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Reliability of Quantitative TUG measures of mobility for use in falls risk assessment

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Abstract— **Recent advances in body-worn sensor technology have increased the scope for harnessing quantitative information from the timed-up-and-go test (TUG), well beyond simply the time taken to perform the test. Previous research has shown that the quantitative TUG method can differentiate fallers from non-fallers with greater success than the manually timed TUG or the Berg Balance Test. In order to advance this paradigm of falls risk estimation it is necessary to investigate the robustness of the quantitative TUG variables. This study investigated the inter-session and intra-session reliability of 44 quantitative TUG variables measured from the shanks and lower back of 33 study participants aged between 55-65yrs. For intra-session reliability, 25 variables demonstrated excellent reliability (ICC>0.75), and 12 demonstrated "fair to good reliability" with ICCs between 0.4 and 0.75. Analysis of test-retest reliability resulted in ICC > 0.75 for 18 out of 44 variables, with 20 variables showing fair to good reliability. Turn time parameters demonstrated poor reliability. We conclude that this is a reliable instrument that may be used as part of a long-term falls risk assessment, with further work required to improve certain turn parameters.**

I. INTRODUCTION

The timed up and go test (TUG) is a clinical tool that is widely used to assess functional balance and mobility, primarily in older adults. Traditionally, the test is scored by manually recording the time taken to rise out of a standardized chair, walk three meters, turn around, walk back, turn and sit back down in the chair. The test has been modified in a number of ways, typically for research purposes, to enable the tester to examine the component parts of the test individually for example [1], or by adding cognitive [2] or additional physical challenges [3] to the test. Recent advances in body-worn sensor technology have increased the scope for harnessing quantitative information from the TUG, well beyond simply the time taken to perform the test. Wireless inertial sensors worn by the participant during the TUG can provide large volumes of angular velocity and acceleration data, which can be used to compute a variety of gait and movement parameters, depending on which body part the sensor is attached to. A previous study has shown that instrumentation of TUG in this manner improved the test's ability to differentiate between early Parkinson's Disease (PD) patients and control subjects [4]. In a recent study conducted at our research facility [5], a cohort of 349 older adults performed a quantitative TUG test, during which two inertial sensors containing gyroscopes and accelerometers were attached to the lower limbs of each participant. Forty-four variables were derived from these sensors during the performance of the TUG, 29 of which provided significant discrimination between patients with a history of falls and those without. Cross-validated logistic regression models were use to retrospectively assess falls risk. When compared, this method (hereafter known as the quantitative TUG) outperformed two standard clinical methods of assessing falls risk (time to complete TUG test (manual TUG) and Berg Balance Scale).

These results suggest that the quantitative TUG method has the potential to be used as part of a longitudinal monitoring protocol for falls risk. In order to advance this concept, it is necessary to investigate the robustness of the sensor-derived variables that were used in the previous study. In addition, we propose to include parameters obtained from a sensor placed on the lower back. A previous study has investigated the test-retest reliability of an instrumented TUG and found temporal gait parameters to be the most reliable measures, with mixed results for spatial gait parameters and sit-to-stand variables [6]. This study required study participants to perform three instrumented TUG trials, and then repeat the same protocol one hour later, removing and replacing the sensors in between. The reliability of an instrumented TUG performed on different days has yet to be established.

The purpose of this study was to further develop the quantitative TUG as a tool for long-term monitoring of falls risks in older adults. Long-term monitoring programmes for falls risks could potentially be most effective if implemented in the "young-old" age group as this would facilitate early detection and hence more successful intervention for sub-clinical age-related functional declines. The aim of this study was to establish both the intra-session and inter-session reliability of a number of important inertial sensor derived movement parameters captured from inertial sensors placed on the legs and lower back during repeated performance of

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the quantitative TUG in "young-old" adults, on two different days.

II. METHODS

A. Participants

33 healthy participants (14M, 19F) were recruited in the 55-65 yrs age category (age: 59.8±2.7 yrs; height: 167.2±7.5 cm; mass: 74.3±13.4 kg). Participants were excluded if they had any neurological or musculoskeletal disorders. All participants signed informed consent and the study was approved by the Institutional research ethics committee.

B. Experimental Procedure

A 3 m walkway was measured out and marked with an "x" on the ground at one end and a horizontal line at the other end. A standardized chair (46 cm high seat, 65 cm arm rests) was placed behind the horizontal line. Inertial sensors were attached to the participants as described below. The participants sat comfortably in the chair and adjusted the chair position to ensure that their toes were directly behind the horizontal line. Verbal instructions on how to perform the TUG were as follows: "When I say the word "go", you will get up from the chair, walk to the "x" on the floor, turn, walk back to the chair and sit back down. You will do this at your normal pace". The participant practiced the task once. Six repetitions of the TUG were then performed with one minute rest periods between each trial. The same tester carried out all trials. The participants were asked to return four weeks later, and were told not to change their normal routines in the interim. When the participants returned they were asked if they had experienced any adverse physical incidents in the intervening time, or whether they had made any changes to their lifestyle. All participants were tested within two hours of their initial testing time. The protocol used in the second testing session was exactly the same as the first testing session, and carried out by the same tester.

C. Data Acquisition

Kinematic data from each patient were acquired using three inertial sensors (SHIMMER, Shimmer Research, Dublin, Ireland), two attached to the anterior aspect of the shank at the level of the tibial tuberosity and one attached to the lumbar spine at the level of L4. The sensors on the shank were attached using a Velcro strap with an elasticized pouch in which a sensor was placed. The sensor was attached to the lumbar spine first with double sided tape and then with additional athletic tape to secure it. Each inertial sensor contained both a tri-axial accelerometer and a tri-axial gyroscope sampling at 102.4 Hz. Data were acquired in real time using a custom-built BioMOBIUS application (http://www.biomobius.org). The inertial sensor data for each test were then exported to text format for subsequent offline analysis. Figure 1 shows a sample of the shank angular velocity signal obtained from a participant performing the TUG test.

D. Quantitative TUG Parameters

The quantitative TUG parameters derived from the inertial sensors have been described in detail elsewhere [5]. Two additional spatial gait parameters were also included, stride length, stride velocity along with the coefficient of variation of both. These variables were calculated using a previously reported method which required data from one gyroscope per leg [7].

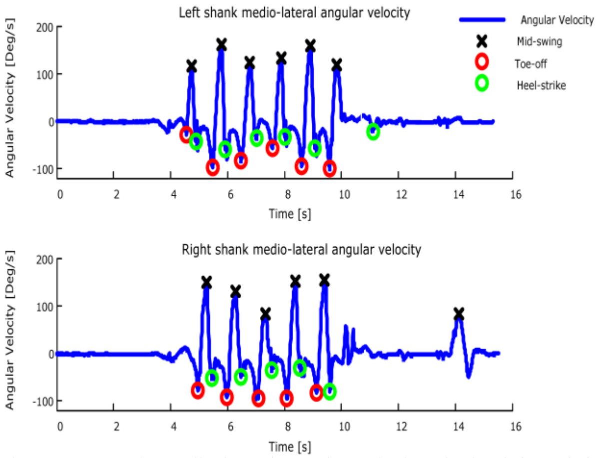

Figure 1: Sample medio-lateral angular velocity obtained from left and right shank-mounted tri-axial gyroscope obtained from a 64 year healthy female while performing the TUG test.

In order to examine the turning phase of each TUG test, the corresponding medio-lateral angular velocity signal was automatically segmented into two walking sections, and a turning section. If the amplitude of a given mid-swing point was more than one standard deviation below the mean amplitude of all mid-swing points, it was considered part of the turn. The turning phase was then defined as that section of the signal, starting at the last heel strike before the first mid-swing in the turn, and ending at the first toe off after the last mid-swing in the turn. A number of novel parameters were then introduced to quantify the turn: The number of steps taken for subjects to turn (Turn Steps), the time taken to turn (Turning Time) and the ratio of the number of steps taken to turn to the time taken to turn (Turn Strides Ratio). In addition to this, acceleration parameters were extracted from the inertial sensor placed on the lumbar spine (Turn Magnitude).

The sit-stand and stand-sit transitions were identified using the filtered, calibrated and rectified ML acceleration recorded at the lumbar spine. The mean value of the ML acceleration for the entire recording, T_{ss}, was used as a threshold to identify the postural transitions. The start of the sit-stand transition was detected as the first data point which exceeded T_{ss}, and the first toe-off time marked the end of the sit-stand transition. The start of the stand-sit transition was identified as the last heel-strike time, and the end of this transition was the last data point in the recording greater than T_{ss}. The RMS amplitude of the ML, AP and SI acceleration for each postural transition were examined.

E. Statistical Analysis

Initially the Mann Whitney version of Wilcoxon rank sum test was used to determine if there was a systematic difference between the means of the quantitative TUG variables between testing sessions ($\alpha<0.05$). Intra-class correlation coefficients (ICCs) were then calculated to assess the test-retest reliability. A 2-way model of ICC(2,k) was employed where the mean of the six trials in both testing sessions was used. Within-session reliability was calculated for each variable using ICC(2,1). The resulting ICCs were then averaged across both testing sessions.

III. RESULTS

TABLE I: SUMMARY OF RELIABILITY ANALYSES. ML IS MEDIO-LATERAL AXIS; AP IS ANTERIO-POSTERIOR AXIS; SI IS SUPERIOR-INFERIOR AXIS; RMS - ROOT MEAN SQUARE; CI IS CONFIDENCE INTERVAL

Variable	Test 1	Test 2	Test-Retest Reliability			Intra-session Reliability		
	Mean±SD	Mean±SD	ICC	95% CI Lower	95% CI Upper	ICC	95% CI Lower	95% CI Upper
Macro Gait Parameters								
Cadence [steps/min]	103.64±13.24	107.51±11.20	0.85	0.70	0.93	0.82	0.74	0.88
No. gait cycles	4.35±0.63	4.34±0.70	0.85	0.70	0.93	0.78	0.69	0.86
No. steps	10.72±1.11	10.83±1.11	0.89	0.78	0.95	0.82	0.75	0.89
Mean gait velocity [cm/s]	115.44±17.42	125.19±15.48	0.88	0.69	0.95	0.97	0.95	0.98
Gait velocity variability [%]	32.79±8.96	29.62±8.89	0.73	0.34	0.89	0.85	0.78	0.91
Spatio-temporal Gait Parameters								
Stance time [s]	0.73±0.13	0.71±0.12	0.75	0.49	0.87	0.77	0.68	0.86
Stance time variability [%]	37.55±15.17	38.43±13.69	0.51	0.02	0.75	0.47	0.34	0.62
Step time [s]	0.62±0.09	0.61±0.09	0.87	0.75	0.94	0.81	0.74	0.88
Step time variability [%]	32.31±18.97	28.88±18.47	0.77	0.53	0.88	0.60	0.48	0.73
Stride time [s]	1.17±0.12	1.14±0.13	0.85	0.70	0.93	0.82	0.75	0.89
Stride time variability [%]	16.94±9.12	18.40±11.05	0.61	0.22	0.81	0.45	0.32	0.60
Swing time [s]	0.51±0.06	0.52±0.07	0.69	0.39	0.85	0.74	0.65	0.83
Swing time variability [%]	23.74±12.89	28.53±15.96	0.38	-0.23	0.69	0.38	0.25	0.54
Stride length [cm]	135.00±8.94	139.68±9.41	0.89	0.72	0.95	0.97	0.96	0.98
Stride length variability [%]	16.61±4.58	15.06±4.10	0.70	0.26	0.88	0.89	0.83	0.93
Angular Velocity (Ang. Vel.) Parameters								
Max ML Ang Vel [deg/s]	168.52±16.64	170.89±16.76	0.91	0.82	0.95	0.79	0.72	0.86
Mean ML Ang Vel [deg/s]	19.32±2.93	21.03±2.31	0.58	0.16	0.79	0.81	0.73	0.88
Min ML Ang Vel [deg/s]	-102.46±15.99	-102.53±11.80	0.83	0.65	0.91	0.67	0.59	0.76
ML Ang Vel variability [%]	166.16±17.21	159.68±10.90	0.14	-0.72	0.57	0.80	0.72	0.87
Max AP Ang Vel Variability	224.85±50.86	227.46±39.10	0.79	0.57	0.89	0.80	0.71	0.87
Mean AP Ang Vel [deg/s]	17.40±2.76	18.42±2.68	0.71	0.42	0.86	0.81	0.74	0.88
Min AP Ang Vel [deg/s]	-209.54±45.08	-204.81±40.23	0.57	0.14	0.79	0.72	0.61	0.82
AP Ang Vel variability [%]	168.90±24.67	163.56±22.76	0.62	0.24	0.81	0.80	0.73	0.87
Max SI Ang Vel [deg/s]	114.49±33.03	107.51±25.28	0.62	0.23	0.81	0.80	0.71	0.87
Mean SI Ang Vel [deg/s]	9.89±2.44	10.44±1.94	0.70	0.40	0.85	0.86	0.80	0.91
Min V Ang Vel [deg/s]	-104.57±28.76	-108.04±33.78	0.61	0.21	0.80	0.77	0.69	0.85
SI Ang Vel variability [%]	171.34±23.46	167.33±21.09	0.60	0.19	0.80	0.81	0.74	0.88
Mean Ang Vel at mid-swing [deg/s]	131.82±13.43	136.36±16.17	0.93	0.87	0.97	0.86	0.80	0.91
Range Ang Vel at Mid-swing [deg/s]	102.15±23.24	103.83±22.69	0.78	0.56	0.89	0.62	0.51	0.74
Turn Parameters								
Turn magnitude [deg/s]	35.55±25.51	35.43±35.71	0.32	-0.37	0.66	0.39	0.27	0.53
Turn mid time [s]	3.12±0.87	2.98±0.42	0.07	-0.87	0.53	0.49	0.43	0.57
Turn Steps	1.89±0.42	2.06±0.39	0.62	0.24	0.81	0.45	0.32	0.60
Turn Strides Ratio	0.84±0.29	0.93±0.26	0.79	0.57	0.89	0.52	0.39	0.66
Turning Time [s]	2.66±1.12	2.36±0.44	0.27	-0.47	0.63	0.39	0.30	0.50
Trunk Acceleration Parameters								
RMS AP sit [g]	0.73±0.18	0.70±0.16	0.65	0.29	0.82	0.68	0.57	0.78
RMS ML sit [g]	0.00±0.00	0.00±0.00	0.64	0.29	0.82	0.68	0.57	0.79
RMS SI sit [g]	0.01±0.00	0.01±0.00	0.60	0.19	0.80	0.62	0.50	0.74
RMS AP stand [g]	0.92±0.29	0.81±0.20	0.49	-0.01	0.75	0.68	0.57	0.78
RMS ML stand [g]	0.00±0.00	0.00±0.00	0.49	-0.02	0.75	0.68	0.57	0.79
RMS SI stand [g]	0.01±0.00	0.01±0.00	0.51	0.02	0.76	0.64	0.52	0.76
RMS acc	1.15±0.05	1.15±0.05	0.77	0.55	0.89	0.84	0.78	0.90
RMS AP [g]	0.39±0.08	0.41±0.08	0.75	0.50	0.87	0.79	0.71	0.87
RMS ML [g]	0.00±0.00	0.00±0.00	0.75	0.49	0.87	0.79	0.71	0.87
RMS SI [g]	1.00±0.00	1.00±0.00	0.02	-1.04	0.49	0.85	0.79	0.90

No systematic difference in means was observed between the two conditions in any variable. Of the 44 variables analyzed for intra-session reliability, 25 demonstrated excellent reliability as interpreted according to Fleiss [8], (ICC>0.75), and 12 demonstrated "fair to good reliability" with ICCs between 0.4 and 0.75. Analysis of test-retest reliability resulted in ICC > 0.75 for 18 out of 44 variables, with another 20 variables showing fair to good reliability. Turn time parameters demonstrated poor reliability. Table I summarizes the test-retest reliability and intra-session reliability results.

IV. DISCUSSION

This study sought to investigate the robustness of quantitative TUG parameters that have been used in a previous investigation [5] and subsequent work [9] in generating statistical models of falls risk. Additional variables were included in the present study from an inertial sensor placed on the lower back. Future work will utilize these variables in a longitudinal predictive study on falls risk. It was therefore necessary to examine both the intra-session and test-retest reliability of these novel sensor-derived variables. This analysis has yielded positive results.

The variables used in this study were largely derived from gyroscopes attached to both shanks where difficulties related to sensor orientation were minimal. The macro gait variables, spatio-temporal gait parameters and angular velocity parameters demonstrate overall high levels of variability. Sit-to-stand and stand-to-sit parameters were derived from the accelerometer at the base of the trunk. The ICCs for test-retest reliability of trunk kinematics in these portions of the quantitative TUG ranged from 0.45-0.65. Salarian *et al.* [6] investigated the test-retest reliability of an instrumented TUG and reported poorer reliability (ICCs: 0.22-0.43) for sit-to-stand trunk parameters than reported here. In contrast, the parameters used to analyze the turn in their study demonstrated good to excellent reliability, whereas certain turn variables in this study yielded much lower ICCs, e.g. turn magnitude, turn time.

An important characteristic of this study is the long-term nature of the test-retest reliability design. Previous studies investigating the reliability of inertial sensor derived gait parameters have retested on the same testing day, removing and replacing the sensors in between tests [6, 10]. The four-week interval in this study was selected to represent a realistic time-frame that might be employed in a care/exercise setting to monitor balance and mobility longitudinally in the home, for example, or to monitor the effects of an intervention. Long-term gait-related reliability measures tend to produce more variable results than within-day reliability measures [11]. It is therefore particularly encouraging that good test-retest reliability was observed in the majority of the quantitative TUG parameters across a four-week period.

Intra-session reliability of sensor-derived TUG variables has not previously been reported. Six trials were performed in each testing session to examine how much variation exists in quantitative TUG parameters between trials. Good to excellent intra-session reliability was observed in most variables. Similar to test-retest reliability, certain variables related to the turn demonstrated poor reliability. Further analysis of this data set will examine the number of trials required within a test session for optimal reliability of the quantitative TUG variables. Such an analysis may identify possible task learning effects within the data.

The choice of cohort for this study was based on the idea that long-term monitoring of balance and mobility could potentially be more successful if initiated in the “young-old” adult population. This would create opportunities for early detection and subsequent intervention of sub-clinical declines in function that may otherwise go unnoticed until they become more onerous problems, at which point intervention becomes more complex. Given that the TUG task was well within the capabilities of all participants, it was unknown if the quantitative TUG parameters would be reliable from trial to trial or between sessions due to the large number of degrees of freedom available to the healthy volunteers. This study confirms that the quantitative TUG parameters are reliable in this “young-old” cohort. However, the poorer reliability observed in the turn parameters may indeed be due to the functional ability of this healthy cohort, and the many movement strategies available to them in performing the turn.

V. CONCLUSIONS

Long-term test-retest reliability and intra-session reliability of the quantitative TUG has been demonstrated in this study. Further work is required to improve the reliability of certain turn parameters. We conclude that this is a reliable instrument that may be used as part of a long-term falls risk assessment and suggest that such an approach could potentially be implemented in the “young-old” adult population.

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