Gait & Posture 61 (2018) 111–116

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

Inertial sensing of the motion speed effect on the sit-to-walk activity

Nikolaos Kondilopoulos, Elissavet N. Rousanoglou*, Konstantinos D. Boudolos

Sports Biomechanics Lab, Section of Sport Medicine & Biology of Exercise, School of Physical Education & Sport Science, National & Kapodistrian University of Athens, Greece

ARTICLE INFO

Keywords:
Segmental acceleration
Temporal pattern
Relative phase
Postural control

ABSTRACT

The STW execution at motion speed faster than normal most possibly enhances the risk for balance loss due to the increase in body segment accelerations. The purpose of the study was to use inertial sensing to examine the effect of motion speed on the STW segmental kinematics and its temporal events. Eighteen young men (20.7 ± 2.0 years) performed STW trials at preferred (PS) and fast (FS) motion speed. Data were collected with Xsens inertial sensors positioned at the trunk, thigh, shank, and foot segments. The maximum segmental values of angular displacement, angular velocity and linear acceleration, the duration of total STW (ttotal), the absolute and relative (% ttotal) phase duration (Flexion, Transition, Extension, Walking) and, the absolute and relative time taken to reach each maximum value were determined. In FS, ttotal and the absolute phase duration (except for Transition), were all significantly shorter ($p = 0.000$). The relative phase duration was not altered ($p > 0.05$), except for the Extension shortening ($p = 0.001$). The maximum angular displacement was altered only for the thigh (decreased, $p = 0.038$) and shank (increased, $p = 0.004$). Maximum angular velocities and linear accelerations were all significantly increased ($p = 0.000$ for all). The absolute time to reach the maximum values shortened in FS ($p \leq 0.05$), while, the relative times were not altered ($p > 0.05$), except for the delayed trunk maximum angular displacement ($p = 0.039$). Inertial sensing appears to identify the motion speed effect on STW segmental kinematics and their temporal events in healthy young men. The results of the study may contribute improving the preventive or rehabilitation interventions in persons with impaired postural control.

1. Introduction

Sit-to-walk (STW) is a critical activity for independent functionality in daily living, with research showing that a normal person rises from the seated position more than 60 times per day [1,2]. Due to its inherent instability [3], STW challenges the locomotor and postural control. At walking initiation, the base of support is decreased and laterally shifted, as the swing leg leaves the ground, a situation predisposing to balance loss [4,5]. When STW is executed faster than normal, the predisposition to balance loss may be enhanced as the increased speed of motion amplifies the accelerations acting on the body [6,7]. Furthermore, moving faster than normal influences two important determinants of dynamic postural control, the trunk oscillation [7,8,9], and the head acceleration [7,10,11]. The limited studies regarding the effect of motion speed on the STW execution [12], examined the total STW duration and the duration of the STW phases without any information about its segmental kinematics. However, a greater understanding of segmental kinematics is considered to improve the sensitivity of mobility screening and to enhance the gait rehabilitation interventions [13]. To the best of our knowledge, there is still a lack of data about the effect of motion speed on the magnitude and timing of the STW segmental kinematics which could contribute to a more comprehensive understanding of this fundamental daily activity.

The use of easily applicable methods to objectively assess the STW activity may assist in optimizing individual application of interventions. Inertial sensing is of increasing popularity as this method appears to be a user friendly, efficient and unobtrusive measurement system and has been successfully validated against other instrumentation for the STW investigation [14,15,16]. A single inertial sensor, positioned on the trunk, is typically used for analyzing STW temporal events [14,15]. Although a single inertial sensor positioned on the trunk may provide reliable information regarding the gross STW movement pattern [14,15], it does not provide detailed information about the lower extremity segmental kinematics. Nevertheless, the lower extremity segmental analysis is an important clinical tool for identification of normal and pathological patterns of fundamental daily movements and may be useful in the evaluation of treatment interventions [13]. Thus, the purpose of the study was to use inertial sensing to examine the effect of motion speed on the STW trunk and thigh, shank and foot segmental

* Corresponding author at: Ethnikis Antistasis 41, Daphne, 172-37, Athens, Greece.
E-mail address: erousan@phed.uoa.gr (E.N. Rousanoglou).

https://doi.org/10.1016/j.gaitpost.2018.01.001
Received 19 March 2017; Received in revised form 28 December 2017; Accepted 1 January 2018

kinematics and its temporal events.

2. Methods

2.1. Participants

Eighteen young healthy male subjects participated in the study (age 20.7 ± 2.0 years, body mass 71.1 ± 8.9 kg, standing height 176.7 ± 4.8 cm and seated height 93.2 ± 3.9 cm). The participants were selected from a total of 24 volunteers who underwent anthropometric screening so as to ensure the inclusion of participants with the lowest group variation in segment lengths and masses, as well as, the exclusion of participants with spinal misalignments and foot deformities. The study was approved by the institutional review board in conformity with the Declaration of Helsinki. All participants signed an informed consent.

2.2. Procedures

The STW task was performed similarly to previous studies [3,12,14,16]. The participants sat on a backless and armless seat platform allowing the seat height standardization to 100% of lower leg length (from ground to knee joint center), and they were asked to keep their arms folded in front of them during the task. The initial body configuration was with hip and knee joint angles at 90°, the feet flat on the floor and two-thirds of the thighs in contact with the seat. They were instructed to look ahead, to distribute their weight evenly and, upon the vocal command “GO”, to stand up and walk toward a target placed 2 m in front of the seat, but they were not required to cover the full distance. They performed the STW task at two speed conditions: a) the preferred speed condition (PS) and b) the fast speed condition (FS). In the PS condition, the subjects were instructed to execute the task at their self-selected speed, while in the FS condition they were instructed to execute the task as if they were hurried to answer the phone or to stop an activated alarm.

2.3. Data collection and analysis

The Xbus Master Kit (four inertial sensors connected to the Xbus Master, Xsens Technologies B.V.) were used for data collection. The inertial sensors (MTx, W38 x L53 x H21 mm, 30 gr each, 50 Hz sampling rate, operational bandwidth of 5G for maximum linear acceleration and 10G for 1200 °/s maximum angular velocity) were positioned at the right lateral side of the trunk, thigh, shank and foot segments, at the estimated position of the segmental center of mass. The Xbus Master was secured around the midwaist of the participants without obstructing their STW movement. Data were collected with the MT Manager 1.6.2 software and transferred via Bluetooth to a computer. Taking as reference the initial seated position, data were aligned to the world reference system, so that pitch, roll, and yaw indicated the rotation around the mediolateral (y) axis, the transverse axis (x) and the vertical (z), respectively. The MTi and MTx User Manual and Technical Documentation [17] provides a detailed description of the Xsens sensor, the estimation of its orientation and the data alignment to the world reference system. The resultant (x, y, and z-axes) maximum values of angular displacement, angular velocity and linear acceleration, respectively, as well as the time taken to reach the maximum values comprised the segmental variables inserted for statistical analysis. The time to reach the maximum values was expressed in absolute (s) and relative (% total STW duration) time units.

The total STW duration (ttotal) and the duration of four STW phases (Flexion, Transition, Extension, and Walking) were also determined. The duration of the STW phases was expressed in absolute (s) and relative (% ttotal) time units. The phase identification, as described further on and illustrated in Fig. 1, was based on Dehail and coworkers [18]. Thus, the initiation of the Flexion and Transition phase was defined by the time points that the trunk and thigh angular displacements exceeded by 2 SD the 200 ms mean value of their resting baseline. The time point that the angular displacement of the trunk indicated its maximum forward tilt defined the initiation of the Extension phase. Finally, the time point when the foot angular position exceeded by 2 SD the baseline value defined the initiation of the Walking phase (foot baseline indicated its full floor contact throughout the previous phases). The Walking phase termination was determined at the time point that the foot angular position returned to the baseline value (full floor contact after walking leg swing), an event that was consistently identified in all trials. The time point that determined the Walking phase termination is a modification of the method used by Dehail and coworkers [18] who used the heel contact of the walking leg; however, the present study aimed solely to the use of inertial sensor data for the definition of STW phases.

In synchronization with the inertial sensors, all trials were videotaped to a) visually inspect that the participants performed a true STW and not a Sit-to-Stand and then walk movement [3] and b) calculate the horizontal velocity (Vx) for the total body center of mass (COM) in order to validate the faster than normal speed of movement in the FS condition. Indeed, in all five trials retained for further analysis, Walking initiation occurred around seat-off while the participants were still rising. The video data were collected with a high speed motion capturing system sampling at 125 Hz (Redlake *Motion*Scope® camera, type PCI 1000S, Redlake Imaging *Motion*Scope Player 2.3 Software). The camera was positioned at a 1.16 m height from the ground and at 8 m distance from the anterior-posterior axis of the movement so that, through the entire STW task, all body segments were clearly visible at the right sagittal plane. A four segment model (head-arm-trunk (HAT), thigh, shank and foot) was used to calculate the total body COM. Reference markers were positioned on the segmental COM. The Dempster’s body segment parameter data for 2D studies were used to calculate the location of the segmental COM [19]. After raw data filtering (4th order Butterworth, cut-off frequency at 10 Hz, Peak Performance Inc. software, Version 8.2, Colorado Springs, USA), the horizontal and vertical displacement of the total body COM were calculated. From the horizontal displacement data and for the time frame of the STW total duration, the mean horizontal velocity of the body COM (COM Vx) was calculated and expressed in m/s.

2.4. Statistical analysis

Means and standard deviations (SD) are used for data presentation. One way repeated analysis of variance was applied to test the significance of the difference between the PS and the FS conditions in all examined variables (SPSS 22.0). The level of significance was set at $p \leq 0.05$. Our aim was to ensure the statistical comparison of trials that best represented a PS and a FS execution. Thus, among the five STW trials in each condition, the one with the median COM Vx was selected for the PS condition, and the one with the highest COM Vx was selected for FS condition.

3. Results

In the FS condition, the COM Vx was significantly increased (+30.4%, PS: 0.681 ± 0.263 m/s, FS: 0.888 ± 0.153 m/s, $p = 0.000$) which validates the faster than normal STW execution. From the 72.4 ± 2.1 cm COM height at the initial resting position, the body COM was raised to 97.0 ± 5.2 cm and 86.9 ± 4.5 cm ($p = 0.000$) at Walking initiation, and to 106.7 ± 3.2 cm and 104.8 ± 3.1 cm ($p = 0.008$) at full body rise, in PS and FS, respectively.

The total STW duration was significantly shorter in the FS than the PS (PS: 1.611 ± 0.183 s, FS: 1.196 ± 0.153 s, $p = 0.000$). With the exception of the Transition phase (PS: 0.238 ± 0.135 s, FS: 0.201 ± 0.102 s, $p = 0.141$), the absolute phase duration was significantly shortened in the FS compared to PS for the Flexion