18 Virtual Reality Training as an Intervention to Reduce Falls

Anat Mirelman, Inbal Maidan, Shirley Shema Shiratzky, and Jeffrey M. Hausdorff

Motor and Cognitive Function and Their Association with Falls

Falls result from interactions between multiple individual and environmental risk factors. Extensive research has identified many risk factors in older people in the community, including previous falls, demographic characteristics (such as female sex and older age), health habits, pain, chronic neurological and musculoskeletal diseases, medications, physical impairments, functional limitations, disabilities, and environmental barriers [1]. Most falls occur during walking and not surprisingly, gait impairments have been associated with an increased risk of falls [2–4]. With aging, elderly individuals generally walk more slowly, with shorter strides,

A. Mirelman (✉) · I. Maidan
Laboratory for Early Markers Of Neurodegeneration (LEMON), Neurological Institute, Tel Aviv Medical Center, Tel Aviv, Israel

Center for the Study of Movement, Cognition and Mobility, Neurological Institute, Tel Aviv Medical Center, Tel Aviv, Israel

Sackler Faculty of Medicine and Sagol School of Neuroscience, Tel Aviv University, Tel Aviv, Israel
e-mail: anatmi@tlvmc.gov.il

S. S. Shiratzky
Center for the Study of Movement, Cognition and Mobility, Neurological Institute, Tel Aviv Medical Center, Tel Aviv, Israel

J. M. Hausdorff
Center for the Study of Movement, Cognition and Mobility, Neurological Institute, Tel Aviv Medical Center, Tel Aviv, Israel

Department of Physical Therapy, Sackler Faculty of Medicine and Sagol School of Neuroscience, Tel Aviv University, Tel Aviv, Israel

Rush Alzheimer's Disease Center and Department of Orthopaedic Surgery, Rush University Medical Center, Chicago, IL, USA
e-mail: jhausdor@tlvmc.gov.il

M. Montero-Odasso, R. Camicioli (eds.), *Falls and Cognition in Older Persons*,
https://doi.org/10.1007/978-3-030-24233-6_18

decreased arm swing and longer double limb support times, and increased stride-to-stride variability [2, 5]. These deficits that are exacerbated in elderly fallers [2, 5], although it is not yet fully clear if these gait changes lead to an increased fall risk or if they are a maladaptive response to falls. Nonetheless, biomechanical processes and falls were, in the past, largely viewed as a failure of gait and balance mechanisms.

Exercise, aimed at improving gait and balance impairments in older adults, reduces the rate and risk of falls [1, 6, 7]. A recent meta-analysis of 88 trials for fall prevention [7] with 19,478 participants demonstrated that exercise reduced the rate of falls in community-dwelling older people by 21%, with greater effects seen from exercise programs that challenged balance and involved more than 3 hours per week of exercise. These findings are based on studies in older adults without significant cognitive impairments. It is now well accepted that cognitive impairment not only increases the risk of falls but may also adversely affects adherence to interventions and the effectiveness of such interventions. Results from fall prevention trials in cognitively intact older people should not be generalized to those with cognitive impairment [1, 8].

Indeed, attributing falls in older individuals only to motor and sensory impairments is overly simplistic. Research over the last decades has clearly demonstrated the strong connection between balance, gait and falls, on the one hand, and cognitive function, on the other hand [9–14]. Dementia and falls often coexist in older adults, gait impairments and falls are more prevalent in individuals with dementia than in those with normal cognitive aging, and this prevalence increases with the severity of cognitive impairment [13]. Specifically the cognitive subdomains of attention and executive function (EF) have been linked to gait alterations and fall risk [9, 10, 12, 15, 16]. For example, worse EF scores at baseline were associated with falls that occurred during a 2-year follow-up among healthy participants who reported no falls at baseline [9]. This relationship makes sense considering the role of EF in task planning, dual tasking, sensory integration, judgment, and reasoning [14, 16]. Dual-task-related gait changes partly depend on the capacity to allocate attention between two tasks performed simultaneously and are mainly related to executive dysfunction.

EF and attention abilities are reduced with aging, placing older adults at higher risk of falling when they attempt to perform two or more tasks simultaneously [17, 18]. These negative effects of aging are even larger among elderly fallers than in the general elderly population [9, 19, 20]. These findings have important implications on every day function. They support the idea that when people are distracted or attempt to perform a task that diverts attention from walking or stepping [19], gait deficits become exacerbated, walking becomes less safe, and the risk of falls increases. Attention and planning are also associated with complex everyday life activities such as obstacle negotiation. Older adults and patients with neurodegenerative conditions often have difficulties with negotiating obstacles, with the lower leg of older adults passing dangerously close to impediments during walking [21, 22].

Due to the multifaceted aspects of falls [23–25], it is only reasonable to posit that therapeutic interventions aimed at reducing fall risk should be designed to address both motor and cognitive aspects of safe gait while also addressing dynamic balance and muscle strength deficits [1, 8, 13, 26–28]. Multifactorial interventions involve several modalities and are usually provided by multidisciplinary professionals. The interventions may include exercise, review and modification of medications, and/or addressing risk factors and home adjustments, and referrals. Physical therapy (PT) is considered a multifactorial intervention as it may include several training modalities. As mentioned above, exercise has become a widely studied fall prevention intervention. However, despite the increasing recognition of the importance of cognition, motor, and obstacle negotiation abilities, multifactorial interventions have generally focused on individual risk factors separately, largely ignoring their interdependence and the role of executive function, attention, and cognitive function, more generally.

Virtual Reality for Motor-Cognitive Training

Virtual reality (VR) is defined as a high-end computer interface that involves real time simulation and interactions through multiple sensory channels [26, 29]. The impetus for using VR for motor-cognitive training is that the technology may enable individualized repetitive practice of motor function, graded in accordance to the needs and level of ability of the person, while engaging in and stimulating cognitive processes, typically in a fun, game-line environment. VR can be used to provide training in a more stimulating and enriching environment than traditional rehabilitation, while providing feedback about performance to assist with the learning of new motor strategies of movement. The realism of the virtual environments provides individuals with the opportunity to safely explore their environments, increasing their sense of autonomy and independence in directing their own therapeutic experience.

VR training can also address emotional aspects. It is challenging and enjoyable which makes the intervention engaging and motivating, VR training can also reduce fear or anxiety of performance and improve exercise compliance and effectiveness in patients with different affective disorders and motor impairments [30–32]. These VR qualities allow for higher intensity of training in short duration protocols with relatively low patient burden [29, 33]. VR protocols can be standardized and replicated and enable domain-specific or multidomain progression, fostering a personalized medicine approach. Based on these many beneficial attributes, VR technology can be well suited to address the multiple motor, cognitive, and emotional aspects required to reduce the risk of falls [24, 26, 33] (Fig. 18.1).

In recent years, there has been a spurt of technological advancement. VR systems have become more affordable and portable allowing for use even in the home environment by unprofessional personnel. Systems differ with respect to their interface and simulation content, the latter is generally chosen to fit the specific goals of the VR intervention. Interfaces to the VR simulation could include a screen and motion camera [26, 34], head-mounted displays or glasses, and include both custom-made and commercially available systems specifically designed for older adults (Fig. 18.2).

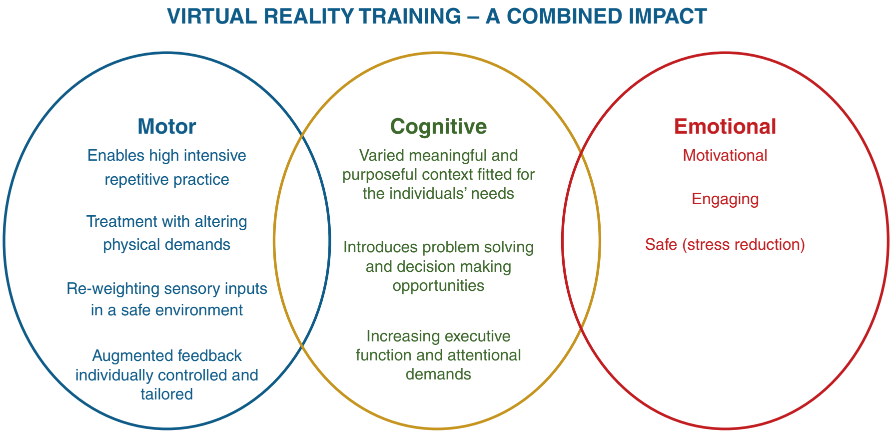

Fig. 18.1 Virtual reality attributes. A combined motor, cognitive, and emotional impact

Fig. 18.2 Different virtual reality systems used for motor-cognitive interventions for the elderly. From the left, a commercial system (Dance–Dance Revolution) [26], the oculus rift head-mounted display [35], and a custom-made system: V-TIME [34]

As previously mentioned, fall prevention interventions should include multiple aspects relating to falls, task-specific and generalized training. The intervention should be centered around the user's needs while applying principles of motor learning to teach new strategies that can be applied in different everyday settings and situations to decrease fall risk [24, 26, 29]. VR can be used as a gateway to functional recovery in the elderly as it allows for the simultaneous focusing on both the physical and cognitive domains to decrease the risk of falls and empower safe community ambulation and function [24, 26]. This approach has the potential to address many of the barriers that currently prevent adaptation of other fall risk treatment programs in clinical settings (e.g., poor compliance to the intervention, poor retention after training, costly, not readily available, and not engaging). Whereas other forms of exercise interventions may be viewed as a boring, highly repetitive burden, VR is fun and challenging, promoting long-term compliance [36].

Virtual Reality for Reducing Falls

A recent meta-analysis summarized evidence on the effectiveness of virtual reality games as compared to conventional therapy or no intervention for improving motor function in the elderly. A total of 28 studies were evaluated among 1121 elderly participants. The study found that VR games significantly improved mobility, balance, and fear of falling after 3–6 and 8–12 weeks of intervention when compared with no intervention and had superior effects on balance improvements (as measured using the Berg balance test), compared to conventional interventions [37].

In addition to the studies that examined the effects of VR on mobility and balance, several studies explored the utility of VR for specifically reducing fall frequency or fall risk (i.e., using fall rate as a primary outcome measure). In one of the earlier studies, Duque et al. [38] evaluated the use of a Balance Rehabilitation Unit (BRU) implemented with VR in 70 older adults with a history of falls (mean 3.4 ± 3 falls in 6 months prior to the study). The BRU is a balance platform combined with visual display presented in front of the user. Participants received either the BRU-training which included two sessions of balance training per week for 6 weeks each lasting 30 minutes or usual care which included an invitation to join an exercise program (following the Otago protocol), medication review, home visit by an occupational therapist, hearing and visual assessment, vitamin D supplementation, and education materials on falls prevention. Both groups showed a significant reduction in the incidence of falls. However, 9 months after the intervention, BRU-training subjects reported a significantly lower number of falls as compared with the controls (1.1 ± 0.7 vs. 2.0 ± 0.2, respectively) and lower levels of fear of falling [38].

Similar findings were observed by Fu et al. [39]. They compared the effects of a 6-week training program (three times a week) of VR, provided by the Nintendo Wii Fit, to conventional strength and stretching exercises on incidence of falls in 60 older adults living in a nursing home. The incidence of falls, measured over the 12 months after the completion of the intervention, improved significantly in both groups. Nonetheless, participants in the Wii Fit training group showed a significantly greater improvement compared to the control group. The results suggest that even in institutionalized older adults with a history of falls, VR training can be used to effectively reduce fall risk and the incidence of falls [39].

Another study using the Wii Fit balance exercises explored the utility of this method for the training of individuals post stroke [40]. The researchers compared the effects of training twice weekly for 10 weeks with the Wii fit compared to a similar dose of conventional physical therapy sessions including stretching, strengthening, and balance exercises. Although there was a significant effect on falls in the VR group after training, the median number of falls prior to the evaluation was small (0–1 or 0–2 in the experimental group and the control group, respectively). Thus, although the findings are encouraging, future studies should explore the value of VR in reducing fall incidence in a larger sample of individuals post stroke [40].

Eggenberger et al. [23] investigated the added value of the VR component as compared to a motor-cognitive intervention and a motor intervention alone. Eighty-nine participants were randomized to three groups: (1) virtual reality video game dancing (DANCE), (2) treadmill walking with simultaneous verbal memory training (MEMORY), or (3) treadmill walking (PHYS). Each program was delivered twice weekly for 20 minutes followed by strength and balance exercises for the duration of 6 months. Fall rates were evaluated for 1-year post intervention. Both motor-cognitive interventions (DANCE and MEMORY) showed a significant advantage in dual task cost and gait variability, proxies of fall risk. Fall frequency was significantly reduced by 77%, from 0.79 falls per person-year at baseline to 0.18 falls per person-year during the first 6-month period after training. However, there was no difference between the training arms [23]. This could potentially be attributed to the small number of participants and the large variability in the number of falls.

Parijat et al. [41] used a head-mounted display to provide a virtual reality scene of a street environment. The VR scene consisted of virtual slips or perturbations (tilts) in the pitch plane at random intervals while participants walked on the treadmill. The researchers investigated whether this type of training is useful in teaching older adults a strategy to avoid slips. Participants received three training sessions using the system while participants in the control group received standard gait training. During evaluations, participants were asked to walk on a slippery surface covered with a 1:1 water and KY-Jelly mixture while wearing a harness. A slip trial was considered a fall if the slip distance exceeded 10 cm, peak sliding heel velocity exceeded the whole body center of mass velocity while slipping, and the participant's body dropped toward the floor after slipping and arrested by the harness before impact. The VR group was able to reduce the frequency of falls from 50% at baseline to 0% in the transfer of training trial, suggesting improved reactive changes after slip. This effect was not observed in the control group. The VR training also had beneficial effects in improving recovery reactions in older adults when encountering a slippery surface, also suggestive of a reduced fall risk [41].

The abovementioned trials (as summarized in Table 18.1) demonstrate the feasibility of using VR for reducing falls and fall risk in older adults in single-center studies with a relatively small number of participants. The V-TIME study [29, 34] is, to date, the largest multicenter randomized controlled trial to directly investigate the use of a VR training approach for the reduction of falls. It examined the effects of VR training in 282 older adults who had a high risk of falls based on a history of two or more falls in the 6 months before the study. Participants included older adults with a history of falls (idiopathic fallers), patients with Parkinson's disease, and individuals with mild cognitive impairments with a history of multiple falls. Subjects were randomly assigned to receive 6 weeks of either treadmill training plus VR or

Table 18.1 Summary of studies that specifically examined the impact VR-based interventions on falls in older adults

Citation	Population			Interventions			Results related to falls
	Condition	Group = N	Age (years)	Type	Sequence	Dose (min/frq/wks)	
da Fonseca (2017)	Patients post-stroke	EXP = 15 CON = 15	53.8 ± 6.3 50.9 ± 10.9	Nintendo Wii fit balance training Conventional physiotherapy	Warm up followed by games of tennis, hula-hoop, soccer, and boxing Stretching, trunk mobilization, standing balance training, and free gait training	60/2/10 60/2/10	No. of falls was significantly reduced only in the EXP group ($p = 0.049$). The between-group comparison of fall frequency was not significant. No follow-up was performed
Duque (2013)	Elderly fallers	EXP = 30 CON = 40	79.3 ± 10 75.0 ± 8.0	Visual-vestibular rehabilitation and postural training VR exercises + usual care Usual care alone	Exercises include three different postural training games with increasing levels of complexity Recommendations regarding exercise, medication review, nutrition, visual and hearing assessment, and home visit by an OT	30/2/6 N/A	After 9 months of follow-up, both groups showed a significant reduction in the incidence of falls ($P < 0.05$) Subjects in the EXP group reported a significantly lower no. of falls as compared with the untrained controls (1.1 ± 0.7 in the EXP group vs. 2 ± 0.2 in the CON group; $P < 0.01$)

(continued)

Table 18.1 (continued)

Citation	Population			Interventions			Results related to falls
	Condition	Group = N	Age (years)	Type	Sequence	Dose (min/frq/wks)	
Eggenberger (2015)	Older adults, cognitive intact (age > 70 years)	DANCE = 24 MEM = 22 PHYS = 25	77.3 ± 6.3 78.5 ± 5.1 80.8 ± 4.7	VR dancing game Treadmill training + verbal memory task Treadmill training alone	Subjects performed stepping sequence on pressure sensitive platforms, in response to visual cues, and according to musical rhythm Treadmill walking while memorizing a sequence of 3 to 20 word list Treadmill walking or running at a constant pace	60/2/26 60/2/26 60/2/26	Frequency of falls was reduced 6 months after the training, as compared to 6 months before the training ($p < 0.001$) No differences were found between the three interventions
Fu (2015)	Older adults living in a nursing home	EXP = 30 CON = 30	82.4 ± 3.8 82.3 ± 4.3	Nintendo Wii fit balance training Conventional balance training	Subjects played games (soccer head, table tilt, and bubble balance) that require weight shifting, manipulating objects while standing and kicking Lower limb strength, tandem standing, and walking, stepping and sit-to-stand exercise, half squats	60/3/6 60/3/6	Incidence of falls over 12 months of follow-up was significantly reduced posttraining in both training arms Baseline no. of falls was comparable between groups. After the training, subjects in the EXP group experienced significantly less falls compared to the CON group ($p < 0.001$)

Parijat (2015)	Healthy older adults	EXP = 12 CON = 12	70.5 ± 6.6 74.2 ± 5.8	Treadmill walking + VR Usual walking over ground	Subjects walked on a treadmill wearing a HMD. Virtual environment of a street introduced virtual slips (perturbations in the Pitch plane of the VR scene) at random intervals Subjects walked on a walkway for 15 minutes X three trials	55/1/1 45/1/1	The EXP group was able to reduce the frequency of slip-induced falls from 50% at baseline to 0% after the training ($p = 0.03$). Although the frequency of falls in the CON group reduced from 50% at baseline to 25% posttraining, the difference was not significant ($p = 0.216$)
Mirelman (2016)	Older adults with recent fall history, including elderly fallers, patients with MCI and people with PD	EXP = 146 CON = 136	74.2 ± 6.9 73.3 ± 6.4	Treadmill training + VR Treadmill training alone	Subjects walked on a treadmill while negotiating virtual obstacles. Level of difficulty was gradually progressed Conventional treadmill walking	45/3/6 45/3/6	Before training, the incident rate of falls was similar in both groups In the 6 months after training, the incident rate was significantly lower in the EXP group than it had been before training ($p < 0{\cdot}0001$), whereas the incident rate did not decrease significantly in the CON group ($p = 0.49$)

treadmill training alone. Both groups trained three times per week for 6 weeks, with each session lasting about 45 min and with training progression individualized to the participant's level of performance. The VR system consisted of a motion-capture camera and a computer-generated simulation projected on to a large screen, including real-life challenges such as obstacles, multiple pathways, and distracters that required continual adjustment of steps (recall Fig. 18.2c). The primary outcome was the incident rate of falls during the 6 months after the end of training.

At 6 months after training, both treadmill training interventions significantly improved markers of fall risk and fall rates were lowered for both interventions, compared with the values from before training, emphasizing the therapeutic value of the active control intervention (i.e., treadmill training alone) [29, 34]. Nonetheless, comparisons within the training groups showed that the reduction in fall rates was only significant in the treadmill training plus VR group (a 55% reduction) and not in the treadmill-training group. Consistent with this finding, a direct comparison of the two training groups showed that the treadmill training plus VR intervention had a significant, positive effect on the incident rate of falls; the rate of falls after training was 42% lower in the treadmill training plus VR arm than in the active control group (Fig. 18.3). The training also had a positive effect on fall risk measures (gait variability during obstacle negotiation and obstacle clearance), improving both to a larger degree than that seen in those who trained on the treadmill without the virtual reality component. The added value of the VR component might be explained by the nature of the training. The motor-cognitive intervention provided by the VR implicitly trained obstacle negotiation strategies in a complex, enriched environment that

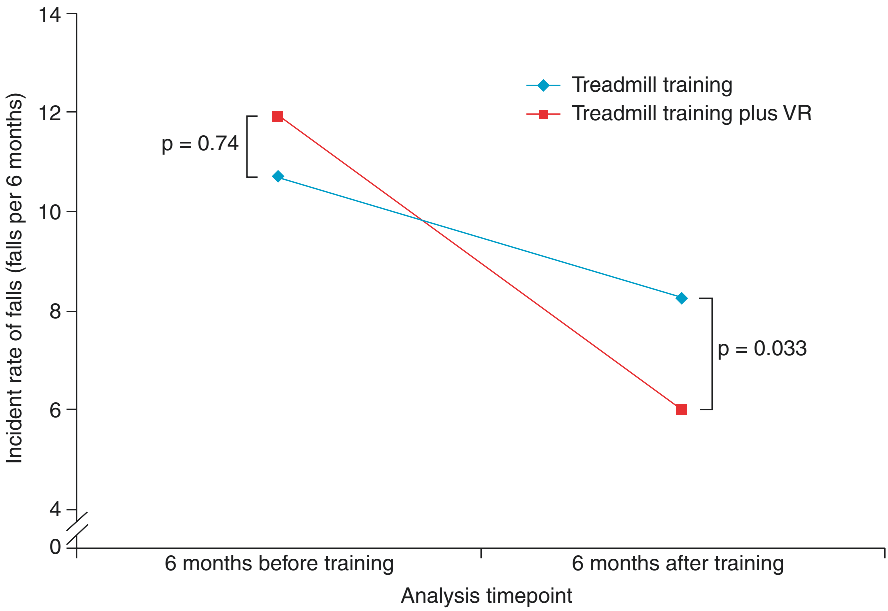

Fig. 18.3 Differences in fall rate before and after training in the V-TIME study [29, 34]

requires focused attention and planning, in a VR environment that mimics everyday walking in the real world and implicitly teaches safe ambulation. Indeed, participants also reported more engagement and satisfaction by the training and reported that they felt more confident [36]. The findings further support the notion that a combined motor-cognitive intervention could be beneficial to reduce fall rates in older adults and those with neurodegenerative conditions [42].

Discussion and Future Directions

The findings from the VR literature on reduction of fall rate in response to intervention are in line with the most effective fall preventions that have assessed more traditional group-based and homed-based exercise interventions in older people and well above the average reduction of 21% for exercise interventions reported in systematic reviews [7]. This could be a result of the interactive environments, which are engaging and enable long duration practice with increased level of challenge. These systems have the potential to influence postural control and fall events by stimulating the sensory cues that are needed for maintaining balance and orientation and by improving motor control patterns as well as cognitive functions and emotional aspects. VR also enables training in high intensity in simulations that are ecologically valid, resembling everyday life situations and allows for training that focuses on the key motor-cognitive aspects that are critical to safe ambulation. It is possible that the positive effects observed in studies with VR are related to improved multitasking and gait adaptability in situations requiring focused attention and planning and these in turn transfer to real-world situation.

The field of VR for falls is still relatively young, with only a limited number of studies specifically examining the effects of VR training on falls in older adults. Future research should explore different populations including older adults with cognitive impairments. Much is still unknown regarding the optimal dosing and intensity of training required to impact falls in older adults and the retention of these effects (beyond what is reported today). In addition, it is imperative to evaluate the effectiveness of this method in clinical instead of research settings, fully evaluating the utility of this approach administered in community gyms and rehabilitation clinics. Lastly, it will be interesting to examine whether this method could be used as part of a fall prevention approach, to treat fall risk before falls become common (i.e., “prehab”) and before any injuries occur.

References

1. Vieira ER, Palmer RC, Chaves PH. Prevention of falls in older people living in the community. BMJ. 2016;353:i1419.
2. Hausdorff JM, Rios DA, Edelberg HK. Gait variability and fall risk in community-living older adults: a 1-year prospective study. Arch Phys Med Rehabil. 2001;82(8):1050–6.
3. Robinovitch SN, Feldman F, Yang Y, Schonnop R, Leung PM, Sarraf T, et al. Video capture of the circumstances of falls in elderly people residing in long-term care: an observational study. Lancet. 2013;381(9860):47–54.

4. Sartini M, Cristina ML, Spagnolo AM, Cremonesi P, Costaguta C, Monacelli F, et al. The epidemiology of domestic injurious falls in a community dwelling elderly population: an outgrowing economic burden. Eur J Pub Health. 2010;20(5):604–6.
5. Legters K. Fear of falling. Phys Ther. 2002;82(3):264–72.
6. Sherrington C, Tiedemann A, Fairhall N, Close JC, Lord SR. Exercise to prevent falls in older adults: an updated meta-analysis and best practice recommendations. N S W Public Health Bull. 2011;22(3–4):78–83.
7. Sherrington C, Michaleff ZA, Fairhall N, Paul SS, Tiedemann A, Whitney J, et al. Exercise to prevent falls in older adults: an updated systematic review and meta-analysis. Br J Sports Med. 2017;51(24):1750–8.
8. Winter H, Watt K, Peel NM. Falls prevention interventions for community-dwelling older persons with cognitive impairment: a systematic review. Int Psychogeriatr. 2013;25(2):215–27.
9. Herman T, Mirelman A, Giladi N, Schweiger A, Hausdorff JM. Executive control deficits as a prodrome to falls in healthy older adults: a prospective study linking thinking, walking, and falling. J Gerontol A Biol Sci Med Sci. 2010;65(10):1086–92.
10. Mirelman A, Herman T, Brozgol M, Dorfman M, Sprecher E, Schweiger A, et al. Executive function and falls in older adults: new findings from a five-year prospective study link fall risk to cognition. PLoS One. 2012;7(6):e40297.
11. Montero-Odasso M, Verghese J, Beauchet O, Hausdorff JM. Gait and cognition: a complementary approach to understanding brain function and the risk of falling. J Am Geriatr Soc. 2012;60(11):2127–36.
12. Montero-Odasso M, Hachinski V. Preludes to brain failure: executive dysfunction and gait disturbances. Neurol Sci. 2014;35(4):601–4.
13. Montero-Odasso M, Speechley M. Falls in cognitively impaired older adults: implications for risk assessment and prevention. J Am Geriatr Soc. 2018;66(2):367–75.
14. Muir SW, Gopaul K, Montero Odasso MM. The role of cognitive impairment in fall risk among older adults: a systematic review and meta-analysis. Age Ageing. 2012;41(3):299–308.
15. Holtzer R, Ozelius L, Xue X, Wang T, Lipton RB, Verghese J. Differential effects of COMT on gait and executive control in aging. Neurobiol Aging. 2010;31(3):523–31.
16. Liu-Ambrose T, Davis JC, Nagamatsu LS, Hsu CL, Katarynych LA, Khan KM. Changes in executive functions and self-efficacy are independently associated with improved usual gait speed in older women. BMC Geriatr. 2010;10:25.
17. Amboni M, Barone P, Hausdorff JM. Cognitive contributions to gait and falls: evidence and implications. Mov Disord. 2013;28(11):1520–33.
18. Hausdorff JM, Schweiger A, Herman T, Yogev-Seligmann G, Giladi N. Dual-task decrements in gait: contributing factors among healthy older adults. J Gerontol A Biol Sci Med Sci. 2008;63(12):1335–43.
19. Alexander NB, Hausdorff JM. Guest editorial: linking thinking, walking, and falling. J Gerontol A Biol Sci Med Sci. 2008;63(12):1325–8.
20. Montero-Odasso M, Wells J, Borrie M. Can cognitive enhancers reduce the risk of falls in people with dementia? An open-label study with controls. J Am Geriatr Soc. 2009;57(2):359–60.
21. Galna B, Murphy AT, Morris ME. Obstacle crossing in people with Parkinson's disease: foot clearance and spatiotemporal deficits. Hum Mov Sci. 2010;29(5):843–52.
22. Maidan I, Eyal S, Kurz I, Geffen N, Gazit E, Ravid L, et al. Age-associated changes in obstacle negotiation strategies: does size and timing matter? Gait Posture. 2018;59:242–7.
23. Eggenberger P, Theill N, Holenstein S, Schumacher V, de Bruin ED. Multicomponent physical exercise with simultaneous cognitive training to enhance dual-task walking of older adults: a secondary analysis of a 6-month randomized controlled trial with 1-year follow-up. Clin Interv Aging. 2015;10:1711–32.
24. Mirelman A, Maidan I, Herman T, Deutsch JE, Giladi N, Hausdorff JM. Virtual reality for gait training: can it induce motor learning to enhance complex walking and reduce fall risk in patients with Parkinson's disease? J Gerontol A Biol Sci Med Sci. 2011;66(2):234–40.
25. Rosso AL, Studenski SA, Chen WG, Aizenstein HJ, Alexander NB, Bennett DA, et al. Aging, the central nervous system, and mobility. J Gerontol A Biol Sci Med Sci. 2013;68(11):1379–86.

26. de Bruin ED, Schoene D, Pichierri G, Smith ST. Use of virtual reality technique for the training of motor control in the elderly. Some theoretical considerations. Z Gerontol Geriatr. 2010 Aug;43(4):229–34.
27. Canning CG, Sherrington C, Lord SR, Close JC, Heritier S, Heller GZ, et al. Exercise for falls prevention in Parkinson disease: a randomized controlled trial. Neurology. 2015;84(3):304–12.
28. Varma VR, Hausdorff JM, Studenski SA, Rosano C, Camicioli R, Alexander NB, et al. Aging, the central nervous system, and mobility in older adults: interventions. J Gerontol A Biol Sci Med Sci. 2016;71(11):1451–8.
29. Mirelman A, Rochester L, Reelick M, Nieuwhof F, Pelosin E, Abbruzzese G, et al. V-TIME: a treadmill training program augmented by virtual reality to decrease fall risk in older adults: study design of a randomized controlled trial. BMC Neurol. 2013;13:15.
30. Ehgoetz Martens KA, Ellard CG, Almeida QJ. Does anxiety cause freezing of gait in Parkinson's disease? PLoS One. 2014;9(9):e106561.
31. Levy F, Leboucher P, Rautureau G, Komano O, Millet B, Jouvent R. Fear of falling: efficacy of virtual reality associated with serious games in elderly people. Neuropsychiatr Dis Treat. 2016;12:877–81.
32. McCann RA, Armstrong CM, Skopp NA, Edwards-Stewart A, Smolenski DJ, June JD, et al. Virtual reality exposure therapy for the treatment of anxiety disorders: an evaluation of research quality. J Anxiety Disord. 2014;28(6):625–31.
33. Cherniack EP. Not just fun and games: applications of virtual reality in the identification and rehabilitation of cognitive disorders of the elderly. Disabil Rehabil Assist Technol. 2011;6(4):283–9.
34. Mirelman A, Rochester L, Maidan I, Del DS, Alcock L, Nieuwhof F, et al. Addition of a non-immersive virtual reality component to treadmill training to reduce fall risk in older adults (V-TIME): a randomised controlled trial. Lancet. 2016;388(10050):1170–82.
35. Saldana SJ, Marsh AP, Rejeski WJ, Haberl JK, Wu P, Rosenthal S, et al. Assessing balance through the use of a low-cost head-mounted display in older adults: a pilot study. Clin Interv Aging. 2017;12:1363–70.
36. Dockx K, Alcock L, Bekkers E, Ginis P, Reelick M, Pelosin E, et al. Fall-prone older People's attitudes towards the use of virtual reality technology for fall prevention. Gerontology. 2017;63(6):590–8.
37. Neri SG, Cardoso JR, Cruz L, Lima RM, de Oliveira RJ, Iversen MD, et al. Do virtual reality games improve mobility skills and balance measurements in community-dwelling older adults? Systematic review and meta-analysis. Clin Rehabil. 2017;31(10):1292–304.
38. Duque G, Boersma D, Loza-Diaz G, Hassan S, Suarez H, Geisinger D, et al. Effects of balance training using a virtual-reality system in older fallers. Clin Interv Aging. 2013;8:257–63.
39. Fu AS, Gao KL, Tung AK, Tsang WW, Kwan MM. Effectiveness of exergaming training in reducing risk and incidence of falls in frail older adults with a history of falls. Arch Phys Med Rehabil. 2015;96(12):2096–102.
40. Pedreira da FE, Ribeiro da Silva NM, Pinto EB. Therapeutic effect of virtual reality on post-stroke patients: randomized clinical trial. J Stroke Cerebrovasc Dis. 2017;26(1):94–100.
41. Parijat P, Lockhart TE, Liu J. Effects of perturbation-based slip training using a virtual reality environment on slip-induced falls. Ann Biomed Eng. 2015;43(4):958–67.
42. Dockx K, Bekkers EM, Van den Bergh V, Ginis P, Rochester L, Hausdorff JM, et al. Virtual reality for rehabilitation in Parkinson's disease. Cochrane Database Syst Rev. 2016;12:CD010760.