A Smartphone-Based Timed Up and Go Test for Parkinson's Disease

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Abstract. The Timed-Up and Go test is a simple yet effective test used to evaluate balance and mobility in conditions that affect movement, such as Parkinson's disease. This test can inform clinicians about the monitoring and progression of the disease by measuring the time taken to complete the test. We used a smartphone app to obtain the phone's inertial data and implemented an algorithm to automatically extract the time taken to complete the test. We considered data collected from six healthy participants performing tests at different speeds. The proposed method was further tested on twelve participants with Parkinson's disease based on a reference measurement in clinic. We show that, for both groups, we obtain good accuracy (RMSE = 3.42 and 1.95 s) and a strong positive correlation (r = 0.85 and 0.83) between estimated duration and ground truth. We highlight limitations in our approach when the test is performed at very low speed or without a clear pause between the test and the user interaction with the phone.

Keywords: mobile Health · Timed Up and Go test · Parkinson's disease

1 Introduction

By observing the overall duration of the Timed Up and Go (TUG) test, clinicians can assess lower extremity function, mobility, and fall risk in various health conditions like Parkinson's Disease (PD) and Multiple Sclerosis (MS) [1]. To perform the test, the patient rises from a chair, walks 3 m, turns around, walks back, and sits down. Traditionally, TUG tests are conducted in hospitals with specialized equipment, generating costs for healthcare and inconveniences for patients. Our research aims to develop a TUG test using only a mobile phone. Challenges for this include usability, reliability, and feasibility for patients doing the test without supervision.

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Research on IMU-based TUG tests has led to smartphone-based approaches for TUG test duration estimation, as demonstrated in [2]. Various methods exist, such as the smartphone apps from Madhushri et al. [3] and Chan et al. [4], both achieving excellent accuracy (limits of agreement: −1.66 s and 2.63 s). However, these methods rely on sternum- and chest-worn smartphone positions which can be uncomfortable and challenging for users without assistance. Subsequently, there is still a need for more user-friendly algorithms that allow unsupervised but reliable smartphone-based TUG tests.

2 Materials and Methods

We integrated our TUG test into the Mobistudy smartphone app [5], guiding users with instructions for how to perform the test. Six healthy volunteers conducted TUG tests at different speeds, with data sampled at 60 Hz. We used a G-Walk device [6] to provide reference measurements and a stopwatch as a backup. Additionally, data from the ParkApp study (Swedish Ethical Review Authority application number 2022-02885-01) was included to test our implementation.

The TUG test is divided into three parts: I) preparation phase, where the patient, after having tapped on the "start" button, inserts the phone in a waistband, II) test phase, where the patient performs the test, standing up from a chair, walking and sitting down, and III) completion phase, where the phone is extracted from the band and the user taps on a "complete" button.

The algorithm (shown in Fig. 1), measures the total time of the test phase. It is based on labelling acceleration magnitude as "motion" when the averaged module is above a threshold (0.8 m/s^2), and "stillness" when below. In ideal conditions, there are three "motion" and two "stillness" segments. The first "motion" segment corresponds to the preparation phase, the second to the test phase, and the last to the completion phase. The number of consecutive equal labels is counted, and based on the number of "motion" segments found, the method for estimating the test duration is chosen. If there are fewer than four "motion" segments, the longest "motion" segment is selected as the test phase, and its total time is easily derived. Otherwise, a stillness-based method is used, where the time between the two longest "stillness" segments is considered as the beginning and end of the test (when the user is sitting).

After the initial estimation, two acceptability checks are performed: looking for a "completion" phase and ensuring the estimated duration is above three seconds. If no "completion" phase is detected, the time to remove the phone is subtracted from the estimate. If the estimated duration is below three seconds, the previously excluded method is used. Threshold values are set empirically based on healthy subject data which are characterised by a great variance in how the test was performed.

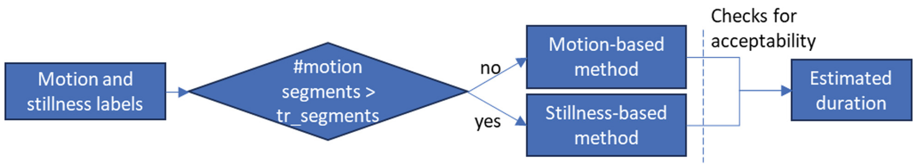

Fig. 1. Test duration estimation algorithm depicting the set of instructions. "tr_segments" is the threshold with which the method, motion-based or stillness-based, is selected.

3 Results

We gathered 34 tests from 6 healthy volunteers and an additional 15 tests from 12 PD patients. For the healthy subjects, we compared reference distances with stopwatch measurements, discarding two recordings due to disparities between references. Evaluation metrics are presented in Table 1. In Fig. 2, panels a.1 and a.2 depict the Bland Altman plot, while panels b.1 and b.2 display the correlation between estimated and reference values.

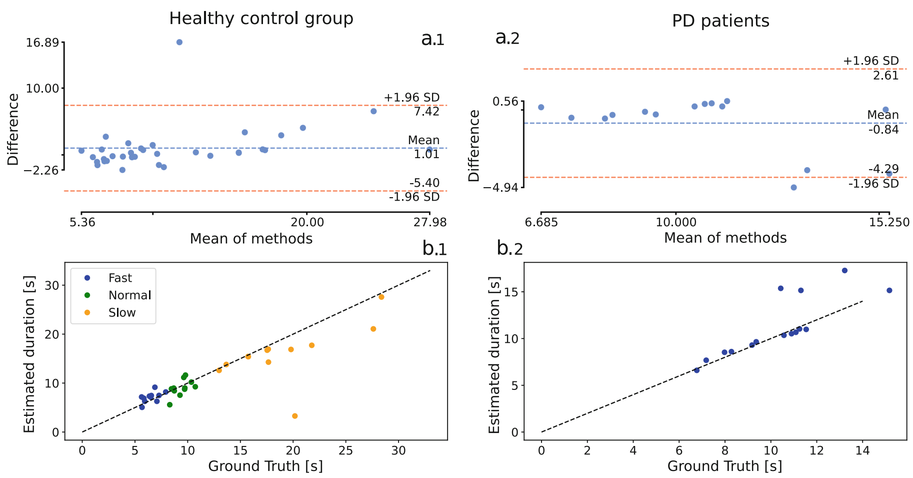

Fig. 2. Plots a.1 and a.2 show the Bland-Altman analysis while plots b.1 and b.2 show the estimated and the reference values match. The Pearson's correlation is 0.85 for the healthy control group and 0.83 for PD patients.

Table 1. Evaluation metrics of the test time measurement in seconds.

	Speed	mean	SD	median	IQR	min	max	corr	RMSE	LoA_low	LoA_high
6 Healthy	All	1.01	3.27	0.33	1.32	−2.26	16.89	0.85	3.42	−5.40	7.42
	Normal	0.37	1.30	0.31	1.54	−1.84	2.72	0.58	1.35	−2.18	2.92
	Fast	−0.61	0.85	−0.63	0.78	−2.26	0.80	0.56	1.04	−2.27	1.04
	Slow	3.08	4.59	0.81	3.35	−0.14	16.89	0.59	5.53	−5.91	12.07
12 PD	All	−0.84	1.76	−0.12	0.74	−4.94	0.56	0.83	1.95	−4.29	2.61

4 Discussion and Conclusion

This study shows how smartphones hand-held can be used to implement a TUG test. Our algorithm was developed on data collected from healthy participants and later validated with data from PD patients. Our TUG duration estimation performs well overall but may result in outliers, especially at extremely slow speeds. The TUG test's Minimal Detectable Change for Parkinson's disease is typically below 3.5 s [7] which is smaller than our limits of agreements.

Errors in the detection of the time are introduced especially in tests at very slow speed from three healthy subjects, and three tests from patients where the user introduced additional movement noise during the sitting phases. Our results are thus not quite as strong as previous studies [3,4]. However, given that our approach provides more user-friendly body positions that can be easily conducted without supervision, we are aiming for future work to improve reliability with gyroscope data and explore more advanced techniques.

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