



Original Article

Where do healthy older adults take more time during the Timed Up and Go test?

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Abstract. [Purpose] We need to regularly evaluate motor function to sustain the health of community-dwelling older adults. Our study aimed to identify the kinematic characteristics of healthy older adults in the Timed Up and Go test because the criteria for assessing the motor function of healthy older adults are unclear in the widely used clinical simple methods. [Participants and Methods] In total, 22 healthy younger and 28 healthy older adults participated in this study. Using a 3D motion analysis system, we measured the time ratios, trajectories, trajectory length per unit time, and body inclination angles during the Timed Up and Go test. We compared the kinematic characteristics of the older and younger adults. [Results] The older adults required a longer time ratio to complete the turn and sit subtasks. The trajectory of the older adults' turn subtask was longer than that of the younger adults. Older adults' body inclination angles during the turn subtask were smaller than that of the younger adults. [Conclusion] Healthy older adults had a different kinematic index from younger adults during the Timed Up and Go turn subtask. Therefore, we suggest the kinematic index of posture and turning radius be used to measure Timed Up and Go as a clinically useful index for understanding the motor characteristics of older adults.

Key words: Healthy older adults, Kinematic indices, Timed Up and Go test

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INTRODUCTION

Today, aging is progressing worldwide, and interest in the health of older adults is increasing. In Japan, the number of older adults that try to exercise regularly is increasing¹⁾. We need to evaluate with a widely clinical method for motor functions regularly to maintain health. Although this can be evaluated using the cut-off point of some mobility test, further information regarding kinematic index (posture, strategy, motor control, etc.) of healthy older adults remains to be elucidated, leaving researchers to be dependent upon subjective reasoning.

The Timed Up and Go (TUG) test is a widely used clinical paradigm to evaluate mobility in older adults. According to a large-scale survey in Japan, TUG test scores were closely associated with important factors related to community health in the older, falls, frequency of outdoor activity, and habitual exercise, confirming its usefulness as a measure of physical function in community health²⁾. Normally, TUG uses only the required time, and the cutoff point for older adults with a high risk of falling has been suggested as 13.5 seconds³⁾. TUG can easily provide us with the time required to assess older adults' risk of falling. On the other hand, TUG is unclear about evaluating each motion; therefore, the clinical evaluation of TUG subtasks remains dependent upon subjective reasoning. In addition, some older adults who have higher levels of functional capacity can complete a TUG test in less than the cutoff point but remain susceptible to falls⁴⁾.

Recent studies have measured TUG using inertial sensors that have a three-axis accelerometer and three-axis gyroscope.

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However, these studies targeted participants with an obvious lowered motor function, for example, Parkinson’s disease or older adults in need of nursing care^{5, 6}.

TUG includes a turn subtask, and TUG composed complex subtasks. Turning has been used as an index of balance ability as represented by “Performance-Oriented Mobility Assessment”⁷ and the “Berg Balance Scale”⁸. It has been reported that older adults with a high risk of falls take a longer time to turn and take a larger number of steps when turning^{9–11}. In addition, when younger adults change direction, the body is tilted toward the center of turning^{12, 13}. Therefore, younger adults may be ensuring limited movement of the Center of Gravity (COG) to minimize required their moving trajectory. It is presumed that older adults find it difficult to turn with the shortest movement from the COG. Nevertheless, these details are unclear.

If we measure each motion during TUG kinematically, we could use TUG as an objective scientific index rather than subjective reasoning. In the future, we may be able to adopt a clinical index to predict motor function using TUG.

Therefore, we divided the TUG test into five subtasks and focused on a kinematic index (time ratio, trajectories, trajectory length per unit time, and body inclination angle) to compare older and younger adults’ TUG turn subtask using a 3D motion capture of older and young adults. Our study intended to identify the kinematic characteristics of healthy older adults. We supposed that evaluating the TUG of healthy older adults kinematically would help identify new TUG indicators for healthy older adults.

PARTICIPANTS AND METHODS

There were 22 healthy younger and 28 healthy older adults who participated in this study (Table 1). The inclusion criteria for healthy older adults were the following: ≥ 65 years old (aged 65–81 years) and living life independently. In addition, they had to be free of any severe cardiopulmonary disease, neurological disorder, musculoskeletal impairment, or any history of falls in the last year. The inclusion criteria for healthy young adults were the following: $20 \leq$ years old (aged 20–22 years); had to be free of motor disability. These participants were excluded if they had dizziness or fatigue or had undertaken any vigorous physical activity or stress before testing. A statistical analysis of the two groups’ height and weight revealed no significant differences. All participants signed a consent form approved by the Institutional Ethics Committee of “Kanagawa University of Human Services” (7-36) and “International University of Health and Welfare graduate school” (14-Ig-111), in accordance with the Declaration of Helsinki. We calculated the sample size to perform an unpaired t-test. The major variables were required TUG time (s), the difference between the two groups was 1.5, the group variance was 1.5, the significance level was 0.05, and the power was 0.9. The required sample size per group was calculated. Accordingly, each group included 22 healthy people and was provided with a set of measurement targets.

The TUG trials were performed on a 3-m-long walkway. Participants stood up after the start cue, turning toward the obstacle of 3 m ahead, and sat down at the same chair which he or she had seated at first. The walking speed at the trial was set at maximum to prevent variation in results. The obstacle was a road cone (height, 43 cm; width, 20 cm; depth, 20 cm).

A ten-camera-based motion measurement system (Vicon612 and MX; Vicon Motion system Ltd., Oxford, UK) recorded 3D motion data from infrared-reflective markers that were attached to each segment about the head (left and right front of head, left and right back of head), torso (C7, T10, jugular notch where the clavicles meet the sternum, xiphoid process of the sternum), arm (left and right acromion, left and right lateral epicondyle approximating elbow joint axis, left and right wrist bar thumb side), pelvis (left and right anterior superior iliac spine, left and right posterior superior iliac spine), leg (hip joint; placed over the lower one-third of the anterior superior iliac spine and greater trochanter, left and right lower lateral one-third surface of the thigh, left and right lateral epicondyle of the knee, left and right medial epicondyle of the knee), and foot (left and right medial malleolus, left and right lateral malleolus, left and right 1st metatarsal head, left and right 5th metatarsal head, left and right calcaneus). Moreover, an infrared-reflective marker was attached to the top of the road cone. Motion data were recorded at a sampling rate of 120 Hz. Marker data were low-pass filtered (cut off: 6 Hz) in Vicon Nexus2 (v.2.3 Vicon, Oxford, UK). Output text components of the markers were then exported to Body Builder (v3.6.4, Vicon, Oxford, UK). Each segment’s center of mass, calculated based on the segmental mass and length, were synthesized to calculate the COG. The data for each participant were averaged over five trials.

In this study, the trajectory of each participant was calculated from the center of the left and right posterior superior iliac spines (Fig. 1), as it was difficult to record without omitting all markers for calculating COG in stand and sit subtasks for our limited measuring space. We divided the trajectory of the left and right of participants’ posterior superior iliac spine during TUG into the following subtasks: stand, forward, turn, return, and sit. The stand subtask was defined as the period between

Table 1. Background features of participants

	Older (n=28)	Younger (n=22)	p value
Age (years)	71.1 \pm 5.0	20.8 \pm 0.8	
Height (m)	1.57 \pm 0.88	1.61 \pm 0.62	0.082
Weight (kg)	55.9 \pm 10.4	54.4 \pm 4.8	0.520
Gender (males/females)	10m / 18f	7m / 15f	
Mean \pm SD.			

the start position and reaching 60 cm in front of that position. The forward subtask was defined as the period from the end of the stand subtask until reaching the obstacle. The turn subtask was defined as the period from the end of the forward subtask until they had moved fully around the obstacle. The sit subtask was defined as the period from reaching 60 cm in front of the start position until fully in the start position. Finally, the return subtask covered the period of walking away from the obstacle back to the start of the sit subtask.

We calculated the time ratio of each subtask to compare the performance of younger and older adults. During the moving section of participants which comprised the subtasks of forward, turn, and return, we calculated a trajectory and trajectory length per unit time. Moreover, we calculated the body inclination angle of the turn subtask.

Time ratio of each subtask (%)

The percentage of five TUG subtasks times; subtasks of stand, forward, turn, return, sit.

The required times of turn subtask / TUG total required times $\times 100$ (%)

Trajectory (m)

We calculated the movement of each participant's center of the right and left posterior superior iliac spine on a horizontal plane as trajectories of subtasks; subtasks of forward, turn, and return.

Trajectory length per unit time (m/s)

We calculated the trajectory length per unit time by dividing trajectories by the required subtask times for forward, turn, and return.

Body inclination angle ($^{\circ}$)

We measured the index for efficient turning by calculating the body inclination angle of the turn subtask. TUG includes turning about 180° ; therefore, it is difficult to define the frontal plane of absolute space. We defined the forward direction of COG per frame, such as the forward direction from one COG frame to the next COG frame (Fig. 2). We projected two points, Center of Head (COH) and Center of Ankles (COA), on the frontal plane perpendicular to the forward direction of the COG: COG-COH (COH coordinated transformation on the frontal plane perpendicular to the forward direction at COG; COHx, COHy, COHz) and COG-COA (COA coordinated transformation on the frontal plane perpendicular to the forward direction at COG; COAx, COAy, COAz).

Body inclination angle θ was the inclination of the line connecting COG-COH to COG-COA, which was calculated using COG-COH, COG-COA, and vertical projection of COG-COH onto the floor (Fig. 2). We calculated the average values of the body inclination angle during the turn subtask (Equation 1)¹⁴.

$$\theta = \arctan \left\{ \frac{\sqrt{(\text{COAx} - \text{COHx})^2 + (\text{COAy} - \text{COHy})^2}}{\text{COHz}} \right\} \quad (1)$$

Participants performed five TUG trials, and we used the average values of the five trials as a representative value. The time ratio of each subtask was compared between younger and older adults. Also, the trajectory, the trajectory length per unit time, and body angle inclination were compared across younger and older adults. We used an independent t-test to analyze the differences between the two groups. All statistical analyses were conducted using SPSS Statistics 22.0 (IBM Corp., Armonk, NY, USA), and the statistical significance threshold was set at 0.05.

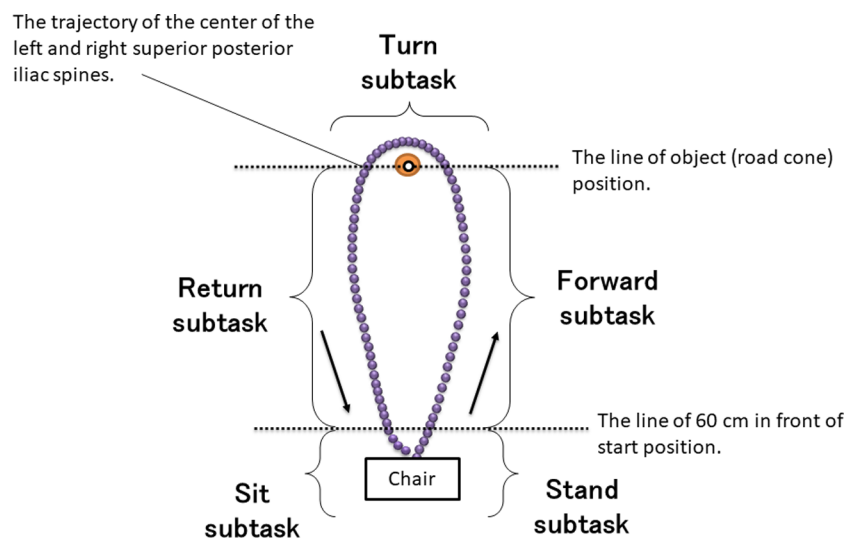


Fig. 1. The definition of subtasks.

In this study, the trajectory of each participant was calculated from the center of the left and right posterior superior iliac spines. The trajectory was divided into five subtasks (stand, forward, turn, return, and sit) during the TUG.

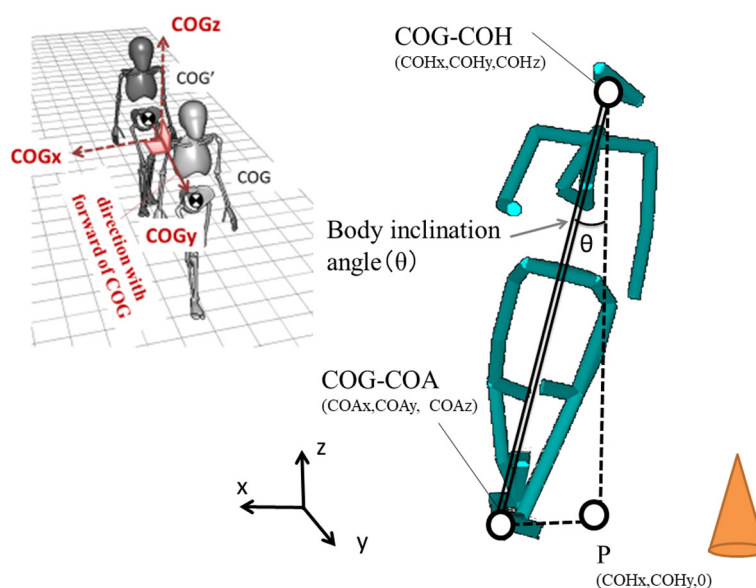


Fig. 2. The method for calculating the body inclination angle.

The method for calculating the body inclination angle during the turn subtask was projected using two points, Center of Head (COH) and Center of Ankles (COA), on the frontal plane perpendicular to the forward direction of the COG: COG-COH (COH coordinated transformation on the frontal plane perpendicular to the forward direction at COG; COHx, COHy, COHz) and COG-COA (COA coordinated transformation on the frontal plane perpendicular to the forward direction at COG; COAx, COAy, COAz). The body inclination angle θ was the inclination of the line connecting COG-COH to COG-COA, which was calculated using COG-COH, COG-COA, and vertical projection of COG-COH onto the floor.

RESULTS

Older adults who participated in this study were healthy independent community-dwelling people. Nevertheless, older adults required a longer time during TUG than younger adults. A comparison of the time ratios of five subtasks indicated that the older group required a longer ratio during the turn and sit subtasks ($p=0.001$, $p=0.039$) (Table 2).

The trajectory of the forward or return subtasks did not differ significantly between the groups. However, older adults had smaller trajectory length per unit time than younger adults ($p<0.001$). Older adults had a longer trajectory during the turn subtask than younger adults ($p<0.001$), with older adults making a wider turn during the TUG. The trajectory length per unit time for older adults had smaller than that of younger adults ($p=0.005$). Meanwhile, the body angle inclination of older adults during the turn subtask was smaller than that of younger adults ($p<0.001$) (Table 3).

Figure 3 illustrates the representative results of the trajectories of both older and young adults in the transversal plane.

DISCUSSION

The results of a comparison of time ratios showed that older adults required a longer ratio during the turn and sit subtasks. For the sit subtask, we analyzed only the time ratio in this study. In previous research, it was reported that older adults with lower motor and cognitive function had difficulties with the smooth translation between turning and sitting during TUG⁶. We also assumed that it would be difficult for older adults to sit after turning during TUG and that the time ratio of the sit subtask would be longer.

On the other hand, for the turn subtask, older adults displayed a longer trajectory than younger adults, and the trajectory length per unit time had smaller in older adults in this study. In this situation, the posture of older adults tended to be more upright than that of younger adults, which was identified as a kinematic characteristic of older adults.

When younger adults changed direction, their bodies tended to tilt toward the center of their turn¹². The degree of the tilt depended on the individual's walking speed¹⁵ and turning radius¹⁶; by adjusting these appropriately, individuals could change direction while minimizing their movement during the turn. In addition, a large frictional force between shoe sole and the floor was needed during the turn subtask to prevent slipping^{17, 18}. The reason is that the share of force between the shoe sole and the floor when turning is larger than when walking straight¹⁹. Indeed, fall rates caused by slipping are much greater when turning than when walking straight¹⁴. Slipping during turning can cause an accident resulting in a femoral fracture in older adults; therefore, they must adopt a strategy to prevent slipping.

In this study, the trajectory of older adults during the turn subtask was longer, and the trajectory length per unit time

Table 2. Time and time ratio of each subtask

	Older (n=28)	Younger (n=22)	p value
TUG time			
TUG (s)	7.2 ± 1.3	5.4 ± 0.6	p<0.001**
Subtasks			
Stand (%)	17.3 ± 1.8	19.1 ± 1.7	0.001††
Forward (%)	25.2 ± 2.3	27.0 ± 2.2	0.008††
Turn (%)	11.4 ± 2.2	8.9 ± 2.8	0.001**
Return (%)	27.4 ± 1.9	28.0 ± 1.8	0.264
Sit (%)	18.5 ± 3.1	16.8 ± 2.3	0.039*

††: Significant difference between younger and older groups (younger>older, p<0.01).

** : Significant difference between younger and older groups (older>younger, p<0.01).

*: Significant difference between younger and older groups (older>younger, p<0.05).

Mean ± SD.

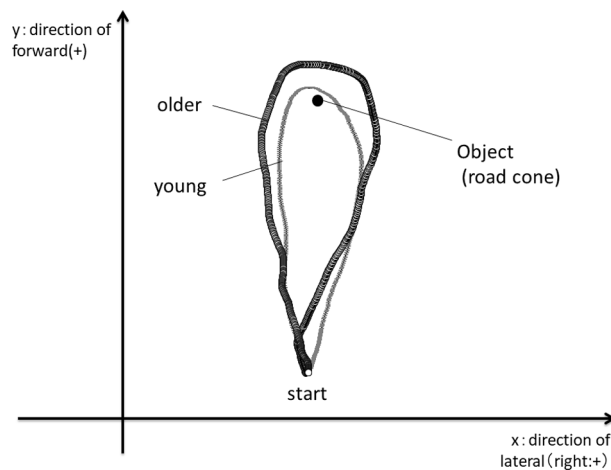
Table 3. Variables of participants

	Older (n=28)	Younger (n=22)	p value
Trajectory (m)			
Forward subtask	2.66 ± 0.09	2.65 ± 0.06	0.719
Turn subtask	0.81 ± 0.23	0.52 ± 0.17	p<0.001**
Return subtask	2.60 ± 0.04	2.63 ± 0.08	0.056
Trajectory length per unit time (m/s)			
Forward subtask	1.50 ± 0.18	1.82 ± 0.05	p<0.001††
Turn subtask	0.98 ± 0.12	1.11 ± 0.15	0.005††
Return subtask	1.35 ± 0.19	1.76 ± 0.08	p<0.001††
Body inclination angle (°)	11.5 ± 3.2	15.3 ± 3.7	p<0.001††

††: Significant difference between younger and older groups (younger>older, p<0.01).

** : Significant difference between younger and older groups (older>younger, p<0.01).

Mean ± SD.

**Fig. 3.** The characteristic of the trajectory in older adults.

This figure illustrates representative results of the trajectories of both older and young adults in transversal plane. The x-axis shows the direction of the lateral (right:+), and the y-axis shows a forward direction (+). The black round marks are shown as the TUG object. The black trajectory indicates older adult, and the gray trajectory indicates younger adult. Older adults had a longer turn subtask trajectory than younger adult because the turning radius was larger in older adult.

decreased. In addition, the posture of older adults tended to be upright because the turning radius of the COG was larger in older adults (Fig. 3). The result of the trajectory length per unit time that older adults' turn subtask decreased; therefore, the time ratio of the turn subtask was longer. We supposed that this was one of the strategies older adults adopted to prevent slipping. In the future, it will be necessary to validate this kinematic index to see if it will change with decreasing motor function.

Even healthy older adults had a different kinematic index from younger adults during the TUG turn subtask. The upright posture and large turning radius can be measured easily visually without using 3D motion capture systems. We suggest that a kinematic index measuring TUG is a useful clinical index for understanding the motor characteristics of older adults.

A limitation of this study was that the results only measured the characteristics of healthy older adults. In the future, it is necessary to validate whether the kinematic index changes with decreasing motor function. In addition, we calculated the trajectory length per unit time with some subtasks instead of speed, which included a lateral direction distance. This index needs to be applied carefully in clinical fields.

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