Do frailty and cognitive impairment affect dual-task cost during walking in the oldest old institutionalized patients?

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Abstract The objective of this study was to investigate dual-task costs in several elderly populations, including robust oldest old, frail oldest old with MCI, frail oldest old without MCI, and frail elderly with dementia. Sixty-four elderly men and women categorized into frail without MCI (age 93.4 ± 3.2 years, $n=20$), frail with MCI (age 92.4 ± 4.2 years, $n=13$), robust (age 88.2 ± 4.1 years, $n=10$), and patients with dementia (age 88.1 ± 5.1 years, $n=21$). Five-meter gait ability and timed-up-and-go (TUG) tests with single and dual-task performance were assessed in the groups. Dual-task cost in both 5-m habitual gait velocity test and TUG test was calculated by the time differences between single and dual-task performance. The robust group exhibited better 5-m gait and TUG test performances in the single and dual-task conditions compared with the other three groups ($P<0.001$), and the frail and frail + MCI groups

exhibited better performances than the dementia group ($P<0.001$). No significant differences were observed between the frail and frail + MCI groups. However, all groups exhibited lower gait velocities in the verbal and arithmetic task conditions, but the dual-task cost of the groups were similar. Robust individuals exhibited superior single and dual-task walking performances than the other three groups, and the frail and frail + MCI individuals exhibited performances that were superior to those of the patients with dementia. However, the dual-task costs, i.e., the changes in gait performance when elderly participants switch from a single to a dual task, were similar among all four of the investigated groups. Therefore, these results demonstrated that the magnitude of the impairment in gait pattern is independent of frailty and cognitive impairment status.

Keywords Frailty · Oldest old · Cognitive impairment · Dual-task walking · Dementia

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Introduction

Frailty is an age-associated syndrome that is characterized by decreases in individuals' biological functional reserves and resistance to stressors. Frailty is associated with declines in several physiological systems and places individuals at particular risk for falls, hospitalization, institutionalization, disability, and death (Campbell and Buchner 1997; Rockwood and Mitnitski 2007; Rodríguez-Mañas et al. 2012; Rodríguez-Mañas and Fried 2015; Walston and Fried 1999). Mild

cognitive impairment (MCI) is viewed as a transitional state between normal cognitive aging and early dementia (Liu-Ambrose et al. 2010; Mhaoláin et al. 2012; Makizako et al. 2012; Susuki et al. 2012). Dementia is a syndrome that represents a major public health problem because it influences individuals' capacities for activities of daily living (ADL) and impairs their social and occupational functions (Heyn et al. 2004). As their dementia progresses, elderly individuals with cognitive disorders generally become frail and institutionalized patients (Heyn et al. 2004; Singh, 2002). One of the major negative consequences of dementia is a severe decline in physical activity, which can be attributed to several causes, including the use of physical restraints to prevent falls (Berzlanovich et al. 2012; Gulpers et al. 2010). Cognitive impairment and dementia have been closely related to frailty because these diseases share some of the same pathophysiological mechanisms, phenotypes, and short- and mid-term consequences (e.g., hospitalization, an increased incidence of falls, disability, institutionalization, and death) (Garcia-Garcia et al. 2011; Hantikainen 1998; Roberston et al. 2013).

Gait impairment is one of the most consistent predictors of falls and is a prevalent feature among older adults with frailty syndrome, cognitive impairment, and dementia (Fried et al. 2001). The traditional gait assessment (i.e., short walking without a second task, like talking) is not sufficiently sensitive to detect subtle gait impairments. A sensitive method for detecting these early interactions is the measurement of the effect that cognitive load has on gait (e.g., during simultaneous talking or counting while walking). It has been demonstrated that the inability to maintain a conversation while walking (i.e., "stopping walking while talking") is a marker of future falls in older adults (Lundin-Olsson et al. 1997; Uemura et al. 2012); therefore, walking while performing a secondary task (the dual-task paradigm) has become the classic method of assessing the interaction between cognition and gait (Casas-Herrero et al. 2013; Doi et al. 2012; Garcia-Garcia et al. 2011; Makizako et al. 2012; Maquet et al. 2010; Montero-Odasso et al. 2012). Dual-task tests reflect executive function, which is an essential cognitive resource for normal walking. Additionally, a strong correlation between timed-up-and-go (TUG) test with a verbal task performance and the incidence of falls among frail nonagenarians has recently been observed (Casas-Herrero et al. 2013).

Recent studies have revealed that older adults with MCI exhibit a higher prevalence of gait impairments than cognitively normal older adults (Maquet et al. 2010; Montero-Odasso et al. 2012). However, it remains to be elucidated whether the dual-task cost is more prominent in the elderly with frailty syndrome, mild cognitive impairment, and/or dementia than in the robust elderly. Additionally, little attention has been given to the association between dual tasks and frailty or to the ability to detect subtle differences in gait patterns between robust elderly, frail patients with and without MCI, and frail patients with dementia based on these tasks. Moreover, understanding gait patterns in elderly at different levels of physical functioning and cognitive function could help to identify different needs in order to implement exercise interventions taking into consideration the physical demand in frail elderly with and without MCI and dementia.

Therefore, the purpose of this study was to investigate dual-task costs in several elderly populations, including robust oldest old, frail oldest old with MCI, frail oldest old without MCI, and frail elderly with dementia. By comparing these four different groups, we sought to elucidate the possible differences in dual-task costs associated with physical frailty and mild and severe cognitive impairment. We hypothesized that the dual-task costs would be prominent in the frail elderly and even greater in frail elderly with MCI or dementia.

Methods

Experimental design

To verify the influences of frailty syndrome, mild cognitive impairment, and dementia on the costs imposed by dual-task walking, we designed a cross-sectional study to compare the following four groups of oldest old (i.e., individuals aged 80 or older) populations performing gait tasks: robust, frail, frail + MCI, and frail patients with dementia after long-term physical restraint. Therefore, gait abilities with and without dual-task conditions (i.e., verbal or arithmetic tasks) were assessed in different tests, and the performances in these different conditions were compared across the different oldest old groups. The study participants were assessed in their institutions on different occasions, and prior to data collection, the participants participated in a familiarization procedure for each test.

Participants

The participants were institutionalized oldest old patients from Tudela and Pamplona (Spain) who were older than 75 years. Seventy elderly subjects completed an ethical consent form, met the necessary requirements to join the study, and participated in the study. After completing the clinical and cognitive evaluations, the 64 elderly men and women were ultimately categorized into one of the following four groups: the frail without MCI group (age 93.4 ± 3.2 years, $n=20$); the frail with MCI group (frail + MCI, age 92.4 ± 4.2 years, $n=13$), the robust group (age 88.2 ± 4.1 years, $n=10$), and the dementia group after long-term physical restraint (age 88.1 ± 5.1 years, $n=21$) (Fig. 1). Six individuals dropped out due to medical complications (three from frail + MCI, and three from dementia group). The participants were included in the appropriate study groups according

to the Fried criteria of frailty or robustness (Fried et al. 2001), the MCI consensus definition provided by Windbland et al. (2004), and dementia diagnoses according to the international standards for Alzheimer's disease multifactorial cause or vascular dementia. The Fried criteria of frailty were determined based on the presence of three or more of the following components: slowness, weakness, weight loss, exhaustion, and low physical activity (Fried et al. 2001). Specifically, physical activity was assessed using a version of Minnesota Leisure Time Activities Questionnaire (Taylor et al. 1978) ascertained physical activities in the prior 2 weeks, plus frequency and duration; weight loss, unintentional of ≥ 5 kg in prior year or, at follow-up, of $\geq$ of body weight when measured in prior year; weakness was assessed by grip strength values lower than percentile 20 %, adjusted for gender and body mass index; exhaustion was self-reported, identified by two questions

Fig. 1 Flowchart for screening, recruitment, allocation, and assessment

from the Center for Epidemiologic Studies Depression (CES-D) scale (Orme et al. 1986); and, slowness was considered as time to walk 5 m lower than percentile 20 % of the population, adjusting for gender and standing height. Robust subjects were institutionalized oldest old who did not match any of Fried criteria, had Barthel index greater than 60, and were able to walk independently. The specific recommendations for the general MCI criteria include the following: (i) the person is neither normal nor demented, (ii) there is evidence of cognitive deterioration exhibited as an objectively measured decline over time or subjective report of decline by the participant and/or an informant in conjunction with objective cognitive deficits, and (iii) the activities of daily living are preserved, and complex instrumental functions are either intact or minimally impaired (Windblad et al. 2004). The participants fulfilled the criteria for MCI if they had subjective memory complaints, they and/or a family member reported cognitive deterioration, they exhibited objective memory impairments in cognitive tests with the absence of significant functional impairments, and they did not have clinical dementia. The diagnosis of dementia was based on medical history, clinical examination, cerebral imaging, an established neuropsychological test battery [Consortium to Establish a Registry for Alzheimer's Disease (CERAD)], the Trail-Making Test and a Clinical Dementia Rating (CDR) (Morris et al. 1993) of 1; thus, the diagnoses of different types of dementia were allowed. Prior to the study, all of the participants underwent a medical assessment. The CDRs of the patients of the present study were between 1 and 2. All of the patients with dementia had experienced at least 9 months of physical restraint (14 ± 3 months) defined as any limitation of an individual's freedom of movement (Hantikainen 1998; Hamers and Huizing 2005) including restraints worn by the person (belts and chest and arm/leg restraints) and those attached to beds (full-enclosure bed rails) or chairs (locked table) (Gulpers et al. 2010). The complete physical characteristics of the participants are presented in Table 1. In the frail groups, the exclusion criteria were the absence of frailty, dementia (dementia group), recent cardiac arrest, unstable coronary syndrome, active cardiac failure, cardiac block, or any unstable medical condition. In the groups without dementia, the exclusion criteria included dementia, disability (defined as a Barthel index lower than 60), and the inability to walk independently. All subjects or their legal guardians agreed to participate in the trial

and completed an ethical consent form. The study was conducted according to the Declaration of Helsinki and was approved by the Ethics Committee of the Public University of Navarra, Spain.

Gait ability and dual-task performance

Gait ability was assessed using the 5-m habitual gait velocity test and the timed-up-and-go (TUG) test. These tests have been extensively used to assess gait ability (Freiberger et al. 2012; Cadore et al. 2013; Casas-Herrero et al. 2013; Martínez-Ramírez et al. 2015). The starting and ending points were marked on the floor with tape lines and included a total distance of 7 m. The first and last meters, i.e., the warm-up and deceleration phases, respectively, were not included in the calculations for the gait assessments. The TUG test consisted of measuring the time required to perform the task of standing up from a sitting position in a chair, walking three meters, turning, returning to the chair, and sitting down. The dual-task paradigm was applied in the 5-m habitual GVT and the TUG test. Two trials were used to measure gait velocity while performing a verbal or counting task. During the verbal fluency dual-task condition, we measured the gait velocity while the participants named animals aloud. During the arithmetic dual-task condition, we measured gait velocity while the participants counted backward aloud from 100 by ones. Because the patients with dementia were not able to perform the TUG test in the dual-task conditions, only the robust, frail, and frail + MCI participants were compared in terms of dual-task performance on the TUG test. Dual-task cost in both 5-m habitual gait velocity test and TUG test was calculated by the time differences between single and dual-task performance. The test-retest reliability coefficients (ICC) were over 0.85 for all gait velocity and TUG variables.

Statistical analysis

The descriptive results are reported as the means $\pm$ SDs. The SPSS statistical software package (version 17.0) was used to analyze all of the data. Normal distribution and homogeneity parameters were verified with the Shapiro-Wilk and Levene tests, respectively. The differences between groups were assessed using two-way analyses of variance (ANOVAs) (condition vs. group) with Tukey's post hoc tests. Significance was defined as $P < 0.05$.

Table 1 Physical characteristics. Mean $\pm$ SD

	Frail + MCI ($n=13$)	Frail ($n=20$)	Robust ($n=10$)	Dementia ($n=21$)
Age (years)	92.4 $\pm$ 4.2	93.4 $\pm$ 3.2	88.2 $\pm$ 4.1	88.1 $\pm$ 5.1
Women/men	9/4	14/6	6/4	9/12
Body mass (kg)	60.8 $\pm$ 7.7	52.3 $\pm$ 12.7	60.5 $\pm$ 7.8	63.8 $\pm$ 9.7
Height (cm)	154.3 $\pm$ 6.8	151.8 $\pm$ 11.7	152.2 $\pm$ 2.2	157.8 $\pm$ 8.7
Body mass index (kg.m ⁻²)	24.7 $\pm$ 3.8	21.4 $\pm$ 3.8	28.3 $\pm$ 4.7*	24.8 $\pm$ 3.0
Schooling level				
Basic uncompleted	2	5	2	5
Basic completed	8	11	6	8
High school completed	2	3	1	6
College complete	1	1	1	2
MEC	23.0 $\pm$ 2.5 [‡]	28.8 $\pm$ 2.9	31.0 $\pm$ 2.6	13.3 $\pm$ 6.3 [†]
CDR	—	—	—	1
5-m gait test (m.s ⁻¹)	0.80 $\pm$ 0.16	0.69 $\pm$ 0.25	1.31 $\pm$ 0.21*	0.36 $\pm$ 0.18 [†]
TUG (s)	20.1 $\pm$ 7.6	19.2 $\pm$ 6.5	9.8 $\pm$ 2.1*	62.7 $\pm$ 38.5 [†]

CDV included hypertension or other cardiovascular disease, included cerebrovascular disease. However, in the robust group, CDV included only hypertension. MEC Mini-Examen Cognoscitivo. CDR Clinical Dementia Rating. *Significant difference from frail groups ($P<0.001$).

[‡]Significant difference from frail, robust, and dementia groups ($P<0.01$). [†]Significant difference from the other groups ($P<0.01$)

Results

Five-meter gait ability test

The results of 5-m gait ability tests are shown in Fig. 2. The robust group exhibited better 5-m gait test performances in the single and dual-task conditions compared with the other three groups ($P<0.001$), and the frail and frail + MCI groups exhibited better performances than the dementia group ($P<0.001$). No significant differences were observed between the frail and frail + MCI groups. Comparison of the gait ability test with and without the arithmetic task revealed significant condition ($P<0.001$) and group effects ($P<0.001$), whereas no significant condition $\times$ group interaction was observed. All four groups exhibited lower gait velocities in the arithmetic task conditions, but the decrements of the groups (i.e., the dual-task costs) were similar. Regarding the gait ability test with the verbal task, significant condition ($P<0.001$) and group effects ($P<0.001$) and a condition $\times$ group interaction ($P<0.05$) were observed. However, analyses of the four groups individually revealed that all groups exhibited lower gait velocities in the verbal task conditions, but the decrements of the groups were similar.

Timed-up-and-go test

The results of TUG tests are shown in Fig. 3. The robust group exhibited better TUG performances compared with the other groups ($P<0.001$), and the frail and frail + MCI groups exhibited better performances than the dementia group ($P<0.001$) (as mentioned in the *Methods* section, comparisons between dementia group and the other groups in the TUG performance were made only in the single-task condition—Table 1). No significant differences were observed between the frail and frail + MCI groups. Regarding the dual-task performances, there were significant differences between the groups in the TUG test with the verbal and arithmetic tasks; the robust group exhibited significantly better performances than the frail and frail + MCI groups ($P<0.001$). Comparisons of the TUG tests with and without the arithmetic task revealed significant condition ($P<0.001$) and group effects ($P<0.001$), but no significant condition $\times$ group interaction was observed. All groups exhibited worse TUG performances in the arithmetic task conditions, but the groups' decrements (i.e., dual-task costs) were similar. Regarding the TUG task with and without the verbal task, significant condition ($P<0.001$) and group effects ($P<0.001$) were

Fig 2 5-m gait velocity test ($\text{m}\cdot\text{s}^{-1}$) (mean $\pm$ SD) in frail + mild cognitive impairment (MCI), frail, robust, and dementia groups. Different letters (*a*, *b*, and *c*) denote differences between groups in each condition ($P<0.001$). *Significant difference from dual task conditions ($P<0.001$)

observed, but there was no condition $\times$ group interaction. All of the groups had poorer TUG performance in the verbal task condition, but the groups' decrements (i.e., dual-task costs) were similar.

Discussion

The main finding of the present study is that all four groups exhibited dual-task costs related to the arithmetic and verbal tasks and that the dual-task costs were similar in all groups. Additionally, the robust individuals exhibited better single and dual-task walking performances than the other three groups, and the frail and frail + MCI individuals exhibited better performances than the patients with dementia. Surprisingly, no significant differences were observed between the frail and frail + MCI groups. These results indicated that the performances related to the dual-task costs were likely independent of the MCI level.

Frailty syndrome is an independent predictor of a decline in cognitive function (Samper-Ternent et al.

2008), and frail individuals have an increased risk of becoming cognitively impaired. This impairment in cognition is more severe in frail subjects over time than in non-frail subjects (Buchman et al. 2007; McGough et al. 2011; Samper-Ternent et al. 2008). Additionally, poor physical outcomes, such as reduced gait velocity and muscle weakness, are associated with cognitive impairment (Samper-Ternent et al. 2008), and these outcomes are physical domains of frailty (Garcia-Garcia et al. 2011). In the present study, we aimed to investigate the possible differences in dual-task costs (i.e., decreases in performance when elderly participants switch from a single to a dual task) (Montero-Odasso et al. 2012) between four groups differentiated by frailty status and cognitive impairment level. A possible explanation for the lack of differences in the functional tests between the frail individuals with and without MCI is that cognitive impairment and frailty are different entities that lie on the same spectrum of disease. Several authors have included cognitive decline in the frailty phenotype because the conditions have similar

Fig 3 Timed-up-and-go test (s) (mean $\pm$ SD) in frail + cognitive impairment (MCI), frail, and robust groups. Different letters (*a* and *b*) denote differences between groups in each condition ($P<0.001$). *Significant difference from dual task conditions ($P<0.001$)

pathophysiologies, similar consequences (e.g., falls, hospitalization, institutionalization, and disability), and similar responses to interventions, such as exercise (Cadore et al. 2013, 2014a, b; Fried et al. 2001; Garcia-Garcia et al. 2011; Hantikainen 1998). Based on tests utilizing dual-task conditions, MCI gait impairments have recently been categorized (i.e., slowing gait velocity and increased gait variability) and exhibited specific associations with executive function and the risk of falls (Maquet et al. 2010; Montero-Odasso et al. 2012). This categorization of gait impairments has not yet been studied among frail and frail + MCI patients using the dual-task paradigm. Recently, Montero-Odasso et al. (2012) reported that frailty is associated with poor performances in several quantitative gait parameters other than velocity, including high stride time gait variability. Additionally, this latter variable is the most sensitive and is a stronger marker of the risk of falls than gait velocity (Maquet et al. 2010; Montero-Odasso et al. 2012). Indeed, it has been reported that decreases in gait velocity due to arithmetic tasks (i.e., dual-task costs) during the TUG test are strongly associated with the risk of falls in frail individuals ($r=0.78$, $P<0.01$) (Casas-Herrero et al. 2013). From this perspective, we hypothesized that the dual-task cost would be greater in the frail individuals and even greater in the individuals with cognitive impairments; however, these associations were not observed in the present study.

It should be highlighted that although no differences in the dual-task cost were observed between the robust and frail groups, the 5-m gait velocity was greater and the TUG time were quite smaller in the robust group in all conditions (i.e., single and dual tasks), which suggests that this group is at a lower risk of falls than the other groups. Furthermore, when compared with the individuals with dementia, the subjects who were frail and with or without MCI exhibited similar decreases in gait ability when switch from a single to a dual-task conditions, but had better performances in all conditions. Indeed, it has been previously shown dementia is associated with very poor physical performance associated with several causes including a severe decline in physical activity levels (Berzlanovich et al. 2012; Gulpers et al. 2010; Zwijsen et al. 2011).

The superior gait performance observed in the robust individuals indicates that poor physical outcomes and dependency are not inevitable consequences of aging

even in the oldest old. Indeed, older adults who practice healthy lifestyles, avoid sedentariness, participate in physical exercise (e.g., walking, strength training, or self-adjusted physical activity), and utilize clinical preventive services are more likely to remain healthy, maintain functionality, and live independently (Cadore et al. 2013; Izquierdo and Cadore 2014).

A possible limitation of the present study could be the sample size, and one could suggest our study was under-powered to detect small differences in the dual-task tests between frail and frail + MCI patients. However, it should be mentioned that the individuals included in this study were institutionalized frail (or robust) adults that are a very special population at greater risk of falls, and our data expand the knowledge regarding influence of frailty and cognitive impairment at different levels in the dual-task cost during walking in these subjects.

Conclusions

In summary, the robust individuals exhibited superior single and dual-task walking performances than the other three groups, and the frail and frail + MCI individuals exhibited performances that were superior to those of the patients with dementia. However, the dual-task costs, i.e., the changes in gait performance when elderly participants switch from a single to a dual task, were similar among all four of the investigated groups. Our results expand the knowledge related to the influences of frailty, cognitive impairment, and dementia on dual-task gait performance because they demonstrated that the magnitude of the impairment in gait pattern is independent of frailty and cognitive impairment status.

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Compliance with ethical standards All subjects or their legal guardians agreed to participate in the trial and completed an ethical consent form. The study was conducted according to the Declaration of Helsinki and was approved by the Ethics Committee of the Public University of Navarra, Spain.

Conflict of interest The authors declare that they have no competing interests.

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