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Complex Gait Is Related to Cognitive Functioning in Older People: A Cross-Sectional Study Providing an Innovative Test

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Keywords

Clinical evaluation · Cognitive impairment · Cognitive task · Fitness · Functional evaluation · Gait performance

Abstract

Background: Many studies have demonstrated an inverse relationship between gait performance and cognitive impairment. The main purposes of this study were: (1) to design and validate a complex gait test (CGT) in older people, (2) to analyze the effects of age and sex on CGT, and (3) to analyze the association between CGT performance and physical functioning and cognitive measures. ***Methods:*** A total of 279 older people (60–97 years) were analyzed in 2019. Fitness tests, gait performance, and several cognitive measures such as the Trail-Walking Test and Montreal Cognitive Assessment were used. ***Results:*** The CGT reported adequate reliability and validity parameters. In the test-retest analysis, the intraclass correlation coefficient was 0.868 ($p < 0.001$). There was a significant correlation between the CGT and Trail-Walking Test ($r = 0.592$; $p < 0.001$). The linear regression analysis showed that the CGT was associated with the Montreal Cognitive Assessment ($R^2 = 0.357$; $p = 0.001$). The binary logistic regression analysis revealed that a high CGT score was a risk factor for mild cognitive impairment (odds ratio 1.201, 95% CI 1.081–1.334; $p = 0.001$). The ROC curve of the mild cognitive impairment was predicted by the CGT performance (area under the curve = 0.768, 95% CI 0.647–0.889; $p < 0.001$), reaching the cut-off point at 20.25 s. ***Conclusions:*** The CGT showed good reliability and validity and may serve as a potential biomarker in mild cognitive impairment prediction in older adults aged 60–97 years.

Introduction

With ageing, physical and cognitive functions are impaired [1, 2]. Older people walk more slowly, have less muscle strength, and poorer memory and reasoning abilities relative to younger adults and to themselves when they were younger. These manifestations are the result of neural cell loss in the frontal, parietal, and temporal lobes, and they strongly depend on hypofunction of the mono-

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aminergic and cholinergic pathways [3, 4]. Therefore, ageing has been associated with frailty and functional limitations due to three factors: an irreversible biological process, deconditioning due to a sedentary lifestyle, and comorbidity effects [5].

Mild cognitive impairment (MCI) especially represents a high risk for developing Alzheimer's disease; moreover, it causes gait deterioration, which increases the risk of falls and institutionalization and is considered an early motor sign of this disease [6]. Previous studies have shown an inverse relationship between physical activity and the risk of developing cognitive decline [7, 8]. Regular physical activity attenuates the age-related decline in brain volume; it is a preventive measure against Alzheimer's disease and dementia [8]. Older people with higher physical fitness and physical activity display more efficient brain activity and superior executive function (EF) [9]. In particular, walking performance is a strong biomarker of health [10]. Gait speed (GS), gait variability, and step length are the most commonly used measures to predict cognitive decline [11–15]. In this regard, the preferred walking speed in older people is an indicator of general health and survival, and safe walking requires intact cognition and executive control [13]. Additionally, deficits in cognitive domains, particularly those related to the prefrontal cortex, contribute to diminished walking performance in complex conditions during older ages [14]. The association between cognition and gait has been analyzed through dual-task studies [15]. Dual tasks during walking, when people are asked to walk and simultaneously perform another cognitively demanding task such as reciting words or calculations, may represent a new methodological approach for the evaluation of brain function and MCI through the cognitive-motor interference [16]. However, the ecological validity of these tests is debatable.

Social ambulation requires the ability to adapt walking characteristics to environmental demands [11]. In this regard, performance in daily activities including walking through obstacles, going up a curb, stepping over a crack in the ground, climbing stairs, multi-surface terrains, avoiding domestic or street hazards, avoiding injurious falls, etc., are associated with EF, motor planning, attention to relevant stimuli, and visual and spatial abilities that are essential to successfully negotiate obstacles [15, 17–19]. Therefore, there is an association between increased gait complexity (e.g., obstacle avoidance) and elevated cortical activity [20]. EF deterioration may reduce the ability to perform efficient motor strategies during these activities [18]. Accordingly, performance of complex walking tasks could represent a simple and effective tool for assessing risk for cognitive deterioration in healthy older people.

Therefore, it is necessary to increase the knowledge of predictive cognitive deterioration models. The current models focus on biological or psychological indicators; however, they show a low-to-moderate predictive ability with large variability, factors that make it necessary to explore new markers [21]. Walking ability might improve the accuracy and specificity of these models because the motor and cognitive functions share neuroanatomical structures and psychological processes [22]. Thus, early motor changes related to ageing predict cognitive impairment; this prediction may indicate that a "motor signature" can be detected in pre-dementia states [16].

From a public health perspective and taking into account the above information, the search for or development of markers or complementary, simple, and efficient tools, especially motor markers, to detect MCI is a novel and intriguing research area. Complex gait could represent a potential marker for cognitive decline prediction. The main purposes of this study were: (1) to design and validate a complex gait test (CGT) in older people, (2) to analyze the effects of age and sex on CGT, and (3) to analyze the association between CGT performance and physical functioning and cognitive measures.

Method

Participants

This cross-sectional study analyzed complex gait in a cohort of older people to validate CGT. A total of 279 older people (206 women and 73 men), aged 60 to 97 years (mean ± SD 72.13 ± 6.72), participated in this study. The mean body mass index (BMI) was 27.19 ± 3.83 (kg/m^2). Participants were recruited from four senior centers in southern Spain (Andalusia). The inclusion criteria were: (a) older than 60 years; (b) free of prosthesis; (c) free of any symptom that a medical examiner deemed as warranting exclusion; (d) not suffering from pathologies associated with increased risk of falls (i.e., Parkinson's disease); (e) independent ambulation; (f) free of any disease that requires daily drugs that would affect gait performance (to avoid any influence on fitness measures). Participants were divided into three age subgroups: 60–69 years (n = 96, 76% women), 70–79 years (n = 145, 75.2% women), and >79 years (n = 38, 63.2% women). To check the reliability, validity, and association of the CGT with several measures of functional capacity, a random sample of participants (included in the total sample) was collected. Each participant provided written informed consent for the study, which was conducted in compliance with the norms of the Declaration of Helsinki (2013 version). The study was approved by the Ethics Committee of the University of Jaen (Spain).

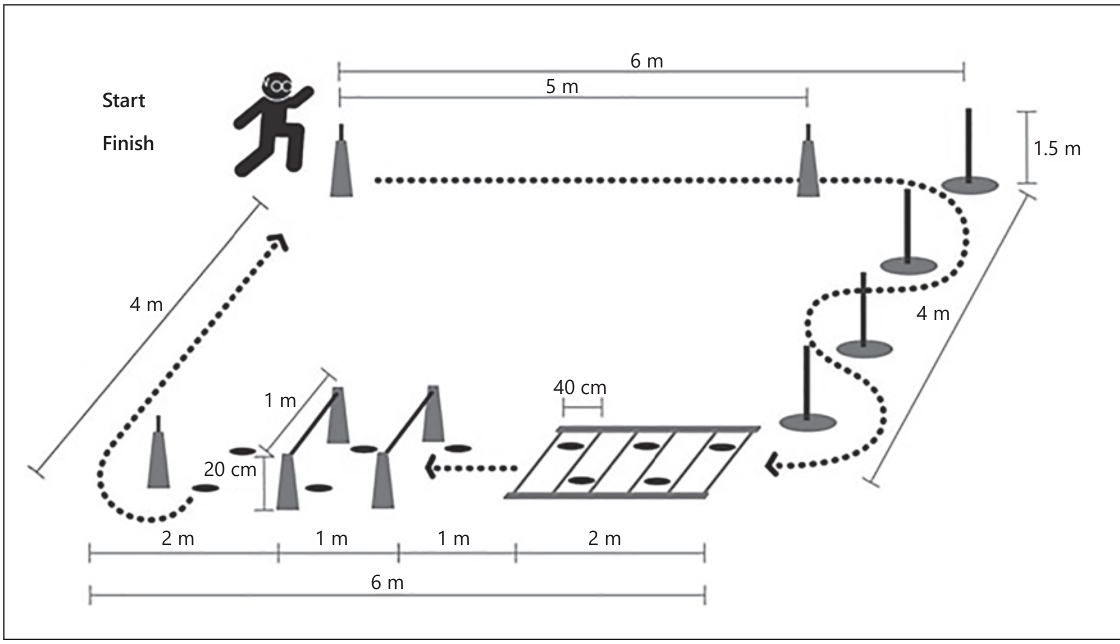

Fig. 1. The CGT.

Materials and Testing

Sociodemographic Variables

Sociodemographic information was recorded using a self-report instrument that included date of birth, marital status, educational status, current occupational status, and health habits, among other questions.

Anthropometric Variables

Body mass (kg) was measured using a weighing scale (Seca 899, Hamburg, Germany) and body height (cm) was measured with a stadiometer (Seca 222). BMI was calculated by dividing body mass (kg) by the square of body height (in m).

Physical Functioning

The main functional capacity components examined were lower-body muscle strength, upper-body muscle strength, and GS. For lower-body muscle strength, the 30-s chair stand test (CST) [23] was used. This test involves counting the number of times within 30 s that individuals can rise to a full stand from a seated position with their back straight and feet flat on the floor and without pushing off the chair with their arms. Each participant performed two trials and the best trial was registered.

For upper-body muscle strength, the handgrip strength test (HS) was used. This test involves using a hand dynamometer with an adjustable grip (TKK 5101 Grip D; Takey, Tokyo Japan). The optimal grip span was calculated with the formula suggested by a previous study [24]. Each participant performed this test twice with each hand. Participants needed to fully extend their arm so that it formed a 30° angle relative to their trunk. The maximum score (in kg) for each hand was recorded, and the mean score of the left and right hand was used in the subsequent analysis.

For gait performance, GS (in s) was measured using two double-light barriers (WITTY; Microgate Srl, Bolzano, Italy; 0.001-s accuracy) that were placed at the beginning and end of a 5-m corridor. The GS test involves walking 5 m in the shortest possible time [25]. The best time of the two trials was recorded and used for the analysis. We did not provide a starting signal so that the subjects were able to individually start the test. Thus, reaction time did not influence our findings. Step length and step length variability in terms of within-participants coefficient of variation (CV) given as a percentage SD/mean × 100% (%CV) were recorded using the OptoGait system (Microgate). In this study, five parallel bars of the device system were placed in a 5-m walkway. The subjects began the test with one foot on the starting line in a frontal erect position, and timing started when subjects passed the first photoelectric cells. To allow for acceleration and deceleration, participants walked 2 m before and after the walkway. The participants were asked to walk with their own shoes at a self-selected walking speed. The only instruction was “walk at your normal speed.” Twelve trials were recorded.

To evaluate complex activities of daily living and independent living skills, the Lawton Instrumental Activities of Daily Living (IADL) Scale [26] was used. The instrument contains eight items; a summary score ranges from 0 (low function, dependent) to 8 (high function, independent) for women and 0 to 5 for men.

Cognitive Measures

The Porteus Maze Test (PMT) [27] and Montreal Cognitive Assessment (MoCA) [13] are the neuropsychological tests recommended to analyze EF and for MCI screening, respectively, in older people [28]. In the PMT, participants must solve a series of increasingly difficult mazes by drawing a continuous pencil line from a given start to finish point without entering a dead end. The usefulness of the PMT as a measure of brain dysfunction is relatively well established [29]. We used the quantitative test age score.

The MoCA is a 30-point test that takes 10 min and evaluates aspects of attention, concentration, orientation, calculation, language, verbal memory, recall, abstraction, visual-spatial ability, and EF. The Spanish version was used [30] and a cut-off score <21 indicates MCI [30–32]

Trail-Walking Test

The Trial-Walking Test (TWT) is an ambulatory test in which the participants walk as rapidly as possible through 15 numbered flags in ascending order. The flags are installed randomly at each of the 15 positions in a 25-m^2 area (5 × 5 m), according to the procedure used by Yamada and Ichihashi [33]. The participants were asked to sequentially move from flag number 1 to 15. A 30-cm-diameter circle was drawn around each flag. The passage was considered successful when the participant stepped on the circle. The trials were timed using a stopwatch to the nearest 0.01 s. The TWT was performed only once. The test score was the running time, with a longer time indicating a poorer performance. The TWT is an early detection tool for MCI [13].

Complex Gait Test

The CGT was performed in an indoor controlled environment that simulated some of the features of social ambulation (Fig. 1). Each participant was instructed to walk in the fastest possible time on a flat and straight 6-m path, then turn right, weave between four posts, turn right again, walk by stepping alternately in a grid of five rectangles and high-step over two obstacles, turn tight one last time and walk 4 m to the finish. The test score was the running time, with a longer time indicating a poorer performance. The CGT was performed twice and the best trial was recorded. This test requires six cones, four flags (1.5 m high), and masking tape to draw the grid.

Procedure

Before the experimental protocol, the anthropometric variables were assessed and familiarization with the physical tests were performed. In three separate sessions (48 h apart), a team of researchers previously trained in conducting the different tests evaluated the participants. During the first testing session, physical fitness tests were administered. In a second session, the gait tests were performed. In a third session, cognitive measures were recorded. The questionnaires were completed individually and in the presence of researchers (they respected data confidentiality and clarified any potential doubts or questions). A week later, a random sample of 30 participants (included in the previous data collection) performed the CGT once again (retest).

Statistical Analysis

Data were analyzed using SPSS v.19.0 for Windows (SPSS Inc., Chicago, IL, USA). The significance level was set at $p < 0.05$. Descriptive data are reported in terms of means, SD, and percentages. Normal distribution (Kolmogorov-Smirnov) and homogeneity (Levene) tests were conducted on all data before analysis. Differences between sex and age groups were analyzed using ANOVA (analysis of variance) adjusted by the Bonferroni test. Additionally, effect sizes for group differences were expressed as Cohen's *d*. Effect sizes are reported as: trivial (<0.2), small (0.2–0.49), medium (0.5–0.79), and large (≥0.8) [34]. A Pearson correlation analysis was conducted between the CGT scores and BMI, physical fitness, cognitive measures, and the TWT (adjusting for age and sex). Additionally, regression analysis was used to determine the association between the CGT and the MoCA (adjusted for age). The CGT performance threshold that best discriminated MCI was determined by using the ROC (receiver operating characteristic) curve. Binary logistic regression was performed using MCI as the dependent variable and the CGT performance as the independent variable. CGT reliability was analyzed by examining the test-retest through the intra-class correlation coefficient (ICC) and Bland-Altman graphic. Finally, concurrent validity was performed by Pearson correlation with the TWT.

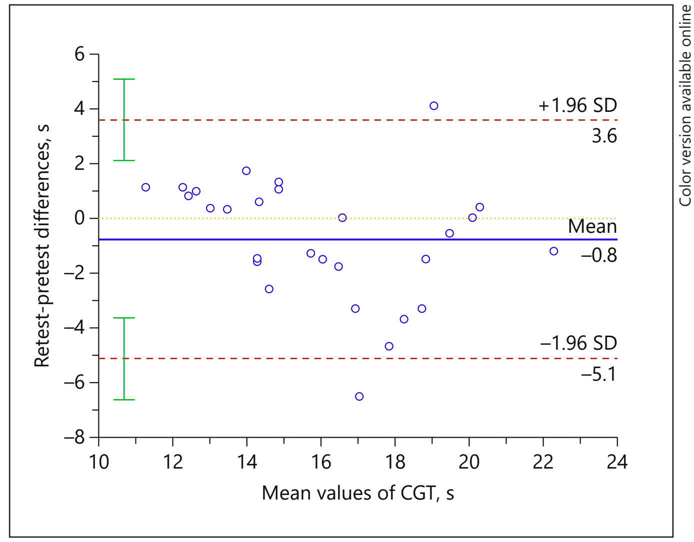

Fig. 2. Bland-Altman graph for CGT performance. The *x*-axis shows mean CGT values and the *y*-axis indicates the different values for CGT test-retest.

Results

The sociodemographic variables showed that 44.8% of participants completed primary schooling, 48.3% were married, and 83.1% were in the middle socioeconomic level. In the test-retest analysis, the initial test time was 16.46 ± 3.32 s and the retest time was 15.70 ± 2.71 s ($p \geq 0.05$). The ICC was 0.868 (95% CI 0.725–0.936; $p < 0.001$). The Bland-Altman graph showed limits of agreement (2 SD) of 3.6 and –5.1 s, and the mean of the differences was –0.8 ± 2.43 s (Fig. 2). Additionally, the Pearson correlation analysis revealed a significant correlation between the initial test and retest ($r = 0.821$; $p < 0.001$). Concurrent validity showed a significant correlation between the CGT and the TWT ($r = 0.592$; $p < 0.001$).

Table 1 shows the age, BMI, and physical functioning (all separated by sex). There were significant differences between sexes in HS ($p < 0.001$), GS ($p = 0.039$), PMT

Table 1. Age, BMI, physical functioning, cognitive measures, and TWT and CGT results (separated by sex)

Variable	Men	Women	*p* value	Cohen's *d*
Age, years	73.30 ± 7.11	71.73 ± 6.56	0.086	0.234
BMI (kg/m^2)	26.91 ± 3.43	27.31 ± 3.97	0.464	0.104
Falls in preceding 3 years, *n*	0.58 ± 0.93	0.65 ± 1.10	0.681	0.066
30-s CST, repetitions	14.60 ± 5.87	15.71 ± 5.33	0.851	0.204
HS, kg	29.40 ± 8.93	19.38 ± 6.11	<0.001	1.404
GS, m/s	1.54 ± 0.51	1.46 ± 0.41	0.039	0.183
Step length, cm	64.45 ± 13.25	61.02 ± 9.25	0.322	0.320
Step length variability, %CV	9.42 ± 8.34	9.61 ± 11.55	0.945	0.018
IADL (0–8 points)	6.08 ± 2.23	6.85 ± 2.03	0.179	0.373
MoCA (0–30 points)	19.50 ± 7.24	19.40 ± 7.30	0.709	0,013
PMT (3–15 mazes)	12.30 ± 3.37	10.01 ± 3.98	0.030	0.607
TWT, s	44.81 ± 9.35	52.17 ± 13.89	<0.001	0.569
CGT, s	17.63 ± 5.76	18.64 ± 5.31	0.008	0.186

Data are presented as the mean ± SD. CST, chair stand test; HS, handgrip strength test; GS, gait speed; IADL, Instrumental Activities of Daily Living; MoCA, Montreal Cognitive Assessment; PMT, Porteus Maze Test; TWT, Trail-Walking Test; CGT, complex gait test.

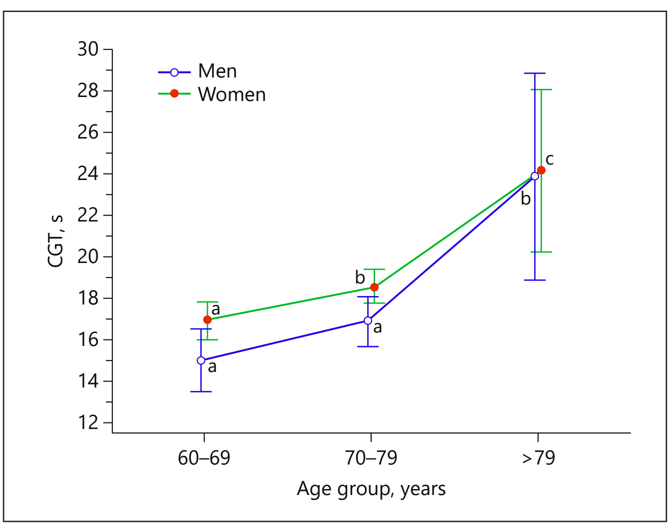

Fig. 3. Age group and sex differences in CGT performance. Different subscript letters indicate significant differences in men or women.

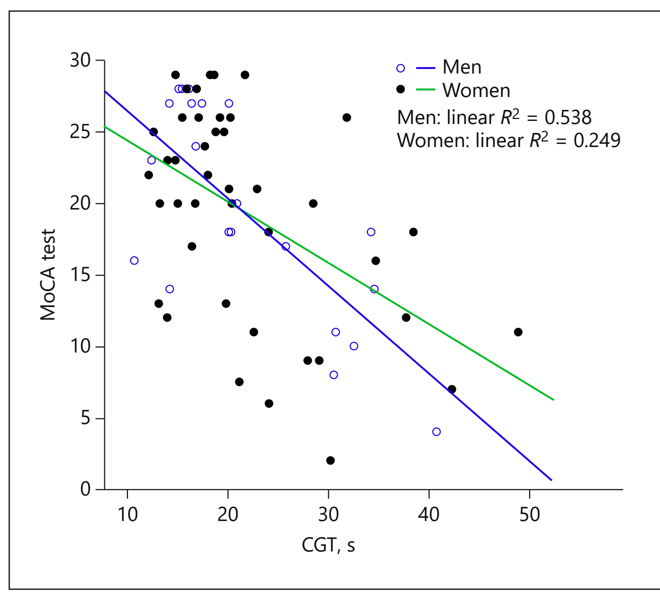

Fig. 4. Linear regression analysis of CGT performance and the MoCA test.

($p = 0.030$), TWT ($p < 0.001$), and CGT ($p = 0.008$), with men performing better than women. There were no significant differences between the sexes for any age group. Post hoc analysis revealed that >79-year-old participants showed a lower CGT performance compared to the 60- to 69-years and 70- to 79-year age groups in both men ($p < 0.001$) and women ($p < 0.001$).

In addition, there were significant differences between the 60- to 69- and 70- to 79-year age groups in women ($p = 0.028$; Fig. 3). Pearson analysis noted a significant correlation between CGT performance and age ($r = 0.526$; $p < 0.001$).

The linear regression analysis showed that the CGT performance was associated with the MoCA ($R^2 = 0.357$; $p = 0.001$; $y = 38.818–0.389x$; Fig. 4). The binary logistic regression analysis revealed that a high CGT score was a

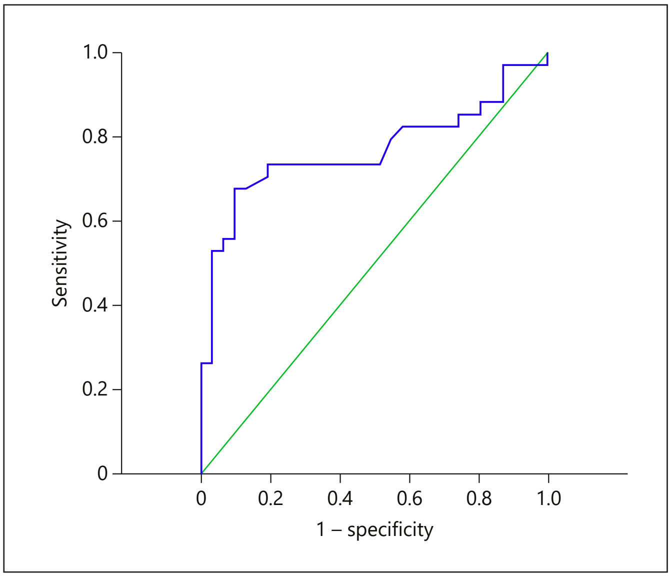

Fig. 5. ROC curve that summarizes the potential of CGT performance to identify MCI.

risk factor for MCI (odds ratio 1.201, 95% CI 1.081–1.334; $p = 0.001$). Figure 5 shows the ROC curve for MCI prediction with CGT performance (area under the curve = 0.768, 95% CI 0.647–0.889; $p < 0.001$). The cut-off point was 20.25 s (sensitivity = 0.676, 1 – specificity = 0.097). Pearson correlation analysis showed significant correlations between the CGT and BMI ($r = 0.144$; $p = 0.020$), CST ($r = -0.346$; $p = 0.011$), HS ($r = -0.471$; $p < 0.001$), GS ($r = -0.664$; $p < 0.001$), step length ($r = -0.591$; $p < 0.001$), CV ($r = 0.571$; $p < 0.001$), IADL ($r = -0.523$; $p < 0.001$), number of falls in the preceding 3 years ($r = 0.208$; $p = 0.002$), and PMT ($r = -0.310$; p = 0.024).

Discussion

The main purpose of this study was to design and validate the CGT in older people. The results indicated adequate reliability and validity for the CGT in older adults. Thus, this test is safe, easy to perform, and highly acceptable for older individuals. The CGT provides a simple and inexpensive tool to measure complex gait in older people, and it might be valuable to perform comparative studies. Moreover, this test represents a feasible task to better understand the relationship between cognitive and locomotive functions. ROC analysis showed good diagnostic accuracy for CGT performance in predicting MCI. Thereby, this test is already in line with the ecological approach regarding the use of gait tasks that are close to real-life conditions, which improves the ecological validity.

A second objective was to examine the influence of age and sex on the CGT. Throughout the sample, men showed greater performance than women; however, no significant differences between sexes for any age group were found. Sex may influence adaptive walking across locomotor tasks such as obstacle crossing and could manifest in a greater risk of mobility impairment in women due to a conservative adaptive walking pattern [19]. Additionally, after 79 years of age, CGT performance decreased significantly in both sexes. This deterioration in the CGT is related to a decrease in IADL, CST, HS, and GS performance. Likewise, previous studies have shown that a reduction in habitual GS is related to a reduction of functional capacity in older people [35, 36]. In this regard, Callisaya et al. [37] showed that several gait factors are associated with age, and sex differences in some of these associations indicate that the aging process may affect gait in men and women differently.

On the other hand, EF is relevant in the performance of complex motor tasks, and thus EF deterioration with ageing may reduce a person's ability to quickly plan efficient motor strategies that are required in the execution of complex, attention-demanding physical tasks, such as stepping over an obstacle, eluding domestic or street hazards, and avoiding dangerous falls [17]. In this regard, a deficit in planning to avoid obstacles could be related to cognitive disorders [38]. According to a previous study [39], these findings demonstrated that even in healthy older people additional attention resources are required for obstacle crossing and recovering from an obstacle crossing step. Whereas walking on curved paths is considered more difficult than that on straight paths, older adults with poor cognitive flexibility tend to exhibit risky walking behavior during more complex walking situations compared to older adults with good cognitive flexibility [40]. In this sense, deficits in higher-order cognitive processing may limit obstacle negotiation abilities in people with MCI, being a potential falls risk [41]. Based on these findings, and considering the third objective of the current study, the data showed that CGT performance was associated with EF (analyzed by PMT and TWT) and the number of falls in the preceding 3 years. Deterioration in visual, orthopedic, and cognitive systems associated with ageing may contribute to the worsening of obstacle-crossing performance [42].

As mentioned earlier, GS, step length, and gait variability are the most commonly used gait measures to predict cognitive decline. Reduced gait performance, including slower GS and shorter stride length during fast-paced walking in the older cognitively impaired population, is associated with alterations in memory, spatial processing, attention, and EF [43]. Likewise, with ageing, gait progressively becomes less automatic and requires higher demands on executive control resources, which normally enable individuals to efficiently tackle mobility tasks [44]. In the current study, CGT performance was significantly correlated with GS, step length, and step length variability. In this regard, a recent study noted that the success rate in the obstacle negotiation in older adults was correlated with stride length, step time CV, and GS [45]; in addition, MoCA scores tended to be related to this performance. Therefore, and according to Kikkert et al. [22], we recommend global analysis of gait, including the circumvention of obstacles during walking, as it occurs in the CGT test, in clinical evaluations of patients with suspected cognitive decline [45].

Some limitations of this study must be mentioned. The main limitation is the cross-sectional design; CGT performance in ageing should be measured in a longitudinal study. Second, the sample included older people in southern Spain, and generalization to a wider population should be made with caution. Third, walking in complex environments involves avoidance of static and dynamic obstacles, but the CGT does not incorporate dynamic obstacles. Despite these limitations, the strength of this study is that it provides a new test to evaluate complex gait in the older population that can serve as a complementary tool for assessing MCI.

Conclusions

The results in the current study showed very good reliability and validity parameters for the CGT in individuals aged 60–97 years. The test is safe, easy to set-up, and acceptable and appropriate for older adults. This combination of findings provides some support for the conceptual premise that motor and cognitive functions are needed to successfully negotiate obstacles. Therefore, performance in complex gait tasks may serve as a potential biomarker in predicting cognitive decline. From a practical standpoint, the authors would recommend including the CGT in the routine clinical evaluation of individuals with suspected cognitive decline.

Statement of Ethics

Each participant provided written informed consent for the study, which was conducted in compliance with the norms of the Declaration of Helsinki (2013 version). The study was approved by the Ethics Committee at the University of Jaen (Spain).

Disclosure Statement

The authors declare no conflicts of interest.

Funding Sources

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Author Contributions

Study design: Pedro Ángel Latorre-Román and Juan Párraga Montilla. Corresponding author, data processing and final approval: Dr. Marcos Muñoz Jiménez. Logistics, registration and data processing: Jesús Salas Sánchez, Pedro Consuegra González, Rafael Moreno del Castillo, Julio Herrador Sánchez, María del Amor López Ivanco, Claudia Linares Jiménez, Juan Francisco Navas Morales. Analysis of data: Pedro Ángel Latorre-Román. Elaboration of the report: Pedro Ángel Latorre-Román and Juan Párraga.

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