Quantitative Evaluation Method of Timed Up and Go Test for Hospitalized Patients Using Inertial Sensors

Sugimoto, Tatsuya

Yoshikura, Ryoto

Kawaguchi, Hiroshi

Izumi, Shintaro

(Citation)
2023 IEEE 19th International Conference on Body Sensor Networks (BSN):1-4

(Issue Date)
2023-12-01

(Resource Type)
journal article

(Version)
Accepted Manuscript

Quantitative Evaluation Method of Timed Up and Go Test for Hospitalized Patients Using Inertial Sensors

Tatsuya Sugimoto[1, 2, *], Ryoto Yoshikura[2], Hiroshi Kawaguchi[2], and Shintaro Izumi[2, 3]
[1]*Department of Rehabilitation, Japanese Red Cross Kobe Hospital,* Kobe, Japan
[2]*Graduate School of Science, Technology and Innovation, Kobe University,* Kobe, Japan
[3]*Osaka Heatcool Inc.,* Osaka, Japan
[*]tatsuya.rgmsqz7@gmail.com

***Abstract*—The purpose of this study was to categorize hospitalized patients based on their Timed Up and Go (TUG) test completion time and level of walking independence, and to compare their movement methods during subphases of the TUG test as measured by inertial sensors between groups. The study included hospitalized patients undergoing rehabilitation who were already independent in walking with a walker. Patients performed the TUG test as quickly as possible with or without a cane. Inertial sensors were attached to the lumbar region, and the acceleration and angular velocity were analyzed. A total of 21 patients were included in the analysis: 9 patients in the Independent Fast (IF) group, who were independent in walking and had a TUG time of less than 13.5 seconds; 6 patients in the Independent Slow (IS) group, who were independent in walking but had a TUG time greater than 13.5 seconds; and 6 patients in the Monitored Slow (MS) group, who required monitoring during walking and had a TUG time greater than 13.5 seconds. The IF group demonstrated significantly lower total TUG time and total number of steps compared to the other two groups, and the IS group had significantly lower values than the MS group. In the sit-to-stand , first walk and second turn phases of TUG, the IF group had significantly higher angular velocity or autocorrelation coefficients for acceleration than the other two groups or MS group, respectively. The IS group had slower TUG times, but their movement methods were closer to that of the IF group, which may indicate recovery. Thus, the movement methods of the TUG test were found to be influenced by movement speed and level of walking independence, in that order.**

Keywords—Timed Up and Go test, level of walking independence, inertial sensors

I. INTRODUCTION

Evaluation of walking in hospitalized patients undergoing rehabilitation and determining the appropriate timing for promoting independence are crucial in preventing disuse syndrome and facilitating early hospital discharge. Walking with a walker is typically deemed safe, however, determining independence for walking with or without a cane can be challenging due to the increased risk of falls. The Timed Up and Go (TUG) test is an objective method for assessing fall risk in clinical settings and the community. It quantifies the required time to stand up from a chair, walk 3 meters, turn around, walk back to the chair, turn again, and then sit down [1]. Based on previous studies involving community-dwelling elderly individuals, a cutoff value of 13.5 seconds or longer has been associated with an increased risk of falls [2]. However, in clinical practice, even if patients do not meet the cutoff values, physical therapists might subjectively evaluate their actual movement methods and deem these patients as independent. This implies that factors beyond just the movement speed, such as the actual movement methods, are considered critical when assessing walking independence.

For an objective evaluation of movement methods, previous studies have divided the TUG test into subphases using inertial sensors attached to the trunk and compared the required time and the acceleration and angular velocity [3-5]. These studies primarily involved community-dwelling older adults or individuals with central nervous system diseases aged between 60s and 70s. It was observed that groups at a higher risk of falling or those with more severe diseases took longer to perform not only the TUG test, but also its subphases, standing up from a chair and turning around, and had lower acceleration and angular velocity. However, no previous studies have measured acceleration or angular velocity in the TUG test in hospitalized patients and compared them according to their level of walking independence. It is conceivable that there would be differences in these items for hospitalized patients as well, depending on their level of walking independence assessed by the physical therapist. Given that inpatients are typically older and exhibit a higher prevalence of frailty and other physical dysfunctions than community-dwelling individuals, it is crucial to elucidate the data for this demographic.

Therefore, the purpose of this study was to categorize hospitalized patients based on their TUG time and level of walking independence, and to compare their movement methods during subphases of the TUG test as measured by inertial sensors between groups.

II. METHODS

A. Patients

A total of twenty-five hospitalized patients undergoing rehabilitation intervention were included in this study. Patients had a mean age of 76.7±7.6 years, and among them, twelve were females. The diseases observed in the patient population included total hip or knee joint replacement, spinal compression fractures, postoperative spinal stenosis, as well as various medical conditions. Patients who were unable to ambulate independently prior to admission and those with a history of complications that could interfere with the measurements were excluded from the study. Prior to the commencement of the study, all patients provided verbal informed consent.

B. Measurement procedures

All patients included in the study had achieved independent ambulation with a walker at the time of measurement. The TUG test was conducted within one week of initiating walking practice with or without a cane. We used a chair with a seat height of 43 cm and a single cone. The required time to complete the following sequence of actions was measured using a stopwatch: standing up from the chair, walking 3 meters, turning around the cone, walking back to the chair, and turning and sitting down on the chair. Patients

This work was partially supported by JST Grant Number JPMJPF2115.

were instructed to perform the TUG as quickly as possible with or without a cane and were evaluated twice. The measurement scene is depicted in Fig. 1.

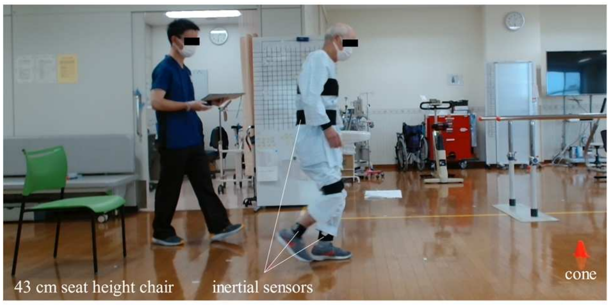

Fig. 1. Example of measurement scene

C. Instruments

Inertial sensors with built-in 3-axis acceleration and angular velocity (Xsens DOT, Xsens) were attached to both lower legs and lower back at the level of the third lumbar vertebrae. These sensors were wirelessly connected to the tablet device (iPad mini, Apple) via Bluetooth and controlled through a dedicated application. Data during TUG were collected at a sampling frequency of 120 Hz.

D. Data Analysis

Patients were divided into three groups based on the time required for TUG test and their level of walking independence assessed by their physical therapists. The groups were defined as follows: Independent Fast (IF) group, who were independent in walking with or without a cane and had a TUG time of less than 13.5 seconds in both of the two trials; Independent Slow (IS) group, who were independent in walking but had a TUG time greater than 13.5 seconds in at least one of the two trials; Monitored Slow (MS) group, who required monitoring for walking and had a TUG time greater than 13.5 seconds.

The subphases of TUG test were identified by analyzing the changes in angular velocity obtained from the lumbar region. The sit-to-stand and stand-to-sit phases were determined based on the pitch angle, while the two turning phases included at the cone (turn 1) and just before stand-to-sit (turn 2) were identified using the yaw angle, following the methodology described in the previous study [6]. Furthermore, the two walking phases were defined as the period from the end of the sit-to-stand phase to the start of the turn 1 phase (walk 1) and from the end of the turn 1 phase to the start of the turn 2 phase (walk 2). A representative example of dividing acceleration and angular velocity data into these subphases is shown in Fig. 2.

The evaluation items were as follows. The time required for each subphase was calculated from the start point to the end point, and total time was calculated from the start of the sit-to-stand phase to the end of the stand-to-sit phase. The number of steps for the walking and turning phases was determined by counting the peak value corresponding to the initial contact based on the combined acceleration data of the both lower legs. The sum of these values was used as the total number of steps. For the sit-to-stand and stand-to-sit phases, the maximum, average, and range (from maximum to minimum) values of the pitch angle of the lumbar were calculated, as reported in the previous study [7]. Similarly, for the turn 1 and 2 phases, the maximum, average, and range values of the yaw angle were calculated. For the walk 1 and 2 phases, the root-mean-square (RMS) and autocorrelation coefficients (ACC) were calculated for each of the three axes of acceleration of the lumbar [8]. However, it is important to note that some patients had only one stride during the walking phase due to their high walking speed. In such cases, the ACC was considered a missing value because it consistently calculated as 1.0 when shifted by one stride. An overview of TUG test and evaluation items are summarized in Fig. 3.

E. Statistical Analysis

All statistical analyses were conducted using Modified R Commander 4.2.2 [9], a modified version of R Commander

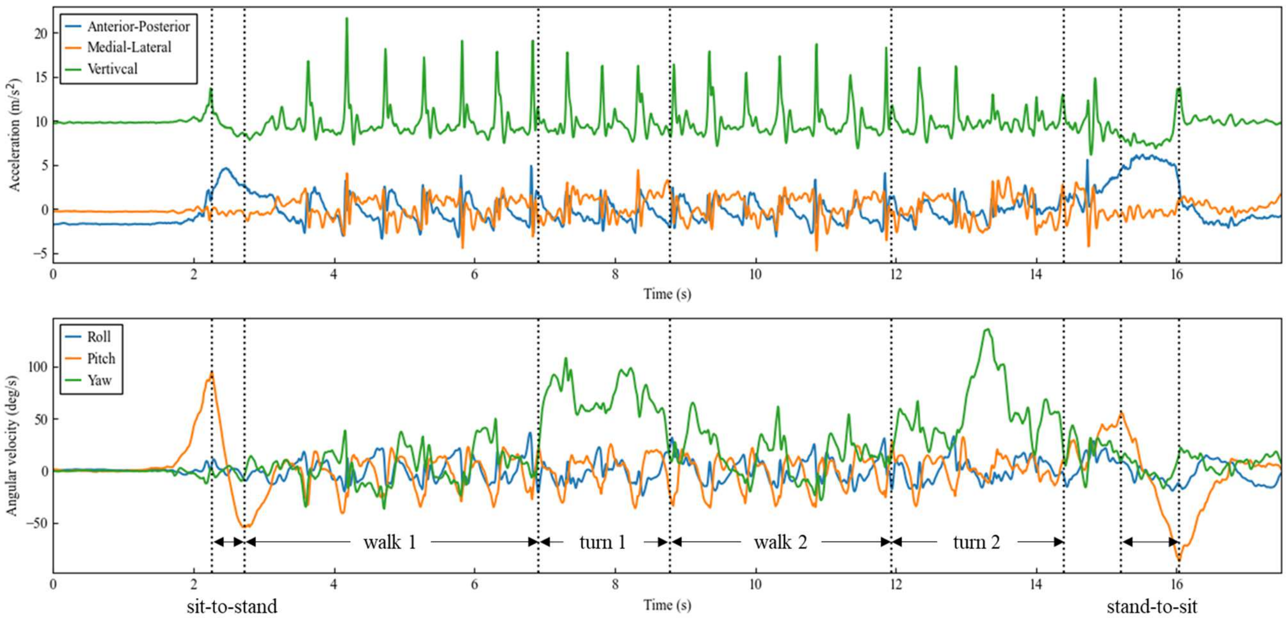

Fig. 2. Example of acceleration and angular velocity of the lumbar during TUG test

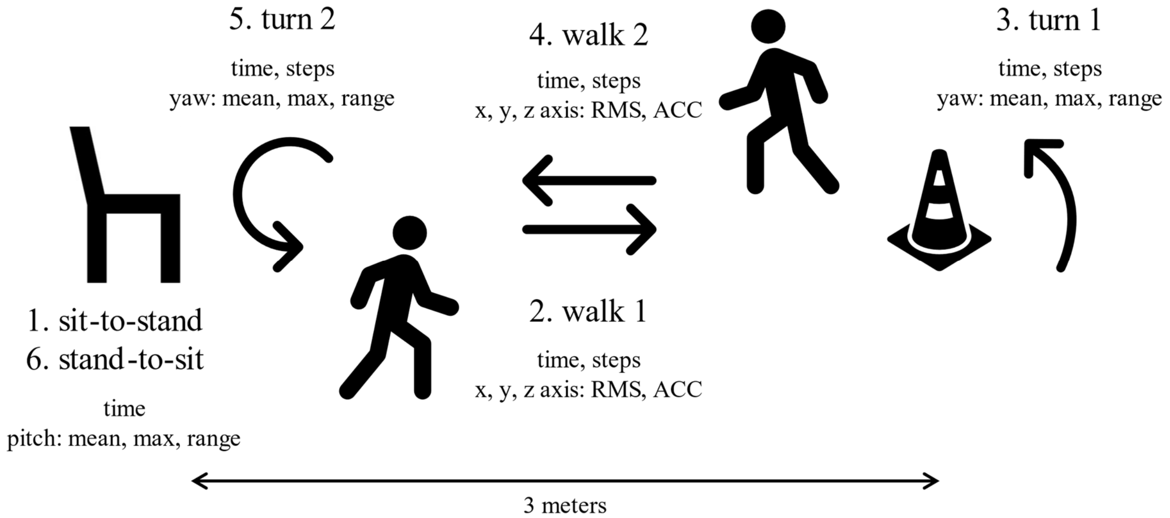

Fig. 3. Overview of TUG test and evaluation items

specifically designed to include statistical functions commonly used in biostatistics. Fisher's exact test was employed to compare gender ratios between the different groups in terms of basic information. For other basic information, which could be assumed to follow a normal distribution, a one-way analysis of variance (ANOVA) was utilized to compare between the groups.

The TUG variables were analyzed using a split-plot factorial design for linear mixed models. This analysis included two factors: between groups as the non-correspondence factor and subphase as the repeated measures factor. Post-hoc tests were performed when a significant main effect or interaction between the groups was observed. The level of statistical significance was set at P value <0.05. Descriptive statistics (mean and standard deviation) were used to summarize the results.

III. Results

Four patients were excluded from the analysis because their TUG time was less than 13.5 seconds and they required monitoring for walking independence. Therefore, a total of 21 patients were included in the analysis, with 9 patients in the IF group, 6 in the IS group, and 6 in the MS group. Nineteen subjects had consistent TUG times (either less than 13.5 seconds or greater than 13.5 seconds) on both trials, and data from the first trial were analyzed. For the remaining 2 subjects, one had TUG time greater than 13.5 seconds on the first trial only, and the other on the second trial only, so data from these trials were analyzed. Basic information for each group is shown in Table I. A one-way ANOVA showed that age had a P value <0.05, but the results of the post-hoc test using Tukey's method all showed P values >0.10. There were no differences between the groups in other items.

The absolute error between the time evaluated from the start of the sit-to-stand phase to the end of the stand-to-sit phase and the time measured with a stopwatch was 0.37 ± 0.20 seconds. Table II shows the results of group comparisons of time and number of steps for the overall TUG test and its subphases. The IF group had the lowest total TUG time and the fewest total number of steps. Both measures were significantly lower in the IF group compared to the other two groups (P<0.01), and significantly lower in the IS group compared to the MS group (P<0.01). Furthermore, the IF group exhibited significantly less time and fewer steps for the walk 1 and 2 phases compared to the MS group (P<0.01). However. there were no significant differences in the time and steps required for each subphase between the IS group and the other two groups.

TABLE I. Basic information of patients

	IF (N=9)	IS (N=6)	MS (N=6)
age (years)	72.1 ± 9.6	76.8 ± 6.6	80.7 ± 3.7
gender	6 M, 3 F	3 M, 3 F	2 M, 4 F
height (cm)	159.5 ± 9.5	157.7 ± 6.5	156.5 ± 12.1
weight(kg)	64.0 ± 15.7	56.7 ± 10.4	60.0 ± 11.1
length of stay (days)	21.7 ± 6.0	25.7 ± 11.7	29.7 ± 3.9

M: male, F: female

TABLE II. Time and number of steps

	IF (N=9)	IS (N=6)	MS (N=6)
Time (s)			
total	9.7 ± 2.3[ab]	14.7 ± 1.3[c]	18.7 ± 3.3
sit-to-stand	0.6 ± 0.3	1.2 ± 0.6	1.8 ± 1.2
walk 1	2.7 ± 0.6[a]	4.0 ± 0.5	5.4 ± 1.6
turn 1	2.0 ± 0.6	2.6 ± 0.5	3.3 ± 0.5
walk 2	2.1 ± 0.8[a]	3.0 ± 1.0	4.4 ± 1.0
turn 2	1.6 ± 0.4	2.2 ± 0.4	2.9 ± 0.6
stand-to-sit	1.1 ± 0.3	1.4 ± 0.6	1.4 ± 0.7
Number of steps			
total	16.2 ± 2.9[ab]	21.8 ± 3.5[c]	28.0 ± 4.9
walk 1	5.1 ± 1.1[a]	7.2 ± 1.7	8.7 ± 1.0
turn 1	3.8 ± 1.5	5.0 ± 1.4	6.3 ± 2.2
walk 2	4.3 ± 1.7[a]	6.2 ± 2.1	8.2 ± 2.1
turn 2	3.0 ± 1.0	3.5 ± 1.8	4.8 ± 1.0

[a] Significant difference between the IF and MS groups with P value <0.01.

[b] Significant difference between the IF and IS groups with P value <0.01.

[c] Significant difference between the IS and MS groups with P value <0.01.

Table III shows the comparison results of acceleration and angular velocity variables between the groups. In the sit-to-stand phase, the mean pitch angle of the IF group was significantly higher than that of the other two groups ($P<0.01$). For the turn 1 phase, the maximum, mean and range of yaw angle were significantly higher in the IF group compared to the other two groups ($P<0.01$ and $P<0.05$), and for the turn 2 phase, they were higher in the IF group compared to the MS groups ($P<0.01$ and $P<0.05$). There were no significant differences in the acceleration RMS for the walk 1 and 2 phases between the groups in any of the three axes. The ACC of acceleration for the anterior-posterior axis for the walk 1 phase was significantly higher in the IF group compared to the other two groups ($P<0.05$). No significant differences were observed in any of the acceleration and angular velocity variables between the IS and MS groups.

TABLE III. ACCELERATION AND ANGULAR VELOCITY VARIABLES

		IF (N=9)	IS (N=6)	MS (N=6)
Pitch (deg/s)				
mean	sit-to-stand	34.2 ± 11.5^{ab}	6.4 ± 7.2	6.8 ± 4.2
	stand-to-sit	-6.7 ± 12.8	-9.0 ± 5.0	-3.0 ± 2.9
max	sit-to-stand	130.1 ± 64.4	77.7 ± 22.1	70.2 ± 26.8
	stand-to-sit	51.0 ± 16.9	45.6 ± 20.0	43.9 ± 16.4
range	sit-to-stand	173.4 ± 69.6	124.7 ± 33.3	105.2 ± 41.7
	stand-to-sit	140.4 ± 48.1	119.7 ± 45.0	111.4 ± 20.5
Yaw (deg/s)				
mean	turn 1	84.5 ± 17.7^{ad}	60.6 ± 9.3	48.5 ± 5.9
	turn 2	81.4 ± 17.1^{a}	65.0 ± 17.0	50.9 ± 8.1
max	turn 1	152.9 ± 27.7^{ad}	116.3 ± 12.6	95.1 ± 15.7
	turn 2	158.6 ± 36.1^{c}	139.5 ± 28.6	101.8 ± 24.6
range	turn 1	129.8 ± 18.7^{ad}	103.4 ± 11.6	88.1 ± 16.5
	turn 2	141.7 ± 32.4^{c}	124.0 ± 26.4	93.0 ± 23.1
ACC				
A-P	walk 1	0.85 ± 0.09^{cd}	0.63 ± 0.17	0.62 ± 0.09
	walk 2	0.90 ± 0.08	0.72 ± 0.24	0.66 ± 0.14
M-L	walk 1	0.75 ± 0.18	0.60 ± 0.10	0.65 ± 0.09
	walk 2	0.82 ± 0.18	0.74 ± 0.22	0.62 ± 0.15
V	walk 1	0.79 ± 0.14	0.62 ± 0.17	0.54 ± 0.16
	walk 2	0.88 ± 0.11	0.75 ± 0.19	0.59 ± 0.19

ACC: autocorrelation coefficients

A-P: anterior-posterior axis, M-L: medial-lateral axis, V: vertical axis

[a] Significant difference between the IF and MS groups with P value <0.01.

[b] Significant difference between the IF and IS groups with P value <0.01.

[c] Significant difference between the IF and MS groups with P value <0.05.

[d] Significant difference between the IF and IS groups with P value <0.05.

IV. DISCUSSION

In this study, hospitalized patients in the early stages of practicing walking with or without a cane were categorized based on the time required for TUG test and their level of walking independence. Then, acceleration and angular velocity data for each subphase were compared between groups.

The results showed that to achieve faster TUG performance, the number of steps should be reduced by increasing the stride length during the walk phases. This strategy appears to be influenced by the level of walking independence. Moreover, there was a significant difference between the IF and MS groups in angular velocity in the turn 2 phase, but the IS group did not differ from the other two groups. Thus, although the IS group had slower TUG times, their movement methods were closer to those of the IF group, which may indicate recovery. This suggests that during the recovery process after a patient's hospitalization or surgery, the movement methods may be stabilized first, followed by improvement of movement speed.

A new finding from this study is that even when the TUG time was 13.5 seconds or longer, patients with walking independence had a faster speed in the second turn, than those with non-independence. This indicates that for patients with slow TUG time, their walking independence can be appropriately determined from their movement methods. Therefore, inertial sensors can be a useful tool for physical therapists in assessing walking independence of hospitalized patients.

V. CONCLUSION

In conclusion, patients with a TUG time less than 13.5 seconds exhibited both overall and subphase movement with high speed and steadiness. Even among patients with a TUG time greater than 13.5 seconds, variations in movement speed and steadiness were observed based on the level of walking independence. This suggests that evaluation of movement methods using inertial sensors may be useful for patients with slow movement speeds and difficulty in determining their level of walking independence.

REFERENCES

[1] D. Podsiadlo and S. Richardson, "The timed 'Up & Go': a test of basic functional mobility for frail elderly persons," J. Am. Geriatr. Soc., vol. 39, no. 2, pp. 142–148, Feb. 1991.

[2] A. Shumway-Cook, S. Brauer, and M. Woollacott, "Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test," Phys. Ther., vol. 80, no. 9, pp. 896–903, Sep. 2000.

[3] A. Galán-Mercant and A. I. Cuesta-Vargas, "Differences in trunk accelerometry between frail and non-frail elderly persons in functional tasks," BMC Res. Notes, vol. 7, p. 100, Feb. 2014.

[4] N. Toosizadeh, J. Mohler, H. Lei, S. Parvaneh, S. Sherman, and B. Najafi, "Motor Performance Assessment in Parkinson's Disease: Association between Objective In-Clinic, Objective In-Home, and Subjective/Semi-Objective Measures," PLoS One, vol. 10, no. 4, p. e0124763, Apr. 2015.

[5] J. M. T. Van Uem et al., "Quantitative Timed-Up-and-Go Parameters in Relation to Cognitive Parameters and Health-Related Quality of Life in Mild-to-Moderate Parkinson's Disease," PLoS One, vol. 11, no. 4, p. e0151997, Apr. 2016.

[6] A. Weiss, A. Mirelman, A. S. Buchman, D. A. Bennett, and J. M. Hausdorff, "Using a body-fixed sensor to identify subclinical gait difficulties in older adults with IADL disability: maximizing the output of the timed up and go," PLoS One, vol. 8, no. 7, p. e68885, Jul. 2013.

[7] P. Ortega-Bastidas, B. Gómez, P. Aqueveque, S. Luarte-Martínez, and R. Cano-de-la-Cuerda, "Instrumented Timed Up and Go Test (iTUG)-More Than Assessing Time to Predict Falls: A Systematic Review," Sensors, vol. 23, no. 7, Mar. 2023, doi: 10.3390/s23073426.

[8] R. Moe-Nilssen and J. L. Helbostad, "Estimation of gait cycle characteristics by trunk accelerometry," J. Biomech., vol. 37, no. 1, pp. 121–126, Jan. 2004.

[9] E. Tsushima, Modified R Commander. "What is Modified R Commander?" https://personal.hs.hirosaki-u.ac.jp/pteiki/research/stat/R/ (accessed 2023-05-27).