

# Timed Up and Go test phases as predictors of future falls in community-dwelling older adults

*Fases do teste Timed Up and Go como predictoras de quedas futuras em idosos da comunidade*

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## Abstract

**Introduction:** The Timed Up and Go (TUG) is a test widely used to assess the risk of falls in older adults. Although it is a complex task, only the total TUG time has been used for evaluation. The widespread use of smartphones has provided the development of applications for monitoring diagnostic procedures. **Objective:** To analyze the ability to predict future falls in older adults. **Methods:** A cohort study (1 year) of 42 participants using the sTUG Doctor. Fall events during 1-year follow-up were monitored by telephone. The number of days between assessment and first fall or last contact was calculated for survival analysis, assessed by unadjusted and adjusted Cox proportional hazards regression models. Tests with  $p < 5\%$  were considered statistically significant and between 5% and 10% were indicative of significance (Epi-Info™ 7.2). **Results:** Falls were observed in 22 (52.38%) participants (fallers). The results indicated that cognitive impairment, depressive symptoms, women, and participants with fear of falling (FES-I) were more likely to fall. Fallers performed worse on all sTUG Doctor phases. Hazard ratios for predicting falls were significant for total TUG time (1.35;  $p = 0.029$ ) and total number of steps (1.52;  $p = 0.057$ ). Total TUG time remained significant when adjusted for sex, age group, FES-I, and depression level. **Conclusion:** The sTUG Doctor was an important tool to predict falls in community-dwelling older adults.

**Keywords:** Accidental falls. Aging. Postural balance. Public health. Technology.

## Resumo

**Introdução:** O Timed Up and Go (TUG) é um teste bastante utilizado para avaliar o risco de quedas em idosos. Embora seja uma tarefa complexa, apenas o tempo total do TUG (TTUGT) tem sido utilizado para avaliação. A propagação dos smartphones proporcionou o surgimento de aplicativos para monitoramento de procedimentos diagnósticos. **Objetivo:** Analisar a capacidade de previsão de quedas futuras em idosos através das fases do TUG utilizando o teste sTUG Doctor. **Métodos:** Estudo de coorte (1 ano) com 42 participantes utilizando o sTUG Doctor. O evento de queda durante um ano de seguimento foi monitorado por meio de contato telefônico. O número de dias entre a avaliação e a primeira queda ou último contato foi calculado para a análise de sobrevivência avaliada por modelos não ajustados e ajustados através de modelos de regressão de risco de Cox. Testes com  $p < 5\%$  foram considerados estatisticamente significantes e entre 5 e 10% indicativos de significância (Epi-Info™ 7.2). **Resultados:** As quedas foram observadas em 22 (52,38%) participantes (caidores). Os resultados indicaram que nível cognitivo, sintomas depressivos, mulheres e participantes com medo de cair (FES-I) são mais propensos a cair. Caidores tiveram pior desempenho em todas as fases do sTUG Doctor. As razões de chance para previsão de queda foram significativas para TTUGT (1,35;  $p = 0,029$ ) e número total de passos (1,52;  $p = 0,057$ ). O TTUGT permaneceu significativo ajustando-se ao sexo, faixa etária, FES-I e nível depressivo. **Conclusão:** O sTUG Doctor foi uma ferramenta importante para prever quedas em idosos da comunidade.

**Palavras-chave:** Acidentes por quedas. Envelhecimento. Equilíbrio postural. Saúde pública. Tecnologia.

## Introduction

The sensory system is responsible for starting the process of developing human body balance and is one of the first systems to undergo changes with the aging process.<sup>1</sup> With aging, the human sensory system is affected by reduced functional reserve in older people and by the diseases that frequently affect this age group. Thus, several stages of postural control are altered, reducing the compensatory ability to maintain balance and, consequently, favoring postural disorders.<sup>2</sup>

Along with aging, the musculoskeletal system also undergoes physiological changes that compromise its functioning. These changes are characterized by a decline in physical capacity related to decreased muscle strength, flexibility, agility, coordination, and joint mobility, which lead to increased postural instability and, consequently, to an increased risk of falls.<sup>3-5</sup> Given this context, several instruments are used to assess body balance in older people and, consequently, the risk of falls. Among them, the Timed Up and Go (TUG) test stands out because it is an easy-to-apply, low-cost test widely used in clinical and research settings.<sup>6</sup>

Currently, the widespread use of smartphones, devices with sophisticated sensors, has provided the development of applications for monitoring diagnostic procedures.<sup>7</sup> Sensors such as accelerometers, gyroscopes, and magnetometers embedded in mobile devices are an inexpensive way to conduct studies of this magnitude. In addition, they have a high level of efficiency and have been used in several studies.<sup>8-10</sup>

In this context, Milosevic et al.<sup>11</sup> implemented a smartphone application (Mobility Suite®) that includes the Smart Timed Up and Go (sTUG) Doctor. The sTUG Doctor application, in addition to the total test time, also evaluates body posture transitions during the TUG test. These quantifications allow us to better assess body kinematics and dynamics, obtaining parameters not yet explored in fall risk prediction.<sup>11</sup> The sTUG Doctor provides instantaneous feedback with the most relevant parameters to the user in the form of a report on the screen.<sup>11</sup>

An advantage of the sTUG Doctor over other sensors is cost-effectiveness, as it only requires a smartphone, a device that is currently inexpensive and used daily by more than half of Brazilians, including older adults.<sup>12</sup> However, its study is recent, and it has been used basically in the field of research. Therefore, exploring this application becomes even more important to support the future introduction of this tool in other environmental contexts, such as in the home and hospital settings.

As falls are a multifactorial event with a significant impact on older adults, mobile technologies combined with well-established fall prediction tests present a simple and viable option for actions in the context of fall prevention. Therefore, this study aimed to analyze the ability to predict future falls in older adults through the TUG test phases using the sTUG Doctor application related to independent variables.

## Methods

This observational, analytical cohort study was conducted in the city of Porto Alegre, southern Brazil, from April 2019 to September 2020. This study was approved by the Research Ethics Committees of Pontifícia Universidade Católica do Rio Grande do Sul (approval no. 3,100,534) and Universidade Federal de Ciências da Saúde de Porto Alegre (approval no. 3,321,411). Written informed consent was obtained from each study participant.

The study population consisted of community-dwelling older adults ( $\geq 60$  years of age) who participated in the study by convenience sampling. The participants were recruited through online public advertisements and leaflets distributed in group-based programs for older people, religious groups, and social media. The sample size was calculated based on the findings of the secondary analysis of the study by Soldera et al.,<sup>13</sup> who observed differences in the participants' performance on the Sensory Organization Test (SOT)/sensory analysis between the fall risk levels classified by the TUG test. To detect this difference, with a significance level of 5% and a power of 80%, a sample size of 90 older adults was necessary.

Older adults who were able to walk independently, without the use of an assistive device, and to understand verbal commands were included. The following variables were evaluated using a questionnaire: sociodemographic data (sex, age, level of education, and monthly income) and clinical and lifestyle data (cognition, depression, number of diseases and medications, self-perceived general health, physical activity, history of falls, and fear of falling).

Older adults were excluded if they had severe sensory deficits (auditory and visual) without proper correction (hearing aid or glasses/lenses), had important motor sequelae caused by stroke, had a diagnosis of Parkinson's disease, experienced dizziness or vertigo at the time of testing, or had severe pain in the lower limbs and/or spine at the time of testing, assessed by a visual analog scale ranging from 0 to 10 (severe pain  $\geq 8$ ).<sup>14</sup> Fear of falling was assessed by the Brazilian version of the Falls Efficacy Scale-International (FES-I),<sup>15,16</sup> cognitive impairment by the Mini-Mental State Examination (MMSE),<sup>17,18</sup> and depressive symptoms by the 15-item Geriatric Depression Scale (GDS-15), a short version of the 30-item scale.<sup>19,20</sup>

The TUG test was used as the main evaluation tool. It is a functional mobility test widely used in research settings to assess fall risk. It evaluates gait performance, body posture transitions, and changes in direction during walking by measuring the time in seconds a person takes to complete the test. The test consists of the following tasks: rising from an armless chair with a backrest, walking a distance of 3 meters, turning around, walking back to the chair, and sitting down.<sup>21</sup> The time taken to complete the test generates a fall risk classification, as follows: low risk ( $< 10$  seconds), moderate risk (10 - 20 seconds), and high risk ( $> 20$  seconds).<sup>22</sup>

The TUG test was performed through the sTUG Doctor application. Each participant performed the test using a smartphone (Android) that was placed on an elastic strap with Velcro closure and attached to the chest, at the level of the sternum. The sTUG Doctor uses the smartphone's built-in gyroscope and accelerometer sensors, recording the total duration of the TUG test, the duration of the sit-to-stand and stand-to-sit transitions, maximum angle change ( $^{\circ}$ ), and maximum angular velocity ( $^{\circ}/s$ ). In this application, feedback is provided instantaneously to the user in the form of a report on the smartphone screen (Figure 1).<sup>11</sup> The number of steps taken to complete the turn was calculated by the lead researcher on videotape and used for analysis.



**Figure 1** - Demonstration of the sTUG Doctor using the Mobility Suite® smartphone application.<sup>37</sup>

Initially, all participants completed a trial to become familiar with the sequence of tasks required by the test. To ensure the quality of the assessment protocol, all procedures were performed by the lead researcher, who was previously trained and deemed competent in the TUG test.

The occurrence of future falls was monitored for 1 year by telephone calls made every 3 months. The participants were divided into two groups (fallers and non-fallers). The distribution of variables was tested by the chi-square test, and parameter means by Student's t test. The number of days between assessment and first fall or last contact was calculated for survival analysis, assessed by unadjusted and adjusted Cox proportional hazards regression models. Variables with a p-value less than 0.2 in the statistical tests between the groups were included in the survival analysis. Older adults were divided into age groups (60-79 years of age = younger older adults;  $\geq 80$  years of age = oldest-old adults), and age was included in the analysis even without such a level of significance for the fall event.<sup>2</sup> P-values less than 5% were considered statistically significant and between 5% and 10% were indicative of significance.<sup>23</sup> According to Bos,<sup>23</sup> p-values indicative of significance may represent significant differences or associations in samples with more robust statistical power. This interpretation is also supported by Paes,<sup>24</sup> who reports p-values less than 10% as "highly indicative." Data were analyzed using Epi Info™ 7.2.

## Results

A total of 42 older adults participated in the study. Table 1 shows the distribution of the sociodemographic, clinical, and lifestyle characteristics of the participants according to the fall event during follow-up. Of those evaluated, 52.38% had a fall event. The rate of falls was higher in women (58.82%) than in men (25%). The mean age of fallers was higher. Regarding age group, the rate of oldest-old fallers was proportionally higher. Fallers obtained higher mean FES-I scores, lower mean MMSE scores, and higher mean GDS-15 scores.

Table 2 shows the participants' performance on the sTUG Doctor test according to the fall event during follow-up.

**Table 1** - Distribution of sociodemographic, clinical, and lifestyle characteristics of participants according to the fall event during follow-up

Variables	Non-fallers	Fallers	p
<b>Sex</b>			
Female	14 (41.18%)	20 (58.82%)	<b>0.091*</b>
Male	6 (75.00%)	2 (25.00%)	
<b>Age</b> (mean $\pm$ SD)	69.10 $\pm$ 6.45	70.54 $\pm$ 8.30	0.535
<b>Age group</b>			
Younger older adult	18 (51.43%)	17 (48.57%)	0.247*
Oldest-old adult	2 (28.57%)	5 (71.43%)	
<b>Level of education</b>			
$\leq 8$ years of education	9 (50.00%)	9 (50.00%)	0.517
$> 8$ years of education	11 (45.83%)	13 (54.17%)	
<b>Monthly income (MMW)</b>			
Up to 2	4 (33.33%)	8 (66.67%)	0.290
From 3 to 4	13 (59.09%)	9 (40.91%)	
More than 4	3 (37.50%)	5 (62.50%)	
<b>Diseases</b>			
With multimorbidity (2+)	12 (46.15%)	14 (53.85%)	0.529
Without multimorbidity	8 (50.00%)	8 (50.00%)	
<b>Medication use</b>			
With polypharmacy (5+)	4 (30.77%)	9 (69.23%)	0.129
Without polypharmacy	16 (55.17%)	13 (44.83%)	
<b>SPH</b>			
Poor	3 (27.27%)	8 (72.73%)	0.110*
Good	17 (54.84%)	14 (45.16%)	
<b>PA</b>			
No	6 (60.00%)	4 (40.00%)	0.296*
Yes	14 (43.75%)	18 (56.25%)	
<b>History of falls</b>			
No	17 (54.84%)	14 (45.16%)	0.110*
Yes	3 (27.27%)	8 (72.73%)	
<b>FES-I</b> (points $\pm$ DP)	20.35 $\pm$ 4.18	22.90 $\pm$ 5.19	<b>0.088</b>
<b>MEEM</b> (points $\pm$ DP)	28.40 $\pm$ 1.90	26.68 $\pm$ 2.98	<b>0.038</b>
<b>GDS-15</b> (Sx $\pm$ DP)	1.40 $\pm$ 1.18	3.95 $\pm$ 3.18	<b>0.002</b>
<b>Total</b>	20 (47.62%)	22 (52.38%)	-

Note: SD = standard deviation; Younger older adult = 60-79 years old; Oldest-old adult = 80 years or older; MMS = minimum monthly wage; SPH = self-perceived health; PA = physical activity; FES-I = Falls Efficacy Scale-International; MMSE = Mini-Mental State Examination; GDS-15 = 15-item Geriatric Depression Scale; Sx = symptoms. \*Fischer's exact test. Other associations were tested by the chi-square test. Results in bold represent significant tests or indicative of significance.

**Table 2** - Performance on the sTUG Doctor test and Timed Up and Go (TUG) fall risk classification according to the fall event during follow-up

Variables	Non-fallers	Fallers	p
<b>sTUG Doctor</b>			
Total TUG duration (s)	8.80 ± 1.55	10.09 ± 1.57	<b>0.010</b>
Sit-to-stand duration(s)	1.21 ± 0.37	1.36 ± 0.33	0.176
Stand-to-sit duration (s)	1.65 ± 0.59	1.70 ± 0.47	0.754
Maximum angle change (°)	37.65 ± 19.58	46.43 ± 14.75	0.107
Maximum angular velocity (°/s)	120.22 ± 43.45	114.87 ± 37.71	0.671
Number of steps	11.75 ± 0.55	12.36 ± 1.09	<b>0.039</b>
Number of steps to complete the turn*	2.95 ± 0.60	3.00 ± 0.43	0.758
<b>Fall risk n (%)**</b>			
Low	17 (58.62)	12( 41.38)	
Moderate	3 (23.08)	10 (76.92)	<b>0.047</b>
High	0 (0.00)	0 (0.00)	

Note: sTUG Doctor variables = mean ± standard deviation; s = seconds.

\*Assessed on videotape. \*\*Established by Podsiadlo and Richardson.<sup>21</sup>

Results in bold represent significant tests or indicative of significance. Comparisons between means were tested by unpaired Student's t test and between frequencies by the chi-square test.

On average, fallers needed more time and took more steps to complete the total test. In addition, they had higher values for the sit-to-stand transition, stand-to-sit transition, and maximum angle change. Conversely, they had lower values for maximum angular velocity. In this study, no older adult was classified as being at high risk of falling. However, of those evaluated, 76.92% of those classified as being at moderate risk of falling fell during follow-up (Table 2).

Table 3 shows the hazard ratios calculated by Cox regression to predict falls at each follow-up month, unadjusted and adjusted models for sTUG Doctor components. FES-I and MMSE were the variables that most influenced fall risk prediction by total TUG duration. This finding demonstrates that fall risk prediction by total TUG duration is influenced but not dependent on the differences between FES-I levels. However, the presence of the MMSE in the model reduced this chance. This result indicates that fall risk prediction by total TUG duration is dependent on the MMSE level.

According to the variable 'number of steps,' GDS-15 and MMSE were the variables that most influenced fall risk prediction. These results demonstrate that fall risk prediction by reduced number of steps is dependent on the GDS-15 and MMSE levels.

**Table 3** - Hazard ratios calculated by Cox regression to predict falls at each follow-up month, unadjusted and adjusted models for sTUG Doctor test parameters

	Unadjusted analysis		Adjusted analysis		Independent variable	
	HR (95% CI)	p	HR (95% CI)	p	HR (95% CI)	p
<b>TUG Total</b>	1.35 (1.03-1.78)	<b>0.029</b>	-	-	-	-
Sex (Male/Female)	0.14 (0.02-1.09)	<b>0.061</b>	0.15 (0.02-1.22)	<b>0.077</b>	1.29 (0.99-1.69)	<b>0.055</b>
Age group	2.28 (0.81-6.37)	0.117	1.84 (0.64-5.28)	0.257	1.32 (1.00-1.75)	<b>0.049</b>
FES-I (points)	1.06 (0.97-1.15)	0.199	1.01 (0.92-1.11)	0.731	1.32 (0.97-1.80)	<b>0.072</b>
GDS-15	1.15 (1.03-1.30)	<b>0.018</b>	1.16 (1.02-1.33)	<b>0.021</b>	1.37 (1.03-1.84)	<b>0.030</b>
MMSE (points)	0.82 (0.71-0.94)	<b>0.006</b>	0.86 (0.72-1.02)	<b>0.093</b>	1.17 (0.85-1.59)	0.318
<b>Number of steps</b>	1.52 (0.98-2.35)	<b>0.057</b>				
Sex (Male/Female)	0.14 (0.02-1.09)	<b>0.061</b>	0.14 (0.01-1.10)	<b>0.062</b>	1.48 (0.97-2.27)	<b>0.067</b>
Age group	2.28 (0.81-6.37)	0.117	1.84 (0.63-5.33)	0.261	1.14 (0.91-2.28)	0.116
FES-I (points)	1.06 (0.97-1.15)	0.199	1.03 (0.95-1.13)	0.403	1.42 (0.91-2.23)	0.117
GDS-15	1.15 (1.03-1.30)	<b>0.018</b>	1.13 (1.00-1.27)	<b>0.041</b>	1.42 (0.89-2.25)	0.132
MMSE (points)	0.82 (0.71-0.94)	<b>0.006</b>	0.84 (0.70-1.00)	<b>0.058</b>	1.11 (0.67-1.84)	0.662

Note: Age group = younger older adult (60-79 years old) and oldest-old adult (≥ 80 years old); HR = hazard ratio; CI = confidence interval; TUG = Timed Up and Go; FES-I = Falls Efficacy Scale-International; GDS = Geriatric Depression Scale (number of depressive symptoms); MMSE = Mini-Mental State Examination. Results in bold represent significant tests or indicative of significance.

## Discussion

The results of the present study showed that the TUG test phases that best predicted falls in community-dwelling older adults were total TUG duration and the number of steps during the TUG test. According to Muir et al.,<sup>25</sup> in general, the gait in older adults is associated with lower speed, shorter step length, and greater base of support compared with young adults. These gait changes may be a strategy to increase stability or a consequence of decreased muscle strength and poor physical performance.<sup>25</sup> In the present study, these changes were not sufficient to prevent falls, as they remained significant for fall risk prediction.

Silva et al.<sup>26</sup> analyzed postural control in older people with and without a history of falls using 3 tests, including the TUG test. The authors observed that fallers needed more seconds to complete the test ( $14.31 \pm 3.33$ ;  $p = 0.025$ ), corroborating the findings of the present study. For Wamser et al.,<sup>27</sup> shorter total TUG time is associated with greater muscle power, gait speed, and functional capacity. Conversely, longer TUG times are directly related to decreased functional mobility and lower limb muscle strength, suggesting that individuals are more prone to falls.<sup>27</sup>

Older persons who are afraid of falling end up adopting different strategies to maintain balance while walking, including a reduction in the number of steps. Fewer steps per minute result in an increase in the double support phase of gait, decreasing the duration of the swing phase to avoid exposure to the postural instability more commonly experienced in the single-leg stance. In addition, other strategies used to reduce the risk of falling include decreased impulse or initial contact, knee extension, widening and narrowing the base of support, and decreased step length and height, with consequent reduction of speed.<sup>26</sup>

The present study addressed falls as a post-assessment event, where more than half of the followed-up older adults fell at least once during the 1-year follow-up. The frequency of falls observed among the participants in this study was higher than that estimated by Brazilian longitudinal studies (25% to 35%).<sup>3,28</sup> It is worth noting that the present study started in April 2019 and ended in September 2020. Most falls observed during follow-up occurred after March 2020, coincidentally during the COVID-19 pandemic.<sup>29</sup> The higher frequency of falls in our sample may be related

to changes in the environment caused by the social restrictions imposed by the pandemic. For Souza et al.,<sup>3</sup> preventing older persons from performing their leisure activities and seeing their family and friends has led to the development of other health-related problems. Social distancing, although it was a critical measure, leads to prolonged exposure to inactivity with subsequent functional status decline and increased fall risk.<sup>3</sup> Therefore, reduced physical activity alone may be a direct cause of the increase in falls at home during the pandemic.

Falls were more common in women than in men. This result is consistent with the study by Moraes et al.,<sup>30</sup> who reported that women experience proportionally more falls than do men possibly because of greater physical frailty, smaller amount of lean mass, and lower muscle strength, in addition to experiencing more physiological changes due to a reduction in hormone levels and bone density caused by menopause.

In this study, a greater change in FES-I, MMSE, and GDS-15 was observed among fallers. For Oliveira et al.,<sup>31</sup> fear of falling is a common consequence of falls, but it can also be a cause of falls. Fear of falling increases the risk of falls when it triggers a functional status decline, reducing the ability to prevent further events.<sup>31</sup> For Cruz et al.,<sup>32</sup> older persons with cognitive impairment may have mobility deficits, slowed movement, behavioral changes, and poorer reaction time when experiencing a loss of balance, thus predisposing them to falls. For Kao et al.,<sup>33</sup> however, depression may be associated with low levels of physical activity, which would lead to a cycle of functional status decline and increased risk of falls. In addition, depression may interact with other medical conditions in older persons, increasing the risk of falls.<sup>33</sup>

Among these variables, there was an influence of fear of falling on total TUG time. Fear of falling may or may not be associated with the fall event, although it is believed that persons who have already fallen are more likely to express this fear.<sup>34</sup> Fear may be protective if it motivates older people to be more careful not to expose themselves to risk, but it may also be a risk if it leads to insecurity and limitations.<sup>34</sup> Moreira et al.<sup>35</sup> highlighted that, in order to reduce the risk of falls, older people use different strategies to maintain balance during gait, which directly interfere with total walk time. Therefore, the findings of the present study allow us to state that the results of total TUG time should be evaluated within the context of fear of falling.



Despite the consensus in the literature on the risk factors for the occurrence of falls in older adults,<sup>31-34</sup> an assessment that allows the prediction of future falls becomes relevant. The use of preventive strategies and interventions to change fall-related risk factors imply the need for an appropriate and reliable screening or assessment tool. The availability of a valid instrument represents many possibilities for researchers and health professionals, as it may facilitate the identification of at-risk individuals, favoring a more appropriate decision-making in relation to proposals for preventive interventions aiming at preservation of their quality of life, maintenance of their safety, non-institutionalization, and consequently, cost reduction for secondary and tertiary care.<sup>36</sup>

We highlight that, to date, no other study was found in the literature that used the assessment of the TUG test phases through the sTUG Doctor application to predict future falls in older adults. Given this scenario, the originality of the research is highlighted, as well as the methodological rigor with which it was conducted. Another relevant point to be highlighted is that, based on the characteristics of the study sample, it is believed that the participants obtained relatively good results because they are healthy community-dwelling older adults, most of whom are physically active, and, possibly, also because of the mean age of the sample.

Finally, the sample size is pointed out as a limitation of the study, since, due to the COVID-19 pandemic, the expected sample size was not reached. Reaching the expected sample size means that it is large enough to provide a good approximation or an estimate for the behavior of the entire population. That is, we have a representative sample of the study population. Therefore, since the results are limited to the findings presented here, it is expected that, in a more favorable context, this research can be replicated with a more satisfactory sample size and including frailer older people, such as institutionalized older adults.

## Conclusion

Fallers performed worse than non-fallers on all TUG test phases. The TUG test phases that best predicted falls were total TUG duration and number of steps, a finding that could be extracted through the use of a smartphone application. Older women, those with fear of falling, cognitive impairment, and depressive symptoms were more likely to fall.

The TUG test phases, evaluated through the sTUG Doctor application, can be variables that might contribute to the prediction of future falls in community-dwelling older adults; however, they should be used with caution. Given the multifactorial context of falls in older adults, these measures may be used when contextualized with other variables. Overall, the application proved to be useful in different environments and health settings and can be used in future investigations.

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## Authors' contributions

All authors contributed to the conception and design of the study, analysis and interpretation of data, writing and review of the manuscript, and have approved the final version.

## References

1. Teixeira CS, Dorneles PP, Lemos LFC, Pranke GI, Rossi AG, Mota CB. Avaliação da influência dos estímulos sensoriais envolvidos na manutenção do equilíbrio corporal em mulheres idosas. *Rev Bras Geriatr Gerontol.* 2011;14(3):453-60. DOI
2. Alves NB, Scheicher ME. Equilíbrio postural e risco de quedas em idosos no município de Garça, SP. *Rev Bras Geriatr Gerontol.* 2011;14(4):763-8. DOI
3. Souza AQ, Pegorari MS, Nascimento JS, Oliveira PB, Tavares DMS. Incidência e fatores preditivos de quedas em idosos na comunidade: um estudo longitudinal. *Cienc Saude Coletiva.* 2019;24(9):3507-16. DOI
4. Gusmão MFS, Reis LA. Efeitos do treinamento sensório-motor no equilíbrio de idosos: revisão sistemática. *Rev Saude Col UEFS.* 2017;7(1):64-70. DOI
5. Pícoli TS, Figueiredo LL, Patrizzi LJ. Sarcopenia e envelhecimento. *Fisioter Mov.* 2011;24(3):455-62. DOI

6. Sprint G, Cook DJ, Weeks DL. Towards automating clinical assessments: a survey of the Timed Up and Go (TUG). *IEEE Rev Biomed Eng.* 2015;8:64-7. [DOI](#)
7. Guzmán JC, Silva RG, Guzmán-Venegas R. Reproducibilidad de los tiempos de ejecución de la prueba de Timed Up and Go, medidos con acelerómetros de smartphones en personas mayores residentes en la comunidade. *Rev Esp Geriatr Gerontol.* 2017;52(5):249-52. [DOI](#)
8. Ponciano V, Pires IM, Ribeiro FR, Marques G, Garcia NM, Pombo N, et al. Is the Timed-Up and Go test feasible in mobile devices? A systematic review. *Electronics.* 2020;9(3):528. [DOI](#)
9. Yang Z, Song C, Lin F, Langan J, Xu W. A smart environment-adapting Timed-Up-and-Go system powered by sensor-embedded insoles. *IEEE Internet Things J.* 2019;6(2):1298-305. [DOI](#)
10. Bao T, Carender WJ, Kinnaird C, Barone VJ, Peethambaran G, Whitney SL, et al. Effects of long-term balance training with vibrotactile sensory augmentation among community-dwelling healthy older adults: A randomized preliminary study. *J. Neuroeng Rehabil.* 2018;15:5. [DOI](#)
11. Milosevic M, Jovanov E, Milenkovic A. Quantifying Timed-Up-and-Go test: A smartphone implementation. *IEEE International Conference on Body Sensor Networks.* 2013;1-6.
12. Mendes GA, Lino LG, Almeida CMR, Faustino AM, Oliveira LMAR, Cruz KCT. Revisão de aplicativos de smartphones relacionados à saúde para idosos - realidade brasileira. *Braz J Dev.* 2021;7(5):48776-89. [Full text link](#)
13. Soldera CLC, Oliveira GG, Bos AJG. Differences in dynamic posturography results between older-adult and oldest-old. *Clin Med J.* 2015;1(4):115-21. [Full text link](#)
14. Gift AG. Visual analogue scales: measurement of subjective phenomena. *Nurs Res.* 1989;38(5):286-8. [DOI](#)
15. Camargos FFO, Dias RC, Dias JMD, Freire MTF. Adaptação transcultural e avaliação das propriedades psicométricas da Falls Efficacy Scale - International em idosos brasileiros (FES-I BRASIL). *Rev Bras Fisioter.* 2010;14(3):237-43. [DOI](#)
16. Camargos FFO. Adaptação transcultural e avaliação das propriedades psicométricas da Falls Efficacy Scale - International: um instrumento para avaliar medo de cair em idosos [master's thesis]. Belo Horizonte: Universidade Federal de Minas Gerais; 2007. 61 p.
17. Bertolucci PHF, Brucki SMD, Campacci SR, Juliano Y. O Mini-Exame do Estado Mental em uma população geral: impacto da escolaridade. *Arq Neuropsiquiatr.* 1994;52(1):1-7. [DOI](#)
18. Folstein MF, Folstein SE, McHugh PR. "Mini-Mental State". A practical method for grading the cognitive state of patients for the clinicians. *J Psychiatr Res.* 1975;12(3):189-98. [DOI](#)
19. Almeida OP, Almeida SA. Confiabilidade da versão brasileira da Escala de Depressão Geriátrica (GDS) versão reduzida. *Arq Neuropsiquiatr.* 1999;57(2B):421-6. [DOI](#)
20. Yesavage JA, Brink TL, Rose TL, Lum O, Huang V, Adey M, et al. Development and validation of a geriatric depression screening scale: a preliminary report. *J Psychiatr Res.* 1982;17(1):37-49. [DOI](#)
21. Podsiadlo D, Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc.* 1991;39(2):142-8. [DOI](#)
22. Wall JC, Bell C, Campbell S, Davis J. The Timed get-up-and-go test revisited: Measurement of the component tasks. *J Rehabil Res Dev.* 2000;37(1):109-13. [Full text link](#)
23. Bos AJG. Epi Info® sem mistérios: um manual prático. Porto Alegre: EDIPUCRS; 2012. 212 p. [Full text link](#)
24. Paes AT. Itens essenciais em bioestatística conferência. *Arq Bras Cardiol.* 1998;71(4):575-80. [DOI](#)
25. Muir BC, Rietdyk S, Haddad JM. Gait initiation: the first four steps in adults aged 20-25 years, 65-79 years, and 80-91 years. *Gait Posture.* 2014;39(1):490-4. [DOI](#)
26. Silva JCA, Silva TCA, Silva LN, Ribeiro MDA, Oliveira SB, Campelo GO. Análise comparativa da manutenção postural estática e dinâmica entre idosos caídores e não caídores. *SANARE.* 2017;16(1):52-9. [Full text link](#)
27. Wamser EL, Valderramas SR, Paula JA, Schieferdecker MEM, Amarante TP, Pinotti F, et al. Melhor desempenho no teste Timed Up and Go está associado a melhor desempenho funcional em idosos da comunidade. *Geriatr Gerontol Aging.* 2015;9(4):138-43. [Full text link](#)
28. Cruz DT, Cruz FM, Chaoubah A, Leite ICG. Fatores associados a quedas recorrentes em uma coorte de idosos. *Cad Saude Colet.* 2017;25(4):475-82. [DOI](#)



29. Brito SBP, Braga IO, Cunha CC, Palácio MAV, Takenami I. Pandemia da COVID-19: o maior desafio do século XXI. *Vigil Sanit Debate*. 2020;8(2):54-63. [DOI](#)
30. Moraes AS, Soares WJS, Lustosa LP, Bilton TL, Ferrioli E, Perracini MR. Características das quedas em idosos que vivem na comunidade: estudo de base populacional. *Rev Bras Geriatr Gerontol*. 2017;20(5):693-704. [DOI](#)
31. Oliveira GG, Pinho MS, Bós AJG. Desempenho de longevos caidores e não caidores na avaliação do Timed Up and Go utilizando um aplicativo de smartphone. *Saude e Pesqui*. 2019;12(2):385-97. [DOI](#)
32. Cruz DT, Cruz FM, Ribeiro AL, Veiga CL, Leite ICG. Associação entre capacidade cognitiva e ocorrência de quedas em idosos. *Cad Saude Colet*. 2015;23(4):386-93. [DOI](#)
33. Kao S, Wang YC, Tzeng YM, Liang CK, Lin FG. Interactive effect between depression and chronic medical conditions on fall risk in community-dwelling elders. *Int Psychogeriatr*. 2012;24(9):1409-18. [DOI](#)
34. Lopes KT, Costa DF, Santos LF, Catro DP, Bastone AC. Prevalência do medo de cair em uma população de idosos da comunidade e sua correlação com a mobilidade, equilíbrio dinâmico, risco e histórico de quedas. *Rev Bras Fisioter*. 2009; 13(3):223-9. [DOI](#)
35. Moreira MA, Oliveira BS, Moura KQ, Tapajós DM, Maciel ACC. A velocidade da marcha pode identificar idosos com medo de cair? *Rev Bras Geriatr Gerontol*. 2013;16(1):71-80. [DOI](#)
36. Chini LT, Pereira DS, Nunes AA. Validação da Ferramenta de Rastreamento de Risco de quedas (FRRISque) em pessoas idosas que vivem na comunidade. *Cienc Saude Coletiva*. 2019;24(8):2845-58. [DOI](#)
37. Madhushri P, Dzhagaryan A, Jovanov E, Milenkovic A. An mHealth Tool Suite for Mobility Assessment. *Information*. 2016; 7(3):47. [DOI](#)