Human Movement Science 89 (2023) 103095

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Interrelation between functional decline and dementia: The potential role of balance assessment

Francesca Biasin [a,1], Chiara Ceolin [a,1,*], Silvia Celli [c], Camilla Terziotti [a], Cecilia Raffaelli [a], Cristiano Bontempi [a], Maria Devita [a,b], Marina De Rui [a], Giuseppe Sergi [a], Alessandra Coin [a]

[a] Department of Medicine (DIMED), Geriatrics Division, University of Padua, Padua, Italy
[b] Department of General Psychology (DPG), University of Padova, Padua, Italy
[c] Department of Internal Medicine, Azienda USL Toscana Centro, Mugello Hospital, Borgo San Lorenzo, Italy

ARTICLE INFO

Keywords:
Older adults
Cognitive impairment
Dementia
Physical performance
MoCA
MMSE
Tinetti test

ABSTRACT

Objective: There has been growing interest in the past few years on the relationship between impairment of motor functions and cognitive decline, so that the first can be considered a marker of dementia. In MCI patients, the deficit in processing visual information interferes with postural control, causing oscillations and instability. Postural control is usually evaluated through the Short Physical Performance Battery (SPPB) test or Tinetti scale, but, to our knowledge, there are no many studies that considered the Biodex Balance System (BBS) in the evaluation of postural controls in MCI patients. The aim of this study was first to confirm the bi- directional relationship between cognitive and motor performance, and then to compare traditional evaluation scales (SPPB and Tinetti) with a biomechanical tool, the BBS.
Materials and methods: Observational retrospective study. In 45 elderly patients with cognitive impairment we evaluated cognition, assessed with the MMSE and MoCA, malnutrition with the MNA, and sarcopenia with DEXA (ASMMI). Motor performance was assessed with SPPB, Tinetti, and BBS.
Results: MMSE correlated more with BBS than with the traditional scales, while MoCA was also correlated with SPPB and Tinetti scores.
Conclusions: BBS had a stronger correlation with cognitive performance compared with the traditional scales. The relationship between MoCA executive items and the BBS tests suggests the usefulness of targeted interventions involving cognitive stimulation to improve motor performance, and motor training to slow the progression of cognitive decline, particularly in MCI.

1. Introduction

Postural control is defined as the ability to maintain or recover balance during static or dynamic activity. It requires integration of the somatosensory, neuromuscular and proprioceptive systems, and plays a primary role in reducing the risk of falling. Postural control is of fundamental importance in the elderly, as it is intrinsically involved in numerous daily activities, such as walking, dressing or

* Corresponding author at: Department of Medicine (DIMED) Geriatrics Division, University of Padua, Via Giustiniani 2, Padua 35128, Italy.
E-mail address: chiara.ceolin.1@studenti.unipd.it (C. Ceolin).
[1] These authors contributed equally to the work.

https://doi.org/10.1016/j.humov.2023.103095
Received 3 September 2022; Received in revised form 3 April 2023; Accepted 24 April 2023
Available online 29 April 2023
0167-9457/

driving a car. Balance and coordination are complex functions, controlled by specific cognitive areas (Montero-Odasso et al., 2014). With aging, the decline in motor functions increases, and this process seems, in particular, to expose individuals to a greater risk of dementia (Morris, Lord, Bunce, Burn, & Rochester, 2016). Motor and cognitive declines influence each other, increasing the probability of falls, fractures and disabilities, which increase the overall frailty of the subject with cognitive impairment (Means & O'Sullivan, 2000).

Given that the impairment of motor functions is a marker of cognitive decline (Marquis et al., 2002; Waite et al., 2005), there has been increasing interest in recent years in gaining a better understanding of cerebro-muscular loop and in the search for new disability prevention strategies based on this association (Basile & Sardella, 2021). One of the most accredited hypotheses concerning this system is that neurodegenerative damage, chronic inflammation, metabolic/oxidative stress, and lifestyle and psycho-social factors are common determinants of both cognitive and motor decline (Grande et al., 2019; Takakusaki, 2017; Tian et al., 2017). Furthermore, motor, cognitive, and sensory functions benefit from cognitive stimulation (for example physical exercise and cognitive training), which positively affects the functional compensation mechanisms and the evolution of neuropathology (Li, Bherer, Mirelman, Maidan, & Hausdorff, 2018). In support of this, a recent meta-analysis showed that patients with mild cognitive impairment (MCI) had a lower walking speed than healthy individuals when performing one or two cognitive tasks (Bahureksa et al., 2016), and also had an impairment of balance. Walking speed is one of the most commonly used tests for evaluating functional autonomy, and is considered a predictor of adverse outcomes, such as falls and mortality; furthermore, it is likely that the deficit in processing visual information that is common in MCI interferes with postural control, causing oscillations and instability (Bahureksa et al., 2016). Postural control is currently estimated with clinical scales for assessing balance, i.e. the Tinetti scale, the Short Physical Performance Battery (SPPB), and the Berg Balance Scale, which have been extensively validated for geriatric populations and are easily repeatable in hospitalized patients and outpatients. Bio-mechanical tools have recently appeared, such as the Biodex Balance System (Biodex Medical Systems, Shirley, NY), which uses a computerized stabilometric platform to analyze changes in the center of gravity under static and dynamic conditions. This device is also useful for assessing balance in young individuals with better cognitive functions (Hinman, 2000).

In light of all this, it is reasonable to expect that a better understanding of the common mechanisms underlying cognitive and motor decline will allow new potential areas of intervention for the prevention of cognitive and functional disability in the elderly to be identified. The aim of this study was first to confirm the bi-directional relationship between cognitive and motor performance, and to compare traditional evaluation scales (SPPB and Tinetti) with a biomechanical tool, the Biodex Balance System (BBS). We then aimed to identify a method for detecting motor decline, especially in individuals with MCI, and also as a possible intervention to slow the progression of cognitive decline.

2. Materials and methods

2.1. Study population

This observational retrospective study was conducted on 45 elderly patients with different degrees of cognitive impairment. Participants were recruited from January 2019 to January 2020 among patients accessing the Centre for Cognitive Disorders and Dementia (CDCD), and were evaluated by a team of specialists at the Geriatric Unit of the same University Hospital. All participants were diagnosed according to standard clinical criteria (NINCDS-ADRDA).

Inclusion criteria were aged 70 years or older and the ability to perform the requested tasks. Exclusion criteria were severe depressive and anxiety disorders, visual and auditory deficits, osteo-articular limitations, hypokinetic syndrome, balance-related diseases, postural hypotension, neurological disorders and invalidating neurological sequelae.

The study protocol was conducted according to good clinical practice guidelines and the ethical standards of the 1964 Declaration of Helsinki as revised in 2000. The study protocol was approved by the local Ethics Committee (protocol number 5234/AO/21). The individuals participating in this study received a thorough explanation of the risks and benefits of inclusion and gave their oral and written informed consent to publish the data.

2.2. Data collection

The following information on each participant was collected by trained physicians, either retrospectively from medical records, or through personal interviews and physical examination.

Cognitive evaluation: The Mini-Mental State Examination (MMSE; (Folstein, Folstein, & McHugh, 1975; Magni, Binetti, Bianchetti, Rozzini, & Trabucchi, 1996)) and the Montreal Cognitive Assessment (MoCA; (Nasreddine et al., 2005)). MMSE is a widely-used test to assess the presence of cognitive impairment in older people. It takes only 10–15 min to administer, although it is not timed, and provides a reliable measure of cognitive impairment and the progression of dementia. The maximum total score is 30 with a score of <24 indicating impairment. Scores are adjusted for age and education. MoCA is a one-page, 30-point test administered in 10 min, which covers the following eight cognitive domains: visuospatial/executive functions, naming, verbal memory registration and learning, attention, abstraction, delayed verbal memory, and orientation. It has been shown to have high sensitivity and specificity as a cognitive screening instrument, and has been validated to detect MCI. The normative data were referred to Santangelo et al. (Santangelo et al., 2015).

Nutritional evaluation: The Mini Nutritional Assessment-Short Form (MNA-SF; (Kaiser et al., 2009)). This is a validated questionnaire, which was administered to participants, or in the case of cognitive impairment, to the patient's caregiver or dietician.

Functional performance: The degree of disability was investigated in terms of the number of Activities of Daily Living (ADL; (Katz, 1983)) and Instrumental Activities of Daily Living (IADL; (Millán-Calenti et al., 2010)) that participants could still manage without assistance.

Body composition. Total body dual-energy X-ray absorptiometry (DXA) examinations were used to measure lean or fat-free mass (FFM), fat mass (FM), and appendicular skeletal muscle mass (ASMM). The ASMM index (ASMMI) was calculated as the ASMM divided by body height in meters squared (Baumgartner et al., 1998).

Physical performance tests. The Short Physical Performance Battery (SPPB; (Pavasini et al., 2016)), the Tinetti Performance-Oriented Mobility Assessment tool (POMA or the Tinetti scale; (Köpke & Meyer, 2006; Tinetti, 1986)), the Biodex Balance System (BBS; (Arnold & Schmitz, 1998; Clark, Rose, & Fujimoto, 1997; Hinman, 2000; Prometti et al., 2016)). SPPB comprises standing balance tests (side-by-side stands, semi-tandem test, and tandem test), gait speed measurement, and timed chair stands test, generating scores between 0 and 12, with higher scores indicating better physical performance. The Tinetti Scale assesses motor performance with regard to balance and gait: the scores for each part, a maximum 16 of for balance, and 12 for gait, are combined to obtain an overall score (maximum 28). BBS, which can be used for both training and testing, measures postural stability in static and dynamic conditions. A computerized stabilometric device measures the individual's ability to maintain the center of gravity along the anterior-posterior (AP) and medial-lateral (ML) axes. The scores generated by the device represent the body's deviation from the center, and are averaged to obtain a General Stability Index (ISG): the higher the index, the worse the performance (greater deviation reflects lower stability) (Arnold & Schmitz, 1998). Apart from this, which is the primary outcome, BBS also measures dynamic control with the Limits of Stability test (LOS), in which the patient moves his/her center of gravity towards nine targets displayed on a screen, without moving the feet, aiming for maximum speed and minimal deviation (Clark et al., 1997). The LOS provides information about balance assessment in a dynamic task: it quantifies the ability to intentionally displace the center of gravity to the patient's stability limits without losing balance, representing a good measure of personal directional control (DC), both general and in specific directions, with higher scores meaning better performances (Hinman, 2000). In the Risk of Falling test the patient has to maintain postural stability on an unstable surface (Prometti et al., 2016).

2.3. *Statistical analyses*

Statistical analyses were performed with SPSS 25 for Windows (SPSS Inc., Chicago, Illinois). Patients' characteristics were expressed as means ± standard deviation for continuous variables, and as counts and percentages for categorical variables. Normality of distribution for the continuous variables was checked with the Kolmogorov-Smirnov test. Differences between mean values were analyzed with a Student's unpaired *t*-test, and between categorical variables with a Chi-square test. Data on the two groups (D and MCI) were analyzed with the U-Mann Whitney test for independent samples, and on the four groups of patients classified by MMSE and MoCA score quartiles with the Kruskall-Wallis test. The Bonferroni correction for multiple comparisons was used. Pearson's correlation coefficients (r) were calculated for normally distributed variables, and Spearman's rank correlation coefficients (rs) for non-normally distributed variables. Partial correlations in all individuals were adjusted for malnutrition, sarcopenia, age, and sex. Significance was assumed at $p \leq 0.05$ for all analyses.

3. Results

The characteristics of our sample at baseline are reported in Table 1. We analyzed 45 individuals (20 males and 25 females) with a mean age of 79.9 ± 4.2 years, 14 of whom had MCI, 31 dementia. Those with dementia scored as follows in the cognitive evaluation:

Table 1
Characteristics of the sample at baseline.

	Dementia *N* = 31	MCI *N* = 14	*p*-value
Age [years]	80.29 ± 4.30	79.29 ± 4.02	0.67
BMI [Kg/m^2]	25.92 ± 4.03	26.20 ± 3.05	0.53
Cognitive evaluation			
MMSE	20.2 ± 3.74	27.53 ± 1.65	<0.001
MOCA	13.03 ± 5.08	21.36 ± 6.03	0.01
Clock test	3.55 ± 3.10	7.53 ± 2.46	<0.001
Nutritional evaluation			
MNA-SF	24.62 ± 2.43	26.71 ± 1.70	*0.02*
Study of sarcopenia			
ASMMI	6.32 ± 1.16	6.52 ± 1.36	0.27
Sarcopenia [n (%)]	11 (35.5%)	4 (28.6%)	0.28
Functional autonomy			
ADL	4.10 ± 1.33	5.50 ± 1.10	0.65
IADL	3.50 ± 2.54	5.64 ± 2.34	0.31

Notes: Numbers are mean ± SD, median (interquartile range), or count (%), as appropriate.
Abbreviations: BMI = body mass index; MMSE = Mini Mental State Examination; MOCA = Montreal Cognitive Assessment; MNA-SF = Mini Nutritional Assessment-Short Form; ASMMI=Skeletal Appendicular Muscle Mass Index; ADL = Activities of Daily Living; IADL = Instrumental Activities of Daily Living.

MMSE 20.2 ± 3.74, MoCA 13.03 ± 5.08, Clock test 3.55 ± 3.10. There were no statistically significant differences between the two groups in terms of weight, height, body mass index (BMI), and functional autonomy scores (ADL and IADL). Nutritional status was better in MCI than in dementia patients (26.71 ± 1.70 vs 24.62 ± 2.43, $p = 0.02$). Rates of sarcopenia were 35.5% in the dementia group, and 28.6% in the MCI group, although there were no significant differences in ASMMI values.

Motor performance analysis revealed that patients diagnosed with dementia had worse scores on SPPB, and the Tinetti scale (Graph 1). A more in-depth analysis, performed by dividing the sample into 4 categories on the basis of MMSE score quartiles, showed significant variations between groups only when assessed for balance with the Tinetti scale, and none with the SPPB test (data not shown). Regarding BBS, significant differences emerged between patients with the best and worst MMSE scores in the postural stability tests, whether general ($p = 0.007$) or along the anterior-posterior ($p = 0.005$) or medial-lateral ($p = 0.006$) axes, and in the time required to complete the test of stability ($p = 0.022$), data not shown.

Table 2 reports the SPPB and Tinetti test scores broken down by MoCA score quartiles. Patients with greater cognitive impairment did worse on both the SPPB and Tinetti motor performance tests. In the BBS tests, the overall stability index ($p = 0.008$), the anterior-posterior ($p = 0.01$) and medial-lateral ($p = 0.001$) stability indices, and the right directional control index ($p = 0.04$) were significantly lower in cognitively impaired patients.

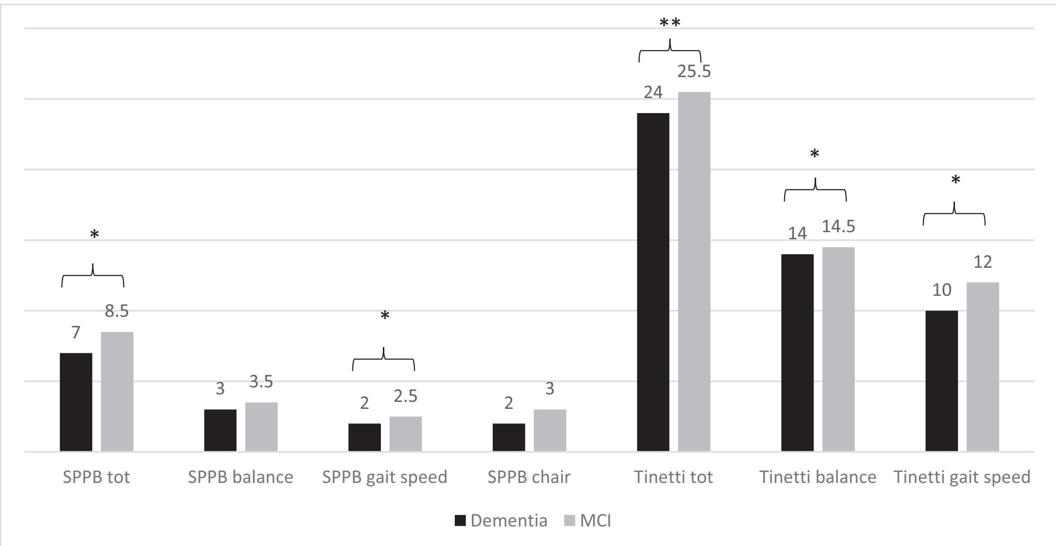
The total scores on the MMSE, and the scores for temporal orientation were correlated with SPPB gait speed scores after correction for age, sex, MNA and ASMMI ($r = 0.41$, $p = 0.02$, and $r = 0.54$, $p = 0.001$, respectively). Balance measured with the Tinetti scale was correlated with the time orientation task in the MMSE ($r = 0.34$, $p = 0.05$). MMSE scores were related to the ISG and total LOS scores (Table 3, Graph 2) after correction for age, sex, MNA and ASMMI. There were also positive correlations between MMSE and LOS scores in the right ($r = 0.38$, $p = 0.031$), forward-left ($r = 0.43$, $p = 0.012$), forward-right ($r = 0.39$, $p = 0.027$), and back-right ($r = 0.36$, $p = 0.042$) directions. The MMSE item most correlated with the BBS tests was attention (data not shown).

Total MoCA scores were related to total SPPB ($r = 0.50$, $p = 0.004$), and SPPB gait speed ($r = 0.45$, $p = 0.01$) and sit to stand tests ($r = 0.40$, $p = 0.020$) after correction for age, sex, MNA and ASMMI. The visuospatial and denomination domains of MoCA evidenced this association most clearly, and these were also significantly correlated with the Tinetti scale ($r = 0.42$, p = 0.01, and $r = 0.41$, p = 0.02, respectively for total Tinetti; $r = 0.43$, p = 0.01, and $r = 0.46$, $p = 0.007$, respectively, for Tinetti gait speed.

Finally, MoCA scores were significantly correlated with postural stability test scores, and with LOS scores for general directional control and the specific directions (Table 3, Graph 2). The MoCA domains with the most evident correlations with the motor tests were the visuospatial ($r = 0.37$, $p = 0.003$ with LOS right and forward-left), naming (r = 0.46, p = 0.007 with LOS forward-left; $r = 0.04$, p = 0.003 with LOS back-left and back-right), and language (r = 0.04, p = 0.003 with LOS total, left, right, back-left; $r = 0.53$, $p = 0.001$ with LOS forward-left; $r = 0.34$, $p = 0.05$ with LOS back-left). Risk of falling was associated only with MoCA naming ($r = -0.35$, p = 0.05).

4. Discussion

Our study shows that patients in advanced stages of cognitive impairment have greater difficulty in postural control, and are therefore more vulnerable to the risk of falls, which can be quantified with the Biodex Balance System (BBS). Regardless of the type of test used to diagnose cognitive impairment, the BSS is able to generate a profile of the patient with compromised stability and directional control in space.



Graph 1. Differences between the two groups in motor tests with the SPPB and Tinetti scales.
* = $p < 0.05$; ** = $p < 0.01$.

Table 2
Physical performance test scores in the sample, divided by MOCA quartiles.

Variable	MOCA ≤ 10 *N* = 13	11 ≤ MOCA ≤ 15 *N* = 9	16 ≤ MOCA ≤ 21 *N* = 11	MOCA ≥ 22 *N* = 12	p-value
SPPB balance	2.50 (0–4)	3 (1–4)	3 (1–4)	4 (1–4)	0.67
SPPB gait speed	2 (1–3)	2 (1–4)	2 (1–4)	3.50 (2–4)	***0.001***
SPPB sit to stand	2 (0–4)	2 (1–4)	1 (1–4)	4 (1–4)	***0.01***
SPPB total	5.50 (1–9)	7 (5–11)	7 (3–12)	10.50 (4–12)	***0.002***
Tinetti balance	13 (4–16)	14 (12–16)	14 (8–16)	16 (10–16)	***0.04***
Tinetti gait speed	8.50 (3–12)	11 (6–12)	10 (2–15)	12 (8–12)	***0.02***
Tinetti total	21 (7–26)	24 (20–28)	24 (13–28)	28 (18–28)	***0.009***
ISG	3.10 (0.30–12.50)	1 (0.30–4.10)	1.10 (0.40–3.40)	0.70 (0.24–1.04)	***0.008***
ISG A-P	2.8 (0.30–9.60)	0.90 (0.30–6)	0.80 (0.30–1.01)	0.50 (0.20–2.70)	***0.01***
ISG M-L	1.30 (0.10–7.90)	0.60 (0.10–3.10)	0.60 (0.20–2.50)	0.20 (0.10–0.90)	***0.001***
LOS total	17 (11–54)	27 (10–62)	40 (14–84)	50 (10–91)	0.35
LOS forward	45 (9–62)	44 (18–89)	50 (3–93)	52 (12–88)	0.47
LOS back	20 (13–18)	31 (13–99)	58 (22–91)	51.5 (5–99)	0.52
LOS left	39 (27–90)	58 (6–93)	66 (26–90)	68 (11–98)	0.56
LOS right	36 (27–56)	54 (16–88)	49 (14–97)	71.50 (32–97)	***0.04***
LOS forward-left	34 (11–64)	59 (14–71)	46 (23–76)	60 (23–92)	0.33
LOS forward -right	32 (20–77)	33 (18–76)	56 (18–87)	64 (11–94)	0.76
LOS back-left	37 (14–67)	40 (16–63)	59 (15–90)	57 (7–98)	0.45
LOS back-right	20 (9–68)	26 (8–91)	54 (16–78)	62.5 (13–95)	0.24
Risk of falling	1.60 (0.50–2.40)	2.15 (0.60–35)	1.40 (0.30–2.2)	0.65 (0.30–3.7)	0.11

Notes: Numbers are mean ± SD, median (interquartile range), or count (%), as appropriate.
Abbreviations: SPPB = Short physical performance battery; ISG = General Stability Index; ISG A-P = General Stability Index Anterior-Posterior; ISG M-L = General Stability Index Medial-Lateral; LOS = Limits Of Stability test.

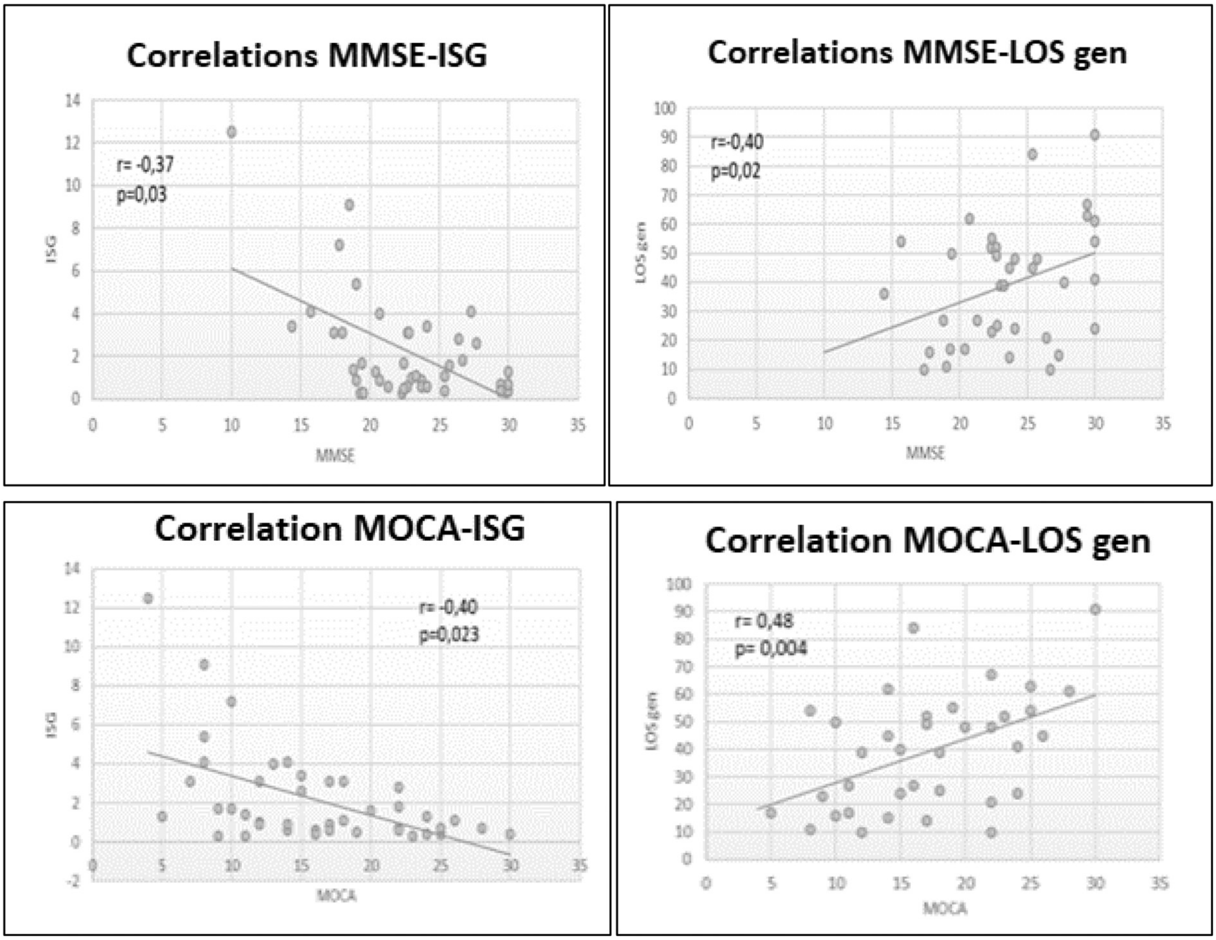
Table 3
Pearson's correlations and confidence intervals between cognitive evaluation tests and General Stability Index and Limits Of Stability at the BBS.

	MMSE	**MoCA**
ISG	−0.37* (−1.63; −0.35)	−0.40* (−2.89;-0.22)
LOS	0.39* (0.03;0.18)	0.48** (0.08;0.31)
LOS right	0.38* (0.05;0.16)	0.48** (0.06;0.26)
LOS back-right	0.36* (0.02;0.15)	0.46* (0.04;0.25)
LOS forward-left	0.43* (0.01;0.15)	0.56** (0.07;0.27)

Abbreviation: ISG = General Stability Index; LOS = Limits Of Stability test. *p < 0.05; ***p* < 0.005; ****p* < 0.001.

Several authors have reported the association between cognitive impairment and motor impairment: Individuals with MCI and Alzheimer's disease are known to walk more slowly and have worse postural control than cognitively healthy individuals (Cohen, Verghese, & Zwerling, 2016; Montero-Odasso et al., 2014). The SPPB and Tinetti scales have been used in clinical practice for many years to assess physical performance. They are both widely validated, require minimally specialized operators, and are cost free (Pavasini et al., 2016). The SPPB scale is a non-specific, but very sensitive test (Pavasini et al., 2016), and a significant correlation between total SPPB scores and the functional status of elderly patients (ADL) has been reported in the literature, as well as the incidence of disability and hospitalization (Corsonello et al., 2012). It also appears to be predictive of mortality, in both hospital and community settings, regardless of age, gender and geographic area (Pavasini et al., 2016). In our study, SPPB scores showed good correlations with cognitive tests with respect to gait speed, but they were not significant for balance. This is probably due to the fact that, while the SPPB tests assess the functionality of the lower limbs, they do not provide a complete overview of the systems involved in maintaining balance. For this reason, the Tinetti scale seems a better predictive tool for falls, being also easy to complete and to administer (Tinetti, 1986). Furthermore, it provides a clinical assessment, and does not require standardized measures. Although various authors have recommended it to assess the risk of falls (Köpke & Meyer, 2006), some studies have shown that the gait section is not useful in this regard (Faber, Bosscher, & Van Wieringen, 2006). In our study, we found significant correlations between the Tinetti scale and some individual MoCA domains (visuospatial, naming). As this instrument is used for the clinical assessment of motor performance, it is likely less precise in detecting the minimal performance changes due to mild cognitive deficits. All in all, in our study there was wide variation in the correlations between the results of the traditional motor performance tests and the results of the cognitive assessment, regardless of whether the patients were evaluated with MMSE or with MoCA.

Analysis of our sample's scores on the BBS tests showed that the patients with the most advanced cognitive decline had the worst performances in static postural control (general stability test, and fall risk test), while in dynamic conditions their poorer performances were particularly evident in directional control towards partial targets. An individual's level of postural control in dynamic conditions is assessed with the stability limits test, which evaluates the subject's ability to direct his/her center of gravity towards an intended target (Clark et al., 1997), and measures the maximum degree to which the subject can move without losing his or her balance. Early detection of poor dynamic postural ability makes it possible to identify those individuals most at risk of falling (Glave, Didier,



Graph 2. Correlations between MMSE and General Stability Index (ISG) and Limits Of Stability (LOS) at the BBS.

Weatherwax, Browning, & Fiaud, 2016). In fact, falls are known to occur more frequently during postural transition or changes of direction (Lusardi et al., 2017). In our study, the stabilometric platform showed that patients with more advanced cognitive deterioration exhibited greater oscillation of the center of gravity, and greater difficulty in making fast linear movements. This is probably due, on the one hand, to poor planning and motor coordination resulting from the deterioration of cognitive processes, and, on the other hand, to difficulties in performing the task, attributable to deficits in understanding the commands and in attention. Curiously, we found stastically differences between MoCA quartiles and LOS right. It could be linked to the the presence of a high number of right-handed patients in our sample (data not shown): in patients with initial cognitive impairment, the compensatory mechanism of the left hemisphere is lost. It is possible that in individuals with better MoCA scores, the loss of visuo-spatial cognitive functions is compensated in both right and left directions. The presence of significant correlations between the scales for assessing cognitive impairment (MMSE and MoCA) and the BBS tests (static and dynamic), which were not found with the SPPB and Tinetti scales, shows that the stabilometric platform is able to more accurately describe the association between cognitive function and postural control, after excluding confounding factors such as age, sex, malnutrition and sarcopenia.

We hope that our results can stimulate further studies to see if BBS could represent the possibility of early detection of postural alterations. This in turn will allow targeted intervention at both the cognitive and motor levels to be offered. It seems that the declines in memory and physical performance have a common pathogenic substrate. In fact, episodic memory is supported by the same central brain areas as postural control (the hippocampus and fronto-hippocampal circuits, in addition to the prefrontal cortex and the striatum) (Montero-Odasso et al., 2014). Exercise has proven to be a valid tool for slowing the loss of volume of gray matter and for increasing the volume of the temporal lobe and hippocampus, slowing the progression of MCI into dementia, regardless of age (Erickson et al., 2010). In these circumstances, MoCA plays an important role in assessing executive functions, while the visuospatial, naming and language domains are particularly associated with motor functions. The relationship between these cognitive domains and the BBS tests suggests that cognitive stimulation interventions targeting executive functions could improve motor performance, and hence reduce the risk of falling.

Given confirmation of the bi-directional relationship between cognitive and motor functions, the BBS platform is not only a valid tool for identifying postural alterations, it can also be used in its training modality as a tool for alleviating cognitive symptoms through exercises that require the exploitation of planning, attention, and working memory.

Our study has several limitations: first of all, the small size of the sample, with impact in the statistical power of analysis, especially considering the correlations tests. We found correlations weak to moderate, although significative. Furthermore, it was not possible to apply the same measurements to controls healthy patients. On the other hand, strengths are the detection of patients with both dementia or cognitive impairment, which have been subjected to a complete evaluation of equilibrium and stability through three different tests.

4.1. Conclusions

Our results lend support to the importance of the BBS stabilometric platform in carrying out a comprehensive assessment of motor performance in elderly people with varying degrees of cognitive impairment. Compared to the traditional SPPB and Tinetti scales, BBS is significantly correlated with cognitive tests, and is less affected by socio-demographic factors and the presence of sarcopenia and malnutrition. Although it is not a screening instrument, it is useful for making a detailed assessment of motor performance, and for identifying early alterations, even in individuals with mild cognitive impairment. The BBS platform's training exercises would be highly suitable for improving both the motor and cognitive performances of such individuals. Expanding on the present case histories and adding to the data gathered so far will allow us to gain further insights in this area.

5. Statements

5.1. Statement of ethics

Study approval statement: The study protocol was conducted according to good clinical practice guidelines and the ethical standards of the 1964 Declaration of Helsinki as revised in 2000. The study protocol was approved by the local Ethics Committee (protocol number 5234/AO/21).

Consent to participate statement: The individuals participating in this study received a thorough explanation of the risks and benefits of inclusion and gave their oral and written informed consent to publish the data.

Funding sources

This research did not receive any specific grants from funding agencies in the public, commercial or not-for-profit sectors.

CRediT authorship contribution statement

Francesca Biasin: Writing – original draft, Data curation. **Chiara Ceolin:** Writing – original draft, Data curation. **Silvia Celli:** Investigation. **Camilla Terziotti:** Investigation. **Cecilia Raffaelli:** Investigation. **Cristiano Bontempi:** Investigation. **Maria Devita:** Supervision, Writing – review & editing. **Marina De Rui:** Supervision, Writing – review & editing. **Giuseppe Sergi:** Supervision, Writing – review & editing. **Alessandra Coin:** Supervision, Writing – review & editing.

Declaration of Competing Interest

There are no known conflicts of interest associated with this publication, and there has been no significant financial support for this work that could have influenced its outcome. The manuscript has been read and approved by all named authors, and there are no other persons who satisfy the criteria for authorship that are not listed. The order of authors listed in the manuscript has been approved by all of the authors. The Corresponding Author is the sole contact for the Editorial process. She is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. We confirm that we have provided a current, correct email address which is accessible by the Corresponding Author.

Data availability

All data generated or analyzed during this study are included in this article. Further enquiries can be directed to the corresponding author.

References

Arnold, B. L., & Schmitz, R. J. (1998). Examination of balance measures produced by the biodex stability system. *Journal of Athletic Training, 33*(4), 323–327 Accessed: May 13, 2022. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/16558529/ Accessed: May 13, 2022. [Online]. Available:.

Bahureksa, L., et al. (2016). The impact of mild cognitive impairment on gait and balance: A systematic review and Meta-analysis of studies using instrumented assessment. *Gerontology, 63*(1), 67–83. https://doi.org/10.1159/000445831

Basile, G., & Sardella, A. (2021). From cognitive to motor impairment and from sarcopenia to cognitive impairment: A bidirectional pathway towards frailty and disability. *Aging Clinical and Experimental Research, 33*(2), 469–478. Feb https://doi.org/10.1007/S40520-020-01550-Y. Feb.

Baumgartner, R. N., et al. (1998). Epidemiology of sarcopenia among the elderly in New Mexico. *American Journal of Epidemiology*. https://doi.org/10.1093/oxfordjournals.aje.a009520

Clark, S., Rose, D. J., & Fujimoto, K. (1997). Generalizability of the limits of stability test in the evaluation of dynamic balance among older adults. *Archives of Physical Medicine and Rehabilitation, 78*(10), 1078–1084. https://doi.org/10.1016/S0003-9993(97)90131-3

Cohen, J. A., Verghese, J., & Zwerling, J. L. (2016). Cognition and gait in older people. *Maturitas, 93*, 73–77. Nov https://doi.org/10.1016/J.MATURITAS.2016.05.005. Nov.

Corsonello, A., et al. (2012). Prognostic significance of the short physical performance battery in older patients discharged from acute care hospitals. *Rejuvenation Research, 15*(1), 41–48. Feb https://doi.org/10.1089/REJ.2011.1215. Feb.

Erickson, K. I., et al. (2010). Physical activity predicts gray matter volume in late adulthood: The cardiovascular health study. *Neurology, 75*(16), 1415–1422. Oct https://doi.org/10.1212/WNL.0b013e3181f88359. Oct.

Faber, M. J., Bosscher, R. J., & Van Wieringen, P. C. W. (2006). Clinimetric properties of the performance-oriented mobility assessment. *Physical Therapy, 86*(7), 944–954. https://doi.org/10.1093/ptj/86.7.944

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). 'Mini-mental state'. A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*(3), 189–198. https://doi.org/10.1016/0022-3956(75)90026-6

Glave, A. P., Didier, J. J., Weatherwax, J., Browning, S. J., & Fiaud, V. (2016). Testing postural stability: Are the star excursion balance test and Biodex balance system limits of stability tests consistent? *Gait & Posture, 43*, 225–227. Jan https://doi.org/10.1016/J.GAITPOST.2015.09.028. Jan.

Grande, G., Triolo, F., Nuara, A., Welmer, A. K., Fratiglioni, L., & Vetrano, D. L. (2019). Measuring gait speed to better identify prodromal dementia. *Experimental Gerontology, 124*. https://doi.org/10.1016/J.EXGER.2019.05.014. Sep.

Hinman, M. R. (2000). Factors affecting reliability of the Biodex balance system: A summary of four studies. *Journal of Sport Rehabilitation, 9*(3), 240–252. https://doi.org/10.1123/jsr.9.3.240

Kaiser, M. J., et al. (2009). Validation of the Mini nutritional assessment short-form (MNA-SF): A practical tool for identification of nutritional status. *The Journal of Nutrition, Health & Aging, 13*(9), 782–788. https://doi.org/10.1007/S12603-009-0214-7

Katz, S. (1983). Assessing self-maintenance: Activities of daily living, mobility, and instrumental activities of daily living. *Journal of the American Geriatrics Society, 31*(12), 721–727. https://doi.org/10.1111/J.1532-5415.1983.TB03391.X

Köpke, S., & Meyer, G. (2006). The Tinetti test: Babylon in geriatric assessment. *Zeitschrift für Gerontologie und Geriatrie, 39*(4), 288–291. Aug https://doi.org/10.1007/S00391-006-0398-Y. Aug.

Li, K. Z. H., Bherer, L., Mirelman, A., Maidan, I., & Hausdorff, J. M. (2018). Cognitive involvement in balance, gait and dual-tasking in aging: A focused review from a neuroscience of aging perspective. *Frontiers in Neurology, 9*(OCT), 1–13. https://doi.org/10.3389/fneur.2018.00913

Lusardi, M. M., et al. (2017). Determining risk of falls in community dwelling older adults: A systematic review and Meta-analysis using posttest probability. *Journal of Geriatric Physical Therapy (2001), 40*(1), 1–36. https://doi.org/10.1519/JPT.0000000000000099

Magni, E., Binetti, G., Bianchetti, A., Rozzini, R., & Trabucchi, M. (1996). Mini-mental state examination: A normative study in Italian elderly population. *European Journal of Neurology, 3*(3), 198–202. https://doi.org/10.1111/J.1468-1331.1996.TB00423.X

Marquis, S., et al. (2002). Independent predictors of cognitive decline in healthy elderly persons. *Archives of Neurology, 59*(4), 601–606. https://doi.org/10.1001/ARCHNEUR.59.4.601

Means, K. M., & O'Sullivan, P. S. (2000). Modifying a functional obstacle course to test balance and mobility in the community. *Journal of Rehabilitation Research and Development, 37*(5), 621–632 Accessed: May 13, 2022. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/11322160/ Accessed: May 13, 2022. [Online]. Available:.

Millán-Calenti, J. C., et al. (2010). Prevalence of functional disability in activities of daily living (ADL), instrumental activities of daily living (IADL) and associated factors, as predictors of morbidity and mortality. *Archives of Gerontology and Geriatrics, 50*(3), 306–310. May https://doi.org/10.1016/J.ARCHGER.2009.04.017. May.

Montero-Odasso, M., et al. (2014). The motor signature of mild cognitive impairment: Results from the gait and brain study. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 69*(11), 1415–1421. Aug https://doi.org/10.1093/GERONA/GLU155. Aug.

Morris, R., Lord, S., Bunce, J., Burn, D., & Rochester, L. (2016). Gait and cognition: Mapping the global and discrete relationships in ageing and neurodegenerative disease. *Neuroscience and Biobehavioral Reviews, 64*, 326–345. May https://doi.org/10.1016/J.NEUBIOREV.2016.02.012. May.

Nasreddine, Z. S., et al. (2005). The Montreal cognitive assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society, 53*(4), 695–699. https://doi.org/10.1111/J.1532-5415.2005.53221.X

Pavasini, R., et al. (2016). Short physical performance battery and all-cause mortality: Systematic review and meta-analysis. *BMC Medicine, 14*(1). https://doi.org/10.1186/S12916-016-0763-7. Dec.

Prometti, P., Olivares, A., Gaia, G., Bonometti, G., Comini, L., & Scalvini, S. (2016). Biodex fall risk assessment in the elderly with Ataxia: A new age-dependent derived index in rehabilitation: An observational study. *Medicine (Baltimore), 95*(10). https://doi.org/10.1097/MD.0000000000002977. Mar.

Santangelo, G., et al. (2015). Normative data for the Montreal cognitive assessment in an Italian population sample. *Neurological Sciences, 36*(4), 585–591. Apr https://doi.org/10.1007/S10072-014-1995-Y. Apr.

Takakusaki, K. (2017). Functional neuroanatomy for posture and gait control. *Journal of Movement Disorders, 10*(1), 1–17. Jan 10.14802/JMD.16062. Jan.

Tian, Q., Resnick, S. M., Bilgel, M., Wong, D. F., Ferrucci, L., & Studenski, S. A. (2017). β-Amyloid burden predicts lower extremity performance decline in cognitively unimpaired older adults. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 72*(5), 716–723. https://doi.org/10.1093/GERONA/GLW183

Tinetti, M. E. (1986). Performance-oriented assessment of mobility problems in elderly patients. *Journal of the American Geriatrics Society, 34*(2), 119–126. https://doi.org/10.1111/j.1532-5415.1986.tb05480.x

Waite, L. M., Grayson, D. A., Piguet, O., Creasey, H., Bennett, H. P., & Broe, G. A. (2005). Gait slowing as a predictor of incident dementia: 6-year longitudinal data from the Sydney older persons study. *Journal of the Neurological Sciences, 229–230*, 89–93. Mar https://doi.org/10.1016/J.JNS.2004.11.009. Mar.