The Journal of Physical Therapy Science

S P T S

Original Article

Reliability of the infrared motion-time acquisition system for each motion segment in the timed up-and-go test

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Abstract. [Purpose] This study aimed to investigate the reliability of an infrared motion-time acquisition system by measuring the time taken for five motion segments (sit-to-stand, forward gait, mid-turn, return gait, and turn-stand-to-sit) in the timed up-and-go test. [Participants and Methods] In total, 30 healthy adults (25.1 ± 4.6 years, 19 males and 11 females) were included in this study. Tester A and Tester B measured the time taken in the timed up-and-go test and its five motion segments with an infrared motion-time acquisition system, and two measurements were made by Tester A and one by Tester B. [Results] Intraclass correlation coefficients of the time taken for the five motion segments in the timed up-and-go test and the intra- and inter-rater intraclass correlation coefficients were greater than 0.9. [Conclusion] Infrared motion-time acquisition systems and its five motion segments are reliable and provide accurate measurements during the timed up-and-go test.
Key words: Timed up-and-go test, Motion-time acquisition, Infrared

INTRODUCTION

The timed up-and-go test (TUG) is a common method to predict falls[1, 2]. While the total TUG time has been analyzed, the effect of each motion segment (sit-to-stand, forward gait, mid-turn, return gait, and turn-stand-to-sit)[3] on the risk of falling at different times has not been considered. Hence, the risk of falls may be incorrectly predicted if the timing of each TUG segment differs among people, but the total time remains the same[4]. It is assumed that the accuracy of the TUG in predicting falls can be improved by dividing it into five motion segments, and then conducting a detailed analysis of the relationship between each motion segment and falls. For this purpose, it is necessary to objectively measure the timing of all motions in the TUG.

Recent studies have relied on a wearable miniaturized inertial sensor system and a three-dimensional (3D) gait analysis system to measure and analyze motion. Lim et al. and Reinfelder et al. used this sensor to study each motion segment in the TUG in fall and non-fall groups of patients with chronic cerebral apoplexy[3] and Parkinson's disease, respectively[4]. However, before the measurement, it is necessary to set the position using professional software, and therefore, the participant needs to wear an auxiliary device. As the device may shift and fall off during the process and can also be affected by interference

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from signals of other electronic equipment, it is necessary to dedicate a significant amount of time to debugging[5, 6]. This can directly affect test efficiency. Although the motion time can also be measured by the 3D gait analysis system[7–10], this technique is expensive and is generally only found in universities and research institutes. Moreover, the debugging and operation of this type of equipment is relatively complicated, requiring the participants to wear more auxiliary devices[11]. Therefore, it is not widely applicable.

Infrared sensing devices can detect the position of moving objects with high sensitivity and accuracy. They have been widely used in sports competition timing, robot biofeedback, object shape measurement, medical treatment, and nursing monitoring[12–15]. The purpose of this study was to explore a new type of motion-time acquisition system with infrared sensing that can be used for the objective measurement of the timing of each motion segment in the TUG. The reliability of this method was also studied.
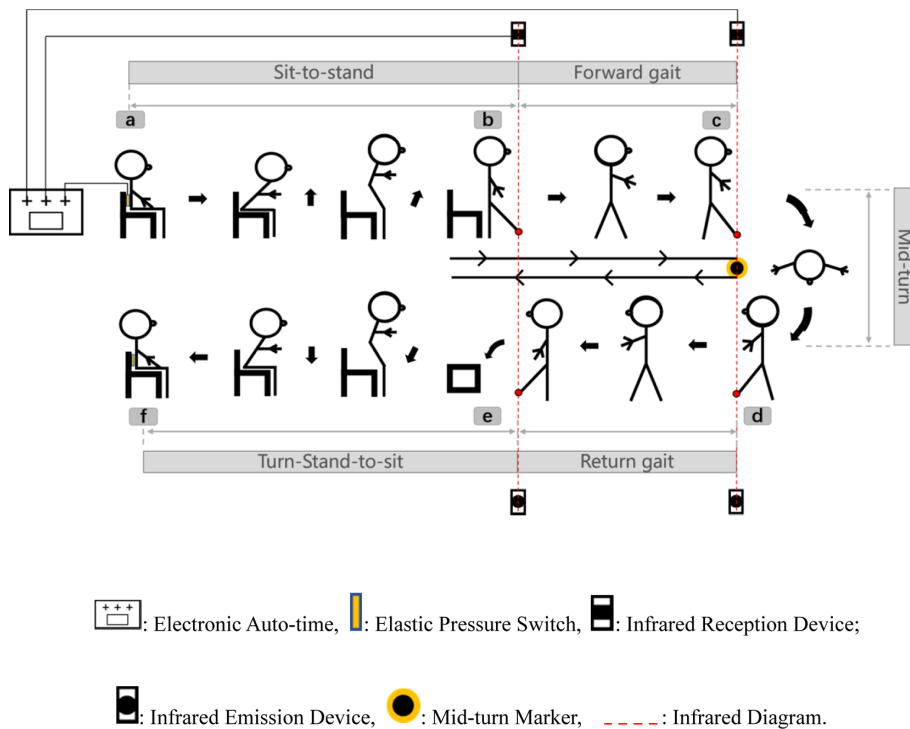
PARTICIPANTS AND METHODS

The participants in this study were 30 healthy adults (25.1 ± 4.6 years, 19 males and 11 females). None of them reported a fall in the past year. Table 1 shows the detailed basic attributes of the sample group. This study was reviewed and approved by the Medical Ethics Review Committee of the International University of Health and Welfare in Japan (Approval No.: 18-Io-134). The purpose and content of this research were explained to the participants, and they all gave their informed consent to participate in the study.

As shown in Fig. 1, an elastic pressure switch with high sensitivity was set at the back of the chair as a sensing device for the start point (a=0 s) and the endpoint (f) of the test. The switch was set to be turned off with pressure and turned on when not pressed. The infrared emission and reception devices (SK-ABT, Fujian Shike Intelligent Technology Co. Ltd., Quanzhou,

Table 1. Attributes of participants (n=30)

Age (years)	25.1 ± 4.6
Height (cm)	169.1 ± 8.1
Weight (kg)	65.1 ± 12.6

Mean ± SD.

□: Electronic Auto-time, ▮: Elastic Pressure Switch, ▬: Infrared Reception Device;

▬: Infrared Emission Device, ●: Mid-turn Marker, ____: Infrared Diagram.

Fig. 1.　Diagram of the time for each segment of the timed up-and-go test with an infrared device.

China) were placed on both sides of the walking starting point and mid-turn markers, with a device distance of 3 m and a height of 20 cm from the ground. Both devices were used to monitor the time nodes of the walking starting point (b), the bend entering point (c), the bend leaving point (d), and the walking ending point (e). The device was connected in parallel with a multi-channel automatic electronic timer (PLC8, Zhejiang Yongtai Electric Appliance Co. Ltd., Jinhua, China; sensitivity of 0.01 s) to automatically record the data of each time node.

To start the test, the participants were required to sit on a chair with their back gently leaning against the back of the chair, hands on their thighs, and feet touching the ground. The participants could independently decide the starting time. They were asked to stand up and walk straight forward, bypass the mid-turn point, and then return to the chair to sit down again. Once their body was leaning against the back of the chair, the TUG was completed[16]. The infrared motion-time acquisition system automatically recorded each time node in the TUG. Detailed data were obtained through an electronic timer, and the total TUG time (f–a) and each motion segment (sit-to-stand [b–a], forward gait [c–b], mid-turn [d–c], return gait [e–d], and turn-to-sit [f–e]) was calculated by subtraction.

As shown in Fig. 2, to conduct the intra-rater reliability test, 30 participants were tested using the same tester (A). The test was performed 3 times a day with an infrared motion-time acquisition system for 2 days and the mean was taken as the final result. To assess inter-rater reliability, 30 participants were tested by tester A and tester B 3 times a day with the infrared motion-time acquisition system in 2 days, and the mean was taken as the final result. Intraclass correlation coefficients (ICCs) were used to analyze the data obtained and verify the intra- and inter-rater reliability of the method. The analysis was conducted using SPSS (Version 22.0; IBM, Armonk, NY, USA) running on Windows.

RESULTS

Table 2 shows the results for the same tester (Tester A) on two separate days, with intra-rater ICCs greater than 0.9. Table 3 shows the results for each tester, with inter-rater ICCs greater than 0.9. The data was confirmed to be normally distributed using the Kolmogorov-Smirnov test.
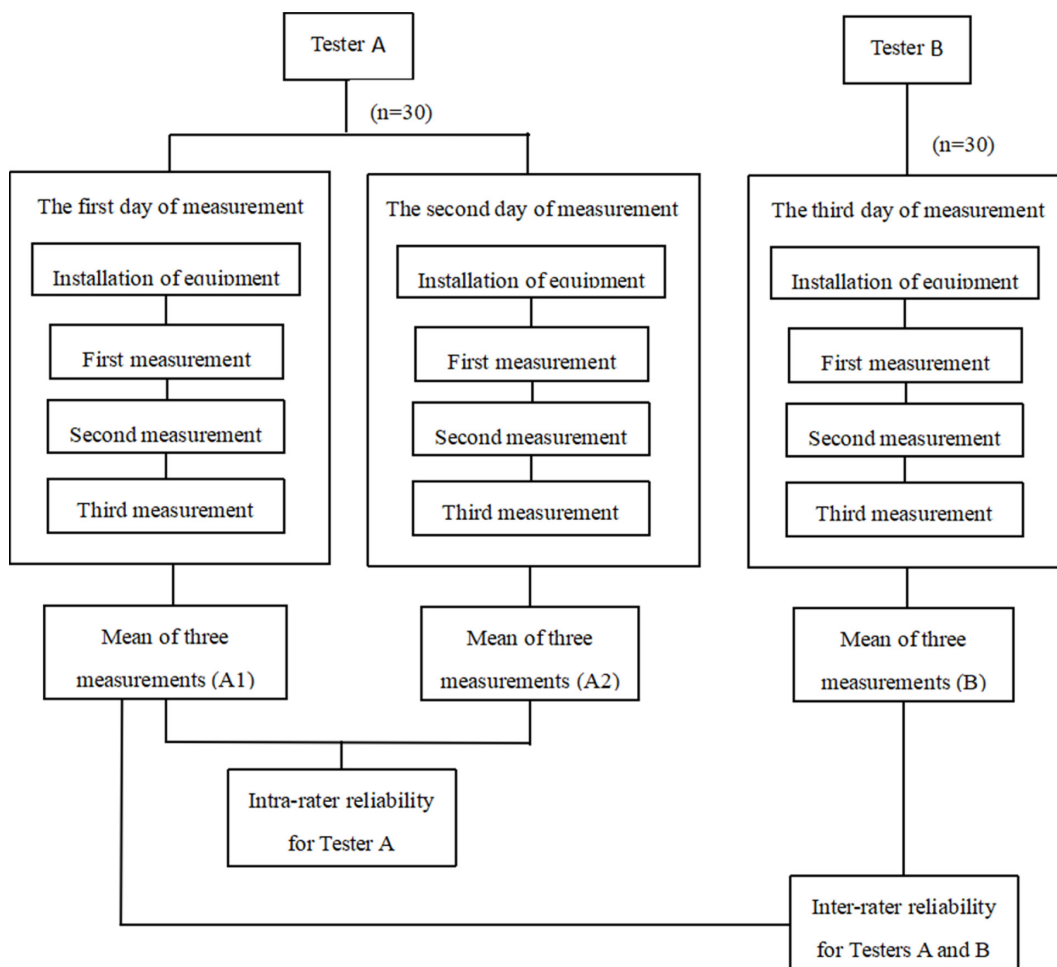

Fig. 2. Participant enrollment flowchart.

Table 2. Intra-rater reliability for Tester A (n=30)

	Mean of the first day (A1)	Mean of the second day (A2)	ICC (1.1)
TUG (s)	6.59 ± 0.82	6.49 ± 0.87	0.973**
Sit-to-stand (s)	1.06 ± 0.16	1.11 ± 0.23	0.916**
Forward gait (s)	1.38 ± 0.20	1.35 ± 0.24	0.945**
Mid-turn (s)	1.53 ± 0.16	1.49 ± 0.18	0.913**
Return gait (s)	1.46 ± 0.20	1.43 ± 0.18	0.936**
Turn-stand-to-sit (s)	1.16 ± 0.18	1.11 ± 0.17	0.920**

TUG: timed up-and-go test; ICC: intraclass correlation coefficient. Mean ± SD. **p<0.01.

Table 3. Inter-rater reliability for Testers A and B (n=30)

	Mean of the first day (A1)	Mean of the third day (B)	ICC (2.1)
TUG (s)	6.59 ± 0.82	6.51 ± 0.81	0.974**
Sit-to-stand (s)	1.06 ± 0.16	1.13 ± 0.21	0.908**
Forward gait (s)	1.38 ± 0.20	1.31 ± 0.18	0.924**
Mid-turn (s)	1.53 ± 0.16	1.57 ± 0.17	0.915**
Return gait (s)	1.46 ± 0.20	1.40 ± 0.16	0.918**
Turn-stand-to-sit (s)	1.16 ± 0.18	1.10 ± 0.22	0.915**

TUG: timed up-and-go test; ICC: intraclass correlation coefficient. Mean ± SD, **p<0.01.

DISCUSSION

According to the findings of this study, the intra- and inter-rater ICCs of the times measured in the TUG and its five motion segments measured by the infrared motion-time acquisition system were greater than 0.9[17]. This indicates that the system and its measurement method are highly reliable.

Considering that the time spent during each of the five motion segments in the TUG is short (generally less than 2 s), it can be challenging to collect data by manual stopwatch recording. Researchers have previously tried to collect data using a camera, but this method requires time-consuming analysis of video data, and the reliability of the results could not be ensured.

The components of the infrared motion-time acquisition system are cheap and simple to install, and they do not require the participant to adapt to any additional devices. The test process was non-invasive, and the participant was not exposed to electronic signals or light. The process of data collection is convenient and does not require computers or complex software. Therefore, this type of device is more practical than others in timing simple tasks.

There are some limitations to this study. This study is a preliminary exploration of the reliability of infrared motion-time acquisition system, so only healthy adults are selected as the experimental subjects. However, as a method of evaluating human walking function, TUG is more used to predict falls of the elderly and stroke patients. Therefore, in future studies, it is necessary to take the elderly and stroke patients and other different populations as objects to verify the reliability of this time acquisition system, so as to make it more widely applied.

In this study, a simple motion-time acquisition system was developed using infrared sensing devices and other equipment. Both intra- and inter-rater reliability were verified for the measurements of the overall time taken in the TUG and for each of its five motion segments. Therefore, this system can be applied to related tests and future research.

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