Gait & Posture 41 (2015) 882–887

Contents lists available at ScienceDirect

Gait & Posture

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

Evaluation of an inertial sensor system for analysis of timed-up-and-go under dual-task demands

Jason T. Coulthard, Tanner T. Treen, Alison R. Oates, Joel L. Lanovaz *

College of Kinesiology, University of Saskatchewan, 87 Campus Drive, Saskatoon, SK S7N 5B2, Canada

ARTICLE INFO

Article history:
Received 9 December 2014
Received in revised form 2 February 2015
Accepted 15 March 2015

Keywords:
Cognitive task
Gait
Spatiotemporal
Kinematics
Human locomotion

ABSTRACT

Functional tests, such as the timed-up-and-go (TUG), are routinely used to screen for mobility issues and fall risk. While the TUG is easy to administer and evaluate, its single time-to-completion outcome may not discriminate between different mobility challenges. Wearable sensors provide an opportunity to collect a variety of additional variables during clinical tests. The purpose of this study was to assess a new wearable inertial sensor system (iTUG) by investigating the effects of cognitive tasks in a dual-task paradigm on spatiotemporal and kinematic variables during the TUG. No previous studies have looked at both spatiotemporal variables and kinematics during dual-task TUG tests. 20 healthy young participants (10 males) performed a total 15 TUG trials with two different cognitive tasks and a normal control condition. Total time, along with spatiotemporal gait parameters and kinematics for all TUG subtasks (sit-to-stand, walking, turn, turn-to-sit), were measured using the inertial sensors. Time-to-completion from iTUG was highly correlated with concurrent manual timing. Spatiotemporal variables during walking showed expected differences between control and cognitive dual-tasks while trunk kinematics appeared to show more sensitivity to dual-tasks than reported previously in straight line walking. Non-walking TUG subtasks showed only minor changes during dual-task conditions indicating a possible attentional shift away from the cognitive task. Stride length and some variability measures were significantly different between the two cognitive tasks suggesting an ability to discriminate between tasks. Overall, the use of the iTUG system allows the collection of both traditional and potentially more discriminatory variables with a protocol that is easily used in a clinical setting.

1. Introduction

Functional tests are used routinely in clinical settings to assess mobility and to screen for issues such as balance challenges and fall risk [1–3]. The timed-up-and-go (TUG) test [4], which involves rising from a seated position, walking to a pre-determined location, turning, and returning to a seated position, is a common test used to assess functional mobility. TUG performance has been associated with mobility status [5] and fall risk [6,7]. The test involves minimal equipment and evaluator training and has been shown to have good test–re-test reliability [8,9]. The sensitivity of the TUG; however, is limited and may not adequately discriminate between variations in gait patterns of those with more subtle pathologies [10].

Recent advances in portable and wearable sensor technology have increased possibilities for detailed spatiotemporal and kinematic measurements in clinical settings. Relatively inexpensive commercial devices like pressure mats and inertial sensors now allow for capture of data previously restricted to fixed, laboratory-based motion capture systems. The TUG is one of the many functional tests that can be measured easily with these new technologies [1,10–17].

To increase the challenge posed by clinical walking tests, a secondary concurrent task is sometimes added. This dual-task paradigm is thought to place additional loads on the brain's executive function centers which, in turn, interferes with motor control tasks such as walking [18]. Previous longitudinal research has shown that slower 10 m walking velocities while performing a cognitive task were significantly associated with recurrent falls [19]. A large body of research conducted on cognitive motor interference dual-task paradigms in straight-line walking suggests that the greatest effect on spatiotemporal gait characteristics comes from cognitive tasks involving mental tracking (MT) that requires withholding information for processing plus manipulation of that information (e.g., counting backwards by sevens) or verbal fluency (VF) that requires spontaneous word production

---

* Corresponding author. Tel.: +1 306 966 1073.
E-mail address: joel.lanovaz@usask.ca (J.L. Lanovaz).

http://dx.doi.org/10.1016/j.gaitpost.2015.03.009
0966-6362/© 2015 Elsevier B.V. All rights reserved.

under pre-specified search conditions (e.g., list names that start with the letter J) [20].

While dual-task effects have been previously investigated in the TUG [21], only time-to-completion has been reported. Changes in gait patterns and trunk kinematics have been shown to occur during regular straight-line walking under dual-task conditions [20] and it is likely that similar alterations occur during the TUG. It is possible that subtle gait changes might be more discriminatory than the single time-to-completion measure [17] and may enhance the utility of the TUG test. To date, no studies have examined spatiotemporal or kinematic variables during dual-task TUG testing.

This study examines a new commercial sensor system (Mobility Lab iTUG, OPAL sensors, APDM Inc, Portalnd, OR) that has been developed using a number of small, wireless, inertial-based sensors that include accelerometers, gyroscopes, and magnetometers [10,22,23]. The accompanying software specifically analyzes the TUG and calculates over 30 different gait variables. To date, the iTUG module of the Mobility Lab system has been primarily used to investigate subtle gait changes, postural transitions and arm swing in persons with Parkinson's disease, with applications in early detection and progression monitoring [10,13,24] and has also been used to examine gait in persons with Multiple Sclerosis [17].

The primary objective of this study is to evaluate the iTUG system during a dual-task protocol in young healthy adults. This study tests two different cognitive dual-tasks (MT and VF), typically used in clinical settings to assess mobility and compares results to previous research in dual-task walking. The secondary objective of this study is to examine any differences between responses to the MT and VF tasks. To the best of our knowledge, this is the first application of the iTUG system to examine dual-task paradigms during the TUG.

2. Methods

A total of 20 English-speaking young adult participants (10 male) were recruited and tested (mean age: 22.5 yrs, SD 2.6 yrs). Participants were eligible if they had no diagnoses of lower limb injury or lower limb surgery within the last 6 months and did not suffer from a neurological disease or recent concussion. The study was approved by the University of Saskatchewan Research Ethics Board and all participants gave informed consent.

Each participant performed a series of TUG tests in a laboratory setting. A standard, armless chair (seat height 44 cm) was placed at one end of a 3.5 m wide level walkway with the return point clearly marked on the floor seven meters from the chair. This distance, standard for the iTUG, is longer than the traditional three meter TUG test. Participants started in a seated position with their feet flat on the floor and hands resting on their laps. They were instructed to stand up, walk to the return point, turn 180°, walk back to the chair, turn 180°, and sit down again. Participants were told to walk at their normal, comfortable pace for all trials. Each participant was allowed one familiarization trial.

Two different cognitive tasks were used in the dual-task paradigm: The first was a mental tracking (MT) task [20] which involved counting backwards by seven's out loud from a given three-digit number. All participants performed five MT trials using the same starting numbers (100, 150, 200, 250, 300) in a random order. The second task was a verbal fluency (VF) task [20] that involved thinking of and clearly verbalizing, in English, as many animal names as possible starting with a given letter. Five VF trials were performed and the letters used (L, D, O, S, and J) were given in a random order. Participants were told which number or letter to use immediately before the trial.

Participants also performed five TUG trials without any cognitive interference (control) resulting in a total of 15 consecutive TUG trials performed by each participant (five control, five MT, five VF) in a randomized order. A 1-min rest period was provided between each TUG trial.

Spatiotemporal and kinematic parameters were collected for all trials using the Mobility Lab system. Each participant wore a total of six sensors positioned on the posterior side of both wrists, directly on top of the distal sternum, posteriorly on the lower lumbar vertebra, and anteriorly on each ankle just proximal to the malleoli (Fig. 1). Data from the sensors were transmitted wirelessly to a base station and laptop computer.

In addition to total time-to-completion, the iTUG software generates kinematic and spatiotemporal variables for all TUG subtasks including the sit-to-stand, straight-line walking, turning, and turn-to-sit phases [10,22,23]. Subtask data included walk phase stride length, stride velocity, cadence, stance time, and double support time. Walk phase kinematic variables included trunk range of motion (ROM) and trunk peak angular velocity in the sagittal, frontal and transverse planes (i.e., about medio-lateral, anterior-posterior and longitudinal axes respectively) along with knee ROM, arm swing ROM and peak arm swing velocity. Knee and arm kinematics were expressed as combined means of left and right sides. Duration of the sit-to-stand phase along with sit-to-stand sagittal trunk ROM and velocity were recorded. For the 180° turn phase, the duration, number of steps, cadence and transverse trunk velocity were captured. At the end of the TUG, the turn-to-sit duration was recorded. Total time spent in straight-line walking was calculated by subtracting the sit-to-stand, turn and turn-to-sit durations from total time-to-completion. Variability was investigated by examining the coefficient of variation (CV) of walk phase spatiotemporal and trunk kinematic parameters. In addition to iTUG, a manual digital stopwatch was used to collect total time-to-completion as per usual clinical TUG protocols [4].

Statistical analysis was done using SPSS (Version 20.0., Armonk, NY, IBM Corp). Data from each condition were averaged for each participant. A linear regression compared total time-to-completion reported by the iTUG system to the traditional stopwatch timing. Repeated measures ANOVAs were used to test for the effect of TUG condition with a significance level set at $p < 0.05$. Sphericity violations were tested using Mauchly's W and Greenhouse–Geisser corrections were applied when necessary. If a significant main effect was found, Bonferonni corrected post hoc tests were used to detect differences between conditions.

3. Results

A strong significant linear relationship was found between stopwatch and iTUG measured total time-to-completion (Fig. 2). The linear regression slope was near unity, while the intercept showed a consistent two second overestimation of time-to-completion by the iTUG system.

Spatiotemporal and kinematic data were expressed as the mean of walking strides detected by the iTUG software (five to eight strides per trial). Time-to-completion was significantly longer in both MT and VF when compared to the control condition (Table 1). Stride length, cadence and stride velocity were significantly decreased in MT and VF compared to control. Stride length during VF was significantly lower than in MT. Double support and stance time both significantly increased in MT and VF with respect to the control condition (Table 1).

Transverse and frontal plane trunk ROM were significantly increased during MT and VF compared to control (Table 1). Peak trunk frontal plane angular velocity also showed a significant increase between control and both dual-task conditions. No differences were seen in trunk kinematics between MT and VF conditions.

Spatiotemporal data variability, as measured by CV, showed some differences between control and dual-task conditions (Table 2). Cadence variability significantly increased in both MT and VF when compared to the control condition. Compared to control, VT showed significantly increased stride length and stride velocity variability. For double support, MT variability was significantly lower compared to both control and VF conditions. The MT condition also had significantly lower variability in trunk transverse ROM compared to control and significantly lower sagittal peak velocity variability compared to control and VF conditions (Table 2).