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Timed Up and Go: seconds or acceleration to measure mobility in healthy older people?

Timed Up and Go: segundos ou aceleração para medir a mobilidade em pessoas idosas saudáveis?

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Resumo: Este estudo investiga a validade convergente entre os recursos de aceleração e os segundos necessários para realizar três variações do teste Timed Up and Go. A amostra foi composta por 73 pessoas idosas ativas e saudáveis não caidoras que residiam na comunidade (São Carlos-SP, Brasil). Os participantes utilizaram um acelerômetro triaxial localizado na cintura ao realizar três variações do TUG. Características de entropia, amplitude e frequência do sinal foram extraídas de todos os dados de acelerometria. O coeficiente de correlação de Pearson foi utilizado para investigar a validade convergente. A média de idade da amostra foi de 70,16 anos (DP=6,79), sendo a idade máxima de 88 anos e a mínima de 60 anos. As mulheres representaram 56,6% (n=41) dos participantes. Houve fraca magnitude de correlações entre os dados de aceleração e os segundos necessários para realizar o TUG simples e suas variações. Observou-se correlação moderada a forte entre as variáveis extraídas do sinal de acelerometria, e forte correlação entre os segundos das variações do TUG. Este resultado demonstra que, embora ambos possam ser usados para medir a mobilidade, eles não medem os mesmos construtos. Associando TUG e acelerômetro e escolhendo apenas uma variação do TUG pode fornecer boa combinação.

Palavras-chave: Pessoa Idosa. Acelerômetro. Processamento de Sinais. Mobilidade.

Abstract: This study investigates the convergent validity between acceleration features and the time needed to complete three variations of the Timed Up and Go (TUG) test. The sample consisted of 73 active and healthy older people who were non-fallers and community-dwelling (São Carlos-SP, Brazil). Participants used a triaxial accelerometer at the waist while performing three variations of the TUG. Entropy, amplitude, and frequency features of the signal were extracted from all accelerometry data. The Pearson correlation coefficient was used to investigate convergent validity. The average age of the sample was 70.16 years (SD=6.79), with a maximum age of 88 years and a minimum of 60 years. Women represented 56.6% (n=41) of participants. There were weak correlations between the acceleration data and the time needed to complete the simple TUG and its variations. Moderate to strong correlations were observed between variables extracted from the accelerometer signal, and strong correlations were found between the TUG variations seconds. This result demonstrates that although both can be used to measure mobility, they do not measure the same constructs. Combining TUG with an accelerometer and choosing only one variation of the TUG may provide a good combination.

Keywords: Older Person. Accelerometer. Signal Processing. Mobility.

Introduction

The demographic transition brought a new reality to the population health parameter. Due to their lower resilience in adapting to environmental changes, older people may be more vulnerable to developing chronic diseases (Weitzel *et al*., 2023). These long-term conditions can interfere with functionality and the ability to perform daily activities (Souza *et al*., 2024).

It is possible to check the level of independence and mobility of older people through functional tests. According to Diniz *et al*. (2021), mobility refers to the frequency, ease, and possibility of daily travel, essential for independence. However, the ability to move around can be reduced with aging (Bochoski *et al*., 2023). Once compromised, mobility can lead to immobility syndrome, one of the main geriatric syndromes that can make the individual totally dependent on daily activities (Mariñansky; Jauregui, 2021). Therefore, it is important to assess the risk of disability in older people, as reduced functional capacity directly affects their independence.

Functional capacity tests such as Timed Up and Go (TUG), Short Physical Performance Battery (SPPB), Six-Minute Walk Test, 8 Foot-Up-and-Go, and Habitual Gait Speed Test were developed to assess functional balance and mobility (Da Silva; Monteiro; Mocarzel, 2021). The TUG, proposed by Podsiadlo and Richardson (1991), assesses functional capacity by observing balance, gait speed, and physical mobility. Such characteristics are evaluated through the seconds that the person needs to carry out the following activities: sit in a chair with arms and, without using the arms as support to get up, walk three meters in a straight line; turn around; walk back three meters and sit on the chair again, without support.

The TUG may present variations when associated with a motor task, or when associated with a dual task. The longer the time spent by the individual to perform the test, the more they would be affected by physical deterioration resulting from age, which would affect their gait and postural control (Podsiadlo; Richardson, 1991). Although widely used, TUG was validated for samples of frail older people living in the community (Podsiadlo; Richardson, 1991), showing low sensitivity in samples with Parkinson's disease and healthy and active individuals, and should be used together with other tests (Mollinedo; Cancela, 2020; Andrade *et al*., 2021).

As an alternative, Gerontechnology promotes technological resources to assist in the daily lives of older people. One of its aspects is using inertial sensors (Diniz *et al*., 2022) as an alternative to the TUG seconds measurement. Some studies were conducted with inertial sensors, such as the accelerometer, to record the individual's gait information with greater precision (Bet; Castro; Ponti, 2019; Buisseret *et al*., 2020). Accelerometers are inertial sensors capable of detecting the most sensitive human movements and providing, in real-time, an electrical acceleration signal of the human body, projected along its axis. This sensor is widely used to collect information about events, such as fatigue, mobility, falls, gait, and balance. Therefore, it can be a good alternative for mobility assessment due to its low cost, small size, easy use, and low energy consumption. Furthermore, it is easy to attach to the body, making it a non-invasive option for monitoring people. Studies have shown that entropy, amplitude, and frequency features of the accelerometer signal are more sensitive for evaluating mobility than functional tests (Senden *et al*., 2012).

However, there are no validation and convergence parameters between TUG variations and accelerometry data in the literature. Convergent validity can be used to understand the extent to which different measures capture a common construct, minimizing ambiguities (Carlson; Herdman, 2012). Studies that verify and compare accelerometer and TUG data can clarify and substantiate their use for clinical and mobility research purposes. On that account, the present study aims to investigate the convergent validity between acceleration data and the seconds necessary to perform the simple TUG and its variations.

Materials and methods

The data collection that generated the data analyzed in the present study was carried out in 2017 (Bet *et al*., 2019) and included a stratified and randomized sample of 73 non-falling, active, and healthy participants over 60 years of age who lived in the community. Participants used an accelerometer located on their waist, close to their center of mass, when performing three variations of the TUG. The sample was calculated considering an error of 5% and power of 90%, based on pilot studies carried out with an accelerometer: Bet *et al*. (2019) and Ponti *et al*. (2017) (Dupont; Plummer 1990), and was randomly selected and stratified among participants from the University of the Third Age (U3A) of São Carlos, São Paulo – Brazil. The project was authorized by the Research Ethics Committee of the Federal University of Sao Carlos (2.668.999/2018).

The inclusion criteria for the study were: being 60 years old or over, not having fallen in the last 6 months, being able to get up without assistance from a chair with arms, being active (more than 150 minutes of physical activity per week), walking without the assistance of assistive devices, and walking without assistance from a person. The exclusion criteria were: having an amputation and/or using a lower limb prosthesis or other device that modifies the gait pattern, presence of lameness; suffering from a health condition that interferes with walking patterns or postural control, such as diseases of the central nervous system (stroke, Parkinson's), peripheral neuromuscular disease, neurocognitive decline; and presence of an important risk factor that compromises safety, assessed at the time of the tests, such as arterial hypotension (less than 90/60 mmHg) or arterial hypertension (greater than 140/100 mmHg), complaints of angina or dyspnea.

The accelerometry variables extracted in this study are features already successfully explored in previous studies to analyze accelerometry signals with TUG tests to identify fallers and risk of falling (Ponti *et al*., 2017; Bet *et al*., 2019; Bet, 2019) and will be detailed below.

Procedures: The accelerometer generates three signals (or time series) as output. These series correspond to acceleration in the three spatial directions, being translated into the x, y, and z axes, or functions of time. We chose to use a fusion between the axes based on the Euclidean distance, which allows accessing the acceleration at each instant, independent of the axis. The equation that calculates the time series used to perform the computational experiments is

$$s(t) = \sqrt{x(t)^2 + y(t)^2 + z(t)^2}$$

where x(t), y(t) It is z(t) is the accelerometer data acquired from the x, y, and z axes, respectively.

This fusion is important because the sensor can be positioned in different ways or rotated during walking, generating axis crossings, which can be misinterpreted by the program that extracts the data. The 100Hz sampling rate allowed the study to guarantee gait analysis up to a frequency of 50Hz. A Butterworth low-pass filter was used to suppress possible noise, which could cause high frequencies in the signal. From the signal power spectrum, s(t), generated by performing the Fast Fourier Transform, features were obtained for gait pattern analysis. Amplitude information was used over time.

Accelerometry Features: The features extracted from the accelerometry signal were:

1) Power Spectrum Entropy (PSE), which calculates the sums of the entropies of the frequencies found. This feature represents an alternative measure of energy compression in the coding transformation (Benesty *et al.*, 2009) and is related to the complexity of information in the power spectrum in the frequency domain and from an energy point of view.

2) The second feature, Power Spectrum Peak Frequency (PSPF), represents the frequencies (Hz) relative to the larger amplitudes. This feature seeks the harmonic components of gait, related to the global speed of the movement.

3) Power Spectrum Peak (PSP): feature that aims to obtain the relative amplitudes for the main frequency components (PSPF). This feature represents the amplitudes corresponding to the fundamental gait frequencies.

4) Weighted Power Spectrum Peak (WPSP): frequency (Hz) relative to the highest amplitude-weighted frequencies. Thus, it is a linear combination between PSP and PSPF.

5) TUG Counts (TC): inspired by counts (or counts per minute), this feature calculates the sum of all power spectrum coefficients, weighted by a linear function.

The equations for calculating the features were taken from Ponti *et al*. (2017) and Bet *et al*. (2019). The source code was made available in a public repository (https://is.gd/BSOEXI). Each feature, PSE, 3 PSPs (PSP1, PSP2, PSP3), 3 PSPFs (PSPF1, PSPF2, PSPF3), WPSP, and TC, were calculated from the spectrum related to the complete accelerometry signal, in other words, the data raw materials without any differentiation of signals relating to each of the TUG executions.

A descriptive analysis was carried out containing average, standard deviation (SD), median, minimum and maximum values. Pearson's Correlation Coefficient (Pearson, 1957) was used to assess convergent validity. This test can be interpreted as follows: variation between -1 to 1, and the perfect link between two variables would be demonstrated by the value closest to -1 or 1 (Benesty *et al.*, 2009). Therefore, in this study the following values, both positive and negative, were adopted as a reference: >0.9 very strong correlation, between 0.7 and 0.9 strong correlation, between 0.5 and 0.7 moderate correlation, between 0.3 and 0.5 low correlation, and <0.3 insignificant correlation (Mukaka, 2012).

Results and discussion

The average age of the sample was 70.16 years (SD=6.79), with a maximum age of 88 years and a minimum of 60 years. Women represented 56.6% (n=41) of participants. The distribution of the average seconds needed to complete the three TUG variations and the accelerometry features extracted from the signal are summarized in Table 1.

Table 1 | Average seconds needed to complete the three TUG variations and the accelerometry features extracted from the signal.

Features	Average (±SD)	Median	Min	Max
	TUG Averages			
TUG-S	9.06 (±2.03)	8.63	5.75	13.77
TUG-M	9.46 (±2.06)	8.96	6.31	14.91
TUG-D	11.37 (±3.46)	10.63	6.73	22.42
	Accelerometry features			
PSE	7.00 (±2.03)	6.76	3.56	13.18
PSP1	4.97 (±1.03)	4.92	3.02	6.79
PSP2	1.61 (±1.00)	1.45	0.21	3.79
PSP3	0.66 (±0.54)	0.59	0.01	1.66
PSPF1	9.64 (±2.27)	10.00	1.00	15.00
PSPF2	12.58 (±8.22)	13.00	1.00	41.00
PSPF3	15.38 (±12.07)	14.00	1.00	49.00
WPSP	43.33 (±14.32)	47.26	0.00	70.85
TC	0.32 (±0.41)	0.14	0.01	2.25

Note: TUG average is presented in seconds. PSPF1, PSPF2, PSPF3 are presented in Hertz (Hz). SD = Standard Deviation. Source: Own authorship.

The Pearson correlation results are presented in Table 2. There was a weak magnitude of correlations between the seconds needed to complete the three TUG variations and the accelerometry features extracted from the signal in the following domains: i) between the timed seconds of the TUG-S and the PSE variable; ii) between the timed seconds of the TUG-M and the PSE variable; iii) between the timed seconds of the TUG-D and the PSP2 variable; iv) between the timed seconds of the TUG-D and the PSP3 variable; v) between the timed seconds of the TUG-D and the WPSP variable; and vi) between the TUG-D timed seconds and the TC variable. A moderate correlation was found: i) between the TUG-D and PSE timed seconds; ii) between the timed seconds of the TUG-S and TC; and iii) between the timed seconds of the TUG-M and TC. No comparison showed a strong or very strong correlation.

On the other hand, the results show that both the TUG-M (p=0.000; r=0.893) and TUG-D (p=0.000; r=0.839) present a strong correlation with the TUG-S; as well as TUG-M and TUG-D (p=0.000; r=0.804). In other words, they both assess the same constructs.

Among the features of accelerometry, a strong correlation was found between i) variable PSE and PSP1 (p=0.000; r=-0.800); and ii) WPSP and PSPF1 (p=0.000; r=0.771). A moderate correlation was found between i) variable PSP2 and PSE (p=0.000; r=0.652); ii) PSP2 and PSP1 variables (p=0.000; r=-0.618); iii) PSP3 and PSE variables (p=0.000; r=0.664); iv) variables PSP3 and PSP1 (p=0.000; r-0.515); v) WPSP and PSE variables (p=0.000; r=-0.639); vi) WPSP and PSP2 variables (p=0.000; r=-0.594); and vii) WPSP and PSP3 variables (p=0.000; r=-0.586). Another three correlations were classified as weak.

Table 2 | Map of correlations between TUG seconds and acceleration variables

	TUG-S	TUG-M	TUG-D
PSE	0.338*[b]	0.317*[b]	0.502*[c]
PSP1	-0.124[a]	-0.137[a]	-0.250*[a]
PSP2	0.227[a]	0.291*[a]	0.325*[b]
PSP3	0.299*[a]	0.263*[a]	0.459*[b]
PSPF1	-0.227[a]	-0.256*[a]	-0.283*[a]
PSPF2	-0.094[a]	-0.172[a]	-0.162[a]
PSPF3	0.066[a]	0.044[a]	-0.023[a]
WPSP	-0.245*[a]	-0.269*[a]	-0.339*[b]
TC	-0.536*[c]	-0.528*[c]	-0.455*[b]

Note: Each cell represents the value of the correlation coefficient between two variables. Colors and color intensity indicate the strength and direction of the correlation. *p ≤ 0.05 according to Pearson correlation. [a]Features that showed negligible correlation; [b]weak correlation; [c] Moderate correlation. Source: Own authorship.

Weiss *et al*. (2010) evaluated TUG performance information in patients with Parkinson's disease and observed that most acceleration parameters did not correlate with TUG duration in seconds. Elledge (2017) identified that scores from a motion sensor-based device (OMNIVR) present a statistically significant correlation with TUG seconds (p < 0.01). However, the device in question uses three-dimensional cameras to measure the patient's movement and not an accelerometer.

This demonstrates one of the objectives of Gerontechnology regarding the use of motion sensors and monitoring technologies to assess mobility and fall risk in older adults. While correlations between accelerometry variables and functional tests like the TUG may be weak, detailed analysis of these signals offers deeper insights into movement patterns, crucial for preventive interventions. The complexity of human movement poses challenges in correlating acceleration parameters with TUG duration, underscoring the need for more advanced technologies and diverse approaches to enhance the quality of life for older people (Marques; Raymundo; Santana, 2013; Felix, 2020).

Ortega-Bastidas *et al.* (2019) also evaluated the correlation between inertial measurement units (IMU), extracted from TUG performance, and the observational clinical application of the TUG test measured on video. The latter were not analyzed in this correlation. A very strong correlation was observed between IMU and conventional visual clinical procedures, both in young adults and older people. Iluz *et al*. (2016) propose that long-term monitoring of movement transitions during activities of daily living by a sensor can provide more information about functional mobility than functional tests. The features delivered by the sensors during three days of monitoring had results of almost equal accuracy to the combination of functional tests and these same features, but when compared to using only functional tests to assess mobility, the method based on sensor features had better precision results.

Guzmán, Silva, and Guzmán-Venegas (2017) evaluated the reproducibility of mobility assessment using TUG steps recorded by a smartphone accelerometer in the lumbar region. They found that these recordings are reproducible, supporting their use in clinical practice, especially in primary care. Soto-Perez-De-Celis *et al*. (2018) assessed the feasibility of using smartphones to evaluate daily activities in older people undergoing chemotherapy, using the TUG for physical performance. Patients were given a smartphone with an accelerometer and pedometer app, concluding that smartphone technology can enhance monitoring and care in resource-limited settings.

Furthermore, Blair *et al*. (2020) verified the acceptability of using videoconferencing for remote assessment of functional tests such as TUG, allowing greater acceptability of interventions for older people with cancer.

The study found a strong correlation between TUG-M, TUG-D, and TUG-S, confirming they assess the same constructs. Dual-task tests like TUG-D are more sensitive to detecting changes in mobility. For independent older adults without cognitive impairment, TUG-D has 96% sensitivity, and TUG-S has 90% (Someshwar; Kunde; Ganvir, 2017). For older adults with Parkinson's, TUG-D sensitivity is 76%, and TUG-S is 41% (Vance *et al*., 2015). Therefore, TUG-D alone could be a practical alternative in clinical settings, reducing the need for multiple tests.

Abdollah *et al.* (2021) verified the validity of a head-worn accelerometer to monitor postural transition during TUG and identified that even only one sensor can provide high accuracy (95%), sensitivity (90%), and specificity (100%) to detect postural transitions and walking events.

The importance of combining assessment methods, such as motion sensors and visual clinical observations, for a more complete analysis of mobility in older people is essential to develop effective interventions in Gerontechnology. Furthermore, monitoring movement transitions during daily activities can provide more valuable insights into functional mobility than isolated functional tests (Ortega-Bastidas *et al*., 2019).

This highlights the importance of integrating continuous monitoring technologies into the daily lives of older people, improving the accuracy and personalization of health interventions. In turn, the acceptance of technologies such as videoconferencing for remote assessments, especially in older people with complex conditions, is another important advance, as it increases treatment adherence and improves quality of life (Felix, 2020). In addition, the validation of devices such as the accelerometer highlights the potential of these technologies in Gerontechnology, offering high accuracy in the detection of postural transitions and gait events, and contributing to the prevention of falls.

A moderate to strong correlation was observed among accelerometry features, indicating they assess the same constructs. The strongest correlations were between PSE and PSP1, and WPSP and PSP1. This can be explained by the fact that mobility information, in terms of frequency and entropy, is largely contained in the amplitude of the fundamental frequency. The second correlation was expected since WPSP is calculated using PSPF1 data.

This study involved healthy, active older people, but it did not include those with motor disabilities, so further research is needed for different gait patterns. Although the sample had 90% power, a larger epidemiological study is recommended. A limitation is that timing was done manually with a stopwatch, which may introduce human error.

Conclusion

The study shows that while both the TUG and accelerometer measure mobility, they assess different constructs. Combining them may increase test sensitivity, though not all TUG variations are necessary due to their strong convergent validity. Selecting the best variation for the target population could save time. This is the first study to explore the correlation between TUG seconds and acceleration, offering guidance for researchers and clinicians on optimizing assessments. It also highlights the potential of Gerontechnology to enhance the accuracy and efficiency of mobility assessments, leading to better interventions and improved quality of life for older people.

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