**Fall risk in older adults mediates the association between executive dysfunction and daily life**

**Abstract**

Introduction *–* The present study aimed to identify signs of frequent fall-related geriatric physiological dysfunction (depression and cognition/executive functions [EF]) as exhibited in daily activities. The role of fall risk in mediating physiological dysfunction, daily activity performance and the quality of life (QOL) was also explored.

Method *–* Participants included123 non-institutionalised older adults. Depression and cognitive status were measured by the Geriatric Depression Scale (GDS-15) and the Montreal Cognitive Assessment (MoCA). Fall risk was determined by a questionnaire, supported by the Time Up and Go test (TUG). The EF were assessed by the Behavior Rating Inventory of Executive Function - Adult Version (BRIEF-A) and the alternate executive function performance test (aEFPT) medication management performance-based assessment. Daily life measures included the Barthel Index of activities of daily living (ADL), the Instrumental ADL Scale and the World Health Organization Quality of Life Brief questionnaire.

Results *–* The prevalence of high fall risk was 32%. High-risk fallers showed greater physiological dysfunction, as recognised in their daily activities. Structural equation modelling (SEM) revealed that the fall risk mediated the associations among depression, executive dysfunction and daily activities.

Conclusion *–* Emotional and cognitive/EF dysfunction that affect people with high fall risk may manifest while older people perform daily activities. Community fall prevention and rehabilitation programmes should screen for such fall-related physiological dysfunction. This would foster a deeper understanding of their impact on daily functions, and should be facilitated by performance-based assessments that imitate daily life scenarios, increase an awareness of the signs of fall risk in a real-life context, and provide strategies to minimise falls and enhance daily function.

**Keywords**:daily life, depression, early screening, executive functions, fall risk, older adults

Introduction

Falling is a major problem in older adults. Approximately 30%–40% of non-institutionalised individuals over the age of 65, fall at least once a year (Swift and Iliffe, 2014). Furthermore, about half of them fall again in the following year and need long-term care (Pellicer-García et al., 2017). The high health costs and severe personal consequences – including injuries, immobilisation, reduced independence in daily activities, and even death, makes the incidence of falls a major public health concern (Barban et al., 2017; de Oliveira et al., 2020).

Yet, studies have revealed that some fallers show resilience and either maintain or improve functioning (Best et al., 2014). Thus, understanding the factors that underlie resiliency or vulnerability among fallers should be identified. Early screening of physiological dysfunction and related restrictions in daily activities that predict falls may facilitate an increased awareness of fall risk and improve prevention programmes (Saftari and Kwon, 2018).

Literature review

Frail older adults are at greater risk of falling. Other geriatric syndromes, such as depression and executive dysfunction, are also more prevalent among people aged 65 and above with a history of falling (Iaboni and Flint, 2013; Parsons et al., 2016; Pellicer-García et al., 2017). Depressive symptoms have been identified as risk factors for falls, independent of antidepressant use (Kvelde et al., 2015).

The relationships among falls, depression and executive dysfunction can be explained by changes that occur in biochemical mechanisms and in structures of the aged brain. These changes include grey matter loss in the somatosensory and motor areas, the prefrontal and inferior parietal cortices (McGinnis et al., 2011), as well as the loss of complexity of neuronal connections (Acker, 2004) that affect motor, emotional and cognitive abilities (Biderman et al., 2002; Gassmann et al., 2009; Kvelde et al., 2015). The high cognitive abilities referred to as executive functions (EF) are responsible for an individual’s controlled, goal-oriented behaviour (Luiten et al., 2013). Thus, EF are essential for motor function, emotional regulation, daily activity performance and the maintenance of an active lifestyle (Caetano et al., 2018; Hahn et al., 2014).

Attention problems and uncontrolled goal-oriented behaviour may significantly impair postural control and an individual’s ability to manoeuvre around obstacles in their environment (Bernard and Lacour, 2017; Di Fabio et al., 2004). Brain imaging studies have shown increased connectivity within the executive network, mediated between the caudate grey matter volume and fall risk, via changes in attention among people with Parkinson’s Disease (PD) (Rosenberg-Katz et al., 2015). Other studies have shown that EF deteriorate prior to, or at the same time as physical performance (Atkinson et al., 2010; Caetano et al., 2018), suggesting that EF are also associated with fall risk in older adults without PD.

The frequent combination of reduced balance, impaired emotional status and executive dysfunction may have far reaching effects on daily life for older adults. They may exhibit decreased independence in basic/instrumental activities of daily living (BADL/IADL) (Fitzgerald et al., 2016) and a significantly reduce quality of life (QOL) (Barban et al., 2017; Christoforou et al., 2018; Cohen, 2014; Laurence and Michel, 2017). Yet, information about the relationship between falls and depression in non-institutionalised older adults is lacking (Pellicer-García et al., 2017).

Several important points may be drawn from the literature. First, it is critical to elucidate key factors that contribute to a loss of function as well as resiliency. Second, as key factors of fall risk, the causative relationships among depression, EF, falls and daily function should be further explored. Yet, many studies that have explored these relationships, have used laboratory or neuro-psychological tools. For example, EF are frequently evaluated by measures, such as the trail making test (TMT) (Reitan, 1955); phonological fluency test (PF) (Borkowisky et al., 1967); and Rey-Osterrieth complex figure test (ROCF) (Rey, 1958). These measures refer to specific EF components and do not provide a thorough understanding of impairments in daily life.

Information gathered from performance-based assessments with ecological validity, in which the task is the central focus is lacking. The use of such tools may enhance our understanding of an individual’s performance in real life (Josman et al., 2009) and reveal the precise manner in which balance-emotional-cognitive difficulties affect daily function. Moreover, by recognising the deterioration in emotional-cognitive/EF aspects during the performance of daily routine activities, early intervention could be provided, which could thereby minimise fall risk.

This approach is supported by the International Classification of Functioning Disability and Health (ICF) of the World Health Organization (WHO, 2001). According to this model, disability is no longer determined by physiological dysfunction but by the interaction with the person’s ability to perform daily activities. Moreover, the performance of daily activities, as well as the QOL, are the main outcomes of intervention efficiency (Engel-Yeger, 2019).

As falls, depression and cognitive decline are usually recognised and detected in primary care, adequate and timely treatment is not always available. Thus, it is essential to increase an awareness among older people, families and health care givers of the emotional-cognitive early signs of falls, and recognise those signs in older people performing daily life activities.

Based on the above, the aims of the present study were to: (1) examine the prevalence of fall risk among non-institutionalised older adults. (2) Identify signs of frequent fall-related geriatric physiological dysfunction (depression and cognition/executive functions), as evident in daily activities, which differ between high and low risk fallers, using self-reports and a performance-based assessment. These assessments aim to reflect the implications of the physiological dysfunction on daily life. (3) Explore the role of fall risk in mediating between physiological dysfunction and daily life.

Method

*Participants*

A total of 123 non-institutionalised adults, aged 65–95 years, were included. The inclusion criteria were as follows: individuals who were not institutionalised in social or health centres, with no signs of severe depression, according to the Geriatric Depression Scale (GDS) (Yesavage et al., 1983); who had a score of 14 or greater on the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005); and were able to understand the purpose of the study and procedures, and were able to sign the informed consent form. Individuals with chronic illnesses such as high blood pressure, diabetes, osteoporosis, osteoarthritis, or urinary incontinence were also included in the study. Most participants used various medications regularly (*n* = 112, 91.1%). The exclusion criteria were as follows: individuals with severe diseases such as Parkinson’s disease, muscular dystrophy, cancer, dementia, severe and acute orthopaedic limitations affecting function, significant visual impairments and those who were restrained to a wheelchair or bed. The socio-demographic information of the study participants is presented in Table 1.

[Insert Table 1 about here]

*Instruments*

A demographic and health status questionnaire, which also included the participants’ current medication uptake.

Depression and cognitive status were measured by the following:

*The Geriatric Depression Scale (GDS-15)* (Yesavage et al., 1983) – a self-report questionnaire with 15 dichotomous items (yes/no questions) designed to screen for depression in older adults. The total score ranges from 0–15 points. A higher score indicated the presence of more symptoms of depression. A score of ≥ 6 indicated a need for a thorough medical/psychiatric assessment. A score of ≥ 11 was considered the cutoff for an indication of depression, and a higher score indicated higher depression severity.

*The MoCA* (Nasreddine et al., 2005) – this short screening tool profiled the cognitive status. The areas of examination included visuo-spatial abilities, EF, attention, language, short-term memory and orientation. The total score was derived by summing the correct answers, to give a maximum of 30 points. The test is highly sensitive in identifying people with mild cognitive impairment (MCI) (83%–90%) (Nasreddine et al., 2005). Based on a sample size of 8411, Lu et al. (2011) noted that the appropriate cutoff score for people without MCI or dementia and without formal education is 13/14. As our study included both participants with and without formal education, the MoCA cutoff score in the current study was set at ≥ 14.

The assessment of fall risk was based on a questionnaire, supported by clinical examination.

Based on the Israeli Ministry of Health (2017), fall risk was determined according to two parameters:

(a) *A* *questionnaire* – that gathered information about the number of falls during the previous year; information about fractures or other significant injuries caused by falls; and information about walking or stability difficulties.

(b) *Time Up and Go test (TUG)* (Podsiadlo and Richardson, 1991) – this clinical examination measured mobility and lower extremity functions and was used as a screening tool for fall risk. The subject was requested to get up from a standard chair, without using upper extremity support, and walk 3 m ahead at a regular pace. The subject was then required to turn around and walk back to the chair and sit down. The subject could have used a walking aid if needed. No physical assistance was given throughout the test; however, the examiner followed the participant to prevent any incidence of falling. The test was conducted twice. However, only the second round was scored. The score reflected the performance time in seconds and was measured by a stopwatch. A shorter performance time indicated better performance. A performance time longer than 13.5 s indicated a greater fall risk (Herman et al., 2011). The high-risk group was defined if one of the following three scenarios occurred: 1- the participant fell twice or more during the previous year; 2- the participant had one fall during the previous year with a significant injury; 3- the participant had one fall during the previous year and a TUG score greater than 13.5 s.

*Assessment of EF by a self-report questionnaire and performance-based assessment:*

*(a) The Behavior Rating Inventory of Executive Function - Adult Version (BRIEF-A)* (Ciszewski et al., 2014) was used to screen for possible executive dysfunction and indicated the subject’s awareness of their own self-regulatory functioning. The BRIEF-A assessed everyday behaviours associated with specific domains of EF in adults, which were summarised in two index scales, the Behavioral Regulation Index (BRI) and the Metacognition Index (MI), as well as another scale reflecting overall functioning (Global Executive Composite [GEC]). The BRI comprised four scales: Inhibit, Shift, Emotional Control and Self-Monitor. The MI comprised five scales: Initiate, Working Memory, Plan/Organise, Task Monitor and Organization of Materials. Behaviour frequency was rated on a Likert scale ranging from ‘rare’ to ‘often’. Raw scores were transformed to *t*-scores (mean = 50, SD = 10). The *t*-scores of 65 or above reflected executive dysfunction.

*(b) The medication management subtest of the Alternate Executive Function Performance Test (aEFPT)* (Hahn et al., 2014) – this was an additional part of the valid performance-based EFPT assessment, which measured EF while the subject was carrying out a daily task. The subject’s functional independence level and the amount of help required during the tasks were also recorded. The four original EFPT tasks were: cooking oatmeal, telephone use, taking medication and paying a bill (Lysack et al., 2003). The aEFPT had four additional tasks, which were similar to the four original tasks but with a novel component to prevent a learning effect from the original form.

In the medication management subtest, subjects were asked to sort medications into a 7-day pill sorter, instead of taking a medication as requested on the original form (Hahn et al., 2014). The subject was instructed to find and sort medicines in a weekly pill sorter. For successful performance, the subject had to ignore distractors (other bottles) and use prospective memory to follow the specific sorting instructions. This medicationmanagement task was selected, as it is a daily common function among older adults, which does not require special facilities (like a stove top for cooking, which was one of the subtests) and can be completed within a relatively short time.

The scoring referred to five EF: initiation, organising, sequencing, safety, and judgement and completion. Each component was scored on a scale of 0–5 points, according to the level of assistance required to complete each the task. The points were allotted as follows: 5 - doing the task for the participant; 4 - physical assistance; 3 - verbal direct instruction; 2 - gestural guidance; 1 - verbal guidance; 0 – independent performance of the task. The score for the complete task ranged from 0–25, and a higher score indicated that more assistance was required (Baum et al., 2008; Hahn et al., 2014).

*Daily life measures:*

*(a) The Barthel Index of ADL* (Mahoney and Barthel, 1965), which measured the performance of BADL in 10 functional domains: eating, bathing, dressing, bowel and bladder control, personal hygiene, transfers, walking on a straight surface and stair climbing. Items were scored in 5-point intervals (0–15), depending on the level of assistance required by the participant. The total score ranged from 0–100. Higher scores indicated better functional ability.

*(b)* *Instrumental Activities of Daily Living Scale (IADL)* (Lawton and Brody, 1969). This interview-based functional assessment consisted of eight components: telephone use, shopping, food preparation, housekeeping, laundry, transportation use, responsibility for personal medication and money. Item scores ranged from 0–3 or 0–4, according to the level of assistance required by the participant. The total score ranged from 0–20. Higher scores indicated better functional ability.

(c) *The World Health Organization Quality of Life Brief questionnaire (WHOQOL-BREF)* (The WHOQOL Group, 1998). This questionnaire was an abbreviated 26-item version of the WHOQOL-100, which is the gold standard for measuring QOL in four domains: physical, psychological, social relationships and environment. Scores in each domain ranged from 0–100. Higher scores represented a higher QOL.

*Procedure*

The study was authorised by the Ethics Committee of the Faculty of Social Welfare and Health Sciences, University of Haifa and Ono Academic College, Israel. Advertisements calling for study participants were published in various neighbourhoods and day-care centres in central Israel. Those who agreed to participate in the study, contacted the study investigator by telephone. During this call, potential participants were required to answer questions that were designed to verify the inclusion criteria. For those who met the inclusion criteria, a meeting was scheduled at their home or at the day-care centre (after obtaining approval from the management of the day-care centres). During the first meeting, each participant signed an informed consent form and continued to complete the evaluation battery of tests, first the demographic and health status questionnaire, then the MoCA, followed by the fall questionnaire, TUG test, and the GDS, BRIEF-A, aEFPT - medication management task, ADL questionnaires and the WHOQOL-BREF. If the participant grew tired during completion of the various tests, the meeting was stopped, and a second meeting was scheduled, to avoid exhaustion and complete all evaluations.

*Statistical analysis*

All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS) for Windows 25.0. The t-test, ANOVA and multivariate analysis of variance (MANOVA) examined whether significant differences existed between groups among all subscales, as well as the total scores of the dependent measures.

Structural equation modelling (SEM) was used to examine the relationships among age, education, depression, EF, performance of activities of daily living, health related QOL and fall risk. The model examined the role of fall risk in mediating between all other parameters and daily life, in terms of ADL performance and health-related quality of life (HRQOL). Fall risk was calculated as a continuous parameter and the evaluation was performed on the general sample. The following fit indices were evaluated: the goodness-of-fit statistic, goodness-of-fit index (GFI), root mean square error of approximation (RMSEA), standardized root mean square residual (SRMR), standardized RMR, and comparative fit index (CFI). Chi-squared tests were used for nested model comparison. The level of significance was set at .05.

Results/Findings

In the present sample, a high fall risk was prevalent among 32% of the sample.

Participants with a high fall risk were slightly older than those with a low fall risk; had fewer years of education; lower cognitive status; higher depression level; greater executive dysfunction, as manifested in the performance-based assessment (EFPT) and in the self-report questionnaire of BRIEF-A (the largest difference being in working memory); more restrictions in BADL/IADL; and lower HRQOL (see Table 2). Gender showed no significant differences between the two groups.

[Insert Table 2 about here]

To examine the role of fall risk in mediating between physiological dysfunction and daily activities, fall risk was calculated as a continuous parameter that included the TUG score (‘0’ = no risk or ‘1’ = fall risk) plus the summary of the fall questionnaire scores. The range of the fall risk score was 0–10 (mean 2.33 ± 2.53).

The correlations between the continuous fall risk score and the other variables were examined. A higher fall risk score was significantly correlated with increased age (r = .34, p < .0001), fewer years of education (r = -.35, p < .0001), higher levels of depression (r = .34, p < .0001), lower cognitive level (r = -.31, p < .0001) and lower total HRQOL (r = -.41, p < .0001). Based on these significant correlations, the variables were entered into the SEM model. The SEM model revealed the following goodness of fit indices: χ2 (25) = 38.275, p = .04; CFI = .97; NFI = .93, RMSEA = .06.

A significant correlation was noted between age and the number of years of education (r = -.32, p < .0001), as well as between age and depression (GDS) (r = .34, p < .0001). Age was directly related to the aEFPT medication management score (β = .18, p = .03), as well as lower performance in IADL (β = -.25, p < .0001). Older adults tended to have lower levels of education, higher levels of depression, reduced EF and restricted IADL.

Higher levels of depression (GDS score) were correlated with fewer years of education (r = -.39, p < .0001) and was directly related to lower metacognition and behavioural regulation (based on the BRIEF-A) (β = .55, p < .0001; β = .42, p < .0001, respectively), as well as lower performance in IADL (β = -.23, p < .0001). Individuals with higher levels of depression were less educated, had reduced EF and lower performance in IADL. Furthermore, lower metacognition (based on the BRIEF-A) was directly related to a higher risk fall and lower HRQOL (β = .34, p = .005; β = -.31, p < .0001, respectively).

Worse performance, as reflected by the aEFPT medication management score, was directly related to fewer years of education (β = -.37, p < .0001) and higher fall risk (β = .32, p < .0001). Fall risk was directly related to lower performance in BADL and IADL (β = -.41, p < .0001; β = -.34, p < .0001) and lower HRQOL (β = -.13, p = .05). Fall risk did not mediate any associations between BRIEF-A-BRI and BADL/IADL; or BRIEF-A-BRI and HRQOL.

However, aEFPT medication management and meta-cognition in the BRIEF-A; and ADL and HRQOL were mediated by fall risk as follows: aEFPT and IADL (standardised indirect effect = -.10) (95% CI: -.23 to -.04, p < .001); aEFPT and BADL (standardised indirect effect = -.13) (95% CI: -.28 to -.04, p < .001); aEFPT and QOL (standardised indirect effect = -.04) (95% CI: -.11 to -.003, p = .03); BRIEF-A-MI and IADL (standardised indirect effect = -.11) (95% CI: -.24 to -.03, p = .003); BRIEF-A-MI and BADL (standardised indirect effect = -.14) (95% CI: -.29 to -.04, p = .004); BRIEF-A-MI and QOL (standardised indirect effect = -.04) (95% CI: -.13 to -.002, p = .04); (see Figure 1). The model explains 27% of the fall risk, 17% of the performance of BADL, 34% of the performance of IADL and 55% of total HRQOL.

To summarise, in older adults, fall risk played a significant role in mediating the associations among depression, executive dysfunction and daily life, as reflected by reduced performance of BADL/IADL and lower HRQOL.

[Insert Figure 1 about here]

Discussion and implications:

Fall prevalence in non-institutionalised older adults was evaluated and its relationship with other known geriatric physiological dysfunction and activities of daily life. In line with the ICF model, this study used standard self-reports, clinical observation and performance-based assessments with ecological validity that mimic daily situations. Although this study was focused on older adults who are still relatively functional, about one third of the study participants had a high fall risk and significantly worse physiological dysfunction than those with a low fall risk. This was evidenced by a tendency towards greater levels of depression, lower cognitive status, lower EF, restricted ADL and lower HRQOL.

The relationship between personal socio-demographic factors, physiological dysfunction (depression, reduced cognition/EF) and fall risk supports the findings of previous reports. Depression was found to be more frequent among individuals of a medium-low socioeconomic status, with higher levels of disability and comorbid conditions (Nicolosi et al., 2011). Fall risk is reportedly associated with, and impacted by depression, reduced processing speed and executive dysfunction (Beauchet et al., 2008; Elderkin-Thompson et al., 2003). These relationships can be explained by the less efficient cortical information processing and reduced attentional resources of the aged brain, which impair memory, EF and emotional status (Laurence and Michel, 2017).

As mentioned above, and similar to previous reports (Laurence and Michel, 2017; Montero-Odasso and Speechley, 2018), the present study showed that depression is associated with reduced EF, while reduced EF is related to high fall risk. Most studies of EF and falls have used traditional assessments and referred to specific domains of EF (e.g. inhibition and working memory) (Best et al., 2014; Caetano et al., 2018). However, the present study used measures that reflected the expression of EF in daily life activities, including the BRIEF-A self-report questionnaire and the performance-based aEFPT medication managementtest.

The results showed that the greatest difference in EF between individuals with high fall risk and those with low fall risk was observed in the BRIEF-A-working memory domain. Earlier reports have shown that attention and memory are more affected by age and have a greater impact on posture control (Laurence and Michel, 2017). Studies have also reported that in older adults, EF mediates the association between motor performance and fall risk (Caetano et al., 2018). Other reports have shown that among individuals with a high fall risk, EF mediates the association between changes in memory and reduced performance in IADL (Royall et al., 2004).

According to the SEM model in the present study, older adults had lower EF and more restricted IADL. Restricted performance of the ADL was directly associated with fall risk. However, regarding EF, the model presented a new perspective that places fall risk as the mediator between executive functions and ADL. It is noteworthy that fall risk mediated between BRIEF-A-meta-cognition and ADL, but not between BRIEF-A-BRI and ADL.

A possible explanation for this finding is associated with the fact that MI components, such as initiation, working memory, planning, monitoring and organisation, are more essential for motor planning, motor control and navigating obstacles in the environment.

Another aspect included in meta-cognition is awareness (Toglia and Kirk, 2000). Awareness is critical for motor performance in challenging environments, especially among older adults. Awareness is a key factor in cognitive rehabilitation and is related to the use of improved strategies for enhanced performance of daily activities (Engel-Yeger et al., 2011; Toglia et al., 2010). These findings emphasise the fact that prevention and intervention programmes to minimise falls in older adults, should screen for EF problems and give special attention to the individual’s meta-cognition and awareness of self-performance and environmental context and cues (Burgess et al., 2006).

In line with the ICF model, clinicians should gather information not only from isolated tasks in a lab setting, but from tasks that mimic daily life scenarios (Chaytor et al., 2006; Odhuba et al., 2005), with reference to the environmental context, where the regulation of balance takes place (Bernard and Lacour, 2017). With this information, clinicians may improve their selection of the best-adapted behavioural strategy (Hahn et al., 2014; Josman et al., 2009). For example, they may be able to determine how the activity should be approached within a certain environment, how to compensate for a slow reaction time, or physical difficulties (Barban et al., 2017), or what environmental adaptations should be established to enhance the adaptive response to environmental demands at home or in the community (Mirelman et al., 2019).

The present study has a few limitations.The study was focused on a specific part of the population, non-institutionalised older adults. The distribution of participants was not equal across the two groups (high fall risk and low fall risk). Future studies should be focused on older adults who live in other settings, such as nursing homes, and examine the differences between men and women, and use larger sample sizes to examine group differences. Cohort studies are also recommended to better understand the effects of ageing on falls, as well as the associated physiological dysfunction and its expression in the daily lives of individuals.

Conclusion:

To summarise, fall risk should be routinely screened among non-institutionalised older individuals and their engagement in physical activity should be encouraged (Ribeiro et al., 2017). Moreover, health services should note that although the ability of older individuals to function in daily activities is related to the effects of their emotional/cognitive/EF status, good balance and a low tendency to fall also play a major role in this relationship. Hence, fall prevention and intervention programmes should be informed by the impact of physiological dysfunction on daily life (Cohen and Kimball, 2003). Such prevention and intervention programmes should also determine impaired emotional-cognitive cues, as expressed during the performance of daily activities among older people, in their natural environment.

Those cues may serve as warning signals that could predict the next fall, and thus lead to early fall risk evaluation and intervention when needed. Intervention programmes should be based on a multi-disciplinary approach and apply models such as the ICF, which are relevant for fall rehabilitation (Saverino et al., 2015). Furthermore, interventions should apply performance-based ecological assessments to identify physiological dysfunction that predict falls in a real-life context. Thus, interventions will be directed more to the individual’s specific needs, interests, resilience and vulnerability, and yield better results in terms of enhanced function and better QOL.

References

Acker JD (2004) Aging, sexual dimorphism, and hemispheric asymmetry of the cerebral cortex: Replicability of regional differences in volume. *Neurobiology of Aging* 25(3): 377–396.

Atkinson HH, Rapp SR, Williamson JD, et al. (2010) The relationship between cognitive function and physical performance in older women: results from the women’s health initiative memory study. *The Journals of Gerontology: Series A* 65A(3): 300–306.

Barban F, Annicchiarico R, Melideo M, et al. (2017) Reducing Fall Risk with Combined Motor and Cognitive Training in Elderly Fallers. *Brain Sciences* 7(2): 19.

Baum CM, Connor LT, Morrison T, et al. (2008) Reliability, validity, and clinical utility of the Executive Function Performance Test: A measure of executive function in a sample of people with stroke. *American Journal of Occupational Therapy* 62(4): 446–455.

Beauchet O, Allali G, Annweiler C, et al. (2008) Does change in gait while counting backward predict the occurrence of a first fall in older adults. *Gerontology* 54(4): 217–223.

Best JR, Nagamatsu LS and Liu-Ambrose T (2014). Improvements to executive function during exercise training predict maintenance of physical activity over the following year. *Frontiers in Human Neuroscience* 8:353.

Biderman A, Cwikel J, Fried AV, et al. (2002). Depression and falls among community dwelling elderly people: A search for common risk factors. *Journal of Epidemiology and Community Health* 56(8): 631–636.

Borkowisky JG, Benton AL and Spreen O (1967) Word fluency and brain damage. *Neuropsychologia* 5(2): 135–140.

[Caetano](https://pubmed.ncbi.nlm.nih.gov/?term=Caetano+MJD&cauthor_id=29055270) MJD, Lord SR, Brodie MA et al. (2018) Executive Functioning, Concern About Falling and Quadriceps Strength Mediate the Relationship Between Impaired Gait Adaptability and Fall Risk in Older People. *Gait & Posture* 59: 188–192.

# [Christoforou](https://pubmed.ncbi.nlm.nih.gov/?term=Christoforou+A&cauthor_id=28608776) A, [van der Linden](https://pubmed.ncbi.nlm.nih.gov/?term=van+der+Linden+ML&cauthor_id=28608776) ML and [Koufaki](https://pubmed.ncbi.nlm.nih.gov/?term=Koufaki+P&cauthor_id=28608776) P (2018) Short-term Effectiveness of a Community-Implemented Falls Prevention Referral Service. *Disability and Rehabilitation* 40(20), 2466–2474.

Ciszewski S, Francis K, Mendella P, et al. (2014) Validity and reliability of the Behavior Rating Inventory of Executive Function Adult Version in a clinical sample with eating disorders. *Eating Behaviors* 15(2): 175–181.

Cohen HS (2014) Use of the Vestibular Disorders Activities of Daily Living Scale to Describe Functional Limitations in Patients with Vestibular Disorders. Journal of Vestibular Research 24(1): 33–38.

[Cohen HS, Kimball KT (2003) Increased independence and decreased vertigo after vestibular rehabilitation.](https://pubmed.ncbi.nlm.nih.gov/12574761/?from_term=Cohen+and+Kimball%2C+2003&from_pos=1) *Otolaryngology–Head and Neck Surgery* 128(1): 60–70.

[De Oliveira Cruz](https://pubmed.ncbi.nlm.nih.gov/?term=Cruz+AO&cauthor_id=30907182) A, [Mota Santana](https://pubmed.ncbi.nlm.nih.gov/?term=Santana+SMM&cauthor_id=30907182) SM, [Marinho Costa](https://pubmed.ncbi.nlm.nih.gov/?term=Costa+CM&cauthor_id=30907182) C, et al. (2020) Prevalence of Falls in Frail Elderly Users of Ambulatory Assistive Devices: A Comparative Study. *Disability and Rehabilitation: Assistive Technology* 15(5): 510–514.

# [Di Fabio](https://pubmed.ncbi.nlm.nih.gov/?term=Di+Fabio+RP&cauthor_id=15571548) RP, [Kurszewski](https://pubmed.ncbi.nlm.nih.gov/?term=Kurszewski+WM&cauthor_id=15571548) WM, [Jorgenson](https://pubmed.ncbi.nlm.nih.gov/?term=Jorgenson+EE&cauthor_id=15571548) EE, et al. (2004) Footlift Asymmetry During Obstacle Avoidance in High-Risk Elderly. *Journal of the American Geriatrics Society* 52(12): 2088–2093.

[Elderkin-Thompson](https://pubmed.ncbi.nlm.nih.gov/?term=Elderkin-Thompson+V&cauthor_id=14591448) V, [Kumar](https://pubmed.ncbi.nlm.nih.gov/?term=Kumar+A&cauthor_id=14591448) A, [Bilker](https://pubmed.ncbi.nlm.nih.gov/?term=Bilker+WB&cauthor_id=14591448) WB, et al. (2003) Neuropsychological Deficits Among Patients With Late-Onset Minor and Major Depression. *Archives of Clinical Neuropsychology* 18(5): 529–549.

[Engel-Yeger](https://pubmed.ncbi.nlm.nih.gov/?term=Engel-Yeger+B&cauthor_id=31829745) B (2019) The involvement of altered sensory modulation in neurological conditions and its relevance to neuro-rehabilitation: a narrative literature review. *Disability and Rehabilitation* 12: 1–10.

# [Engel-Yeger](https://pubmed.ncbi.nlm.nih.gov/?term=Engel-Yeger+B&cauthor_id=20731563) B, [Durr](https://pubmed.ncbi.nlm.nih.gov/?term=Durr+DH&cauthor_id=20731563) DH, [Josman](https://pubmed.ncbi.nlm.nih.gov/?term=Josman+N&cauthor_id=20731563) N (2011) Comparison of Memory and Meta-Memory Abilities of Children With Cochlear Implant and Normal Hearing Peers. *Disability and Rehabilitation* 33(9): 770–777.

[Fitzgerald](https://pubmed.ncbi.nlm.nih.gov/?term=Dever+Fitzgerald+T&cauthor_id=26474116) TD, [Hadjistavropoulos](https://pubmed.ncbi.nlm.nih.gov/?term=Hadjistavropoulos+T&cauthor_id=26474116) T, [Williams](https://pubmed.ncbi.nlm.nih.gov/?term=Williams+J&cauthor_id=26474116) J, et al. (2016) The impact of fall risk assessment on nurse fears, patient falls, and functional ability in long-term care. *Disability and Rehabilitation* 38 (11), 1041–1052.

Gassmann KG, Rupprecht R and Freiberger E, IZG Study Group (2009) Predictors for occasional and recurrent falls in community-dwelling older adults. *Zeitschrift für Gerontologie und Geriatrie* 42(1): 3–10.

# [Hahn](https://pubmed.ncbi.nlm.nih.gov/?term=Hahn+B&cauthor_id=25397771) B, [Baum](https://pubmed.ncbi.nlm.nih.gov/?term=Baum+C&cauthor_id=25397771) C, [Moore](https://pubmed.ncbi.nlm.nih.gov/?term=Moore+J&cauthor_id=25397771) J, et al. (2014) Development of Additional Tasks for the Executive Function Performance Test. *American Journal of Occupational Therapy* 68(6): e241–e246.

Herman T, Giladi N and Hausdorff JM (2011) Properties of the ‘timed up and go’ test: more than meets the eye. *Gerontology* 57(3): 203–210.

[Iaboni](https://pubmed.ncbi.nlm.nih.gov/?term=Iaboni+A&cauthor_id=23570891) A and [Flint](https://pubmed.ncbi.nlm.nih.gov/?term=Flint+AJ&cauthor_id=23570891) AJ (2013) The Complex Interplay of Depression and Falls in Older Adults: A Clinical Review. *The American Journal of Geriatric Psychiatry* 21(5): 484–492.

Israeli Ministry of Health (2017) Fall Prevention National Program. Available at: <https://www.health.gov.il/PublicationsFiles/FallPreventionNationalProgram.pdf> (accessed November 2017).

Josman N, Elbaz Schenirderman A, Klinger E, et al. (2009) Using virtual reality to evaluate executive functioning among persons with schizophrenia: A validity study. *Schizophrenia Research* 115(2–3): 270–277.

[Kvelde](https://pubmed.ncbi.nlm.nih.gov/?term=Kvelde+T&cauthor_id=25262556) T, Lord SR, Close JCT, et al. (2015) Depressive symptoms increase fall risk in older people, independent of antidepressant use, and reduced executive and physical functioning. *Archives of Gerontology and Geriatrics* 60(1): 190–195.

Laurence BD and Michel L (2017) [The Fall in Older Adults: Physical and Cognitive Problems.](https://pubmed.ncbi.nlm.nih.gov/28874111/?from_term=falls+and+elderly+and+executive+functions+&from_pos=6) *Current Aging Science* 10(3): 185–200.

Lawton MP and Brody EM (1969) Assessment of older people: Self- maintaining and instrumental activities of daily living. *The Gerontologist* 9(3): 179–186.

Lu J, Li D, Li F, et al. (2011) Montreal cognitive assessment in detecting cognitive impairment in Chinese elderly individuals: a population-based study. *Journal of Geriatric Psychiatry and Neurology* 24(4): 184–190.

Luiten PG, Nyakas C, Eisel U, et al. (2013) Aging of the brain. In: Pfaff DW and Volkow ND. *Neuroscience in the 21st Century*. New York: Springer-Verlag, pp.2239–2272.

Mahoney FI and Barthel DW (1965) Functional evaluation: The Barthel Index. *Maryland State Medical Journal* 14: 61–65.

McGinnis SM, Brickhouse M, Pascual B, et al. (2011) Age-related changes in the thickness of cortical zones in humans. *Brain Topography* 24(3–4): 279–291.

# [Mirelman](https://pubmed.ncbi.nlm.nih.gov/?term=Mirelman+A&cauthor_id=30975519) A, [Bonato](https://pubmed.ncbi.nlm.nih.gov/?term=Bonato+P&cauthor_id=30975519) P,  [Camicioli](https://pubmed.ncbi.nlm.nih.gov/?term=Camicioli+R&cauthor_id=30975519) R, et al. (2019) Gait impairments in Parkinson's disease. *The Lancet Neurology* 18(7): 697–708.

Montero-Odasso M and Speechley M (2018) [Falls in Cognitively Impaired Older Adults: Implications for Risk Assessment And Prevention.](https://pubmed.ncbi.nlm.nih.gov/29318592/?from_term=falls+and+elderly+and+executive+functions+&from_pos=7) *Journal of the American Geriatrics Society* 66(2): 367–375.

Nasreddine Z, Phillips N, Bédirian V, 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.

[Nicolosi](https://pubmed.ncbi.nlm.nih.gov/?term=Nicolosi+GT&cauthor_id=21486519) GT, [da Silva Falcão](https://pubmed.ncbi.nlm.nih.gov/?term=Falc%C3%A3o+DV&cauthor_id=21486519) DV, [Tavares Batistoni](https://pubmed.ncbi.nlm.nih.gov/?term=Batistoni+SS&cauthor_id=21486519) SS, et al. (2011) Depressive symptoms in old age: relations among sociodemographic and self-reported health variables. *International Psychogeriatrics* 23(6): 941–949.

# [Parsons](https://pubmed.ncbi.nlm.nih.gov/?term=Parsons+J&cauthor_id=26693802) J, [Mathieson](https://pubmed.ncbi.nlm.nih.gov/?term=Mathieson+S&cauthor_id=26693802) S, [Jull](https://pubmed.ncbi.nlm.nih.gov/?term=Jull+A&cauthor_id=26693802) A, [et al](https://pubmed.ncbi.nlm.nih.gov/?term=Parsons+M&cauthor_id=26693802). (2016) Does vibration training reduce the fall risk profile of frail older people admitted to a rehabilitation facility? A randomised controlled trial. *Disability and Rehabilitation* 38(11): 1082–1088.

[Pellicer-García](https://pubmed.ncbi.nlm.nih.gov/?term=Pellicer-Garc%C3%ADa+B&cauthor_id=28927514) B, [Antón-Solanas](https://pubmed.ncbi.nlm.nih.gov/?term=Ant%C3%B3n-Solanas+I&cauthor_id=28927514) I, [Moreno-González](https://pubmed.ncbi.nlm.nih.gov/?term=Moreno-Gonz%C3%A1lez+S&cauthor_id=28927514) S, et al. (2017) Prevalence of Depression and Associated Factors in Non-institutionalized Older Adults With a Previous History of Falling. *Archives of Psychiatric Nursing* 31(5): 493–498.

Podsiadlo D and Richardson S (1991) The Timed “Up & Go”: a test of basic functional mobility for frail elderly persons. *Journal of American Geriatrics Society* 39(2): 142–148.

Reitan RM (1955) The relation of the Trail Making Test to organic brain damage. *Journal of Consulting Psychology* 19(5): 393–394.

Rey A (1958) *Memorisation D’une Serie de 15 Mots en 5 Repetitions; L’examen Clinique en Psycologie*. Paris: Presses Universitaires de France.

Ribeiro KM, Freitas RV, Ferreira LM, et al. (2017) Effects of balance Vestibular Rehabilitation Therapy in elderly with Benign Paroxysmal Positional Vertigo: a randomized controlled trial. *Disability and Rehabilitation* 39(12): 1198–1206.

[Rosenberg-Katz](https://pubmed.ncbi.nlm.nih.gov/?term=Rosenberg-Katz+K&cauthor_id=26233691) K, [Herman](https://pubmed.ncbi.nlm.nih.gov/?term=Herman+T&cauthor_id=26233691) T, [Jacob](https://pubmed.ncbi.nlm.nih.gov/?term=Jacob+Y&cauthor_id=26233691) Y, et al. (2015) Fall risk is associated with amplified functional connectivity of the central executive network in patients with Parkinson's disease. *Journal of Neurology* 262(11): 2448–2456.

# Royall DR, Palmer R, Chiodo LK, et al. (2004) Declining executive control in normal aging predicts change in functional status: The Freedom House Study. *Journal of the American Geriatrics Society* 52(3): 346–352.

[Saftari](https://pubmed.ncbi.nlm.nih.gov/?term=Saftari+LN&cauthor_id=29685171) LN and  [Kwon](https://pubmed.ncbi.nlm.nih.gov/?term=Kwon+OS&cauthor_id=29685171) OS (2018) Ageing vision and falls: a review. *Journal of Physiological Anthropology* 37(1): 11.

[Saverino](https://pubmed.ncbi.nlm.nih.gov/?term=Saverino+A&cauthor_id=24865406) A, [Moriarty](https://pubmed.ncbi.nlm.nih.gov/?term=Moriarty+A&cauthor_id=24865406) A, [Rantell](https://pubmed.ncbi.nlm.nih.gov/?term=Rantell+K&cauthor_id=24865406) K, et al. (2015) A qualitative description of falls in a neuro-rehabilitation unit: the use of a standardised fall report including the International Classification of Functioning (ICF) to describe activities and environmental factors. *Disability and Rehabilitation* 37(4): 355–362.

Swift [CG and](https://pubmed.ncbi.nlm.nih.gov/?term=Swift+CG&cauthor_id=25468853) [Iliffe](https://pubmed.ncbi.nlm.nih.gov/?term=Iliffe+S&cauthor_id=25468853) S (2014) Assessment and prevention of falls in older people - Concise guidance. *Clinical Medicine (London, England)* 14(6): 658–662.

The WHOQOL Group (1998) Development of the World Health Organization WHOQOL-BREF Quality of Life Assessment. *Psychological Medicine* 28(3): 551–558.‏

[Toglia](https://pubmed.ncbi.nlm.nih.gov/?term=Toglia+J&cauthor_id=20235769) J,  [Johnston](https://pubmed.ncbi.nlm.nih.gov/?term=Johnston+MV&cauthor_id=20235769) MV, [Goverover](https://pubmed.ncbi.nlm.nih.gov/?term=Goverover+Y&cauthor_id=20235769) Y, et al. (2010) A multicontext approach to promoting transfer of strategy use and self regulation after brain injury: An exploratory study. *Brain Injury* 24(4): 664–677.

Toglia J and Kirk U (2000) [Understanding awareness deficits following brain injury.](https://pubmed.ncbi.nlm.nih.gov/11455082/?from_term=toglia+and+awareness&from_pos=4) *NeuroRehabilitation* 15(1): 57–70.

World Health Organization (2001) International classification of functioning, disability and health. Geneva: World Health Organization.

Yesavage JA, Brink TL, Rose TL, et al. (1983) Development and validation of a geriatric depression screening scale: a preliminary report. *Journal of Psychiatric Research* 17(1): 37–49.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Table 1.** **Comparison of socio-demographic parameters, cognitive status, depression, executive functions, performance of activities of daily living and quality of life between groups.** |  |  |  |  |
|  | Total sample | Low fall risk (n = 84) | High fall risk (n = 39) | Statistical  significance of differences between high-risk/low-risk fallers# |
| Age (years, mean ± SD) | 78.63 ± 7.57 | 77.81 ± 7.66 | 80.74 ± 6.99 | 0.05 |
| Gender - men (%) | 41.5 | 70.6 | 29.4 | NS |
| Widows (%) |  | 29.8 | 53.8 | 0.01 |
| Living alone (%) | 38.2 | 65.1 | 34.9 | 0.017 |
| Years of education (mean ± SD) | 14.73 ± 2.71 | 13.77 ± 4.37 | 10.74 ± 4.43 | 0.05 |
| Moderate/poor socioeconomic status (%) | 35 | 27.4 | 51.3 | 0 .010 |
| Frail (%) | 38 | 12.7 | 50 | 0 |

# Qualitative variables: Chi-squared test; Quantitative variables: *t*-test

NS = not significant

**Table 2.** **Comparison of depression, EF, ADL and HRQOL between high-risk and low-risk fallers.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  | Low fall risk (n = 84)  mean ± SD | High fall risk (n = 39)  mean ± SD | Statistical  significance of differences between high-risk and low-risk fallers# |
| MoCA |  | 23.29 ± 3.74 | 20.94 ± 4.11 | 0.003 |
| Depression (GDS) (mean ± SD) |  | 2.76 ± 2.78 | 3.85 ± 2.73 | 0.05 |
| aEFPT Medication Management |  | 2.21 ± 2.84 | 4.22 ± 4.63 | 0.05 |
| BRIEF-A | Inhibition | 49.25 ± 9.21 | 51.53 ± 9.97 | NS |
|  | Shift | 55.23 ± 12.17 | 60.05 ± 15.55 | NS |
|  | Emotional control | 54.62 ± 13.35 | 61.81 ± 15.54 | 0.01 |
|  | Self-monitor | 45.17 ± 8.13 | 49.14 ± 11.21 | 0.03 |
|  | *Initiate* | 51.23 ± 10.11 | 55.54 ± 16.26 | NS |
|  | *Working memory* | 55.98 ± 12.83 | 64.53 ± 16.72 | 0.003 |
|  | *Plan/organise* | 54.44 ± 11.83 | 57.61 ± 15.19 | NS |
|  | *Task monitor* | 51.81 ± 9.85 | 55.28 ± 13.24 | NS |
|  | *Organization of materials* | 50.68 ± 12.97 | 52.25 ± 12.98 | NS |
|  | BRI | 41.30 ± 8.88 | 45.51 ± 10.95 | 0.01 |
|  | MI | 56.97 ± 12.16 | 61.60 ± 15.97 | 0.05 |
|  | GEC | 97.82 ± 19.32 | 107.11 ± 25.83 | 0.02 |
| BADL |  | 97.82 ± 6.14 | 92.01 ± 10.65 | 0.004 |
| IADL |  | 19.62 ± 4.17 | 16.23 ± 5.81 | 0.003 |
| HRQOL | Physical | 69.29 ± 18.83 | 54.79 ± 20.93 | 0 |
|  | Psychological | 75.46 ± 16.52 | 68.43 ± 18.58 | 0.04 |
|  | Social | 76.24 ± 18.25 | 71.91 ± 20.52 | NS |
|  | Environmental | 76.52 ± 14.68 | 69.54 ± 15.68 | 0.02 |
|  | Total | 74.37 ± 14.17 | 66.16 ± 16.27 | 0.006 |

# Quantitative variables: *t-*test; ANOVA; MANOVA = multivariate analysis of variance.

NS = not significant; EF = executive functions; ADL = activities of daily living; HRQOL = health-related quality of life; MoCA = Montreal Cognitive Assessment; GDS = Geriatric Depression Scale; aEFPT = alternate executive function performance test; BRIEF-A = Behavior Rating Inventory of Executive Function - Adult Version; BRI = Behavioral Regulation Index; MI = Metacognition Index;

GEC = Global Executive Composite; BADL = basic activities of daily living; IADL = instrumental activities of daily living. *BRIEF-A-MI components are marked in italics.*

**Figure 1.** **Structural equation modelling – the risk of falls mediates the association between executive dysfunction and daily life.**