Original Article

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Consistency of Sit-to-walk Movement in Children with Typical Development Based on the New Non-Overlapping Phases

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Abstract:

Objective: This study aimed to define sit-to-walk (STW) movement without phase overlap. In addition, the intrasubject and test-retest repeatability of movement events were measured.

Material and Methods: Fifteen healthy children aged between 7 and 12 years old participated in the study. A three-dimensional motion analysis system was used to gather and process the kinematic and kinetic data. Two sessions of STW movement were performed with a one-week interval. The intraclass correlation coefficient (ICC) with 95.0% confidence interval (CI) was calculated to determine the repeatability of the new proposed phases at each point of a movement event. The adjusted coefficient of multiple correlation (CMC) was used to evaluate the similarities of the entire STW waveforms.

Results: Nine phases of STW were identified by the demands of movement performance. The ICC values indicated poor to excellent intrasubject (0.36-0.97) and test-retest repeatability (0.30-0.96). Poor repeatability was observed at the hip (0.30-0.44), knee (0.36), and ankle (0.47 and 0.49) joints only during the gait cycle. The CMC values demonstrated high to excellent (>0.75) intrasubject and test-retest repeatability, indicating the similarities of STW waveforms.

Conclusion: Additional phase definitions of STW demonstrated an acceptable level of repeatability in the childhood population. Variations in the lower extremities could be related to the fluidity with which these children performed at the point of gait initiation. Thus, variability in joint angles could be produced by the different fluidities of initial walking.

Keywords: children, kinematics, kinetics, repeatability, sit-to-walk

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Introduction

Sit-to-walk (STW) is a complex movement that develops throughout one's lifespan[1]. It consists of rising from sitting and immediately initiating walking. To achieve the task, individuals require a high control of balance and lower limb strength, especially hip and knee muscles[1,2]. This earliest definition of STW from a biomechanical perspective included 4 phases: flexion momentum, extension, unloading, and stance. These phases were based on the continuous movements observed in young healthy adults[3]. These definitions have been applied to data analysis in the majority of STW studies. However, there was an overlapping of phases while individuals attempted to stand up and started to walk regarding the initiation of gait, which was started around the seat-off event before the body was in the upright position[4]. Therefore, an examination of this task using these definitions might not yield sufficient information for practical implementation, particularly in cases where individuals do the STW variation in accordance with their health conditions or even in children. Therefore, additional phases are possibly needed in order to identify the precise STW event that would interact with any existing health issues or while under development[5].

In children with typical development (TD), the neuromuscular systems and functional skills are not fully developed[6]. Consequently, balance control is not well organized due to less coordination between visual, vestibular, and somatosensory information[7]. As age increases, an integration of motor, sensory, and cognitive functions improves, leading to better control of movements[8]. Hence, their STW performance is probably not consistent when compared to young adults. Since this transitional movement is commonly performed in daily functions, kinematic patterns during STW in children with TD can be a reference to determine movement compensation in children with health conditions. It is necessary to clarify whether the differences in kinematic outcomes are caused by an actual change in performance or an observational error[9]. Three-dimensional (3D) motion-analysis systems are commonly considered the gold standard for measuring movement performance; however, there is no study providing any data regarding how the consistency of STW movement would be produced in children with TD. Thus, repeatable marker alignment data within the same day and on different occasions are recommended in order to confirm test results[8].

By proposing a new definition of STW phases, this study enhances the understanding of the complex transition from sitting to walking, particularly in children with TD. In addition, intrasubject and test-retest repeatability ensure that the methods used for analyzing STW movements are consistent and reproducible. Therefore, this study aimed to propose a new definition of the STW phases for biomechanical analysis. In addition, the study also evaluated intrasubject and test-retest repeatability of STW movement in children with TD, aged 7 to 12 years, using a 3D motion-capture system.

Material and Methods

Participants

Fifteen healthy children with TD aged 7 to 12 years participated in the study based on convenience sampling. The sample size (n=14) was calculated based on an estimation of sample size for a reliability study, in which the minimum acceptable and expected levels of reliability were 0.5 and 0.8, respectively (α=0.05, β=0.2, and the number of repetitions per subject=5). Inclusion criteria: children who were able to perform child-level activities without physical and mental interference, reported by their parents, had a normal body mass index, and had no visual impairments that could not be corrected by glasses or contact lenses. Excluded were children with a history of surgery or fracture of the lower extremities or trunk in the past 6 months, a leg length discrepancy of ≥1 cm, a history of adhesive allergy, or fever or pain, along with those who had taken any medication causing drowsiness or fatigue in the last 24 hours. All of the children agreed to participate in the study, and informed consents were obtained from their parents or guardians. Ethical approval was granted by The Research Ethics Review Committee for Research Involving Human Research Participants, Group I, Chulalongkorn University (COA No. 144/66).

Procedure

A descriptive design was used to gather kinematic data. A 3D motion-analysis system (Motion Analysis Corporation, Santa Rosa, CA, USA) with 8 motion-capture cameras (Raptor E), and motion-analysis software (Cortex, version 8.1 and KinTools RT, version 2.0, Motion Analysis Corporation, Santa Rosa, CA, USA) were used to gather kinematic data and analyze the patterns of STW movement. Demographic data comprising age, gender, weight, height, and dominant leg were measured at enrolment. The participants were required to wear a vest and shorts and be shoeless. Twenty-nine reflexive markers were placed at anatomical landmarks according to the Modified Helen Hayes marker set model, with 3 additional attachments (one at the right greater trochanter and 2 at the seat of the adjustable chair)[10]. For the starting position, the chair height was individually adjusted in accordance with the lower leg length of each participant, which allowed the hip and knee joints to be close to 90° of flexion as well as ankle dorsiflexion. Thigh support was set at 25% of the upper leg length. Both feet were placed on the force plates, shoulder-width apart. The foot alignment of each participant was drawn as a reference point for foot placement.

The participants were instructed to rise from the chair and walk forward to the end of a walkway, approximately 3 meters, at their preferred speed and pattern with their arms beside their bodies. A few practice sessions were allowed in order to become familiar with the instructions and environment. After the first testing session, all of the participants were requested to repeat the marker placement and motion capture a one-week interval. Five completed STW movement trials from each testing session were used for the data analysis. The joint angle data were collected by a trained tester on 2 days with an interval of 1 week. The tester was trained and supervised by a specialized physical therapist with 3D-motion capture for more than 15 years.

Data processing

The kinematic and kinetic data were analyzed using KinTool RT (version 2.0, Motion Analysis Corporation, Santa Rosa, CA, USA) with the fourth-order Butterworth and cut-off frequency of 6 Hz. Movement was measured between the body movement velocity of 0.01 m/s and the first heel contact of the stance limb. Five STW trials within the same day were used to evaluate the intrasubject repeatability for both testing days. The test-retest repeatability was analyzed by the average of 5 STW trials from the 2 testing days.

Data analysis

The changing of angular displacement and vertical ground reaction force (vGRF) were used to define the phases and movement events of STW transition based on the characteristics of sit-to-stand and gait initiation (GI). Joint movements during STW at each event were presented as degrees of movement. Since STW is a continuous movement, the angular displacements of each joint for the entire task were demonstrated as a kinematic waveform. The Shapiro-Wilk test indicated a normal distribution of joint angle parameters. The intraclass correlation coefficient (ICC) was used to evaluate the repeatability of the measurement at each point of the movement event. The $ICC_{(3, 1)}$ and $ICC_{(3, k)}$ with a 95% confidence interval (CI) were used to determine the agreement of intrasubject and test-retest measurements, respectively. ICC values below 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and above 0.9 were considered to have a poor, moderate, good, and excellent agreement, respectively[11]. The adjusted coefficient of multiple correlation (CMC) was used to analyze the similarities of the waveform parameters[12]. A correlation (R_a) nearly equal to 1 means that the waveforms were similar and reflect the high repeatability of the tests. If the R_a is close to 0, the waveforms were dissimilar, which means that the tests have a low repeatability. The CMC values were interpreted based on a previous study as follows[13]:

R_a between 0.65 and 0.75=moderate repeatability

R_a between 0.75 and 0.85=good repeatability

R_a between 0.85 and 0.95=very good repeatability

R_a between 0.95 and 1.00=excellent repeatability

Results

The demographic data of the participants are shown in Table 1. Most were right-leg dominant, except one who preferred to use both legs to complete the tests.

Phases

Nine phases of the STW movement were defined. An illustration of the STW phases is shown in Figure 1. Phases, and their starting and ending events are identified in Table 2. These events were determined by the changing of vertical displacement, the vGRF, and motion data.

The intraclass correlation coefficient of intra-subject and test-retest

Table 3 shows the ICC with 95% CI of intrasubject and test-retest repeatability of each joint movement. The $ICC_{(3, 1)}$ for the first and the second intrasubject repeatability ranged from 0.49 to 0.97 and 0.36 to 0.91, respectively. The $ICC_{(3, k)}$ for test-retest repeatability ranged from 0.30 to 0.96.

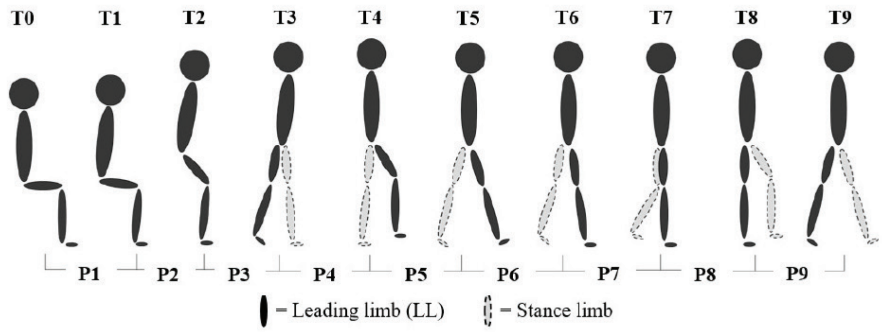
Table 1 Demographic data

Characteristic	Value
Age (yr)	9.1±1.6
Weight (kg)	32.05±9.16
Height (m)	1.35±0.11
Dominant leg (n)	
Left/right/both	0/14/1
Gender (n)	
Male/female	7/8

Table 2 Definition of phases and movement events of sit-to-walk

Phases	Starting event	Ending event
P1: Seat-off	Velocity of the body move=0.01 m/s (T0)	Displacement of greater trochanter (T1)
P2: Weight transferring	Displacement of greater trochanter (T1)	Maximum GRF of the LL (T2)
P3: Unloading of leading limb (LL)	Maximum GRF of the LL (T2)	GRF of the LL=0 N (T3)
P4: Mid swing of LL	GRF of the LL=0 N (T3)	Shank of the LL in the vertical line (T4)
P5: Terminal swing of LL	Shank of the LL in the vertical line (T4)	First heel contact of the LL (T5)
P6: Double support	First heel contact of the LL (T5)	GRF of SL=0 N (T6)
P7: Unloading of stance limb (SL)	GRF of SL=0 N (T6)	Thigh of SL moves parallel to another side (T7)
P8: Mid swing of SL	Thigh of SL moves parallel to another side (T7)	Shank of SL in the vertical line (T8)
P9: Terminal swing of SL	Shank of SL in the vertical line (T8)	First heel contact of SL (T9)

P=phase, T=time point, vGRF=vertical ground reaction force



(P=phase, P1=seat-off, P2=weight transferring, P3=unloading of LL, P4=mid swing of LL, P5=terminal swing of LL, P6=double support, P7=unloading of SL, P8=mid swing of SL, P9=terminal swing of SL, T=time point)

Figure 1 Phases of sit-to-walk (STW) movement

The adjusted coefficient of multiple correlation of intrasubject and test-retest

Table 4 shows the means and standard deviations of the intrasubject and test-retest CMC of each joint movement in the sagittal plane. These values were averaged from the CMCs of all the participants. The CMCs for intrasubject repeatability in the first and second sessions ranged between 0.846 and 0.982. The values for each joint between these sessions were relatively close. The CMCs for test-retest repeatability were lower than the intrasubject values (R_a=0.772 to 0.967). All of the CMCs for intrasubject and test-retest repeatability were greater than 0.75. The highest CMCs were for hip movements for both intrasubject repeatability (R_a=0.980 to 0.982) and test-retest repeatability (R_a=0.967). The CMCs for ankle movements were lower than the other joints for the intrasubject and test-retest values (R_a=0.846 to 0.906 and 0.772, respectively).

Discussion

In the current study, STW movement has been defined into 9 phases without any overlapping. In addition, reliability analysis was conducted in order to observe the kinematic quantities of this transition in children with TD, using a 3D motion-analysis system. The intrasubject and test-retest reliability at each point of a movement event ranged from poor to excellent, while the similarities of movement waveforms ranged from good to excellent levels. These results are essential for both research and clinical purposes because variations of movement can be produced by participants or testing errors.

Nine phases of STW were proposed by the demands of this movement performance. Three major differences were considered as follows: Firstly, the point of peak vGRF that shifted to the leading limb (LL) after the seat-off event was added. The previous study included this action with the point of seat-off as they found a correlation between these 2 actions[3]. In adults, this vGRF was supposed to significantly shift to the LL as it is necessary for the generating of propulsive impulses at the point of GI[14]. However, this pattern was not demonstrated exactly in the current study since some of the children performed symmetrical weight bearing or shifted their peak vGRF to the stance limb (SL). This can be explained by the incomplete development of postural control at this age for children, influencing their ability to maintain balance during the changing of body position[15]. Therefore, the children equally distributed their body weight on both legs or shifted to the SL in order to maintain their body stability before GI. Secondly, an

Table 3 Intrasubject and test-retest repeatability measured by the ICC with 95% CI

Event	Repeatability		ICC (95% CI)							
			Trunk	Pelvis	Leading hip	Stance hip	Leading knee	Stance knee	Leading ankle	Stance ankle
T0	Intra subject	day 1	0.63 (0.42–0.83)	0.90 (0.81–0.96)	0.90 (0.79–0.96)	0.87 (0.76–0.95)	0.90 (0.80–0.96)	0.95 (0.90–0.98)	0.88 (0.77–0.95)	0.97 (0.94–0.99)
		day 2	0.67 (0.46–0.85)	0.88 (0.77–0.95)	0.91 (0.82–0.96)	0.92 (0.84–0.97)	0.90 (0.80–0.96)	0.91 (0.83–0.97)	0.85 (0.72–0.94)	0.88 (0.77–0.95)
	Test-retest		0.70 (0.17–0.90)	0.92 (0.76–0.97)	0.88 (0.64–0.96)	0.88 (0.66–0.96)	0.81 (0.42–0.94)	0.62 (–0.04–0.87)	0.70 (0.10–0.90)	0.79 (0.41–0.93)
T1	Intra subject	day 1	0.50 (0.27–0.75)	0.83 (0.69–0.93)	0.82 (0.68–0.93)	0.87 (0.75–0.95)	0.80 (0.64–0.91)	0.77 (–0.60–0.90)	0.65 (0.43–0.84)	0.68 (0.47–0.85)
		day 2	0.57 (0.35–0.79)	0.88 (0.78–0.95)	0.87 (0.76–0.95)	0.94 (0.87–0.97)	0.74 (0.56–0.89)	0.78 (0.62–0.91)	0.70 (0.50–0.86)	0.81 (0.65–0.92)
	Test-retest		0.77 (0.34–0.92)	0.91 (0.75–0.97)	0.90 (0.70–0.96)	0.89 (0.70–0.96)	0.92 (0.76–0.97)	0.73 (0.23–0.91)	0.88 (0.64–0.96)	0.78 (0.07–0.93)
T2	Intra subject	day 1	0.64 (0.43–0.83)	0.92 (0.84–0.97)	0.74 (0.56–0.89)	0.81 (0.65–0.92)	0.58 (0.36–0.80)	0.63 (0.41–0.83)	0.66 (0.45–0.84)	0.80 (0.63–0.91)
		day 2	0.59 (0.37–0.81)	0.91 (0.82–0.96)	0.83 (0.70–0.93)	0.88 (0.77–0.95)	0.73 (0.55–0.88)	0.73 (0.54–0.88)	0.83 (0.68–0.93)	0.85 (0.73–0.94)
	Test-retest		0.78 (0.32–0.93)	0.91 (0.72–0.97)	0.93 (0.78–0.97)	0.92 (0.75–0.97)	0.85 (0.47–0.95)	0.68 (0.12–0.89)	0.82 (0.47–0.94)	0.89 (0.51–0.97)
T3	Intra subject	day 1	0.57 (0.35–0.80)	0.71 (0.51–0.87)	0.55 (0.32–0.78)	0.65 (0.43–0.84)	0.67 (0.46–0.85)	0.83 (0.68–0.93)	0.65 (0.44–0.84)	0.78 (0.62–0.91)
		day 2	0.57 (0.34–0.79)	0.80 (0.64–0.91)	0.70 (0.46–0.85)	0.66 (0.46–0.85)	0.70 (0.51–0.87)	0.75 (0.57–0.89)	0.53 (0.30–0.76)	0.85 (0.73–0.94)
	Test-retest		0.89 (0.68–0.96)	0.72 (0.17–0.90)	0.66 (–0.03–0.89)	0.74 (0.25–0.91)	0.96 (0.89–0.99)	0.94 (0.83–0.98)	0.79 (0.36–0.93)	0.92 (0.62–0.98)
T4	Intra subject	day 1	0.59 (0.37–0.81)	0.62 (0.41–0.82)	0.67 (0.46–0.85)	0.68 (0.48–0.86)	0.68 (0.47–0.86)	0.87 (0.76–0.95)	0.67 (0.46–0.85)	0.78 (0.61–0.91)
		day 2	0.52 (0.29–0.76)	0.72 (0.53–0.88)	0.60 (0.38–0.81)	0.65 (0.43–0.84)	0.65 (0.44–0.84)	0.71 (0.51–0.87)	0.67 (0.46–0.85)	0.80 (0.65–0.92)
	Test-retest		0.89 (0.66–0.96)	0.52 (–0.23–0.83)	0.36 (–0.72–0.78)	0.51 (–0.30–0.83)	0.90 (0.71–0.97)	0.93 (0.80–0.98)	0.67 (0.01–0.89)	0.87 (0.56–0.96)
T5	Intra subject	day 1	0.53 (0.30–0.77)	0.68 (0.48–0.86)	0.82 (0.67–0.92)	0.70 (0.50–0.86)	0.77 (0.59–0.90)	0.83 (0.69–0.93)	0.76 (0.58–0.90)	0.70 (0.51–0.87)
		day 2	0.56 (0.33–0.79)	0.80 (0.64–0.92)	0.70 (0.51–0.87)	0.78 (0.62–0.91)	0.65 (0.44–0.84)	0.79 (0.63–0.91)	0.66 (0.45–0.85)	0.62 (0.40–0.82)
	Test-retest		0.83 (–0.01–0.96)	0.55 (–0.17–0.84)	0.42 (–0.42–0.79)	0.39 (–0.48–0.78)	0.78 (0.36–0.93)	0.91 (0.73–0.97)	0.94 (0.82–0.98)	0.84 (0.47–0.95)

Table 3 (continued)

Event	Repeatability		ICC (95% CI)							
			Trunk	Pelvis	Leading hip	Stance hip	Leading knee	Stance knee	Leading ankle	Stance ankle
T6	Intra subject	day 1	0.71 (0.52–0.87)	0.76 (0.59–0.90)	0.81 (0.66–0.92)	0.69 (0.49–0.86)	0.67 (0.47–0.85)	0.63 (0.41–0.83)	0.51 (0.27–0.75)	0.78 (0.62–0.91)
		day 2	0.66 (0.45–0.85)	0.85 (0.72–0.94)	0.70 (0.50–0.87)	0.87 (0.75–0.95)	0.57 (0.34–0.79)	0.64 (0.43–0.83)	0.72 (0.52–0.87)	0.66 (0.45–0.84)
	Test-retest		0.90 (0.49–0.97)	0.67 (0.09–0.89)	0.59 (−0.12–0.86)	0.40 (−0.45–0.78)	0.72 (0.20–0.91)	0.64 (0.02–0.88)	0.47 (−0.65–0.83)	0.88 (0.61–0.96)
T7	Intra subject	day 1	0.66 (0.45–0.85)	0.75 (0.56–0.89)	0.77 (0.60–0.90)	0.77 (0.60–0.90)	0.52 (0.29–0.76)	0.74 (0.56–0.89)	0.49 (0.26–0.74)	0.76 (0.58–0.90)
		day 2	0.63 (0.42–0.83)	0.85 (0.73–0.94)	0.79 (0.62–0.91)	0.77 (0.59–0.90)	0.57 (0.35–0.79)	0.36 (0.14–0.64)	0.76 (0.58–0.90)	0.71 (0.52–0.87)
	Test-retest		0.90 (0.69–0.97)	0.68 (0.08–0.89)	0.52 (−0.28–0.83)	0.44 (−0.57–0.81)	0.70 (0.14–0.90)	0.84 (0.52–0.95)	0.48 (−0.68–0.83)	0.91 (0.75–0.97)
T8	Intra subject	day 1	0.61 (0.39–0.82)	0.77 (0.59–0.90)	0.73 (0.54–0.88)	0.85 (0.72–0.94)	0.72 (0.53–0.88)	0.94 (0.88–0.98)	0.72 (0.53–0.88)	0.87 (0.76–0.95)
		day 2	0.58 (0.36–0.80)	0.87 (0.76–0.95)	0.69 (0.49–0.86)	0.81 (0.66–0.92)	0.64 (0.43–0.83)	0.43 (0.21–0.70)	0.79 (0.63–0.91)	0.80 (0.64–0.91)
	Test-retest		0.87 (0.49–0.96)	0.73 (0.22–0.91)	0.53 (−0.37–0.84)	0.31 (−1.29–0.77)	0.83 (0.50–0.94)	0.87 (0.61–0.95)	0.83 (0.47–0.94)	0.81 (0.46–0.94)
T9	Intra subject	day 1	0.68 (0.48–0.86)	0.81 (0.66–0.92)	0.76 (0.58–0.89)	0.83 (0.69–0.93)	0.55 (0.33–0.78)	0.87 (0.75–0.95)	0.65 (0.43–0.84)	0.75 (0.57–0.89)
		day 2	0.62 (0.41–0.82)	0.91 (0.82–0.96)	0.82 (0.67–0.92)	0.86 (0.74–0.94)	0.74 (0.55–0.88)	0.62 (0.40–0.82)	0.75 (0.57–0.89)	0.89 (0.77–0.96)
	Test-retest		0.86 (0.55–0.96)	0.75 (0.29–0.92)	0.72 (0.19–0.90)	0.30 (−1.27–0.77)	0.79 (0.37–0.93)	0.75 (0.28–0.92)	0.94 (0.82–0.98)	0.81 (0.46–0.94)

CI=confidence interval, ICC=intraclass correlation coefficient

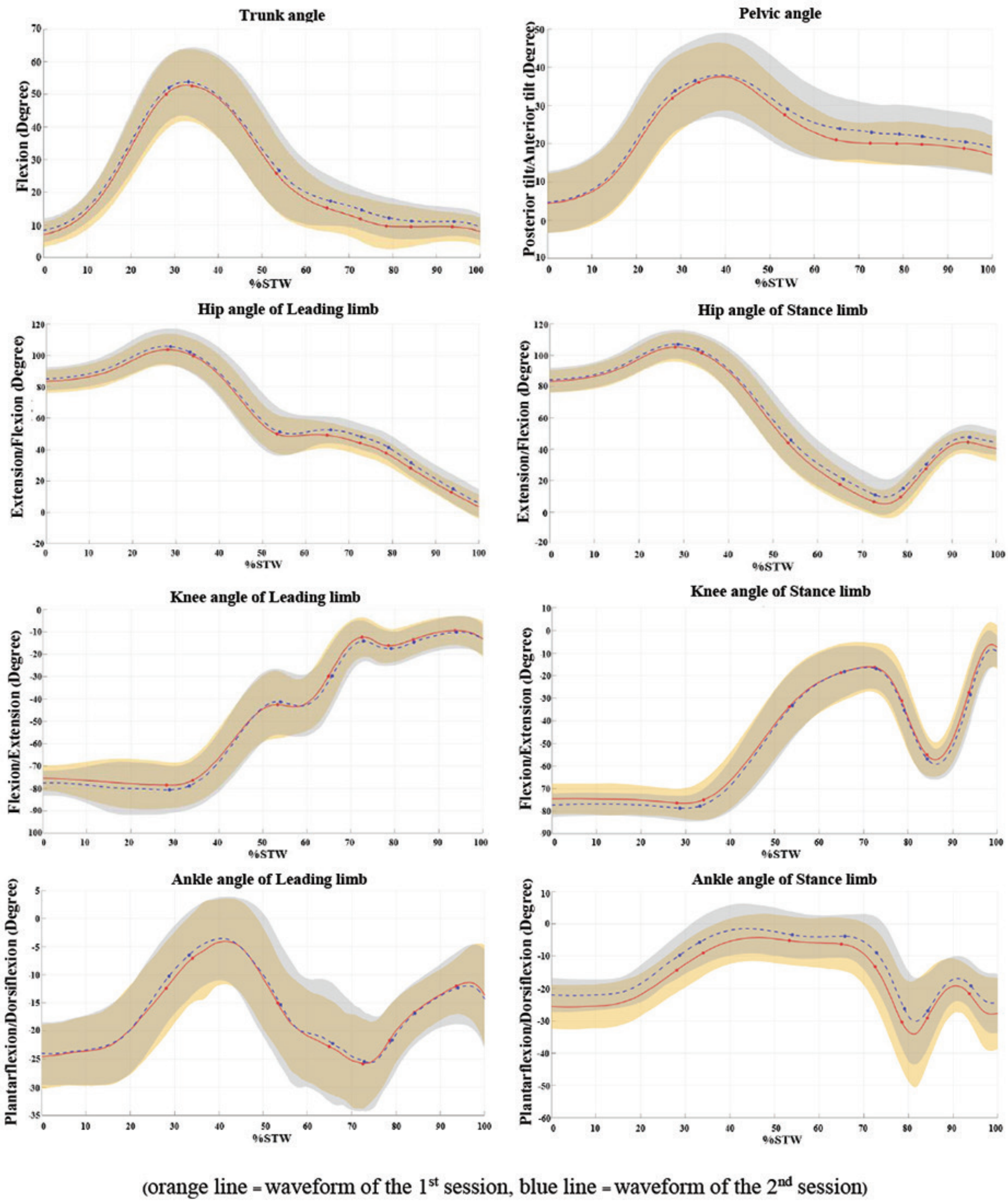
Table 4 Means and standard deviations of intrasubject and test-retest repeatability measured by the CMC

Joint angle		Intrasubject CMC	Test-retest CMC
Trunk	1st session	0.933±0.039	0.917±0.047
	2nd session	0.935±0.059	
Pelvis	1st session	0.932±0.046	0.861±0.077
	2nd session	0.933±0.038	
Hip			
Leading limb	1st session	0.980±0.013	0.958±0.031
	2nd session	0.981±0.013	
Stance limb	1st session	0.981±0.018	0.967±0.025
	2nd session	0.982±0.013	
Knee			
Leading limb	1st session	0.971±0.018	0.966±0.014
	2nd session	0.977±0.011	
Stance limb	1st session	0.963±0.026	0.952±0.021
	2nd session	0.968±0.023	
Ankle			
Leading limb	1st session	0.846±0.086	0.772±0.130
	2nd session	0.853±0.090	
Stance limb	1st session	0.900±0.056	0.842±0.092
	2nd session	0.906±0.053	

CMC=coefficient of multiple correlation

unloading phase has been indicated by the vGRF on LL that was 0 N/kg, reducing the overlapping of the phases. Lastly, the first cycle of gait was included to determine the pattern of STW because the stability of postural control will not be presented until individuals reach the third step after fluidly walking from the sitting position[16]. Thus, including the first gait cycle will be useful for further studies in populations with health conditions, as its deviations could provide important information on essential rehabilitation programs.

Evaluating the ICC at each point of a movement event showed poor to excellent repeatability of STW with the current proposed phases. Most ICC values ranged between moderate and excellent. On the testing day, $ICC_{(3, 1)}$ less than 0.5 was found at the knee joint of SL (0.36 and 0.43) and the ankle joint of LL (0.49) during the second step. For test-retest repeatability, $ICC_{(3, k)}$ lower than 0.5 was found at both hips (0.30 to 0.44) and the ankle joint of LL (0.47 and 0.48) after gait was initiated. Poor repeatability was found only during the gait cycle, which may be related to the initiation of gait from an unstable condition[4]. Generally, GI was performed from a quiet standing. However, this action during STW transition can be generated when the body is in a static or dynamic condition. These lower ICC values could be caused by intrapersonal factors, as well as the testing procedures. Based on the self-selected speed and pattern of movement, the children could decide to initiate their gait before, immediately, or after their body was in the upright position. In addition, the practical effect could slightly lower the test-retest repeatability regarding whether the children were familiar with the task, which may have reduced movement duration in some phases, especially on the second testing day[17]. Consequently, the different speeds during STS and GI may influence the degrees of pelvic and hip angles[18,19]. As such, variation of joint range of motion at the same point of movement, particularly between 2 testing days, could be presented depending on the fluidity and speed that children used to perform the movement[20].



STW=sit-to-walk

Figure 2 Kinematic waveforms for the entire STW cycle

In contrast, the CMC values demonstrated good to excellent intrasubject and test-retest repeatability of STW movements. This suggests that the reproducibility of waveforms at each joint movement, especially at the hips and knees, were very close to each other both in and between testing sessions (as shown in Figure 2). It could be explained that because the ICC reported the precise degree of joint angle at each point of movement, while the kinematic waveform displayed the range of joint displacement within 100% of the movement cycle, it is probable that the CMC results of these joints were higher than the ICC values. The joint angle displacements from the repeated efforts were similar for the whole task, even if the STW movement durations could vary. The lower values of the ICC and the CMC at the ankle joint of the LL could be explained by differences in foot position at the initial contact with the ground[21]. At the self-selected walk speed, heel contact is a common pattern of foot support performed at the initial strike in healthy children. However, midfoot contact can be found in children who walk barefoot, or the entire sole may touch the ground at the initial contact in children with flatfoot[22].

Conclusion

Nine phases of STW were proposed without the overlapping of movement events. The current findings show that agreement measurement provided acceptable levels of intrasubject and test-retest repeatability while considering the differences in angular displacement during the first gait cycle due to the fluidity and speed of STS and GI.

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Conflict of interest

The authors have no conflicts of interest to declare.

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