950) | 1.653 | 0.751 (0.017–0.937) | 1.972 | 4.412 |
| Hip (°) | 0.733 (0.418–0.917) | 1.729 | 0.994 (0.975–0.998) | 1.141 | 2.553 |
| Knee (°) | 0.897 (0.735–0.931) | 1.632 | 0.990 (0.959–0.997) | 2.279 | 5.099 |
| Ankle (°) | 0.994 (0.982–0.998) | 0.453 | 0.232 (from –0.399 to 0.694) | 5.651 | 12.641 |

CI – confidence interval; MDC is based on 95% CI

Table 3. Intraclass correlation coefficient (ICC), standard error of measurement (SEM), and minimal detectable change (MDC) values for within and between sessions of all kinetic parameters

| Parameters | Within session | | Between session | | |
|---|---|---|---|---|---|
| | ICC (95% CI) | SEM | ICC (95% CI) | SEM | MDC |
| Vertical ground reaction force (N/kg) | 0.635 (0.273–0.880) | 0.327 | 0.778 (0.107–0.945) | 0.228 | 0.510 |
| Hip extension moment (Nm/kg) | 0.895 (0.730–0.970) | 0.087 | 0.977 (0.908–0.994) | 0.040 | 0.090 |
| Knee extension moment (Nm/kg) | 0.813 (0.559–0.945) | 0.053 | 0.946 (0.784–0.987) | 0.032 | 0.072 |
| Ankle plantar flexion moment (Nm/kg) | 0.820 (0.573–0.974) | 0.041 | 0.953 (0.810–0.988) | 0.017 | 0.038 |

CI – confidence interval; MDC is based on 95% CI

## Discussion

To our knowledge, this is the first study of the within- and between-session reliabilities, and of the MDC of the temporal, kinematic, and kinetic parameters during STS tasks in typical children. The results indicate that the temporal parameter achievements were excellent, the kinematic parameters presented as poor to excellent, and the kinetic parameters showed fair to excellent reliabilities in both within- and between-session analyses.

To achieve an excellent level of test and retest reliability, the variations influencing the reproduction of data must be considered, including the intrinsic and extrinsic variabilities. The intrinsic variability was caused by the individuals themselves in order to perform similar movement patterns. Generally, intrinsic variability could be estimated by measuring the reliability of the movement trials within the same session [20]. A previous study proposed, however, that children had more variability of movement during STS tasks than adults [14]. In the current study, we found that almost all the parameters within sessions, including the temporal parameters; the trunk, hip, knee, and ankle angle in the sagittal plane; the pelvis, knee, and ankle angle in the frontal and transverse planes; and the peak moment showed excellent reliability, which implies that the children in our study showed less intra-individual variability across trials. The differences in the results between the present study and the previous study could be partly explained by the age of the participants and the initial sitting position. In the present study, the mean age of the subjects was 9.8 years, whereas the mean age of the participants in the previous study equalled 6.6 years [14]. The older children appeared to have greater ability to control their balance during the STS task than younger ones [13]. Additionally, the position of the arms at the initial sitting in this study was across the body, whereas in the previous study, the participants kept their arms beside their bodies [14]. These arm positions might cause a difference in variation of the STS task. Therefore, the parameters mentioned above could reliably reproduce the testing results in single-session studies. Alternatively, some parameters that included the pelvic angle in the sagittal plane, the trunk, and hip angles in the frontal and transverse planes, and the peak vertical ground reaction force had fair to good reliability. Using these parameters for the testing results in single session studies, especially in typical children, should be interpreted with caution.

Extrinsic variability could arise from many sources, such as change of marker position during movement, the location of body landmarks, and the placement of markers. It is commonly accepted that the most important source of extrinsic variability in 3D motion capture is the placement of markers [15]. Therefore, the reliability of the movement across sessions on separate days has been investigated. In the present study, all parameters showed excellent reliability except the trunk and ankle angles in the frontal and transverse planes. The excellent reliability obtained in this study might be due to the standardizing marker placement methods, procedures, and trained assessor [21]. In addition, using the mean scores of each parameter, as we did in this study, can minimize the variation of measurement, especially in child population [9, 19, 21–23]. Furthermore, Chorin et al. [24] suggested in 2015 that 3 trials of the STS movement should be applied in order to acquire high repeatability. For the trunk and ankle angles in the frontal and transverse planes, these parameters showed poor to good reliability during STS tasks. This might occur from the trunk and ankle movements in the frontal and transverse planes during STS movement, which have a small range of motion [11]. Therefore, a few changes in the starting position may lead to high variance and low reliability of the values.

Information on the number of measurement errors was important to determine whether a measurement was reliable enough for clinical decisions. For STS, this study is the first report that provides SEM of kinematic variables in children. It revealed that the SEM values of kinematic variables in the sagittal plane were less than 2°, both within and between sessions. In the frontal and transverse planes, both within and between sessions, the SEM values of kinematic variables were less than 5°, except for the value obtained from the ankle in the transverse plane, which was about 6°. Previously, the errors of kinematic measurement were reported for gait analysis. The errors that occurred in the sagittal plane were less than 4°, whereas the values in the frontal and transverse planes varied depending on the joints (1–34°). The highest error was seen in the hip (16–34°) in the transverse plane [15]. In gait analysis, errors between 2 and 5° can possibly be regarded as reasonable, whereas errors greater than 5° could mislead clinical interpretation. Moreover, it has been suggested that an error of 2° or less is likely to be acceptable [15]. Therefore, the present study assumed errors of 2° or less as acceptable for the STS task.

In addition, our study provided the MDC values of temporal, kinematic, and kinetic parameters during STS tasks. These data could constitute a point of reference when interpreting data from other population groups. Using healthy children in this study could offer the chance to identify measurement errors resulting from the methods or procedures. However, these values probably vary among laboratories and patient populations, so it is important to identify the MDC values before testing.

The presented study is subject to some limitations. The sample size was based on the median sample size of gait reliability studies. This may have affected the results, given the differences in trial representation, as gait is a continuous skill with multiple trials included in reliability analyses versus the more discrete task of STS. In addition, most of the participants in this study were female. However, gender might not affect the results, as there is no evidence showing that gender influences the kinematic and kinetic data. Moreover, the mean values of total movement time in the present study (1.50 ± 0.39 s) and the previous study (1.40 ± 0.14 s), conducted among typical male children (mean age: 9.5 years) [13], were similar. Nevertheless, to affirm the gender issue, further research should investigate the effects of gender on the performance of the STS task in children.

## Conclusions

The present study revealed that the biomechanical parameters of the STS tasks, both within and between sessions in typical children, were reliable and could be used for research purposes.

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## Disclosure statement

No author has any financial interest or received any financial benefit from this research.

## Conflict of interest

The authors state no conflict of interest.

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