

DISS. ETH NO. 21604

# **Cognitive-motor interventions**

–

## **A novel approach to improve physical functioning in older adults**

A thesis submitted to attain the degree of  
DOCTOR OF SCIENCES of ETH ZURICH  
(Dr. sc. ETH Zurich)

Presented by  
GIUSEPPE PICHIERRI  
MSc ETH HMS

born on 06.07.1979

citizen of Niederglatt (Zurich) and Italy

accepted on the recommendation of  
PD Dr. Eling D. de Bruin  
Prof. Dr. Kurt Murer  
Prof. Dr. David P. Wolfer

2014



## Table of Contents

<b>Chapter 1</b>	<b>General Introduction</b>	7 – 24
<b>Chapter 2</b>	<b>Use of virtual reality technique for the training of motor control in the elderly – Some theoretical considerations</b> <i>Article published in Z Gerontol Geriat 2010, 43:229–234</i>	25 – 41
<b>Chapter 3</b>	<b>Cognitive and cognitive-motor interventions affecting physical functioning: a systematic review</b> <i>Article published in BMC Geriatrics 2011, 11:29</i>	43 – 87
<b>Chapter 4</b>	<b>The effects of a cognitive-motor intervention on voluntary step execution under single and dual task conditions in older adults: a randomized controlled pilot study</b> <i>Article published in Clinical Interventions in Aging 2012;7 175–184</i>	89 – 113
<b>Chapter 5</b>	<b>A cognitive-motor intervention using a dance video game to enhance foot placement accuracy and gait under dual task conditions in older adults: A randomized controlled trial (ISRCTN05350123)</b> <i>Article published in BMC Geriatrics 2012, 12:74</i>	115 – 147
<b>Chapter 6</b>	<b>Assessment of the test-retest reliability of a foot placement accuracy protocol in assisted-living older adults</b> <i>Article published in Gait &amp; Posture 38 (2013) 784–789</i>	149 – 166
<b>Chapter 7</b>	<b>General Discussion</b>	169 – 186
<b>Chapter 8</b>	<b>Summary / Zusammenfassung</b> <b>Danksagungen</b> <b>PhD curriculum</b> <b>Curriculum vitae</b>	189 – 213



# One

Chapter

## General Introduction

The improvement of physical functioning and the prevention of falls in the older population have been of great interest since the 1980's [1-3]. 'Physical functioning' refers to the ability to conduct a variety of activities ranging from self-care (instrumental activities of daily living) to more challenging mobility tasks that require balance abilities, strength or endurance, e.g. walking or standing, important for achieving or maintaining an independent way of living [4,5]. A fall is defined as a situation in which a person unintentionally comes to the ground or to some lower level other than as a consequence of sustaining a violent blow, a loss of consciousness, or a sudden onset of paralysis as in stroke or epileptic seizure [6]. The interest in this topic lies in the fact that the decline of physical functioning and above all the increasing incidence of falls are under the many undesirable ancillary effects of the natural aging process and can lead as the case may be to a premature admission to care homes, the loss of independence or even to an increasing rate of morbidity, or mortality [7, 8].

Fall prevention is of particular importance when considering the steady increase of life expectancy of human beings. Thanks to better sanitation, higher standards of living and a well-organized and efficient health care system, life expectancy has nearly doubled during the last century. In Switzerland, for instance, from 1900 to 2011 life expectancy increased from 49 to about 85 years in women and from 46 to about 80 years in men [9]. It has been observed that approximately one third of the population over 65 years of age statistically experience a fall each year. The incidence of falls even increases to 50% in people aged 85 and over [8,10]. Falls are by now the leading cause of hospitalization related to injuries in older adults. The major injuries that result from a fall are, besides soft tissues injuries, serious fractures of the wrist, the elbow, the trunk, the head and the hips [11,12]. Fear of falling is a common reported concern in older adults, especially in individuals who have already experienced a fall, and can lead to a further decrease in activity of daily life, a further decline in physical functioning and to a general decrease in quality of life [13, 14].

## 1.1. Causes of a fall

The causes of a fall are still in dispute. The increased incidence of falls has long been attributed to the decline of physical abilities, reduced sensory functions, and to the slowdown of psychomotor processing, all being common consequences of the natural aging process [15–17]. The decline in muscle mass and strength is a natural process of aging which already begins at the young age of 30. Muscle mass declines by 10%–15% per decade, and even accelerates at older ages [18, 19]. Additionally, the reduction in muscle power (strength x velocity of movement) due to the decline in mass and contractile speed of the skeletal muscles leads to relevant restrictions in activities of daily life [19, 20]. This may cause slowing, and increases variability of gait patterns or gives rise to insecurities in balance, representing a possible major cause of a fall [21–23].

The American Geriatrics Society has suggested risk factors that seem to be related to the higher risk for falling in institutionalized or community-dwelling older adults [7]. The main proposals included factors related to poor physical functioning like muscle weakness, gait and/or balance deficits, and associated factors like previous falls, together with the use of assistive devices due to reduced abilities (*Table 1.1*). In the past these aspects have long been regarded as the main factors for the occurrence of a fall in older adults. Not surprisingly, to date fall prevention programs for older adults mainly focus on improving physical functioning by conducting interventions including physical exercise to rehabilitate muscle strength and postural balance skills. The solution of the fall problem, however, is not that simple as it appears. The origin of a fall is more likely to be an individual framework composed of various risk factors rather than the result of one or two factors alone. In addition to physical and functional impairments, this framework also includes cognitive impairments, the influence of prescribed medications and environmental conditions [11].

## 1.2. The role of cognition

One particular potential risk factor for falls has been overlooked in the past, namely the presence of cognitive impairments in older adults. Recent research suggests a link

between gait dysfunctions and cognitive impairments [4]. In fact older adults with cognitive impairments have a higher susceptibility to falling than peers without cognitive impairments [24]. Older adults or younger persons with neurological impairments, people suffering from the consequences of traumatic brain injuries or a stroke event, together with sufferers from dementia show similar impairments of walking abilities, i.e. slower gait speed and an increased stride time variability, as well as limitations in postural balance abilities [25,26]. Gait dysfunctions are included among the many risk factors for falls. Older adults with slow gait velocity, gait instability, or increased step length variability have an increased risk of falls [26].

**Table 1.1** Results of univariate analysis of most common risk factors for falls identified in 16 studies that examined risk factors [7]

Risk Factor	Significant/Total*	Mean RR-OR <sup>#</sup>	Range
Muscle weakness	10/11	4.4	1.5 – 10.3
History of falls	12/13	3.0	1.7 – 7.0
Gait deficit	10/12	2.9	1.3 – 5.6
Balance deficit	8/11	2.9	1.6 – 5.4
Use assistive device	8/8	2.6	1.2 – 4.6
Visual deficit	6/12	2.5	1.6 – 3.5
Arthritis	3/7	2.4	1.9 – 2.9
Impaired ADL	8/9	2.3	1.5 – 3.1
Depression	3/6	2.2	1.7 – 2.5
Cognitive impairment	4/11	1.8	1.0 – 2.3
Age > 80 years	5/8	1.7	1.1 – 2.5

\* Number of studies with significant odds ratio or relative risk ratio in univariate analysis/total number of studies that included each factor; <sup>#</sup> Relative risk ratios (RR) calculated for prospective studies, odds ratios (OR) calculated for retrospective studies; ADL = activities of daily living.

Until recently gait has been assumed to be an automated task without the need for higher-level cognitive inputs. This holds true for younger or middle-aged individuals. Walking is a complex cognitive task [27]. The impact of cognitive functions on gait in the older population, however, can be easily observed in every day situations. Older adults tend to stop walking while talking [28,29] or seem to walk around with blinders on, focusing their attention on their walking path, blocking out what is going on around



themselves, e.g. other pedestrians or the traffic. This observation is explained by the assumption that cognitive resources intended for regulating the gait cycle come into conflict with cognitive resources needed to hold a conversation or to register the changing environmental conditions. One of the tasks will automatically be preferred to the other. So they either stop walking and hold the conversation or observe their surroundings, or conversely they stop talking or stop observing in order to continue on their walk. This phenomenon has been consistently observed throughout many studies and the poorer performance of older adults in dual task conditions is one of the most typical symptoms of the natural aging process [30].

The impact of cognitive deficiencies on gait or postural balance is extensively underpinned by a very substantial number of studies investigating the abilities of older adults to manage a situation in which they are told to perform a motor task while simultaneously executing a cognitive task [31]. This situation is referred as a dual task situation. For instance, we can observe slowing of gait speed and/or an increased variability of gait patterns like stride time, step length, or step width when older adults are told to execute a cognitive task like calculating backwards from a number in steps of seven or list words with a specific initial letter [15,32–34]. In addition, increasing reaction times were observed in stepping responses when older adults are challenged by simultaneous cognitive tasks [35]. Walking on the street is nothing else than a typical dual task situation that we encounter almost every day. Hence, it is not surprising that the most frequent causes for a fall are tripping, slipping or misplacing steps whilst walking without any hazardous behavior even on level surfaces [36–38]. It has been observed that older adults are at particular risk to experience a fall while they walk in busy environments [15,39].

### **1.3. The special role of executive functions**

A challenging problem related to falls is that they can potentially occur in different situations during daily activities and, unfortunately, in most of cases without any notice. They can occur while standing motionless, during the phase of gait initiation or during walking itself, even on level surfaces. Our body is constantly challenged by different

internal influences (muscle weakness, illness, fatigue, mood, cognitive impairments, vision problems) as well as by external ones (obstacles, crowds, traffic, weather) all of which constitute a potential threat to postural stability. These circumstances demand intact cognitive functions to register potential threatening situations at an early stage, to plan and execute the correct motor answer to the special condition in order to prevent a trip or a fall. In recent fall prevention research the decline of cognitive functions that regulate these abilities has been suggested as a major cause of falls in addition to the decline of physical functioning [40,41]. In fact, impaired cognitive functions that regulate these skills may negatively affect the ability to plan and react to changing demands, possibly increasing fall risk [26].

The ability to counteract these threats is regulated by specific cognitive functions called executive functions. 'Executive functions' is an umbrella term for higher-level cognitive functions involved in the control, the regulation, and the management of lower-level cognitive processes, such as planning, working memory, problem solving, initiation, inhibition, mental flexibility, task switching, and attention [42]. There is still a heated debate on the brain structures responsible for the regulation of the these functions. The frontal lobes have long been assumed to be the only brain structures responsible for executive functions [43]. Increasing evidence, however, suggests that multiple brain areas forming a specific network are involved in cognitive processes as complex as the executive functions [42, 44]. It has been observed that older adults perform more poorly than younger adults on many classic neuropsychological tests of executive function (e.g. the Color-Word Stroop task or the Trail-Making test A & B) [45]. This suggests that natural aging is associated with a decline of executive functions [46–48].

Neuropsychological studies have observed activation in the prefrontal cortex, the anterior part of the frontal lobes, during dual task conditions but not under single task situations [49, 50]. Further, even age-specific activation of prefrontal cortex in response to a dual task challenge has been observed. In a study by Ohsugi et al. [51] young and older adults performed a single motor task (stepping), a single cognitive task (performing calculations) or a dual task, that was the performance of the motor and cognitive task

simultaneously. Both younger and older adults demonstrated an increased prefrontal cortex activity during the dual task activity, though higher and longer activation of the prefrontal cortex was observed in the older group. These results suggest that dual task activity imposes a greater cognitive load on older adults compared to younger.

The observation that older adults show poorer performances in dual task situations compared to younger adults, and that this may be in part attributable to the declines in executive functions [40] led to the assumption that the focus of effective fall prevention programs should possibly be the implementation of approaches that address the cognitive decline and the dysfunctions in cognitive processes, especially of the executive functions. There is growing evidence that rather than isolated physical or cognitive activity, the combination of both better supports the healthy functions of executive function, working memory, and the ability to divide and select attention [52–55]. Therefore, older adults should be challenged and trained by a cognitive-motor approach that is the performance of physical training with a simultaneous challenge of cognitive functions stimulating the required abilities to control gait and postural balance in dual task situations, as experienced in everyday life. The assumption that older adults could benefit to a greater extent from a cognitive-motor approach than from physical training alone is the underlying hypothesis of the present doctoral thesis.

#### **1.4. How it all started**

The story of the present doctoral thesis began with the performance of interventional and observational pilot studies at the Institute of Human Movement Sciences and Sport (IBWS) of the ETH (Swiss Federal Institute of Technology) Zurich. Projects in the context of a master's thesis in the field of 'Human Movement Science and Sport' laid the foundations for the development of the study questions presented in this thesis. The research group at the IBWS of the ETH Zurich knew early on that the combination of motor and cognitive elements and its implementation in training programs for the elderly could constitute an approach with a great potential for improving physical functioning in the older population. Two interventional pilot studies were performed using the combination of

motor and cognitive elements. The settings of these studies were comparable. Whereas the control groups received a traditional physical exercise program consisting of strength and balance exercises, the cognitive-motor groups performed either a computer-based training program that focused on selective and divided attention skills [56] or a computerized dancing game in addition [57]. The results showed excellent rates of training adherence and high levels of enjoyment among the participants. More significantly, in the cognitive-motor groups compared to the control groups the interventions were observed to produce greater reductions in the fear of falling, and stronger improvements in walking abilities (i.e. decreased dual task costs of walking) or shortened foot reaction times. These observations instigated the further development of the cognitive-motor approach and finally the realization of this doctoral thesis.

### **1.5. The aims of this doctoral thesis**

This doctoral thesis discusses approaches that require consideration with a view to including a stimulating cognitive factor in fall prevention programs. Therefore it investigates the current state of research into using cognitive elements in fall prevention and collects data on interventions with the aim of improving physical functioning in older adults. Further, in its experimental section this doctoral thesis presents a novel training approach that combines traditional physical exercise, i.e. progressive strength and balance exercise, with an interactive dance computer game as the cognitive factor, especially adapted to the needs of older adults. The game as cognitive-motor element simulates a dual task situation thus stimulating the ability to comprehend, plan, adapt and execute specific movements, properties attributed to the executive function system.

The aim of the experiments was primarily to investigate if a cognitive-motor approach with an additional attention-demanding dance computer game is feasible and accepted by older adults. Additionally, the experiments examined if such an approach is better suited to improving physical abilities related to gait, i.e. walking abilities and gait initiation under dual task conditions, or the accuracy of foot placement during walking compared to the usual care offered in senior hostels or through physical exercise alone.

The objective of the cognitive-motor element was to develop a training method that can be easily performed in any senior hostel without the need of a laboratory setting or any complicated or expensive technical equipment.

### **1.6. The outline of this thesis**

In a first step (**Chapter 2**) this doctoral thesis offers some theoretical considerations based on the findings of the previous cognitive-motor pilot studies conducted at the Institute of Human Movement Sciences and Sport of the ETH Zurich. It is concerned with the experiences made with computer-based approaches serving as a potential method for the inclusion and stimulation of cognitive functions in exercise programs for older adults. The importance and potential benefits of using virtual reality environments or interactive video games as a novel approach to improve physical functioning in older adults under attention-demanding circumstances are discussed and suggestions for the design of future studies are made.

On the basis of this discussion a systematic review of literature on cognitive and cognitive-motor interventions affecting physical functioning in older adults is presented in **Chapter 3**. This review pursues the objective of examining the existing literature regarding the use of cognitive or combined cognitive-motor interventions. The aim is to evaluate the level of evidence for this approach in the older population, to determine the methodological quality of the existing studies, and to identify strategies that might be used in future intervention type studies for older adults.

**Chapters 4, 5, and 6** constitute the experimental section of this doctoral thesis. These chapters describe the application of the cognitive-motor approach in senior hostels in the context of two randomized controlled trials performed in four senior hostels in Switzerland. **Chapter 6** constitutes a study, which investigates the test-retest reliability of a protocol used in the experiment described in **Chapter 5** to assess foot placement accuracy during walking.

In **Chapter 4** a randomized controlled pilot study is described which aims to explore whether a cognitive-motor exercise program that combines traditional physical exercise

with a dance computer game is better suited to improve the voluntary stepping responses of older adults under attention-demanding dual task conditions. Residents of two senior hostels of the city of Zurich perform either twice-weekly cognitive-motor exercise for 12 weeks ( $n = 9$ ) or continue with the usual care offered at their hostels ( $n = 6$ ). As the main outcome, a measure voluntary step execution under single and dual task conditions is recorded at baseline and post intervention.

**Chapter 5** describes a randomized controlled trial performed in two senior hostels in the Canton of Zurich with the aim to compare two training groups that achieve similar amounts of strength and balance exercise where one group receives an intervention that includes additional computer game dancing. The dance group ( $n = 15$ ) absolves a twelve-week cognitive-motor exercise program twice weekly that comprises progressive strength and balance training supplemented with additional computer game dancing. The control group ( $n = 16$ ) performs only the strength and balance exercises during this period. Main outcome measures are foot placement accuracy performance during walking, gait performance under dual task conditions, and falls efficacy.

In **Chapter 6** this doctoral thesis offers the results of an experiment to analyze the test-retest reliability of the protocol used to assess foot placement accuracy performance in the context of the randomized controlled trial presented in **Chapter 5**. One observer assesses twenty-five elderly subjects in two sessions with 48 hours as time interval between the measurements. The main outcome measures are foot placement distance errors, intraclass correlation coefficients (ICC), and the smallest detectable difference value (SDD).

This doctoral thesis concludes with a general discussion where the main results, methodological issues, clinical implications, suggestions for future work, and the conclusions are outlined (**Chapter 7**). Finally, a short summary of the doctoral thesis in English and German is provided in **Chapter 8**.

## References

1. Duthie EH, Jr.: Falls. *Med Clin North Am* 1989, 73(6):1321-1336.
2. Mossey JM: Social and psychologic factors related to falls among the elderly. *Clin Geriatr Med* 1985, 1(3):541-553.
3. Livesley B: Falls in older age. *Br Med J (Clin Res Ed)* 1984, 289(6445):568-569.
4. Woollacott M, Shumway-Cook A: Attention and the control of posture and gait: a review of an emerging area of research. *Gait Posture* 2002, 16(1):1-14.
5. Hays RD, Liu H, Spritzer K, Cella D: Item response theory analyses of physical functioning items in the medical outcomes study. *Med Care* 2007, 45(5 Suppl 1):S32-38.
6. Gibson M, Andres R, Isaacs B, Radebaugh T, Worm-Peters J: The prevention of falls in later life. A report of the Kellogg International Work Group on the prevention of falls by the elderly. *Danish Medical Bulletin* 1987, 34(4):1-24.
7. Guideline for the prevention of falls in older persons. American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention. *J Am Geriatr Soc* 2001, 49(5):664-672.
8. Berg WP, Alessio HM, Mills EM, Tong C: Circumstances and consequences of falls in independent community-dwelling older adults. *Age Ageing* 1997, 26(4):261-268.
9. Schweizerisches Bundesamt für Statistik. *Statistisches Jahrbuch der Schweiz*. In. Neuchâtel; 1900 - 2011.
10. Gill T, Taylor AW, Pengelly A: A population-based survey of factors relating to the prevalence of falls in older people. *Gerontology* 2005, 51(5):340-345.
11. Rubenstein LZ, Josephson KR: The epidemiology of falls and syncope. *Clin Geriatr Med* 2002, 18(2):141-158.
12. Tinetti ME, Williams CS: Falls, injuries due to falls, and the risk of admission to a nursing home. *N Engl J Med* 1997, 337(18):1279-1284.
13. Howland J, Peterson EW, Levin WC, Fried L, Pordon D, Bak S: Fear of falling among the community-dwelling elderly. *J Aging Health* 1993, 5(2):229-243.
14. Yardley L, Beyer N, Hauer K, Kempen G, Piot-Ziegler C, Todd C: Development and

- initial validation of the Falls Efficacy Scale-International (FES-I). *Age Ageing* 2005, 34(6):614-619.
15. Bock O: Dual-task costs while walking increase in old age for some, but not for other tasks: an experimental study of healthy young and elderly persons. *J Neuroeng Rehabil* 2008, 5:27.
  16. Lajoie Y, Gallagher SP: Predicting falls within the elderly community: comparison of postural sway, reaction time, the Berg balance scale and the Activities-specific Balance Confidence (ABC) scale for comparing fallers and non-fallers. *Arch Gerontol Geriatr* 2004, 38(1):11-26.
  17. Tinetti ME, Speechley M: Prevention of falls among the elderly. *N Engl J Med* 1989, 320(16):1055-1059.
  18. Lindle RS, Metter EJ, Lynch NA, Fleg JL, Fozard JL, Tobin J, Roy TA, Hurley BF: Age and gender comparisons of muscle strength in 654 women and men aged 20-93 yr. *J Appl Physiol* 1997, 83(5):1581-1587.
  19. Paterson DH, Jones GR, Rice CL: Ageing and physical activity: evidence to develop exercise recommendations for older adults. *Can J Public Health* 2007, 98 Suppl 2:S69-108.
  20. Porter MM: Power training for older adults. *Appl Physiol Nutr Metab* 2006, 31(2):87-94.
  21. Daley MJ, Spinks WL: Exercise, mobility and aging. *Sports Med* 2000, 29(1):1-12.
  22. Hausdorff JM, Edelberg HK, Mitchell SL, Goldberger AL, Wei JY: Increased gait unsteadiness in community-dwelling elderly fallers. *Arch Phys Med Rehabil* 1997, 78(3):278-283.
  23. Inzitari M, Newman AB, Yaffe K, Boudreau R, de Rekeneire N, Shorr R, Harris TB, Rosano C: Gait speed predicts decline in attention and psychomotor speed in older adults: the health aging and body composition study. *Neuroepidemiology* 2007, 29(3-4):156-162.
  24. 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.



25. Allali G, van der Meulen M, Assal F: Gait and cognition: the impact of executive function. *Schweizer Archiv für Neurologie und Psychiatrie* 2010, 161(6):195-199.
26. Taylor ME, Ketels MM, Delbaere K, Lord SR, Mikolaizak AS, Close JC: Gait impairment and falls in cognitively impaired older adults: an explanatory model of sensorimotor and neuropsychological mediators. *Age Ageing* 2012, 41(5):665-669.
27. Hausdorff JM, Yogev G, Springer S, Simon ES, Giladi N: Walking is more like catching than tapping: gait in the elderly as a complex cognitive task. *Exp Brain Res* 2005, 164(4):541-548.
28. Lundin-Olsson L, Nyberg L, Gustafson Y: „Stops walking when talking“ as a predictor of falls in elderly people. *Lancet* 1997, 349(9052):617.
29. Beauchet O, Annweiler C, Dubost V, Allali G, Kressig RW, Bridenbaugh S, Berrut G, Assal F, Herrmann FR: Stops walking when talking: a predictor of falls in older adults? *Eur J Neurol* 2009, 16(7):786-795.
30. Beurskens R, Bock O: Age-related deficits of dual-task walking: a review. *Neural Plast* 2012, 2012:131608.
31. Verhaeghen P, Steitz DW, Sliwinski MJ, Cerella J: Aging and dual-task performance: a meta-analysis. *Psychol Aging* 2003, 18(3):443-460.
32. Laessoe U, Hoeck HC, Simonsen O, Voigt M: Residual attentional capacity amongst young and elderly during dual and triple task walking. *Hum Mov Sci* 2008, 27(3):496-512.
33. Li KZ, Lindenberger U, Freund AM, Baltes PB: Walking while memorizing: age-related differences in compensatory behavior. *Psychol Sci* 2001, 12(3):230-237.
34. Lindenberger U, Marsiske M, Baltes PB: Memorizing while walking: increase in dual-task costs from young adulthood to old age. *Psychol Aging* 2000, 15(3):417-436.
35. Melzer I, Oddsson LI: The effect of a cognitive task on voluntary step execution in healthy elderly and young individuals. *J Am Geriatr Soc* 2004, 52(8):1255-1262.
36. Talbot LA, Musiol RJ, Witham EK, Metter EJ: Falls in young, middle-aged and older community dwelling adults: perceived cause, environmental factors and injury. *BMC Public Health* 2005, 5:86.

37. Campbell AJ, Borrie MJ, Spears GF, Jackson SL, Brown JS, Fitzgerald JL: Circumstances and consequences of falls experienced by a community population 70 years and over during a prospective study. *Age Ageing* 1990, 19(2):136-141.
38. Berg WP, Alessio HM, Mills EM, Tong C: Circumstances and consequences of falls in independent community-dwelling older adults. *Age Ageing* 1997, 26(4):261-268.
39. Holtzer R, Verghese J, Xue X, Lipton RB: Cognitive processes related to gait velocity: results from the Einstein Aging Study. *Neuropsychology* 2006, 20(2):215-223.
40. Hsu CL, Nagamatsu LS, Davis JC, Liu-Ambrose T: Examining the relationship between specific cognitive processes and falls risk in older adults: a systematic review. *Osteoporos Int* 2012, 23(10):2409-2424.
41. Yogev-Seligmann G, Hausdorff JM, Giladi N: The role of executive function and attention in gait. *Mov Disord* 2008, 23(3):329-342; quiz 472.
42. Alvarez JA, Emory E: Executive function and the frontal lobes: a meta-analytic review. *Neuropsychol Rev* 2006, 16(1):17-42.
43. Royall DR, Lauterbach EC, Cummings JL, Reeve A, Rummans TA, Kaufer DI, LaFrance WC, Jr., Coffey CE: Executive control function: a review of its promise and challenges for clinical research. A report from the Committee on Research of the American Neuropsychiatric Association. *J Neuropsychiatry Clin Neurosci* 2002, 14(4):377-405.
44. Duffy JD, Campbell JJ: Regional prefrontal syndromes: A theoretical and clinical overview. In: *The frontal lobes and neuropsychiatric illness*. Edited by Salloway SP, Malloy PF, Duffy JD. Washington, DC, US: American Psychiatric Publishing, Inc.; 2001: 113-123.
45. Daniels K, Toth J, Jacoby L: The Aging of Executive Functions. In: *Lifespan Cognition: Mechanisms of Change*. Edited by Bialystok E, Craik FIM. New York, USA: Oxford University Press, Inc.; 2006.
46. Crawford JR, Bryan J, Luszcz MA, Obonsawin MC, Stewart L: The executive decline hypothesis of cognitive aging: do executive deficits qualify as differential deficits and do they mediate age-related memory decline? *Aging, Neuropsychology, and Cognition* 2000, 7(1):9-31.

47. Ardila A, Ostrosky-Solis F, Rosselli M, Gomez C: Age-related cognitive decline during normal aging: the complex effect of education. *Arch Clin Neuropsychol* 2000, 15(6):495-513.
48. O'Sullivan M, Jones DK, Summers PE, Morris RG, Williams SC, Markus HS: Evidence for cortical „disconnection“ as a mechanism of age-related cognitive decline. *Neurology* 2001, 57(4):632-638.
49. D'Esposito M, Detre JA, Alsop DC, Shin RK, Atlas S, Grossman M: The neural basis of the central executive system of working memory. *Nature* 1995, 378(6554):279-281.
50. Koechlin E, Basso G, Pietrini P, Panzer S, Grafman J: The role of the anterior prefrontal cortex in human cognition. *Nature* 1999, 399(6732):148-151.
51. Ohsugi H, Ohgi S, Shigemori K, Schneider EB: Differences in dual-task performance and prefrontal cortex activation between younger and older adults. *BMC Neurosci* 2013, 14:10.
52. Baddeley A: Working memory: looking back and looking forward. *Nat Rev Neurosci* 2003, 4(10):829-839.
53. Della Sala S, Baddeley A, Papagno C, Spinnler H: Dual-task paradigm: a means to examine the central executive. *Ann NY Acad Sci* 1995, 769:161-171.
54. Klingberg T: Limitations in information processing in the human brain: neuroimaging of dual task performance and working memory tasks. *Prog Brain Res* 2000, 126:95-102.
55. Silsupadol P, Shumway-Cook A, Lugade V, van Donkelaar P, Chou LS, Mayr U, Woollacott MH: Effects of single-task versus dual-task training on balance performance in older adults: a double-blind, randomized controlled trial. *Arch Phys Med Rehabil* 2009, 90(3):381-387.
56. de Bruin ED, van Het Reve E, Murer K: A randomized controlled pilot study assessing the feasibility of combined motor-cognitive training and its effect on gait characteristics in the elderly. *Clin Rehabil* 2013, 27(3):215-225.
57. de Bruin ED, Reith A, Dörflinger M, Murer K: Feasibility of Strength-Balance Training Extended with Computer Game Dancing in Older People; Does it Affect Dual

Task Costs of Walking? *J Nov Physiother* 2011, 1(104): Accessible at <http://www.omicsgroup.org/journals/2165-7025/2165-7025-2161-2104.php?aid=3350>.





# Two Chapter

## Use of virtual reality technique for the training of motor control in the elderly: some theoretical considerations

de Bruin ED<sup>1</sup>, Schoene D<sup>2</sup>, **Pichierri G**<sup>1</sup> and Smith ST<sup>2</sup>

<sup>1</sup>Institute of Human Movement Sciences and Sport, ETH Zurich, Switzerland

<sup>2</sup>Neuroscience Research Australia, Sydney

published in *Z Gerontol Geriat* 2010, 43:229–234

## **Abstract**

Virtual augmented exercise, an emerging technology that can help to promote physical activity and combine the strengths of indoor and outdoor exercise, has recently been proposed as having the potential to increase exercise behavior in older adults. By creating a strong presence in a virtual, interactive environment, distraction can be taken to greater levels while maintaining the benefits of indoor exercises which may result in a shift from negative to positive thoughts about exercise. Recent findings on young participants show that virtual reality training enhances mood, thus, increasing enjoyment and energy.

For older adults virtual, interactive environments can influence postural control and fall events by stimulating the sensory cues that are responsible in maintaining balance and orientation. However, the potential of virtual reality training has yet to be explored for older adults. This manuscript describes the potential of dance pad training protocols in the elderly and reports on the theoretical rationale of combining physical game-like exercises with sensory and cognitive challenges in a virtual environment.

**Keywords:** *geriatric adults, virtual reality, virtual environment, physical activity, indoor exercise*



## 2.1. Background

Decline in physical function is a common feature of older age and has important outcomes in terms of physical health related quality of life, falls, health care use, admission to residential care and mortality [1, 2]. The most common reason for loss in functional capabilities in the aged, however, is inactivity or immobility [3–5]. Even in the absence of overt pathology, motor functioning [cf. International Classification of Functioning (ICF) by the World Health Organization, Geneva (*see <http://www.who.int/classification/icf>*)] can deteriorate, as is illustrated by the incidence and impact of falls in ageing populations [6]. Falls are amongst the most common reasons for medical intervention in the elderly and their occurrence might initiate a vicious circle that causes fear of falling, nursing home admittance and loss of independence [7]. Falls among older adult populations often occur during walking, and gait dysfunction is included among the many risk factors for falls [8, 9].

Until recently, gait was considered an automated motor activity requiring minimal higher-level cognitive input [10]. Maintenance of postural control during activities of daily living does not usually place high demands on attention resources of healthy young or middle-aged people. In contrast however, when sensory or motor deficits occur due to natural ageing processes, the complex generation of movement may have to be restructured, and movements may then be controlled and performed at an associative or a cognitive stage [11]. When the benefits from the movement automation are lost, the postural control of aged people can be expected to be more vulnerable to cognitive distractions and additional tasks [11]. The link between cognition, gait, and the potential for falls is indeed being increasingly recognized [12] and is for example reflected in a special issue in the *Journal of Gerontology: Biological Sciences and Medical Sciences* (63A (12), 2008).

Negative plastic changes in the brain often occur naturally in later life when people begin to stereotype and simplify behaviors that previously were quite complex and elaborated. As people age, a self-reinforcing, downwards spiral of reduced interaction with challenging environments and reduced brain health significantly contribute to this cognitive decline [13].

## **2.2. Physical exercise to restore postural balance and walking function**

Because difficulties of walking are a key factor in loss of independence for older individuals [14, 15] treatment of gait disorders is designed to optimize gait for the purpose of improving function. Previous studies have shown that physical exercise is effective [16] and may reduce gait variability in elderly [17]. Current evidence shows that interventions that aim to improve locomotor function in older people should preferably include strength training in combination with balance and coordination exercises [16, 18]. However, common interventions usually focus on the physical aspects of training while overlooking the specific rehabilitation of executive functions [19], a set of cognitive abilities that control and regulate other abilities and behaviors.

A central element of successful cognitive rehabilitation for older adults should be the design of interventions that either re-activate disused or damaged brain regions, or that compensates for decline in parts of the brain through the activation of compensatory neural reserves [20]. Cognitive activity or stimulation could be a protective factor against the functional losses in old age. Because spatial and temporal characteristics of gait are also associated with distinct brain networks in older adults it can be hypothesized that addressing focal neuronal losses in these networks may represent an important strategy to prevent mobility disability [21]. Interventions should, as previous research suggests, focus thereby on executive functioning processes [22] and should include enriched environments that provide physical activities with decision-making opportunities because these are believed to be able to facilitate the development of both motor performance and brain functions [23]. Executive cognitive functions are involved in the control and direction (planning, monitoring, activating, switching, inhibiting) of lower level, more modular, or automatic functions [24].

## **2.3. Virtual augmented exercises**

Involvement of real-time simulation in an environment, scenario or activity that allows for user interaction via multiple sensory channels as an approach to user-computer interface can be defined as virtual reality [25]. Virtual reality (VR) system complexity

ranges from cheap, readily available video gaming consoles such as the Nintendo Wii, Sony Playstation or Microsoft Xbox, through to dedicated, high costs systems such as the GestureTek IREX. The less complex and cheaper systems that require physical movement by the game player sometimes are referred to as exergames. VR techniques are rapidly expanding across a variety of disciplines. The use of virtual reality environments for virtual augmented exercise has recently been proposed as having the potential to increase exercise behavior in older adults [26] and also has the potential to influence cognitive abilities in this population segment [27]. The potential is based on strong presence (the feeling of being there) which is achievable in an interactive virtual environment and that is followed by greater distraction. Weiss and colleagues [28] suggest that virtual reality platforms provide a number of unique advantages over conventional therapy in trying to achieve rehabilitation goals.

First, virtual reality systems provide ecologically valid scenarios that elicit naturalistic movement and behaviors in a safe environment that can be shaped and graded in accordance to the needs and level of ability of the patient engaging in therapy. Second, the realism of the virtual environments allows patients the opportunity to explore independently, increasing their sense of autonomy and independence in directing their own therapeutic experience. Third, the controllability of virtual environments allows for consistency in the way therapeutic protocols are delivered and performance recorded, enabling an accurate comparison of a patient's performance over time. Finally, virtual reality systems allow the introduction of „gaming“ factors into any scenario to enhance motivation and increase user participation [29].

The use of gaming elements can also be used to take patients' attention away from any pain resulting from their injury or movement. This occurs the more a patient feels involved in an activity and again, allows a higher level of participation in the activity, as the patient is focused on achieving goals within the game [30]. In combination with the benefits of indoor exercises such as safety or independence from weather conditions, such a distraction may result in a shift from negative to positive thoughts about exercise.

Many different forms of equipment can be used in order to create different kinds of

virtual environments. The basic components of all forms are a computer, usually with a special graphics card for the fast computation and drawing of two- (2D) or three-dimensional (3D) visual images, display devices through which the user views the virtual environment, hardware devices used to monitor movement kinematics or that provide haptic and force feedback to participants, and especially written software that enables all of these components to work in synchrony [31]. There are both more immersive 3D and less immersive 2D virtual environments. The latter are more kindred to looking through a window at a scene. Immersion refers to the establishment of the feeling of being inside and a part of the VR world.

### **2.4. VR and exergames as motor rehabilitation training**

Although VR applications have been used in research and entertainment applications since the 1980s, it was only during the late 1990s that VR systems began to be developed and studied as potential tools to enhance and encourage participation in rehabilitation. Several studies have since emerged suggesting the potential of virtual reality as a successful treatment and assessment tool in a wide variety of applications, most notably in the fields of motor and cognitive rehabilitation. In young subjects, it has already been shown that exercising on a stationary bike combined with a virtual cycling race enhances enjoyment and reduces tiredness [32], and promotes gains in cognitive function in brain-injured individuals [33]. For older adults interactive virtual environments can influence postural control and therefore fall events by stimulating the sensory cues that are responsible in maintaining balance and orientation [34].

Exergaming interventions (dance pad stepping, Wii balance board) improved parameters of static balance more than a traditional balance program in young healthy adults after 4 weeks of training [35]. Merians and colleagues [36] found that exercise conducted using a virtual reality interface enhanced the training of hand movements in patients post stroke, resulting in improved function of the fingers, thumb, and overall range of motion. These researchers also found that an improvement later transferred to real world tasks, demonstrating that VR-based therapy has the potential to encourage

a level of exercise intensity and participation that is comparable to conventional interventions [36]. The special value of VR training paradigms is believed to be due to the concordance of visual and proprioceptive information during training, thus updating the way seniors perceive their body with their environment [37]. Beside this stimulation, virtual environments provide salient feedback about the movement performance, and the difficulty of the task can be adapted according to the subject's ability, which is particularly important for older adults. Virtual environments have also the potential to specifically include motor learning enhancing features that activate motor areas in the brain [38]. In addition the findings of You and colleagues suggest that VR training could induce reorganization of the sensorimotor cortex in chronic stroke patients [39]. However, the potential of such virtual reality trainings has yet to be explored for older adults.

In the following, to cite an example, we describe a low cost video game-based approach to training and rehabilitation of stepping ability that can potentially be used to reduce the risk of falls in older adults or for rehabilitation of balance control in stroke, spinal cord injury or other motor-impaired patients. We describe the theoretical considerations that indicate the potential of this technology for elderly together with some preliminary results from our research groups.

## **2.5. Exergame use for motor control training in the elderly**

Interactive, user input devices such as dance pads are a low cost, interactive method of exergaming. These games, e.g. "Dance Dance Revolution" (DDR) or "Pump" are played on a dance pad sensor, which measures about 1 m<sup>2</sup> and has between four and eight step panels (arrows). The pad is connected to a visual display screen such as a television or computer screen that provides step direction instructions to the player via a system of scrolling arrows that typically rise slowly from the bottom to the top of the screen. As the arrows scroll up to the top of the screen, they cross over a set of four corresponding arrow silhouettes. The player must step on the corresponding mat arrow as the scrolling arrow crosses its silhouette (*Figure 2.1*). Sequences of steps can range in difficulty from simple marching or walking patterns to those with varied rates and irregular patterns that

challenge coordination and attention. It has been suggested that feed-forward planning of gait and posture is diminished in older adults. Motor adaptation is one mechanism by which feed-forward commands can be updated or fine-tuned [40].

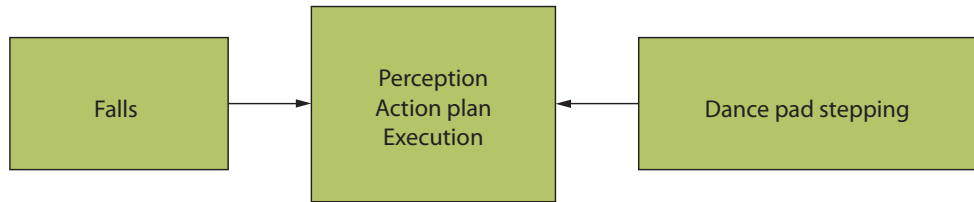
The ability to make timely, appropriately directed steps underpins our ability to maintain our balance and move unaided through our environment [41]. Stepping, which involves changing the base of support (BOS) relative to our center of mass (COM), also provides the means by which we are able to counter potentially destabilizing events such as slips, trips and missteps and avoid obstacles. Protective stepping may be initiated volitionally when a threat to balance is perceived, or induced reflexively when a disturbance moves the COM relative to the BOS at a speed that prevents engagement of volitional strategies. Initial studies suggest that both volitional and induced stepping abilities are significantly impaired in older versus younger individuals and are good predictors of falls. Compared to younger adults, older adults, particularly those with a history of falling, tend to be slower in initiating volitional step responses [42], make inappropriately directed or multiple short steps in response to an external perturbation of balance [43] and in response to lateral perturbations have an increased chance of collision between the swing and stance legs during compensatory stepping [44]. There is evidence, however, to suggest that the timing of volitional stepping [45, 46], as well as the execution of successful steps for recovery of balance following an induced slip [47], can be significantly improved in older adults following repetitive training of stepping responses. Maki and colleagues [48] have recently suggested a protocol for step training which specifically targets the kinds of stepping abilities that contribute to falls such as collisions between legs during lateral perturbation or the tendency for older adults to take multiple, short laterally directed steps in response to an anterior-posterior perturbation. Although the training techniques they suggest are well suited to specifically train compensatory stepping ability their approach requires use of large devices (custom motion platforms [48], treadmills [47, 49], systems employing weights and pulleys [46], low resistance slip platforms) or the supervision of trained therapists [45]. None of these techniques could be easily or economically incorporated into home-based training programs. Dance pad games require the player to



**Figure 2.1:** Training set-up for the dance pad game. The core game play involves the player moving his or her feet to a set pattern, stepping in time to the general rhythm or beat of a song. During normal game play, arrows scroll upwards from the bottom of the screen and pass over a set of stationary arrows near the top (upper red circle) referred to as the “guide arrows” or “receptors”. When the scrolling arrows overlap the stationary ones, the player must step on the corresponding arrows on the dance platform (lower red circle), and the player is given a judgement for their accuracy (Marvelous, Perfect, Great, Good, Boo/Almost, Miss/Boo) [51].

make rapid step responses from either leg to a target location in response to a presented visual stimulus. They not only involve controlled body weight transfers that are similar to the step responses required to avoid many falls as well as requiring a narrow base of support and well-coordinated quick movements. They further require cognitive work, e.g. sensing of stimuli, paying attention and making quick decisions. This interaction of sensory, information processing and neuromuscular systems is similar to the step responses required to avoid many falls and is therefore suitable as an intervention in a fall-specific context (*Figure 2.2*).

One hurdle facing the successful use of such exercise video games (or exergames) in older adult and functionally impaired populations is that many off-the-shelf video games are too complex for use by these groups. Video games must therefore be developed to take into consideration the cognitive and physical limitations, as well as the interest sets, of older adults. In the following we discuss the ways in which research groups in general could address these issues and in which our respective research teams are presently involved.



**Figure 2.2:** Processes involved in avoiding a fall and in dance pad stepping.

## 2.6. The use of DDR to date

The Sydney-based research group at Neuroscience Research Australia (DS & STS) has recently begun a research program aimed at developing age-appropriate DDR (Dance Dance Revolution)-style video games. The aim of this group is to both engage older adults in home-based step training exercises to reduce their falls rate as well as monitoring fall risk. In particular they aim to develop a low-cost approach to engage older adults in fall prevention training that can be placed into the houses of individuals, many of them living in regional, remote parts of Australia. A recently published paper [50] describes a series of studies conducted to develop and establish characteristics of DDR videogame play in older adults. Participants aged 70 and above were asked to make simple step movements in response to vertically drifting arrows presented on a video screen. Step responses were detected by a modified USB DDR mat and characteristics of stepping performance such as step timing, percentage of missed target steps and percentage of correct steps, were recorded by purpose built software. Drift speed and step rate of visual stimuli were modified to increase task difficulty. Performance of older adults decreased as stimulus speed and step rate were increased. Optimal step performance occurred for a stimulus speed of  $17^\circ$  of visual angle per second and a step rate of one step every 2 seconds. At fast drift speeds (up to  $35^\circ$ /second), participants were more than 200 ms too slow in coordinating their steps with the visual stimulus. Younger adults were better able to perform the stepping task across a wider range of drift speeds than older adults.

Data of another recently finished study from this group indicate that the dance pad is a valid and reliable assessment instrument to measure the choice stepping reaction



time in old and young people, a test that has shown to be predictive for falls in the elderly [42]. This offers the opportunity to assess the fall risk of older adults on a regular basis from the comfort of their own home. The aim of a recently finished study in Zurich was to assess and compare the effects of a physical training program that included a VR dance simulation computer game against usual care exercise interventions for elderly residential care dwellers on relative dual tasking costs of walking [51]. These costs refer to the fact that many older adults exhibit a reduced ability to perform two tasks at the same time, e.g. walking at preferred speed is compared to walking at preferred speed whilst counting backwards. This study showed that elderly who were training physically, in combination with a VR dance game that required decision making, showed significant decreases in the relative dual task costs (DTC) of walking. These walking parameters did not change in individuals that trained with more traditional forms of training in usual care programs.

The possibility of improving gait while performing dual tasks has not been well studied in general [10] and, to the best of our knowledge, this study [51] is one of the first that showed an effect on DTC-related walking. This study, which has been submitted for publication as a full text article, used dancing in a virtual environment as dual task training, where subjects were expected to observe the environment for drifting arrows and at the same time were initiating dance steps (*Figure 2.1*).

## **2. 7. Conclusions**

For older adults virtual, interactive environments have large potential to influence postural control and fall events by stimulating the sensory cues that are responsible in maintaining balance and orientation and by improving stepping patterns. However, the potential of virtual reality training has yet to be explored in sufficiently powered randomized controlled trials. Dance pad games, where repetitive medio-lateral and anterior-posterior steps are required offer a novel, yet effective, technique for training stepping ability in older adults. Future research should develop, implement and evaluate VR exercise scenarios for various sub-populations that can be identified within the elderly adult population. In such projects an attempt could be made to get insight into the concept of motor learning in

VR and the relationship between cognitive functions and balance and gait skills in elderly.

**Conflict of interest**

The corresponding author states that there are no conflicts of interest.

## References

1. Freedman VA, Martin LG, Schoeni RF: Recent trends in disability and functioning among older adults in the United States: a systematic review. *Jama* 2002, 288:3137-3146.
2. Gill TM, Kurland B: The burden and patterns of disability in activities of daily living among community-living older persons. *J Gerontol A Biol Sci Med Sci* 2003, 58:70-75.
3. Goldspink DF: Ageing and activity: their effects on the functional reserve capacities of the heart and vascular smooth and skeletal muscles. *Ergonomics* 2005, 48:1334-1351.
4. Pluijm SM, Visser M, Puts MT et al: Unhealthy lifestyles during the life course: association with physical decline in late life. *Aging Clin Exp Res* 2007, 19:75-83.
5. Taylor AH, Cable NT, Faulkner G et al: Physical activity and older adults: a review of health benefits and the effectiveness of interventions. *J Sports Sci* 2004, 22:703-725.
6. Moreland J, Richardson J, Chan DH et al: Evidence-based guidelines for the secondary prevention of falls in older adults. *Gerontology* 2003, 49:93-116.
7. Hausdorff JM, Edelberg HK, Mitchell SL et al: Increased gait unsteadiness in community-dwelling elderly fallers. *Arch Phys Med Rehabil* 1997, 78:278- 283.
8. Campbell AJ, Borrie MJ, Spears GF: Risk factors for falls in a community-based prospective study of people 70 years and older. *J Gerontol* 1989, 44:M112-117.
9. Rubenstein LZ, Robbins AS, Schulman BL et al: Falls and instability in the elderly. *J Am Geriatr Soc* 1988, 36:266-278.
10. Yogev-Seligmann G, Hausdorff JM, Giladi N: The role of executive function and attention in gait. *Mov Disord* 2008, 23:329-342; quiz 472.
11. Laessle U, Hoeck HC, Simonsen O, Voigt M: Residual attentional capacity amongst young and elderly during dual and triple task walking. *Hum Mov Sci* 2008, 27:496-512.
12. Alexander NB, Hausdorff JM: Guest editorial: linking thinking, walking, and falling. *J Gerontol A Biol Sci Med Sci* 2008, 63:1325-1328.
13. Mahncke HW, Bronstone A, Merzenich MM: Brain plasticity and functional losses in

- the aged: scientific bases for a novel intervention. *Prog Brain Res* 2006, 157:81-109.
14. Alexander NB: Gait disorders in older adults. *J Am Geriatr Soc* 1996, 44:434-451.
  15. Sauvage LR Jr, Myklebust BM, Crow-Pan J et al: A clinical trial of strengthening and aerobic exercise to improve gait and balance in elderly male nursing home residents. *Am J Phys Med Rehabil* 1992, 71:333-342.
  16. Mian OS, Baltzopoulos V, Minetti AE, Narici MV: The impact of physical training on locomotor function in older people. *Sports Med* 2007, 37:683-701.
  17. 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, 82:1050-1056.
  18. Skelton DA, Beyer N: Exercise and injury prevention in older people. *Scand J Med Sci Sports* 2003, 13:77-85.
  19. Studer M: Rehabilitation of executive function: to err is human, to be aware-divine. *J Neurol Phys Ther* 2007, 31:128-134.
  20. Hogan M: Physical and cognitive activity and exercise for older adults: a review. *Int J Aging Hum Dev* 2005, 60:95-126.
  21. Rosano C, Aizenstein H, Brach J et al: Special article: gait measures indicate underlying focal gray matter atrophy in the brain of older adults. *J Gerontol A Biol Sci Med Sci* 2008, 63:1380-1388.
  22. Rapport LJ, Hanks RA, Millis SR, Deshpande SA: Executive functioning and predictors of falls in the rehabilitation setting. *Arch Phys Med Rehabil* 1998, 79:629-633.
  23. Yan JH, Zhou CL: Effects of motor practice on cognitive disorders in older adults. *Eur Rev Aging Phys Act* 2009, 6:67-74.
  24. Cicerone K, Levin H, Malec J et al: Cognitive rehabilitation interventions for executive function: moving from bench to bedside in patients with traumatic brain injury. *J Cogn Neurosci* 2006, 18:1212-1222.
  25. Adamovich SV, Fluet GG, Tunik E, Merians AS: Sensorimotor training in virtual reality: a review. *Neuro Rehabilitation* 2009, 25:29-44.
  26. Van Schaik P, Blake J, Pernet F et al: Virtual augmented exercise gaming for older adults. *Cyberpsychol Behav* 2008, 11:103-106.

27. Zelinski EM, Reyes R: Cognitive benefits of computer games for older adults. *Gerontechnology* 2009, 8:220-235.
28. Kizony R, Raz L, Katz N et al: Video-capture virtual reality system for patients with paraplegic spinal cord injury. *J Rehabil Res Dev* 2005, 42:595-608.
29. Holden M, Todorov E: Use of virtual environments in motor learning and rehabilitation. In: *Stanney K (ed) Handbook of virtual environments: design, implementation, and applications*. Mahwah, NJ, Erlbaum, 2002, pp 999-1026.
30. Sanchez-Vives MV, Slater M: From presence to consciousness through virtual reality. *Nat Rev Neurosci* 2005, 6:332-339.
31. Holden MK: Virtual environments for motor rehabilitation: review. *Cyberpsychol Behav* 2005, 8:187-211; discussion 212-189.
32. Plante T, Aldridge A, Bogden R, Hanelin C: Might virtual reality promote the mood benefits of exercise? *Computers in Human Behavior* 2003, 19:495-509.
33. Grealy MA, Johnson DA, Rushton SK: Improving cognitive function after brain injury: the use of exercise and virtual reality. *Arch Phys Med Rehabil* 1999, 80:661-667.
34. Virk S, McConville KM: Virtual reality applications in improving postural control and minimizing falls. *Conf Proc IEEE Eng Med Biol Soc* 2006, 1:2694-2697.
35. Brumels KA, Blasius T, Cortright T et al: Comparison of efficacy between traditional and video game based balance programs. *Clinical Kinesiology: Journal of the American Kinesiotherapy Association* 2008, 62:26-31.
36. Merians AS, Poizner H, Boian R et al: Sensorimotor training in a virtual reality environment: Does it improve functional recovery poststroke? *Neurorehabil Neural Repair* 2006, 20:252-267.
37. Bisson E, Contant B, Sveistrup H, Lajoie Y: Functional balance and dual-task reaction times in older adults are improved by virtual reality and biofeedback training. *Cyberpsychol Behav* 2007, 10:16-23.
38. Cross ES, Kraemer DJ, Hamilton AF et al: Sensitivity of the action observation network to physical and observational learning. *Cereb Cortex* 2009, 19:315-326.
39. You SH, Jang SH, Kim YH et al: Virtual reality-induced cortical reorganization and

- associated locomotor recovery in chronic stroke: An experimenter-blind randomized study. *Stroke* 2005, 36:1166-1171.
40. Tseng SC, Stanhope SJ, Morton SM: Visuomotor adaptation of voluntary step initiation in older adults. *Gait Posture* 2010, 31:180-184.
  41. Shumway-Cook A, Woollacott MH: *Motor control: theory and practical applications*. Baltimore, Williams & Wilkins, 1995.
  42. Lord SR, Fitzpatrick RC: Choice stepping reaction time: a composite measure of falls risk in older people. *J Gerontol A Biol Sci Med Sci* 2001, 56: M627-632.
  43. McIlroy WE, Maki BE: Age-related changes in compensatory stepping in response to unpredictable perturbations. *J Gerontol A Biol Sci Med Sci* 1996, 51:M289-296.
  44. Maki BE, Edmondstone MA, McIlroy WE: Age-related differences in laterally directed compensatory stepping behavior. *J Gerontol A Biol Sci Med Sci* 2000, 55:M270-277.
  45. Jobges M, Heuschkel G, Pretzel C et al: Repetitive training of compensatory steps: A therapeutic approach for postural instability in Parkinson's disease. *J Neurol Neurosurg Psychiatry* 2004, 75:1682-1687.
  46. Rogers MW, Johnson ME, Martinez KM et al: Step training improves the speed of voluntary step initiation in aging. *J Gerontol A Biol Sci Med Sci* 2003, 58:46-51.
  47. Pai YC, Bhatt TS: Repeated-slip training: an emerging paradigm for prevention of slip-related falls among older adults. *Phys Ther* 2007, 87:1478-1491.
  48. Mansfield A, Peters AL, Liu BA, Maki BE: A perturbation-based balance training program for older adults: study protocol for a randomised controlled trial. *BMC Geriatr* 2007, 7:12.
  49. Shimada H, Obuchi S, Furuna T, Suzuki T: New intervention program for preventing falls among frail elderly people: the effects of perturbed walking exercise using a bilateral separated treadmill. *Am J Phys Med Rehabil* 2004, 83:493-499.
  50. Smith ST, Sherrington C, Studenski S et al: A novel dance dance revolution (DDR) system for inhome training of stepping ability: basic parameters of system use by older adults. *Br J Sports Med* 2011, 45(5):441-445.
  51. de Bruin ED, Reith A, Dörflinger M, Murer K Feasibility of strength-balance training

Use of virtual reality technique extended with computer game dancing in older people; does it affect dual task cost of walking?. *J Nov Physiother* 2011, 1(104): Accessible at <http://www.omicsgroup.org/journals/2165-7025/2165-7025-2161-2104.php?aid=3350>.





# Three Chapter

## **Cognitive and cognitive-motor interventions affecting physical functioning: A systematic review**

**Pichierri G<sup>1</sup>, Wolf P<sup>2</sup>, Murer K<sup>1</sup> and de Bruin ED<sup>1</sup>**

<sup>1</sup>Institute of Human Movement Sciences and Sport, ETH Zurich, Switzerland

<sup>2</sup>Department of Mechanical and Process Engineering, ETH Zurich, Switzerland

published in *BMC Geriatrics* 2011, 11:29 ([www.biomedcentral.com/1471-2318/11/29](http://www.biomedcentral.com/1471-2318/11/29))

## **Abstract**

*Background:* Several types of cognitive or combined cognitive-motor intervention types that might influence physical functions have been proposed in the past: training of dual-tasking abilities, and improving cognitive function through behavioral interventions or the use of computer games. The objective of this systematic review was to examine the literature regarding the use of cognitive and cognitive-motor interventions to improve physical functioning in older adults or people with neurological impairments that are similar to cognitive impairments seen in aging. The aim was to identify potentially promising methods that might be used in future intervention type studies for older adults.

*Methods:* A systematic search was conducted for the Medline/Premedline, PsycINFO, CINAHL and EMBASE databases. The search was focused on older adults over the age of 65. To increase the number of articles for review, we also included those discussing adult patients with neurological impairments due to trauma, as these cognitive impairments are similar to those seen in the aging population. The search was restricted to English, German and French language literature without any limitation of publication date or restriction by study design. Cognitive or cognitive-motor interventions were defined as dual-tasking, virtual reality exercise, cognitive exercise, or a combination of these.

*Results:* 28 articles met our inclusion criteria. Three articles used an isolated cognitive rehabilitation intervention, seven articles used a dual task intervention and 19 applied a computerized intervention. There is evidence to suggest that cognitive or cognitive-motor methods positively affect physical functioning, such as postural control, walking abilities and general functions of the upper and lower extremities, respectively. The majority of the included studies resulted in improvements of the assessed functional outcome measures.

*Conclusions:* The current evidence on the effectiveness of cognitive or cognitive-motor interventions to improve physical functioning in older adults or people with neurological impairments is limited. The heterogeneity of the studies published so far does not

allow defining the training methodology with the greatest effectiveness. This review nevertheless provides important foundational information in order to encourage further development of novel cognitive or cognitive-motor interventions, preferably with a randomized control design. Future research that aims to examine the relation between improvements in cognitive skills and the translation to better performance on selected physical tasks should explicitly take the relation between the cognitive and physical skills into account.

### **3.1. Background**

Age-related deteriorations in physical functioning have been attributed to decreases in sensory or motor system function [1]. 'Physical functioning' refers to the ability to conduct a variety of activities ranging from self-care (instrumental activities of daily living) to more challenging mobility tasks that require balance abilities, strength or endurance, e.g. walking or standing, important for achieving or maintaining an independent way of living [2,3]. Until recently, for example, gait was considered an automated motor activity requiring minimal higher-level cognitive input [4]. Therefore, it seemed only logical that prevention of falls was mainly focused on exercises that address the modifiable physical aspects of fall related mobility impairments, e.g. strength and balance training [5–7]. Consistent evidence has been accumulated that regular physical training can improve muscle strength, aerobic capacity and balance, and delay the point in time when older adults need assistance to manage activities of daily living [5]. Maintenance of postural control during activities of daily living does not usually place high demands on attentional resources of healthy young or middle-aged people. In contrast, when sensory or motor deficits occur due to the natural aging process, the complex generation of movement may have to be adjusted. Movements may then be controlled and performed at an associative or a cognitive stage. Consequently, the postural control of older adults might be more vulnerable to cognitive distractions and additional tasks [8]. Recent research indicates that the influence of motor and sensory impairments on falls is in part moderated by the executive functions [9] and, thus, some of the causes of gait disturbances might also be

attributed to changes in the executive functions [4], e.g., changes in divided attention [10,11]. 'Executive function' refers to cognitive processes that control and integrate other cognitive activities [12,13], and this term has been used to describe a group of cognitive actions that include: dealing with novelty, planning and implementing strategies for performance, monitoring performance, using feedback to adjust future responding, vigilance, and inhibiting task-irrelevant information [12] of lower level, more modular, or automatic functions [14]. Common tasks of daily life require attention, rapid motor planning process, and effective inhibition of irrelevant or inappropriate details. Older adults, however, experience increasing difficulties in maintaining multiple task rules in working memory [15].

These findings imply that in addition to physical forms of training, we should possibly also consider cognitive rehabilitation strategies that aim to influence physical functioning, e.g., walking behavior of older adults [16]. The question remains, however, what the best strategies are, that can support achieving this aim.

Several types of cognitive or cognitive-motor interventions that might be able to improve physical functioning have been proposed in the past: cognitive rehabilitation interventions, training of dual-tasking abilities, and the use of computer games or virtual reality [4,17].

Cognitive rehabilitation, defined by the Brain Injury Interdisciplinary Special Interest Group (BI-ISIG) of the American Congress of Rehabilitation Medicine as a „systematic, functionally-oriented service of therapeutic cognitive activities, based on an assessment and understanding of the person’s brain-behavior deficits“ [18], has shown to be effective in clinical practice [19,20].

Cognitive rehabilitation interventions have been developed to ameliorate cognitive problems experienced by healthy older adults [21,22], and for adults suffering from traumatic brain injury [19,23,24], with the goal of maximizing their current cognitive functioning and/or reducing the risk of cognitive decline. Some of the cognitive interventions, however, also show transfer effects to physical functioning. Specific motor imagery protocols seem to improve mobility in people with stroke [25].

Cognitive-motor interventions are interventions that combine a cognitive with a physical rehabilitation task, e.g. strength and balance exercises together with cognitive exercises or performing dual-tasking exercises. Interventions that used dual-tasking paradigms demonstrated negative effects on postural control or gait while performing a concurrent cognitive task in older adults [26,27], in patients with brain injury [28,29] and Alzheimer's disease [30]. Several authors have suggested that procedures to improve the dual task performance of elderly should be included in fall prevention programs [31].

Computerized interventions can be divided into biofeedback based systems or systems that use elements of virtual reality. Becoming aware of various physiological functions by using instruments that provide information on the activity of those same systems is considered biofeedback training. The goal, thereby, is to be able to manipulate these systems at will. Processes that can be controlled include for example dynamic balance on a force platform where visual feedback gives information about the center of pressure movements [32]. In virtual reality, in contrast to biofeedback training, environments are created that allow users to interact with images and virtual objects that appear in the virtual environment in real-time through multiple sensory modalities [32,33]. Playing of computer games induced cognitive benefits in older adults [34], and is proposed as a training strategy that may transfer to physical activity related tasks [4].

All three strategies, cognitive rehabilitation, training of dual-tasking abilities, and computerized interventions, have mainly been applied to individuals with stroke, with traumatic brain injury or elderly. Although it seems intuitive that these groups cannot be compared because of the different underlying causes for their respective brain deficits, this may not actually be the case [35,36]. Studies using a neuropsychological deficit profile methodology suggest that the pattern and extent of cognitive decline associated with these conditions is similar, at least partly, for both cognitive and motor deficits [36,37]. This implies that the treatment approaches needed to remediate the observed deficits are theoretically also comparable.

The objective of this systematic review is to examine the literature regarding the use of cognitive and cognitive-motor interventions to improve physical functioning in

older adults and in adults with neurological impairments. The aim is to identify strategies that have the potential to affect physical functioning and that might be used in future intervention type studies for older adults. The specific questions that we asked were:

1. What types of cognitive and cognitive-motor intervention methods have been used to influence physical functioning of older adults or adults with neurological impairments?
2. What is the level of evidence for cognitive and cognitive-motor interventions to influence physical functioning in these populations?
3. What is the methodological quality of these studies?

The underlying assumption that drives these questions is that (changes in) cognition also has an impact on physical functioning.

### **3.2. Methods**

#### **3.2.1. Data sources and search strategies**

In a first step we undertook a scoping review to gain an overview about existing interventions or systematic reviews on this topic. In addition to studies conducted with older adults, interventions with traumatic brain injury patients and patients with stroke were found. Like older adults, people with brain injury or stroke show difficulties with postural balance, exhibit gait insecurities when performing dual tasks and have cognitive deficits evident in working memory, attention, and information processing [35,38]. Additionally it has been shown that people with brain injuries show similar characteristics as older adults with an advanced aged-related cognitive decline. The patterns of cognitive decline observed in patients after traumatic brain injury resembles that of classic aging processes [35,39,40].

The search strategy was focused on older adults over the age of sixty-five. Although we are aware that cognitive and physical deficits in patients with brain injury are not fully comparable with the natural aging process we additionally searched further studies with brain injured patients. We also decided to include studies conducted with stroke patients arising from our search, because of their methodological importance for this review and

the possible applicability of the applied methods in the general older population.

We developed an individualized electronic search strategy for the Medline/Premedline, PsycINFO, CINAHL, and EMBASE databases in collaboration with a librarian from the Medicinal Library of the University of Zurich. The search was restricted to English, German, and French language literature. There was no limitation of publication date or restriction by study design. The final search was performed in July 2010.

Table 3.1 Search strategy	
Area	Search terms
Population	(aging or aged or elder*); exp Aged; exp Brain Injuries ((injur* or trauma*) adj2 (brain or head or craniocerebral))
Outcomes/ Physical aspect	((quantify* or measure* or assess* or investigat* or examin* or evaluat*) adj5 (gait or walk* or balance or movement or mobility or posture or "motor function" or "physical functioning" or frailty) (balance adj3 (training or impair* or effect*)) postural balance, gait, walking; Accidental Falls [Prevention and Control] equilibrium, postur*
Intervention	(strateg* adj3 (training or learning or cognit* or metacognit*)) ((cognit* or metacognit*) adj3 (intervention or rehabilitation or task or strateg* or therap*)); (goal adj1 (setting or planning or attain* or achiev* or direct* or orient* or manag*)); (self adj3 (talk or evaluat*)) (self adj3 (awareness or monitoring or control or instruction or regulation)) ("executive functions" or metacognition or awareness or "problem solving" or metamemory or attention); biofeedback, user-computer interface (action game* or virtual reality or video game*); (computerized adj10 training); (computer* adj10 biofeedback); ((cognitive or dual) adj5 task "self-directed learning", "task performance", mental imager*

We used medical sub-headings as search terms, including the following main terms for the population: *aged, elder, old, aging, brain/head/craniocerebral injury, trauma*; for cognitive aspects: *cognition, meta-cognition, learning, awareness, attention, self-directed learning, executive function*; for motor functions: *gait, walking, balance, movement, mobility, posture, motor function, accidental falls, training, exercise, physical functioning* and for the interventions of interest: *cognitive therapy/rehabilitation/intervention, problem solving, biofeedback, virtual reality, video game, action game, computerized training, user-computer interface, dual task* (Table 3.1). The search strategy was initially run in Medline/Premedline

and then adapted to the search format requirements of the other databases included in this review. The search results were supplemented by articles found through hand search by scanning reference lists of identified studies.

### 3.2.2. Study collection

After duplicate citations were removed, two reviewers (GP, EDdB) determined which articles should be included within the systematic review by scanning the titles, abstracts and keywords applying the inclusion and exclusion criteria (*Table 3.2*). A study was considered eligible for inclusion in the review when it was examining the results of a cognitive or cognitive-motor intervention on physical functioning of older adults.

As mentioned in the introduction, we included any study that arose from our search concerning people with traumatic brain injury or stroke patients. Cognitive and cognitive-motor interventions were considered studies that included cognitive rehabilitation or a combination of cognitive rehabilitation and physical exercise, respectively. We did not include studies that solely carried out single tests without an intervention. We adopted the definition of the Brain Injury Interdisciplinary Special Interest Group (BI-ISIG) of the American Congress of Rehabilitation Medicine for cognitive rehabilitation to guide our search. Studies evaluating the effectiveness of pharmacological therapy were excluded. If title, abstract or key words provided insufficient information for a decision on inclusion, the methods section of the full-text article was considered.

### 3.2.3. Data extraction and data synthesis

The following data were extracted from the studies: (1) characteristics of the studied population: number of participants, disease and age, (2) characteristics of the interventions: the design, frequency and duration of the intervention, co-interventions, and control intervention; (3) characteristics of the outcomes: outcome measures and results (*Tables 3.3 and 3.4*).

The included studies were divided into three groups: a) cognitive rehabilitation, b) dual task interventions and c) computerized interventions. Computerized interventions



included every study using an electronic game or task that involves interaction with a user interface to generate visual feedback on a display device. Because we expected the interventions and reported outcome measures to be markedly varied, we focused on a description of the studies and their results, and on qualitative synthesis rather than meta-analysis.

**Table 3.2** List of inclusion and exclusion details

Area	Inclusion details
Population	Any elderly subjects over 65 years, adult (aged > 18 years) brain trauma patients, studies with stroke patients
Study type	Intervention studies of any type, including case studies and non-randomized trials
Intervention	Cognitive or cognitive-motor rehabilitation intervention (physical exercise must include a cognitive aspect)
Outcomes	Outcomes focus on general physical functioning and mobility of upper or lower extremities
Exclusion details	
Purely physical training, interventions without training period (tests), dual task intervention without concurrent cognitive task, animal studies, reviews, methodological, theoretical or discussion papers, studies that examine the effect of physical exercise on cognition.	

#### 3.2.4. Assessment of study quality

As the basis for our critical appraisal of the studies, a checklist designed for assessing the methodological quality of both randomized and non-randomized studies of healthcare interventions developed by Downs and Black [41] was used. The checklist assesses biases related to reporting, external validity, internal validity, and power. Seven items concerning follow-up analyses (items 9, 17 and 26), allocation concealment (items 14 and 24), adverse effects (item 8), and representativeness of treatment places and facilities (item 13) were not considered in this review. The items were excluded because we were not primarily interested in possible long-term effects of cognitive or cognitive-motor interventions but rather in short-term effects of the interventions on motor functioning.

**Table 3.3** Included studies reported by design and subject specifications

Study	Design	n	Subjects	Age: range or mean [years]
<b>Cognitive Rehabilitation Interventions</b>				
Batson et al 2006	RCT	6	Community dwelling older adults	65–80
Dunsky et al 2008	Non-RCT	17	Community dwelling adults with hemiparetic stroke	44–79
Hamel & Lajoie 2005	RCT	20	Older adults	65–90
<b>Dual task Interventions</b>				
Shigematsu et al 2008	RCT	63	Community dwelling older adults	65–74
Shigematsu et al 2008	RCT	39	Community dwelling healthy adults	65–74
Silsupadol et al 2006	Case study	3	Older adults with history of falls	82, 90 and 93
Silsupadol et al 2009	RCT	21	Older adults	75.0 ± 6.1
Vaillant et al 2006	RCT	68	Community dwelling older women with osteoporosis	73.5 ± 1.6
You et al 2009	RCT	13	Older adults with history of falls	68.3 ± 6.5
<b>Computerized Interventions</b>				
Bisson et al 2007	Pre-Post	24	Community dwelling older adults	VR: 74.4 ± 3.65; BF: 74.4 ± 4.92
Broeren et al 2008	Pre-Post	22	Community dwelling adults with stroke	67.0 ± 12.5
Buccello-Stout et al 2008	RCT	16	Older adults	66–81
Clark et al 2009	Case study	1	Woman resident of a nursing home with unspecified balance disorders	89
de Bruin et al 2010	Two groups control	35	Older adults living in a residential care facility	IG: 85.2 ± 5.5; CG: 86.8 ± 8.1
Deutsch et al 2009	Case study	2	Chronic phase post-stroke	34 and 48
Hatzitaki et al 2009	RCT	48	Community-dwelling healthy older women	70.9 ± 5.7
Hinman 2002	RCT	88	Community-dwelling older adults	63–87
Jang et al 2005	RCT	10	Patients with stroke	57.1 ± 4.5
Kerdoncuff et al 2004	RCT	25	Patients with stroke	59.5 ± 13.5
Lajoie 2003	RCT	24	Community-dwelling elderly	IG: 70.3; CG: 71.4
Mumford et al 2010	Case study	3	Patients with TBI	20, 20 and 21
Sackley et al 1997	RCT	26	Patients with stroke	41–85
Srivastava et al 2009	Pre-Post	45	Patients with stroke	45.5 ± 11.2
Sugarman et al 2009	Case study	1	Patent with stroke	86
Talassi et al 2007	Case-control	54	Community-dwelling older adults with MCI or MD	42–91
Wolf et al 1997	RCT	72	Independently living older adults	CBT: 77.7 ± 6.5; TC: 77.7 ± 5.6; CG: 72.2 ± 4.9
Yang et al 2008	RCT	20	Patients with stroke	30–74
Yong Joo et al 2010	Pre-Post	16	Rehabilitation inpatients within 3 months post-stroke	64.5 ± 9.6

*Abbreviations:* RCT = Randomized controlled trial; Non-RCT = Non-randomized controlled trial; TC = Tai Chi; VR = Virtual reality; BF = Biofeedback; IG = Intervention group; CG = Control group

**Table 3.4** Included studies reported by subjects, outcomes measures, intervention, control and results

Study	Subjects	Outcome measures	Intervention	Control	Results
<b>Cognitive Interventions</b>					
Batson et al, 2007	n=6; community-dwelling elderly; age range: 65–80 years	<ul style="list-style-type: none"> <li>Standardized measures of balance, gait speed and balance confidence</li> <li>BBS, ABC</li> <li>TUG</li> </ul>	Mental imagery plus physical practice; 6 weeks: 2x/week for 50min	Health education plus physical practice 6 weeks: 2x/week for 50min	<ul style="list-style-type: none"> <li>Significant results for TUG only for the group as a whole</li> <li>No significant results for either group or for the group as a whole for remaining measures</li> </ul>
Dunsky et al, 2008	n=17; community dwelling adults with hemiparetic stroke; age range: 44–79 years	<ul style="list-style-type: none"> <li>Spatiotemporal and kinematic gait parameters</li> <li>Tinetti POMA</li> <li>FMA</li> <li>Modified FWCI</li> </ul>	Motor imagery training; 6 weeks: 3 x/week for 20min	None	<ul style="list-style-type: none"> <li>Spatiotemporal parameters: significant improvements in mean gait speed at baseline and follow-up; stride length, paretic and non-paretic step length increased significantly at post-intervention</li> <li>Significant increase of sagittal ROM of the paretic knee, joint</li> <li>Significant increase of gait symmetry after intervention</li> <li>Treatment effect size was moderate for most of the variables</li> </ul>
Hamel and Lajoie, 2005	n=20; older adults; age range: 65–90 years	<ul style="list-style-type: none"> <li>A-P &amp; M-L postural oscillations</li> <li>Reaction time to auditory stimuli</li> <li>BBS</li> <li>ABC</li> </ul>	Mental imagery training; 6 weeks: daily practice	No involvement in any type of training	<ul style="list-style-type: none"> <li>MI-group became more stable after training, while sway of control group increased when compared to pre-test</li> <li>A-P postural oscillation significantly decreased in MI-group</li> <li>Significant decrease in reaction time task for MI-group</li> <li>No significant outcomes on BBS and ABC scales</li> </ul>

**Table 3.4** Included studies reported by subjects, outcomes measures, intervention, control and results (*continued*)

Study	Subjects	Outcome measures	Intervention	Control	Results
<b>Dual task Interventions</b>					
Shigematsu et al, 2008	n=63; community dwelling older adults; age range: 65–74 years	<ul style="list-style-type: none"> <li>Physical tests of balance, leg strength and coordination</li> <li>Self-reported occurrence of falls or trips</li> <li>Step-recording with pedometers</li> </ul>	Square-Stepping Exercise (SSE); 12 weeks: 2x/week for 70min	Supervised walking (W); 12 week: 1x week for 70min	<ul style="list-style-type: none"> <li>Functional fitness of lower extremities improved more in SSE than in W</li> <li>No significantly lower rate of falls per trip for SSE compared to W</li> </ul>
Shigematsu et al, 2008	n=39; community-dwelling healthy adults; age range: 65–74 years	<ul style="list-style-type: none"> <li>Chair stands, leg extension power, single-leg balance with eyes closed, functional reach, standing up from a lying position, stepping with both feet, walking around two cones, 10m-walk, Sit &amp; Reach</li> </ul>	Square-Stepping Exercise (SSE); 12 weeks: 2x/week for 70min	Strength and balance training; 12 weeks: 2x/week for 70min	<ul style="list-style-type: none"> <li>SSE: significant within-group improvement in one-leg balance</li> <li>SB: Significant improvement of functional reach</li> <li>Performances on remaining test were significantly better for both groups</li> </ul>
Silsupadol et al, 2006	n=3; older adults with self-reported history of falls or concerns about impaired balance; age: 82, 90 and 93 years	<ul style="list-style-type: none"> <li>Medio-lateral COM displacement and single task (ST) and dual task (DT)</li> <li>BBS, ABC</li> <li>DGI</li> <li>TUG</li> </ul>	Dual task balance training with fixed-(FP) or variable-priority (VP); 4 weeks: 3x/week for 45min	Single task balance training; 4 weeks: 3x/week for 45min	<ul style="list-style-type: none"> <li>Balance improved in all 3 participants, BBS, DGI and ABC scores increased</li> <li>Time to complete TUG decreased under both conditions (participants who received DT-training showed more improvement in TUG under DT than under ST and vice versa)</li> <li>Subject who received DT-training using VP, showed improvements on other dual tasks that were not directly trained (novel task)</li> <li>Follow-up (2 weeks): time to perform TUG decreased for all subjects</li> <li>Follow-up (3 months): Clinical measures of balance were retained; TUG in subject with FP further improved (9%)</li> </ul>

**Table 3.4** Included studies reported by subjects, outcomes measures, intervention, control and results (*continued*)

Study	Subjects	Outcome measures	Intervention	Control	Results
Silsupadol et al, 2009	n=21; elderly adults; mean age: 75 ± 6.1 years	<ul style="list-style-type: none"> <li>Self-selected gait speed under single and dual task conditions</li> <li>Gait temporal-distance measurements</li> <li>BBS, ABC</li> <li>Average angle of frontal plane COM position and ankle joint center (AJC)</li> </ul>	Dual task balance training with fixed- (FP) or variable-priority (VP); 4 weeks: 3x/week for 45min	Single task balance training; 4 weeks: 3x/week for 45min	<ul style="list-style-type: none"> <li>All participants improved gait speed under ST conditions</li> <li>DT-groups walked significantly faster under DT conditions. No significant difference in gait speed under DT conditions for ST-group</li> <li>All participants improved balance under ST conditions</li> <li>ABC Scale: ST group increased their level of confidence more than DT groups</li> <li>BBS Scale: improvements in BBS were comparable across training groups</li> <li>Follow-up: DT-training with VP instructions demonstrated a training effect on DT-gait speed at the end of the second week of training and also after 3 months follow-up</li> <li>All groups showed a significantly smaller AJC-angle after training when walking under ST- conditions</li> <li>Under DT-conditions reduction of AJC-angle was significant for all groups, but was greater for the VP-group than for the ST-group and FP-group</li> <li>No significant effects on AJC-angle in a novel (untrained) DT-condition for all groups</li> </ul>
Valliant et al, 2006	n=68; community-dwelling older women with osteoporosis mean age: 73.5 ± 1.6 years	<ul style="list-style-type: none"> <li>TUG &amp; TUG-DT</li> <li>One Leg Balance (OLB) and OLB with concurrent task (OLB-DT)</li> </ul>	Physical exercise while counting, memorizing or reciting (dual task); 6 weeks: 2x/week	Physical exercises (single task); 6 weeks: 2x/week	<ul style="list-style-type: none"> <li>Adding cognitive tasks did not significantly alter the effects of the exercise program</li> <li>2 weeks follow-up: Significant improvements for all outcome measures in both groups; TUG time improved more in single task group than in dual task group</li> <li>3 months follow-up: Improvements in TUG-DT significantly greater in dual task group than in the single task group</li> </ul>

**Table 3.4** Included studies reported by subjects, outcomes measures, intervention, control and results (continued)

Study	Subjects	Outcome measures	Intervention	Control	Results
You et al, 2009	n=13; older adults with history of falls; mean age: 68.3 ± 6.5 years	<ul style="list-style-type: none"> <li>Gait speed</li> <li>A-P &amp; M-L COP deviation</li> </ul>	Cognitive Gait Intervention (CGI); 6 weeks: 5x/week for 30min	Placebo version of CGI; 6 weeks: 5x/week for 30min	<ul style="list-style-type: none"> <li>No significant difference in the M-L COP or A-P COP deviation measures neither in control nor experiment group</li> <li>Significant increase in gait speed in control group but not in experimental group</li> </ul>
<b>Computerized Interventions</b>					
Bisson et al, 2007	n=24; community dwelling older adults; mean age: VR 74.4 ± 3.65 years, BF 74.4 ± 4.92 years	<ul style="list-style-type: none"> <li>Static balance</li> <li>Simple auditory reaction time task</li> <li>CB&amp;M</li> </ul>	Dynamic balance training with visual biofeedback (BF) or in virtual reality (VR); 10 weeks: 2x/week for 30min	None	<ul style="list-style-type: none"> <li>Mean CB&amp;M scores for both groups increased significantly from baseline to post-training and retention, no difference between groups</li> <li>Static balance: no differences between groups and no training effect on variability of COP displacement; Significant task effect and interaction between directions of sway and tasks</li> <li>Reaction time: no group effect; significant main effect of time; reaction time at baseline significantly higher compared to post-training and retention; both groups improved their reaction time equally</li> </ul>
Boeren et al, 2008	n=22; community dwelling persons with stroke; mean age: 67 ± 12.5 years	<ul style="list-style-type: none"> <li>Manual Ability measurements (BBT and ABILHAND)</li> <li>Trail Making Test B</li> <li>Kinematics of upper extremities (velocity, hand-path ratio, and more)</li> </ul>	3D computer game play with haptic device and unsupported upper extremities; 4 weeks: 3 x/week for 45min	Continued participation in usual physical activities	<ul style="list-style-type: none"> <li>BBT: Increase in treatment group by 9%</li> <li>ABILHAND: No significant changes in both groups</li> <li>TMT-B: median time decreased for completing the task in both groups</li> <li>Kinematics: Time to complete the VR task and HPR decreased significantly in treatment group</li> <li>Hand trajectories are qualitatively more restrained, self-controlled, smoother and less clutters after training</li> </ul>

**Table 3.4** Included studies reported by subjects, outcomes measures, intervention, control and results (*continued*)

Study	Subjects	Outcome measures	Intervention	Control	Results
Burcello-Stout et al, 2008	n=16; older adults; age range: 66–81 years	<ul style="list-style-type: none"> <li>Time to complete an obstacle course with 13 soft obstacles</li> <li>Number of penalties on obstacle course</li> </ul>	Walking straight on a treadmill in a rotating virtual room; 4 weeks: 2 x/week for 20min	Walking straight on a treadmill in a static virtual room; 4 weeks: 2 x/week for 20min	<ul style="list-style-type: none"> <li>Average time scores to complete obstacle course and average penalty scores significantly decreased in experimental group after intervention and at retention (4 weeks)</li> </ul>
Clark et al, 2009	n=1; woman resident of a nursing home with unspecified balance disorders; age: 89 years	<ul style="list-style-type: none"> <li>BBS; ABC</li> <li>DGI</li> <li>TUG</li> <li>MMSE</li> </ul>	Nintendo Wii Bowling game; 2 weeks: 3x/week for 60 min	None	<ul style="list-style-type: none"> <li>Improvements in all outcome measures</li> <li>Self-reported improvements in balance, ambulation ability and confidence</li> </ul>
de Bruin et al, 2010	n=35; older adults living in a residential care facility; mean age: CGD 85.2 ± 5.5 years, UC 86.8 ± 8.1 years	<ul style="list-style-type: none"> <li>Gait temporal-distance measurements</li> <li>Dual task costs of walking</li> <li>ETGUG</li> <li>FES-I</li> </ul>	Computer game dancing (CGD) plus progressive resistance training; 12 weeks: 2x/week for 45–60min	Usual care physical intervention (UC); 12 weeks: 1x/week for 30–45min	<ul style="list-style-type: none"> <li>DTC: Significant decrease in DTC of walking velocity and stride time in CGD-group. No significant changes in DTC of cadence and step time in both groups</li> <li>ETGUG: no significant time effect in both groups</li> <li>FES-I: no significant time effect in both groups</li> </ul>
Deutsch et al, 2009	n=2; in chronic phase post-stroke patients; age: 48 and 34 years	<ul style="list-style-type: none"> <li>Gait speed</li> <li>Six-minute walk test (meters)</li> <li>BBS; ABC</li> <li>DGI</li> <li>TUG and TGU-DT</li> </ul>	Nintendo Wii Sports and Wii Fit Programs; 4 weeks: 3x/week for 60min	Balance and coordination activities in different conditions; 4 weeks: 3x/week for 60min	<ul style="list-style-type: none"> <li>Gait speed increased for both participants (retained at follow-up)</li> <li>Gait endurance increased modestly for both participants</li> <li>DGI and ABC scores increased for both participants</li> <li>TUG and TUG-DT time decreased for both participants; Control subject showed further improvement at post-test</li> </ul>

**Table 3.4.** Included studies reported by subjects, outcomes measures, intervention, control and results (*continued*)

Study	Subjects	Outcome measures	Intervention	Control	Results
Hatzitaki et al, 2009	n=48; community-dwelling healthy older women; mean age: 70.89 ± 5.67 years	<ul style="list-style-type: none"> <li>• Static postural sway data: COP displacement in A-P and M-L direction</li> <li>• Angular excursion of lower leg, pelvis and trunk</li> </ul>	Balance training on platform with visual feedback in A-P or M-L direction; 4 weeks: 3x/week for 25min	No involvement in any type of training	<ul style="list-style-type: none"> <li>• Normal quiet stance: No significant changes in COP displacement and angular kinematics in either of the two training groups.</li> <li>• Significant effect of training on interlimb COP asymmetry in A-P group</li> <li>• Sharpened Romberg Stance: Significant reduction of COP displacement in A-P group, no adaptations in M-L group. A-P group showed significantly decreased peak amplitude and SD of lower leg rotation in the pitch direction and of trunks medio-lateral rotation. No significant changes in the M-L group</li> </ul>
Hinman, 2002	n=88; community-dwelling elderly; age range: 63-87 years	<ul style="list-style-type: none"> <li>• BBS</li> <li>• MFES</li> <li>• Timed 50-foot walk test (TWT)</li> <li>• Simple reaction time</li> </ul>	Computerized Balance Training (CBT) or Home program of balance exercises (HEP); 4 weeks: 3 x/week for 20min	No involvement in any type of training	<ul style="list-style-type: none"> <li>• Subjects in both training groups showed slight improvements in all measures. Subjects of control group improved to a lesser degree</li> </ul>
Jang et al, 2005	n=10; patients with hemiparetic stroke; mean age: 57.1 ± 4.5 years	<ul style="list-style-type: none"> <li>• BBT</li> <li>• FMA</li> <li>• Manual Function test</li> <li>• Several fMRI data</li> </ul>	VR game exercise with IREX system focusing on reaching, lifting and grasping; 4 weeks: 5x/week for 60min	No involvement in any type of training	<ul style="list-style-type: none"> <li>• Significant difference between the groups, VR group improved in motor functions, control group did not show any change</li> <li>• Cortical activation was reorganized from contralateral to ipsilesional activation in the laterality index</li> </ul>
Kerdoncuff et al 2004	n=25; patients with stroke; mean age: 59.5 ± 13.5	<ul style="list-style-type: none"> <li>• FMA</li> <li>• Gait evaluation</li> <li>• Barthel Index</li> <li>• Measurement of functional independence (MFI)</li> <li>• Sway measurements on force platform</li> </ul>	Progressive balance training with visual biofeedback plus traditional training; 3 weeks: 5x/week	Traditional training; 3 weeks: 5x/week	<ul style="list-style-type: none"> <li>• Improvements in gait: speed for control group, decrease for intervention group</li> <li>• Improvements in FMA, MFI and Barthel Index for both groups</li> <li>• Improvements of force platform parameters with closed eyes</li> </ul>



**Table 3.4.** Included studies reported by subjects, outcomes measures, intervention, control and results (continued)

Study	Subjects	Outcome measures	Intervention	Control	Results
Lajoie, 2003	n=24; community-dwelling elderly; mean age: 67.0.3 years, CG 71.4 years	<ul style="list-style-type: none"> <li>BBS, ABC</li> <li>Auditory-verbal reaction test</li> <li>Postural sway data</li> </ul>	Computerized Balance Training; 8 weeks: 2x/week for 60min	No involvement in any type of training	<ul style="list-style-type: none"> <li>BBS: Significant difference for CBT-group after intervention</li> <li>ABC: No significant changes</li> <li>Significant decrease of reaction time in CBT-group after intervention</li> <li>Postural sway: No significant changes in both groups</li> </ul>
Mumford et al., 2010	n=3; patients with TBI; mean age: 20.3 years	<ul style="list-style-type: none"> <li>Movement accuracy</li> <li>Movement speed</li> <li>Movement efficiency</li> <li>BBT</li> <li>MAND</li> </ul>	Table-top VR-System for moving objects to cued locations with augmented movement feedback; 12 weeks: 1x/week for 60min	None	<ul style="list-style-type: none"> <li>Accuracy: Improvements after intervention and maintained in 2 of 3 patients</li> <li>Speed: No improvement after intervention for either hand</li> <li>Efficiency: Improved performance efficiency for all participants after intervention</li> <li>BBT: moderate improvements</li> <li>MAND: moderate improvements</li> </ul>
Sackley et al., 1997	n=26; stroke patients; age range: 41-85 years	<ul style="list-style-type: none"> <li>Stance symmetry and sway</li> <li>Rivermead Motor Assessment</li> <li>Nottingham 10 Point ADL Scale</li> </ul>	Balance training using visual feedback; 4 weeks: 3x/week for 60min	Balance training without visual feedback; 4 weeks: 3x/week for 60min	<ul style="list-style-type: none"> <li>Treatment group demonstrated significantly better performance when compared with controls for stance symmetry and for functional performance (ADL and Gross Function scores)</li> <li>Sway values showed a tendency to greater improvement</li> </ul>
Srivastava et al., 2009	n=45; stroke patients; mean age: 45.51 ± 11.24 years	<ul style="list-style-type: none"> <li>BBS</li> <li>Balance Index</li> <li>Dynamic Limits of Stability scores</li> <li>Walking ability</li> <li>Barthel Index</li> </ul>	Balance training on force platform with visual feedback; 4 weeks: 5x/week for 20min	None	<ul style="list-style-type: none"> <li>Statistically significant differences at the end of training for all outcome measures</li> <li>Statistically significant differences for all outcomes at 3 months follow-up</li> </ul>

**Table 3.4.** Included studies reported by subjects, outcomes measures, intervention, control and results (*continued*)

Study	Subjects	Outcome measures	Intervention	Control	Results
Sugarman et al, 2009	n=1; woman 5 weeks after stroke; age: 86 years	<ul style="list-style-type: none"> <li>BBS</li> <li>Functional Reach</li> <li>TUG</li> <li>Postural Stability Index (STI)</li> <li>Stability Score (ST)</li> </ul>	Nintendo Wii Fit balance training plus standard physical therapy with emphasis on functional activities; 4 x 45min	None	<ul style="list-style-type: none"> <li>Modest improvements in BBS and Functional Reach tests</li> <li>TUG time decreased</li> <li>Modest improvements in postural stability tests</li> </ul>
Talassi et al, 2007	n=54; community-dwelling older adults with mild cognitive impairment (MCI) or mild dementia (MD); age range: 42–91 years	<ul style="list-style-type: none"> <li>PPT</li> <li>Basic and instrumental ADL</li> </ul>	Computerized cognitive training (CCT), occupational therapy (OT) and behavioral training (BT); 3 weeks: 4x/week for 30–45min	Same program with physical rehabilitation program (PT) instead of CCT	<ul style="list-style-type: none"> <li>Participants with MCI showed significant improvements in PPT</li> <li>Unspecific control program showed no significant effects</li> </ul>
Wolf et al, 1997	n=72; independently living older adults; mean age: CBT 77.7±6.5 years, TC 77.7±5.6 years; Control Group 75.2±4.9 years	<ul style="list-style-type: none"> <li>Postural stability measurements under defined conditions</li> <li>Fear of Falling Questionnaire</li> </ul>	Computerized Balance Training (CBT) or Tai Chi (TC); 15 weeks: CBT 1x/week for 60min, TC 2x/week for 60min	Educational intervention (ED); 15 weeks: 1x/week for 60min	<ul style="list-style-type: none"> <li>CBT: improved postural stability</li> <li>TC: no improvements in postural stability, but reduction of fear of falling occurred</li> </ul>
Yang et al, 2008	n=20; adults with stroke; age range: 30–74 years	<ul style="list-style-type: none"> <li>Walking speed</li> <li>Community walk test (CWT)</li> <li>Walking Ability Questionnaire (WAQ)</li> <li>ABC</li> </ul>	Virtual reality-based treadmill training; 3 weeks: 3x/week for 20min	Treadmill training; 3 weeks: 3x/week for 20min	<ul style="list-style-type: none"> <li>VR-Group: significant improvement in all outcomes post-training and significant improvements in walking speed, CWT and WAQ score 1 month after completion of program</li> <li>CG: significant improvements in CWT post-training and in follow-up period, significant improvements of WAQ score at follow-up</li> </ul>
Yong Joo et al, 2010	n=16; rehabilitation inpatients within 3 months post-stroke; mean age: 64.5 ± 9.6 years	<ul style="list-style-type: none"> <li>FMA</li> <li>Motricity Index</li> <li>Modified Ashworth Scale (MAS)</li> <li>Visual Analogue Scale for upper limb pain</li> </ul>	Upper limb exercises with Nintendo Wii in addition to usual rehabilitation; 2 weeks: 6x/week for 30min	None	<ul style="list-style-type: none"> <li>Significant improvements in the FMA and Motricity Index scores</li> </ul>

*Abbreviations:* BBS = Berg Balance Scale; ABC = Activities-specific Balance Confidence Scale; CB&M = Functional Balance and Mobility; COP = Centre of Pressure; COM = Centre of Mass; DGI = Dynamic Gait Index; TUG = Timed Up and Go Test; TUG-DT = Timed Up and Go Test Dual Task; ETGUG = Expanded Timed Up and Go Test; MMSE = Mini Mental State Examination; ADL = Activities of Daily Living; BBT = Box and Block Test; WAND = Mc Carron Assessment of Neuromuscular Dysfunction; FMA = Fugl-Meyer Assessment of Upper Limb Motor Function; FES-1 = Falls Efficacy Scale International; MFES = Tinetti's Modified Falls Efficacy Scale; POMA = Performance Oriented Mobility Assessment; FCWI = Functional Walking Categories Index; PPT = Physical Performance Test

The blinding of participants and investigators, the assessment of adverse effects, and the representativeness of the treatment places were also excluded. We considered these as being of minor significance for this review.

The remaining 20 items were applied by two reviewers (GP, EDdB) to assess the methodological quality of the studies. The total possible score was 22 points. The scoring for statistical power (item 27) was simplified to a choice between 0, 1 or 2 points depending on the level of power to detect a clinically important effect. The scale ranged from insufficient ( $\beta < 70\% = 0$  points), sufficient ( $\beta = 70\text{--}80\% = 1$  point) or excellent ( $\beta > 80\% = 2$  points). To assess the level of agreement between the investigators a Cohen's kappa analysis was performed on all items of the checklist. In accordance with Landis and Koch's benchmarks for assessing the agreement between raters a kappa-score of 0.81–1.0 was considered 'almost perfect', 0.61–0.8 was 'substantial', 0.41–0.6 was 'moderate', 0.21–0.4 was 'fair', 0.0–0.2 'slight' and scores  $< 0.0$  'poor' [42]. Disagreements were resolved by consensus.

The PRISMA-statement was followed for reporting items of this systematic review [43].

### **3.3. Results**

#### **3.3.1. Study selection**

The search provided a total of 2349 references (*Figure 3.1*). After adjusting for duplicates, 1697 remained. Of these 1671 were discarded because they provided only physical exercise ( $n = 159$ ), did not discuss outcomes or population of interest ( $n = 89$ ), constituted review articles or were no interventional studies ( $n = 217$ ), executed only single tests ( $n = 246$ ) or were clearly out of scope of this review ( $n = 944$ ). The remaining 26 potentially relevant articles were supplemented by 10 additional references retrieved by citations and author tracking, resulting in a total of 36 articles being eligible for full-text reading. After full-text reading eight articles were excluded because they did not report outcomes of interest ( $n = 1$ ), applied no intervention ( $n = 1$ ), applied no training ( $n = 4$ ), or were theoretical articles ( $n = 2$ ). One article appeared to be a written summary of a poster presentation and represented an included article ( $n = 1$ ).

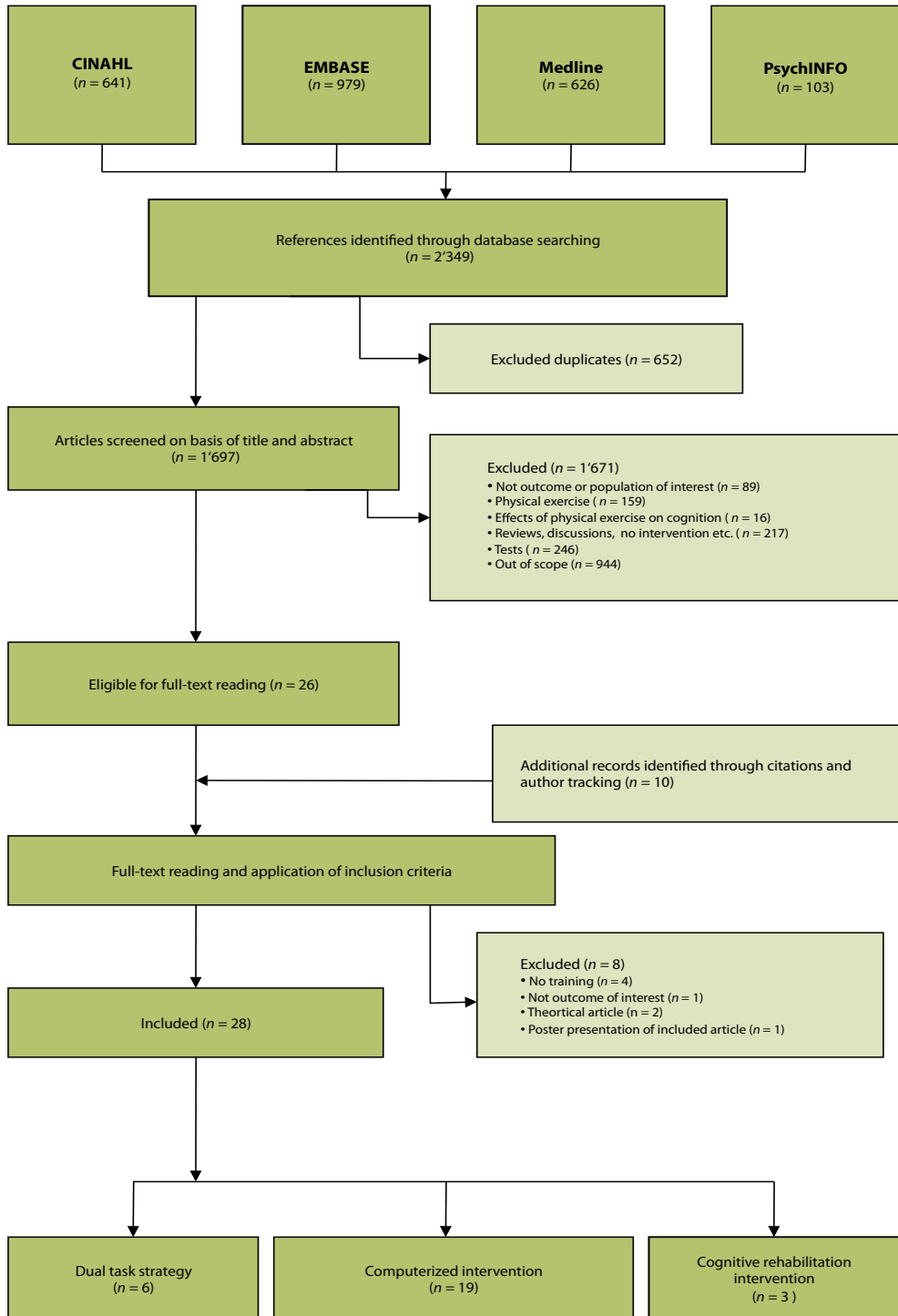


Figure 3.1 Study selection flow chart

### 3.3.2. Characteristics of included studies

Of the 28 studies finally selected for the review 27 were published in English [32,44–70] and one in French [71]. The publication dates range from 1997 [67] to 2010 [48,56,69]. In the selected studies participants were older adults partially with history of falls [47,70], balance disorders [47,62], with mild cognitive impairments [65] or osteoporosis [66]. Ten studies were concerned with patients after stroke [45,49,50,54,57,63,64,68,69,71] and one study with traumatic brain injury patients [56].

From the 28 included articles three used an isolated cognitive rehabilitation intervention [44,50,51], seven articles used a dual task intervention [58–62,66,70] and 19 applied a computerized intervention [32,45–49,52–57,63–65,67–69,71]. From the seven articles concerning dual-tasking two articles arise from the same intervention [60,61] leading us to regard it as one single study.

In 22 studies, a cognitive rehabilitation intervention, dual task training or a computerized intervention were used as the only intervention for the participants [32,45–47,49–52,54–63,66–70]. In six studies the interventions were applied as additional items to a traditional physical or balance training [44,48,53,64,65,71]. The reported outcomes involved different assessments of balance, gait or functional mobility.

Balance was assessed with the help of postural sway measurements [32,44,51,52,57,62,67,71], with the Berg Balance Scale [44,47,49,51,53,55,60–64], with the Activities-specific Balance Confidence Scale [44,47,49,51,55,60–62,68], with the Functional Balance and Mobility test [32], with the Balance Index [63] and with one-leg-stance tests [59,66]. Gait measurements included measurements of kinematic parameters [44,48–50,60,61,68,70], the Timed Up & Go Test [44,47–49,62,64,66], the Dynamic Gait Index [47,49,62], or step recording with pedometers [58]. Functional Mobility assessments were determined by manual ability measurements [45,54], functional reach tests [64], the Physical Performance Test [65], the Rivermead Motor Assessment [57], The Nottingham 10 Point ADL Scale [57], the Box and Block Test [45,54,56] and the Fugl-Meyer Assessment of Upper Limb Motor Function [50,54,69,71].

### 3.3.3. Methods used and their effects

#### 3.3.3.1. Cognitive rehabilitation interventions

From the three articles evaluating the effects of a cognitive rehabilitation intervention on motor outcomes, two examined the effects of mental imagery on physical functioning of older adults aged between 65 and 90 years [44,51]. In the third study, the participants were community-dwelling adults between 44 and 79 years of age suffering from hemiparetic stroke [50]. The three studies investigated the effect of mental imagery training on postural balance [44,51] and on gait [44,50]. Mental imagery training consisted of either visual imagery training, i.e. participants are expected to view themselves from the perspective of an external observer, or of kinesthetic imagery exercise, i.e. participants imagine experiencing bodily sensations that might be expected in the exercise. The trainings lasted six weeks with a training frequency ranging from daily [51], twice weekly [44] to three times weekly [50]. Two studies used a pure cognitive rehabilitation method [50,51] whereas one study combined mental practice with additional physical exercise [44].

The studies show reduction of postural sway [51], and improvements in gait speed [44] and gait symmetry [50]. No improvements were shown for balance confidence [44].

Hamel and Lajoies' [51] results show a significant reduction of anterior-posterior postural oscillations suggesting that mental imagery training over a six-week period helps to improve postural control of the elderly. The study of Batson et al. [44] combined mental imagery with physical exercise. The control group underwent a health education program in addition to the physical training. Gait speed, expressed by improvement in Timed Up-and-Go test performance, increased for all study participants. These results imply that the improvement in gait speed were attained through the physical practice regardless of whether combined with mental imagery or not. This conjecture is supported by the fact that the two groups under observation converge to each other for the Timed Up-and-Go test measures following the intervention. In the pretest phase, there was a large, meaningful difference for the Timed Up-and-Go test between the mental imagery and physical practice subjects (Cohen's  $d = 1.2$ ) that decreases to Cohen's  $d = 0.55$  at the end of intervention. The results showed no improvement in balance confidence, as expressed

by non-significant results neither on the Berg Balance Scale nor on the Activities-specific Balance Confidence Scale. The study of Dunsky et al. [50] showed improvements of spatiotemporal gait parameters and gait symmetry in people with chronic poststroke hemiparesis after mental imagery. There was no control group in this study to support these results.

### 3.3.3.2. *Dual task interventions*

The methods varied from walking or balancing with a concurrent mental task like memorizing words, reciting poems, or computing mental arithmetic tasks [60–62,66,70] to a square-stepping exercise where participants executed forward, backward, lateral and oblique step patterns on a thin felt mat [58,59]. The training lasted between 4 weeks [60–62], 6 weeks [70] or 12 weeks [58,59,66]. No dual task study was found on stroke patients or people with traumatic brain injury. The study of Shigematsu et al. [58] showed improvements in functional fitness of lower extremities. The results on gait patterns and postural sway are controversial. Silsupadol et al. [60–62] showed improvement of gait speed under dual task conditions and a reduction of body sway, whereas You et al. [70] and Vaillant et al. [66] found no improvements in gait and stability after a dual task intervention. No other physical outcomes were reported.

The studies conducted by Silsupadol et al. [60–62] compared three different balance training approaches: single task balance training, dual task balance training with fixed-priorities and dual task balance training with variable-priority. Single task training consisted of exercises for body stability with or without object manipulation and/or body transport. In the dual task condition, concurrent auditory and visual discrimination tasks and computing tasks were added to the balance training. In the fixed-priority condition the subject was instructed to direct the attention with equal priority to both the postural and additional tasks. In the variable-priority condition half the training was done with the instruction to mainly prioritize the postural task and the other half with the instruction to mainly prioritize the additional task. All participants improved self-selected gait speed under single task testing conditions. Under dual task testing conditions, however, only

participants who received dual task training showed significant improvements in self-selected gait speed (with moderate effect sizes of 0.57 between single task and fixed-priority and 0.46 between single task and variable-priority). All groups significantly improved on the Berg Balance Scale under single task conditions. Participants in the variable-priority training group additionally showed an average of 56% reduction in body sway compared to only 30% of the fixed-priority and single task group. Overall, the study showed that variable-priority instruction was more effective in improving both balance and physical performance under dual task conditions than either the single task or the fixed-priority training approaches. In contrast to the fixed-priority training group, the variable-priority group showed long-term maintenance effects on dual task gait speed for three months after the end of training.

In contrast to the results of Silsupadol et al., You and colleagues [70] found no improvements in gait and stability after their dual task intervention that lasted six weeks. Results of the gait tests showed a significant increase in gait velocity in the control group, which underwent single task training, but not in the experimental group. No statistically significant differences in the deviation of medio-lateral and anterior-posterior center of pressure were found between the groups. Vaillant et al. [66] did not find additional improvements through the addition of a cognitive task to the physical task either. The exercise sessions were effective in improving performance on two balance tests, improvements, however, were not attributable to the dual task training.

Shigematsu et al. [58,59] developed an alternative approach to exercise for dual task abilities in community-dwelling older adults. A square-stepping exercise was performed on a thin mat with the instruction to step from one end of the mat to the other according to a step pattern provided, which could be made progressively more complex. Results showed that square-stepping exercise was equally effective as strength training to improve lower-extremity functional fitness. Compared to a weekly walking session, however, participants of the square-stepping exercise group showed a greater improvement in functional fitness of the lower-extremity.



### 3.3.3.3. Computerized interventions

Nineteen studies investigated the effects of a computerized intervention to improve physical abilities. The studies were distributed over the populations of interest as follows: nine interventions treating older adults [32,46–48,52,53,55,65,67], nine interventions treating patients with stroke [45,49,54,57,63,64,68,69,71] and one study treating young adults with traumatic brain injury [56]. Fifteen studies investigated the effects on lower extremities [32,46–49,52,53,55,57,63–65,67,68,71], whereas four studies analyzed the effects on upper extremities [45,54,56,69]. The interventions included various methods and ideas for the implementation of computers into a training session. Talassi et al. [65] used a computerized cognitive program [72,73], to stimulate cognitive functions, e.g. visual search, episodic memory or semantic verbal fluency, by a specific group of exercise for older adults with mild cognitive impairments or mild dementia. Buccello-Stout et al. [46] used a sensorimotor adaptation training to improve functional mobility in older adults. Participants walked on a treadmill while viewing a rotating virtual scene providing a perceptual-motor mismatch [46].

Seven studies used the method of computerized dynamic balance training with visual feedback technique [52,53,55,57,63,67,71]. The tasks required to move a cursor through weight-shifting on a screen representing the center of pressure (COP) position to specified targets [32,53,55,63,67] or on a predefined sine wave trajectory [52]. In one study, the feedback signal displayed the weight distribution and weight-shifting with moving columns, showing stance symmetry [57]. In another study researchers designed the task of visual feedback training in a more playful way, projecting the cursor for center of pressure as a caterpillar moving on the screen [71].

A total of ten studies described an approach, which included interactive virtual reality games or applications [32,45,47–49,54,56,64,68,69]. Seven studies out of this ten were conducted on stroke patients [32,45,49,54,64,68,69], two studies on older adults [47,48] and one on patients with traumatic brain injury [56]. The virtual reality applications were varied. There were elaborated and expensive systems, enabling the participants to see themselves in the virtual environment and to play games like juggling a virtual

ball [32] or saving a ball as a soccer keeper [54]. Virtual devices consisting of a semi-immersive workbench with which participants were able to reach and interact with three-dimensional objects [45], a table-top virtual reality based system requiring the patients to move an object to cued locations while receiving augmented movement feedback [56] and virtual reality based treadmill training [68]. Furthermore, commercially available low-cost interactive video game console systems [47,49,64,69] or dance simulation games [48] were applied.

The computerized cognitive training program proposed by Talassi et al. [65] produced an improvement in functional status, measured by the Physical Performance Test [74], in patients with mild cognitive impairments, while a physical rehabilitation program did not show any significant effects. The sensorimotor adaptation training for older adults developed by Buccello-Stout et al. [46] resulted in better performance on an obstacle course after the intervention compared to the control group, who walked on the treadmill without rotation of the virtual scenario.

Some of the interventions providing balance training with visual feedback improved simple auditory reaction time [32,55] postural balance and stability [32,55,57,63,67,71], gait speed [63], functional status, and performance [55,57,63,71]. The intervention conducted by Hatzitaki et al. [52] revealed that weight-shifting training in anterior-posterior direction only induces improvements in standing balance of older adults. In contrast, the studies of Lajoie et al. [55] and Bisson et al. [32] showed no improvements in postural sway after computerized balance training in older adults. Hinman and colleagues [53] also found no improvements neither in balance, gait speed nor in simple reaction time compared to the control group. The results of Kerdoncuff et al. [71] even showed a reduction of gait speed in stroke patients treated with visual biofeedback compared to an increase in gait speed for the control group treated with a traditional physical rehabilitation program.

The methods using immersive computer technologies resulted in improved motor functions of upper extremities and a cortical activation by the affected movements from contralesional to ipsilesional activation in the laterality index after virtual reality intervention in patients with chronic stroke [54]. Older adults benefited from training

in terms of improved functional abilities, postural control and simple auditory reaction times [32]. A virtual rehabilitation program with the help of a semi-immersive virtual reality workbench, in a non-hospital environment, resulted in qualitatively improved manual trajectories and increased movement velocity of the trained upper extremities for patients with stroke, without any transfer to real-life activities [45].

A virtual reality based treadmill intervention conducted by Yang et al. [68] requested patients with stroke to walk on a treadmill while observing a virtual scenario of the typical regional community. The scenarios consisted of lane walking, street crossing, striding across obstacles, and park stroll with increasing levels of complexity. Participants improved their walking speed and walking ability at post-training as well as after one month after the training.

Effects on motor functions were also observed in studies using so-called off the shelf computer game systems. Four studies proposed a training program using the Nintendo Wii console [47,49,64,69]. Three of them were case studies and exemplified that a training with a commercially available computer game system can be applied for older adults [47] and for the treatment of balance problems after stroke [49,64]. The participants performed physical training using the Wii Fit system. Using the approach of the weight- shifting method with visual feedback, the Wii Fit games were controlled by shifting body weight on the platform combined with a challenging game [64]. The activities on the Nintendo Wii console were selected to practice balance, coordination, strengthening, endurance or bilateral upper extremity coordination [47,49]. Subjects very much enjoyed the interventions resulting in better balance and mobility performance [47,64], improvements in gait speed, gait endurance and balance [49]. A recently published study using the Nintendo Wii console [69] resulted in improvements in upper extremity functions in post stroke patients.

A study conducted by de Bruin et al. [48] studied the transfer effects on gait characteristics of elderly who executed a traditional progressive physical balance and resistance training with integrated computer game dancing. The task of the dancing game consisted of stepping on arrows on a dance pad. Results indicated a positive effect

of the computer game dancing training on relative dual task costs of walking, e.g., stride time and step length. The more traditional physical training showed no transfer effects on dual task costs related gait characteristics.

### **3.3.4. Quality evaluation**

The agreement on study quality between the two reviewers was 'almost perfect'. The estimated Kappa value was 0.96 with a confidence interval ranging between 0.95 and 0.98. The percentage of agreement between the two reviewers was 98.18%. The quality scores ranged from 7 to 22 points out of a maximum of 22. The mean quality score was 13.46 points (range: 7–22 points), the median value was 6.5 points and the mode was 12 points. The mean score for reporting was 6.57 points (maximum: 9 points; range: 4–9 points), for external validity 0.68 (maximum: 2 points; range: 0–2 points), for internal validity (bias) 3.71 points (maximum: 5 points; range: 2–5 points), for internal validity (confounding) 2.25 (maximum: 4 points; range: 0–4 points).

Table 3.5 summarizes the results of the quality assessment for the three intervention types: cognitive rehabilitation interventions, dual task interventions, and computerized interventions.

## **3.4. Discussion**

An increased incidence of falls among older adults is one of the most serious problems of mobility impairment. It has been suggested that effective programs to prevent falls in older adults should focus on training both physical and cognitive aspects. The aim of this systematic review was to examine the literature on the effects of cognitive and cognitive-motor interventions to improve physical functioning of older adults with additional insights from studies conducted with brain injured adults or patients with stroke.

Our search resulted in relatively few studies that evaluated a cognitive or a cognitive-motor intervention. Twenty-eight articles were found including studies with older adults or patients with neurological impairments. Our results show that the method of combining physical exercise with cognitive elements to improve physical functioning is not yet

**Table 3.5** Assessment of methodological quality

		Reporting								External validity			Internal validity Bias				Internal validity Confounding									
Study		Hypothesis/aim/objective clearly described	Main outcomes clearly described in the introduction or methods section	Participants' characteristics clearly described	Intervention clearly described	Distribution of principal confounders clearly described	Main findings of the study clearly described	Estimation of random variability for main outcomes provided	Actual probability values reported (e.g. 0.035 rather than <0.05)	Total (max: 9)	Subjects asked to participate representative for the entire population from which they were derived	Subjects prepared to participate representative of the entire population from which they were recruited	Total (max: 2)	Attempt to blind those measuring the main outcomes	No retrospective unplanned subgroup analyses	Statistical tests used to assess the main outcomes appropriate	Compliance with intervention's reliable	Main outcome measure accurate (valid and reliable)	Total (max: 5)	Patients in different intervention groups	Patients recruited over the same period of time	Study subjects randomized to intervention groups	Adequate adjustment for confounding	Total (max: 4)	Power (max: 2)	Total Score (max: 22)
		COG	Batson	1	1	1	1	0	1	0	0	5	0	0	0	0	1	1	1	1	4	1	1	1	0	3
Dunsky	1		1	1	1	0	1	1	0	6	1	1	2	0	1	1	1	1	4	0	0	0	0	0	2	14
Hamel & Lajoie	1		1	1	1	0	0	0	0	4	0	0	0	0	1	1	0	1	3	1	1	1	0	3	0*	10
DT	Shigematsu <sup>a</sup>	1	1	1	1	2	1	1	1	9	1	1	2	1	1	1	1	1	5	1	1	1	1	4	2	22
	Shigematsu <sup>b</sup>	1	1	1	1	2	1	1	1	9	0	0	0	0	1	1	1	1	4	1	1	1	1	4	2	19
	Silsupadol 2006	1	1	1	1	0	1	0	0	5	0	0	0	0	1	0	1	1	3	0	0	0	0	0	0	8
	Silsupadol 2009	1	1	1	1	2	1	1	1	9	0	0	0	1	1	1	1	1	5	1	1	1	1	4	0	18
	Vaillant	1	1	1	1	0	1	1	1	7	1	1	2	0	1	1	1	0	3	1	1	1	0	3	0	15
	You	1	1	1	1	2	1	1	1	9	0	0	0	0	1	1	0	1	3	1	1	1	0	3	0	15
COM	Bisson	1	1	1	1	0	1	0	0	5	1	1	2	0	1	1	1	1	4	1	1	0	0	2	0*	13
	Broeren	1	1	1	1	1	1	1	0	7	0	0	0	0	1	0	0	1	2	0	0	0	0	0	0	9
	Buccello-Stout	1	1	1	1	1	1	0	0	6	1	0	1	0	1	1	1	1	4	1	1	1	0	3	0*	14
	Clark	1	1	0	1	0	1	0	0	4	0	0	0	0	1	0	1	1	3	0	0	0	0	0	0	7
	de Bruin	1	1	1	1	1	1	1	1	8	1	0	1	0	1	1	1	1	4	1	1	0	1	3	0	16
	Deutsch	1	1	1	1	0	1	0	0	5	0	0	0	1	1	0	1	1	4	0	1	1	0	2	0	11
	Hatzitaki	1	1	0	1	0	1	1	0	5	1	0	1	0	1	1	0	1	3	1	1	1	0	3	0	12
	Hinman	1	1	0	1	0	1	1	1	6	1	0	1	0	1	1	0	1	3	1	1	1	0	3	0	13
	Jang	1	1	1	1	2	1	1	0	8	0	0	0	1	1	1	1	1	5	1	1	1	1	4	0	17
	Kerdoncuff	1	1	1	1	1	1	1	1	8	1	0	1	0	1	1	1	1	4	1	1	1	1	4	0	17
	Lajoie	1	1	1	1	0	1	1	0	6	0	0	0	0	1	1	0	1	3	1	1	0	0	2	0*	11
	Mumford	1	1	1	1	0	1	0	0	5	0	0	0	0	1	1	1	1	4	0	0	0	0	0	0	9
	Sackley	1	1	1	1	2	1	1	0	8	1	0	1	1	1	1	1	1	5	1	1	1	1	4	1	19
	Srivastava	1	1	1	0	0	1	1	0	5	0	0	0	0	1	1	1	1	4	0	0	0	0	0	0*	9
	Sugarman	1	1	0	1	0	1	0	0	4	0	0	0	0	1	0	1	1	3	0	0	0	0	0	0	7
	Talassi	1	1	0	1	1	1	1	1	7	1	0	1	0	1	1	1	1	4	1	1	0	0	2	0	14
Wolf	1	1	1	1	2	1	1	1	9	0	0	0	0	1	1	1	0	3	1	1	1	1	4	0	16	
Yang	1	1	1	1	1	1	1	1	8	1	1	2	1	1	1	1	1	5	1	1	1	0	3	0	18	
Yong Joo	1	1	1	1	0	1	1	1	7	1	1	2	0	1	1	0	1	3	0	0	0	0	0	0	12	

Abbreviations: COG = Cognitive Rehabilitation Intervention; DT = Dual task Intervention; COM = Computerized Intervention; \* unable to determine

systematically part of the current interventions for older adults or patients with neurological impairments. The methodological heterogeneity and the numerous feasibility studies are indicators for a topic still being in its fledgling stage.

The results of the few studies identified in this review, however, justify larger studies with older adults. There is evidence that cognitive or cognitive-motor interventions positively affect physical functioning, such as postural control, walking abilities and general functions of upper and lower extremities. The majority of the included studies resulted in improvements of the assessed functional outcome measures. The next sections will discuss the three different intervention types applied in more detail.

### **3.4.1. Cognitive rehabilitation interventions**

The prevalent technique used was mental imagery, which involved the participants imagining themselves in a specific environment or performing a specific activity, without actually performing it [75]. Brain-imaging studies showed that comparable brain areas are activated during actual performance and during mental rehearsal of the same tasks [76,77]. Hamel and Lajoie [51] suggest that after mental imagery the motor control task becomes more automatic, leading to a decrease in attentional demands directed toward the control of the motor task.

Our search resulted in three relevant studies that applied mental imagery. In one study [44] improvements in physical functioning were shown in both the intervention and the control group and in a second study [50], a missing control group made it impossible to assess whether improvements in physical functioning were attained through mental practice or not. Thus, as for now it is not possible to determine whether an isolated cognitive rehabilitation intervention based on mental imagery is able to improve physical functioning in older adults. There is evidence about the effectiveness of mental imagery in improving physical functioning of other populations than older adults [25,75]. It seems fair to state that larger randomized control studies should be performed in order to provide more insights in the impact of mental imagery in older adults.

### 3.4.2. Dual task interventions

Research has shown that dual task interventions may help participants to automate a task, to focus on other tasks and consequently, to free the individual's processing capacity. After dual task exercise more attention is available to process external information and therefore to react faster on sudden disturbances [32]. The included studies showed that it was generally feasible to apply dual task interventions, namely combining a traditional physical intervention with a variety of cognitive tasks, in community-dwelling older adults with balance impairments. During the selection stage of this review, numerous studies were identified studying the dual task abilities of older adults, though only six studies were found which integrated the method of dual-tasking in a program designed to improve physical functioning. Two studies included relatively simple cognitive tasks like computing or reciting poems. Both studies showed no improvements in physical functioning that were clearly attributable to the dual task intervention.

Using dual task exercises with variable-priority or using a complex stepping task may both be closer to real-life conditions as compared to computing while walking. The studies of Silsupadol et al. [60-62] and Shigematsu et al. [58,59] applied a more challenging way of attention-demanding tasks, and, presumably thus, offered advantages in terms of rate of learning compared to more simple cognitive tasks. Results show improvements in functional fitness of lower extremities, balance and gait speed. The latter has been reported as a global indicator of functional performance in older adults and is a good predictor of falls [78].

Shigematsu and colleagues in addition provided a challenging leg exercise, which was suggested to enhance neural functions by reducing response latency and by effectively recruiting postural muscles resulting in an improving of the interpretation of sensory information. Caution seems to be indicated in relation to the transfer effects of this form of training. The pre- and post-tests that were used to assess the effects of training were similar to the cognitive and motor tasks assigned in the interventions. Thus, it cannot be excluded that learning effects were observed instead of real improvements in underlying functional motor skills. From this viewpoint, it is not surprising that participants in dual

task groups performed better in the post-tests.

The dual task interventions showed satisfying study quality with a mean of 16.2 points out of a maximum of 22 points. However, the results about the effect of dual task interventions on physical functioning are controversial. In addition, analogue to the cognitive rehabilitation interventions, the limited number of studies performing dual task training hampers a generalization of results.

### **3.4.3. Computerized interventions**

Computerized interventions varied from force platforms with visual biofeedback with relatively simple graphics [52,53,55,57,67,71], to video capture systems that enabled the participant to see her/himself on a screen with attractive and realistic graphics allowing to immerse into the virtual environment [32,46,54,68]. A third set of studies used commercially available video game consoles that combined the simplicity of a weight-shifting training on a platform with the elaborated graphics and motivating games of a video capture system [47-49,64,69]. The study quality of the computerized interventions articles was lower (mean value of 12.8 points out of a maximum of 22 points) as compared with the value of the dual task studies (16.2 points). In contrast to the dual task interventions, however, the results of the computerized interventions showed a consistent positive effect on various physical abilities in older adults, patients with traumatic brain injury, and stroke patients. Computerized interventions can also be effectively used in clinical settings. Remarkable is that every study reported that participants were more motivated and compliant with the computerized setting in comparison to conventional physical training programs. Computerized interventions may have engaged people who otherwise would lack interest to undergo a traditional exercise program.

The effects of the video games on cognitive aspects of the participants have, remarkably, not been a specific focus of the various studies. It seems, however, that computer games have the potential to also train cognitive functions [34], including attention and executive functions [22]. Combined with physical exercise a video game or a virtual environment requires sensory-motor function inputs as well as cognitive inputs.



The participant is required to orientate her/himself, attend, comprehend, recall, plan and execute appropriate responses to the visual cues provided on the screen [69]. The visual aspect is crucial since with aging, vision remains important in maintaining postural control [79]. Virtual environments have also the potential to specifically include motor learning enhancing features that activate motor areas in the brain [80]. In addition You and colleagues suggest that virtual reality training could induce reorganization of the sensorimotor cortex in chronic patients [81].

As we know from the principles of motor learning, repetition is important for both motor learning and the cortical changes that initiate it. The repeated practice must be linked to incremental success at some task or goal. A computerized intervention constitutes a powerful tool to provide participant repetitive practice, feedback about performance and motivation to endure practice [82]. In addition, it can be adapted based on an individual participant's baseline motor performance and be progressively augmented in task difficulty. Weiss and colleagues [83] suggested that virtual reality platforms provide a number of unique advantages over conventional therapy in trying to achieve rehabilitation goals.

First, virtual reality systems provide ecologically valid scenarios that elicit naturalistic movement and behaviors in a safe environment that can be shaped and graded in accordance to the needs and level of ability of the patient engaging in therapy. Secondly, the realism of the virtual environments gives patients the opportunity to explore independently, increasing their sense of autonomy and independence in directing their own therapeutic experience. Thirdly, the controllability of virtual environments allows for consistency in the way therapeutic protocols are delivered and performance recorded, enabling an accurate comparison of a patient's performance over time. Finally, virtual reality systems allow the introduction of „gaming“ factors into any scenario to enhance motivation and increase user participation [84]. The use of gaming elements can also be used to take patients' attention away from any pain resulting from their injury or movement. This occurs the more a patient feels involved in an activity and again, allows a higher level of participation in the activity, as the patient is focused on achieving goals

within the game [85]. In combination with the benefits of indoor exercises such as safety, independence from weather conditions, this distraction may result in a shift from negative to positive thoughts about exercise [17].

#### **3.4.4. General methodological considerations**

A central element of successful cognitive rehabilitation for older adults should be the design of interventions that either re-activate disused or damaged brain regions, or that compensates for decline in parts of the brain through the activation of compensatory neural reserves [86]. Cognitive activity or stimulation could be a protective factor against the functional losses in old age. Because spatial and temporal characteristics of gait are also associated with distinct brain networks in older adults it can be hypothesized that addressing focal neuronal losses in these networks may represent an important strategy to prevent mobility disability [87]. Interventions should, as previous research suggests, focus thereby on executive functioning processes [9], and in particular on the executive function component divided attention [11], and should include enriched environments that provide physical activities with decision-making opportunities because these are believed to be able to facilitate the development of both motor performance and brain functions [88]. This review encourages the further development of virtual reality interventions, preferably with a randomized control design.

Future research that aims to examine the relation between virtual reality environments and improvements in both cognitive and walking skills, and the translation to better performance on selected physical tasks, should design the training content such that the relation between the cognitive and physical skills are more explicitly taken into account, e.g. specific elements of divided attention are integrated in the scenario. Many of the studies of this review were small and may have lacked statistical power to demonstrate differences, if such differences were present. In addition, the interventions were of relatively short duration and heterogeneous in their design, and most subjects investigated were stroke survivors. Most studies did not specifically focus on physical functioning outcomes from which it is known that these relate to brain functioning. For example, spatial and

temporal dual task cost characteristics of gait are especially associated with divided attention in older adults [11], and are dependent of the nature of the task investigated (preferred versus fast walking).

#### **3.4.5. Future directions**

Future research that aims to examine the relation between improvements in cognitive skills and the translation to better performance on selected physical tasks should take the relation between the cognitive and physical skills into account. The majority of the authors, and above all this holds true for the studies using computerized interventions, does not specifically mention or is even not aware of the potential cognitive aspects of their interventions.

#### **3.4.6. Limitations**

We developed and utilized a structured study protocol to guide our search strategy, study selection, extraction of data and statistical analysis. However, limitations of this review should be noted. First, a publication bias may have been present, as well as a language bias, given that we considered only interventions described in published studies and restricted our search to English, French, and German language publications. Second, as there were only few randomized trials, we also included observational studies, the results of which may be affected by confounding bias due to the absence of random assignment. An additional limitation is that we did not investigate the effect of the interventions in separate populations. One study included in the analysis for example assessed subjects with MCI and dementia [65]. It can very well be argued that the results of cognitive interventions may be expected to be different between cognitively intact, MCI, and demented subjects. This point should be considered in future reviews on this topic.

### **3.5. Conclusions**

The current evidence on the effectiveness of cognitive or cognitive-motor interventions to improve physical functioning in older adults or patients with traumatic brain injury is

limited. Yet overall, as the most studies included in this review showed, these interventions can enhance physical functioning. The heterogeneity of the studies published so far does not allow defining the training methodology with the greatest effectiveness. This review nevertheless provides important foundational information in order to encourage further development of novel cognitive or cognitive-motor interventions, preferably with a randomized control design. Future research that aims to examine the relation between improvements in cognitive skills and the translation to better performance on selected physical tasks should take the relation between the cognitive and physical skills into account. The majority of the authors, and above all this holds true for the studies using the computerized design, does not specifically mention or is even not aware of the potential cognitive aspects of their interventions.

### **Acknowledgements**

The authors would like to thank Dr. Martina Gosteli of the Medicinal Library of the University of Zurich for her help in elaborating the search strategy.

### **Authors' contributions**

Conception and design: GP, EDdB; screening: GP, EDdB, data abstraction: GP, EDdB; data interpretation: GP, EDdB; manuscript drafting: GP, EDdB, PW; KM, GP, EDdB and PW critically revised the manuscript for its content and approved its final version.

### **Competing interests**

The authors declare that they have no competing interests.

## References

1. Woollacott M, Shumway-Cook A: Attention and the control of posture and gait: a review of an emerging area of research. *Gait Posture* 2002, 16(1):1-14.
2. Hays RD, Liu H, Spritzer K, Cella D: Item response theory analyses of physical functioning items in the medical outcomes study. *Med Care* 2007, 45(5 Suppl 1):S32-38.
3. Kane RL, Radosevich DM: Generic Health Outcomes Measures. In: *Conducting Health Outcomes Research*. 1 edition. Edited by: Brown M, Heverling C. Sudbury: Jones 2011:91.
4. Yogev-Seligmann G, Hausdorff JM, Giladi N: The role of executive function and attention in gait. *Mov Disord* 2008, 23(3):329-342, quiz 472.
5. Sherrington C, Whitney JC, Lord SR, Herbert RD, Cumming RG, Close JC: Effective exercise for the prevention of falls: a systematic review and meta-analysis. *J Am Geriatr Soc* 2008, 56(12):2234-2243.
6. McDermott AY, Mernitz H: Exercise and older patients: prescribing guidelines. *Am Fam Physician* 2006, 74(3):437-444.
7. Paterson DH, Jones GR, Rice CL: Ageing and physical activity: evidence to develop exercise recommendations for older adults. *Can J Public Health* 2007, 98(Suppl 2):S69-108.
8. Laessoe U, Hoeck HC, Simonsen O, Voigt M: Residual attentional capacity amongst young and elderly during dual and triple task walking. *Hum Mov Sci* 2008, 27(3):496-512.
9. Rapport LJ, Hanks RA, Millis SR, Deshpande SA: Executive functioning and predictors of falls in the rehabilitation setting. *Arch Phys Med Rehabil* 1998, 79(6):629-633.
10. Sheridan PL, Solomont J, Kowall N, Hausdorff JM: Influence of executive function on locomotor function: divided attention increases gait variability in Alzheimer's disease. *J Am Geriatr Soc* 2003, 51(11):1633-1637.
11. de Bruin ED, Schmidt A: Walking behaviour of healthy elderly: attention should be paid. *Behav Brain Funct* 2010, 6:59.
12. Bryan J, Luszcz MA: Measurement of executive function: considerations for detecting

- adult age differences. *J Clin Exp Neuropsychol* 2000, 22(1):40-55.
13. Shallice T: Specific impairments of planning. *Philos Trans R Soc Lond B Biol Sci* 1982, 298(1089):199-209.
  14. Cicerone K, Levin H, Malec J, Stuss D, Whyte J: Cognitive rehabilitation interventions for executive function: moving from bench to bedside in patients with traumatic brain injury. *J Cogn Neurosci* 2006, 18(7):1212-1222.
  15. Rosano C, Aizenstein H, Cochran J, Saxton J, De Kosky S, Newman AB, Kuller LH, Lopez OL, Carter CS: Functional neuroimaging indicators of successful executive control in the oldest old. *Neuroimage* 2005, 28(4):881-889.
  16. Scherder E, Eggermont L, Visscher C, Scheltens P, Swaab D: Understanding higher level gait disturbances in mild dementia in order to improve rehabilitation: 'Last in-first out'. *Neurosci Biobehav Rev* 2011, 35(3):699-714.
  17. 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, 43(4):229-234.
  18. Harley JP, Allen C, Braciszewski TL, Cicerone KD, Dahlberg C, Evans S, Foto M, Gordon WA, Harrington D, Levin W, et al: Guidelines for cognitive rehabilitation. *NeuroRehabilitation* 1992, 2:62-67.
  19. Cicerone KD, Dahlberg C, Malec JF, Langenbahn DM, Felicetti T, Kneipp S, Ellmo W, Kalmar K, Giacino JT, Harley JP, et al: Evidence-based cognitive rehabilitation: updated review of the literature from 1998 through 2002. *Arch Phys Med Rehabil* 2005, 86(8):1681-1692.
  20. Rohling ML, Faust ME, Beverly B, Demakis G: Effectiveness of cognitive rehabilitation following acquired brain injury: a meta-analytic reexamination of Cicerone et al.'s (2000, 2005) systematic reviews. *Neuropsychology* 2009, 23(1):20-39.
  21. Acevedo A, Loewenstein DA: Nonpharmacological cognitive interventions in aging and dementia. *J Geriatr Psychiatry Neurol* 2007, 20(4):239-249.
  22. Jobe JB, Smith DM, Ball K, Tennstedt SL, Marsiske M, Willis SL, Rebok GW, Morris JN, Helmers KF, Leveck MD, et al: ACTIVE: a cognitive intervention trial to promote

- independence in older adults. *Control Clin Trials* 2001, 22(4):453-479.
23. Faucounau V, Wu YH, Boulay M, De Rotrou J, Rigaud AS: Cognitive intervention programmes on patients affected by Mild Cognitive Impairment: a promising intervention tool for MCI? *J Nutr Health Aging* 2010, 14(1):31-35.
  24. Thornton KE, Carmody DP: Efficacy of traumatic brain injury rehabilitation: interventions of QEEG-guided biofeedback, computers, strategies, and medications. *Appl Psychophysiol Biofeedback* 2008, 33(2):101-124.
  25. McEwen SE, Huijbregts MP, Ryan JD, Polatajko HJ: Cognitive strategy use to enhance motor skill acquisition post-stroke: a critical review. *Brain Inj* 2009, 23(4):263-277.
  26. Brown LA, Shumway-Cook A, Woollacott MH: Attentional demands and postural recovery: the effects of aging. *J Gerontol A Biol Sci Med Sci* 1999, 54(4):M165-171.
  27. Maylor EA, Allison S, Wing AM: Effects of spatial and nonspatial cognitive activity on postural stability. *Br J Psychol* 2001, 92 Part 2:319-338.
  28. Haggard P, Cockburn J, Cock J, Fordham C, Wade D: Interference between gait and cognitive tasks in a rehabilitating neurological population. *J Neurol Neurosurg Psychiatry* 2000, 69(4):479-486.
  29. McCulloch K: Attention and dual-task conditions: physical therapy implications for individuals with acquired brain injury. *J Neurol Phys Ther* 2007, 31(3):104-118.
  30. Camicioli R, Howieson D, Lehman S, Kaye J: Talking while walking: the effect of a dual task in aging and Alzheimer's disease. *Neurology* 1997, 48(4):955-958.
  31. Pellecchia GL: Dual-task training reduces impact of cognitive task on postural sway. *J Mot Behav* 2005, 37(3):239-246.
  32. Bisson E, Contant B, Sveistrup H, Lajoie Y: Functional balance and dual-task reaction times in older adults are improved by virtual reality and biofeedback training. *Cyberpsychol Behav* 2007, 10(1):16-23.
  33. Sveistrup H: Motor rehabilitation using virtual reality. *J Neuroeng Rehabil* 2004, 1(1):10.
  34. Zelinski EM, Reyes R: Cognitive benefits of computer games for older adults. *Gerontechnology* 2009, 8(1):220-235.

35. Bashore TR, Ridderinkhof KR: Older age, traumatic brain injury, and cognitive slowing: some convergent and divergent findings. *Psychol Bull* 2002, 128(1):151-198.
36. Hinkebein JH, Martin TA, Callahan CD, Johnstone B: Traumatic brain injury and Alzheimer's: deficit profile similarities and the impact of normal ageing. *Brain Inj* 2003, 17(12):1035-1042.
37. Goldstein G, Shelly CH: Similarities and differences between psychological deficit in aging and brain damage. *J Gerontol* 1975, 30(4):448-455.
38. McDowd JM, Filion DL, Pohl PS, Richards LG, Stiers W: Attentional abilities and functional outcomes following stroke. *J Gerontol B Psychol Sci Soc Sci* 2003, 58(1):P45-53.
39. Broglio SP, Tomporowski PD, Ferrara MS: Balance performance with a cognitive task: a dual-task testing paradigm. *Med Sci Sports Exerc* 2005, 37(4):689-695.
40. Parker TM, Osternig LR, van Donkelaar P, Chou LS: Recovery of cognitive and dynamic motor function following concussion. *Br J Sports Med* 2007, 41(12):868-873, discussion 873.
41. Downs SH, Black N: The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and nonrandomised studies of health care interventions. *J Epidemiol Community Health* 1998, 52(6):377-384.
42. Landis JR, Koch GG: An application of hierarchical kappa-type statistics in the assessment of majority agreement among multiple observers. *Biometrics* 1977, 33(2):363-374.
43. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gotzsche PC, Ioannidis JP, Clarke M, Devereaux PJ, Kleijnen J, Moher D: The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *J Clin Epidemiol* 2009, 62(10):e1-34.
44. Batson G, Feltman R, McBride C, Waring J: Effect of mental practice combined with physical practice on balance in the community-dwelling elderly. *Activities, Adaptation & Aging* 2007, 31(2):1-18.
45. Broeren J, Claesson L, Goude D, Rydmark M, Sunnerhagen KS: Virtual rehabilitation



- in an activity centre for community-dwelling persons with stroke. The possibilities of 3-dimensional computer games. *Cerebrovasc Dis* 2008, 26(3):289-296.
46. Buccello-Stout RR, Bloomberg JJ, Cohen HS, Whorton EB, Weaver GD, Cromwell RL: Effects of sensorimotor adaptation training on functional mobility in older adults. *Journals of Gerontology Series B: Psychological Sciences & Social Sciences* 2008, 63B(5):P295-300.
  47. Clark R, Kraemer T: Clinical use of Nintendo Wii bowling simulation to decrease fall risk in an elderly resident of a nursing home: a case report. *J Geriatr Phys Ther* 2009, 32(4):174-180.
  48. de Bruin E, Dörflinger M, Reith A, Murer K: The effect of dance dance revolution gaming compared to conventional physical training on dual task walking costs in elderly. *Parkinsonism and Related Disorders* 2010, 16: S59.
  49. Deutsch J, Robbins D, Morrison J, Guarrera Bowlby P: Wii-Based Compared to Standard of Care Balance and Mobility Rehabilitation for Two Individuals Post-Stroke. *Virtual Rehabilitation International Conference* 2009, 117-120.
  50. Dunskey A, Dickstein R, Marcovitz E, Levy S, Deutsch J: Home-based motor imagery training for gait rehabilitation of people with chronic poststroke hemiparesis. *Archives of Physical Medicine and Rehabilitation* 2008, 89(8):1580-1588.
  51. Hamel MF, Lajoie Y: Mental imagery. Effects on static balance and attentional demands of the elderly. *Aging - Clinical and Experimental Research* 2005, 17(3):223-228.
  52. Hatzitaki V, Amiridis IG, Nikodelis T, Spiliopoulou S: Direction-induced effects of visually guided weight-shifting training on standing balance in the elderly. *Gerontology* 2009, 55(2):145-152.
  53. Hinman MR: Comparison of two short-term balance training programs for community-dwelling older adults. *J Geriatr Phys Ther* 2002, 25(3):10.
  54. Jang SH, You SH, Hallett M, Cho YW, Park C, Cho S, Lee H, Kim T: Cortical reorganization and associated functional motor recovery after virtual reality in patients with chronic stroke: an experimenter-blind preliminary study. *Arch Phys Med Rehabil*

- 2005, 86(11):2218-2223.
55. Lajoie Y: Effect of computerized feedback postural training on posture and attentional demands in older adults. *Aging Clin Exp Res* 2004, 16(5):363-368.
  56. Mumford N, Duckworth J, Thomas PR, Shum D, Williams G, Wilson PH: Upper limb virtual rehabilitation for traumatic brain injury: initial evaluation of the elements system. *Brain Inj* 2010, 24(5):780-791.
  57. Sackley CM, Lincoln NB: Single blind randomized controlled trial of visual feedback after stroke: effects on stance symmetry and function. *Disabil Rehabil* 1997, 19(12):536-546.
  58. Shigematsu R, Okura T, Nakagaichi M, Tanaka K, Sakai T, Kitazumi S, Rantanen T: Square-stepping exercise and fall risk factors in older adults: a single-blind, randomized controlled trial. *J Gerontol A Biol Sci Med Sci* 2008, 63(1):76-82.
  59. Shigematsu R, Okura T, Sakai T, Rantanen T: Square-stepping exercise versus strength and balance training for fall risk factors. *Aging Clin Exp Res* 2008, 20(1):19-24.
  60. Silsupadol P, Lugade V, Shumway-Cook A, van Donkelaar P, Chou LS, Mayr U, Woollacott MH: Training-related changes in dual-task walking performance of elderly persons with balance impairment: a doubleblind, randomized controlled trial. *Gait Posture* 2009, 29(4):634-639.
  61. Silsupadol P, Shumway-Cook A, Lugade V, van Donkelaar P, Chou LS, Mayr U, Woollacott MH: Effects of single-task versus dual-task training on balance performance in older adults: a double-blind, randomized controlled trial. *Arch Phys Med Rehabil* 2009, 90(3):381-387.
  62. Silsupadol P, Siu KC, Shumway-Cook A, Woollacott MH: Training of balance under single- and dual-task conditions in older adults with balance impairment. *Phys Ther* 2006, 86(2):269-281.
  63. Srivastava A, Taly AB, Gupta A, Kumar S, Murali T: Post-stroke balance training: Role of force platform with visual feedback technique. *J Neurol Sci* 2009, 287(1-2):89-93.
  64. Sugarman H, Weisel-Eichler A, Burstin A, Brown R: Use of the Wii Fit system for the treatment of balance problems in the elderly: A feasibility study. 2009, 111-116.

65. Talassi E, Guerreschi M, Feriani M, Fedi V, Bianchetti A, Trabucchi M: Effectiveness of a cognitive rehabilitation program in mild dementia (MD) and mild cognitive impairment (MCI): a case control study. *Arch Gerontol Geriatr* 2007, 44(Suppl 1):391-399.
66. Vaillant J, Vuillerme N, Martigne P, Caillat-Miousse JL, Parisot J, Nougier V, Juvin R: Balance, aging, and osteoporosis: effects of cognitive exercises combined with physiotherapy. *Joint Bone Spine* 2006, 73(4):414-418.
67. Wolf SL, Barnhart HX, Ellison GL, Coogler CE: The effect of Tai Chi Quan and computerized balance training on postural stability in older subjects. Atlanta FICSIT Group. Frailty and Injuries: Cooperative Studies on Intervention Techniques. *Phys Ther* 1997, 77(4):371-381, discussion 382- 374.
68. Yang YR, Tsai MP, Chuang TY, Sung WH, Wang RY: Virtual reality-based training improves community ambulation in individuals with stroke: a randomized controlled trial. *Gait Posture* 2008, 28(2):201-206.
69. Yong Joo L, Soon Yin T, Xu D, Thia E, Pei Fen C, Kuah CWK, Kong KH: A feasibility study using interactive commercial off-the-shelf computer gaming in upper limb rehabilitation in patients after stroke. *J Rehabil Med* 2010, 42(5):437-441.
70. You JH, Shetty A, Jones T, Shields K, Belay Y, Brown D: Effects of dual-task cognitive-gait intervention on memory and gait dynamics in older adults with a history of falls: a preliminary investigation. *NeuroRehabilitation* 2009, 24(2):193-198.
71. Kerdoncuff V, Durufle A, Petrilli S, Nicolas B, Robineau S, Lassalle A, Le Tallec H, Ramanantsitonta J, Gallien P: Interest of visual biofeedback training in rehabilitation of balance after stroke. *Ann Readapt Med Phys* 2004, 47(4):169-176, discussion 177-168.
72. Tonetta M: Il TNP, un software che opera in ambiente Windows. Atti del 4. Convegno Nazionale Informatica, Didattica e Disabilità Napoli, (in Italian); 1995.
73. Tonetta M: Riabilitazione neuropsicologica e TNP (training neuropsicologico). *Aspetti teorici e pragmatici*. New Magazine Publisher, Trento (in Italian); 1998.
74. Reuben DB, Siu AL: An objective measure of physical function of elderly outpatients. The Physical Performance Test. *J Am Geriatr Soc* 1990, 38(10):1105-1112.
75. Mulder T: Motor imagery and action observation: cognitive tools for rehabilitation. *J*

- Neural Transm* 2007, 114(10):1265-1278.
76. Ehrsson HH, Geyer S, Naito E: Imagery of voluntary movement of fingers, toes, and tongue activates corresponding body-part-specific motor representations. *J Neurophysiol* 2003, 90(5):3304-3316.
  77. Mulder T, de Vries S, Zijlstra S: Observation, imagination and execution of an effortful movement: more evidence for a central explanation of motor imagery. *Exp Brain Res* 2005, 163(3):344-351.
  78. Hardy SE, Perera S, Roumani YF, Chandler JM, Studenski SA: Improvement in usual gait speed predicts better survival in older adults. *J Am Geriatr Soc* 2007, 55(11):1727-1734.
  79. Perrin PP, Jeandel C, Perrin CA, Bene MC: Influence of visual control, conduction, and central integration on static and dynamic balance in healthy older adults. *Gerontology* 1997, 43(4):223-231.
  80. Cross ES, Kraemer DJ, Hamilton AF, Kelley WM, Grafton ST: Sensitivity of the action observation network to physical and observational learning. *Cereb Cortex* 2009, 19(2):315-326.
  81. You SH, Jang SH, Kim YH, Hallett M, Ahn SH, Kwon YH, Kim JH, Lee MY: Virtual reality-induced cortical reorganization and associated locomotor recovery in chronic stroke: an experimenter-blind randomized study. *Stroke* 2005, 36(6):1166-1171.
  82. Holden MK: Virtual environments for motor rehabilitation: review. *Cyberpsychol Behav* 2005, 8(3):187-211, discussion 212-189.
  83. Kizony R, Raz L, Katz N, Weingarden H, Weiss PL: Video-capture virtual reality system for patients with paraplegic spinal cord injury. *J Rehabil Res Dev* 2005, 42(5):595-608.
  84. Holden MK, Todorov E: Use of virtual environments in motor learning and rehabilitation. In: *Handbook of virtual environments design implementation and applications*. Edited by: Stanney KM. Mahwah, NJ. Lawrence Erlbaum Associates; 2002:999-1026.
  85. Sanchez-Vives MV, Slater M: From presence to consciousness through virtual reality. *Nat Rev Neurosci* 2005, 6(4):332-339.

86. Hogan M: Physical and cognitive activity and exercise for older adults: a review. *Int J Aging Hum Dev* 2005, 60(2):95-126.
87. Rosano C, Aizenstein H, Brach J, Longenberger A, Studenski S, Newman AB: Special article: gait measures indicate underlying focal gray matter atrophy in the brain of older adults. *J Gerontol A Biol Sci Med Sci* 2008, 63(12):1380-1388.
88. Yan J, Zhou C: Effects of motor practice on cognitive disorders in older adults. *Eur Rev Aging Phys Act* 2009, 6(2):67-74.



# Four Chapter

## **The effect of a cognitive-motor intervention on voluntary step execution under single and dual task conditions in older adults: a randomized controlled pilot study**

**Pichierri G<sup>1</sup>, Coppe A<sup>1</sup>, Lorenzetti S<sup>2</sup>, Murer K<sup>1</sup> and de Bruin ED<sup>1</sup>**

<sup>1</sup>Institute of Human Movement Sciences and Sport, ETH Zurich, Switzerland

<sup>2</sup>Institute for Biomechanics, Department of Health Sciences and Technology, ETH Zurich, Switzerland

published in *Clinical Interventions in Aging* 2012;7 175–184

## **Abstract**

*Background:* This randomized controlled pilot study aimed to explore whether a cognitive-motor exercise program that combines traditional physical exercise with dance video gaming can improve the voluntary stepping responses of older adults under attention-demanding dual task conditions.

*Methods:* Elderly subjects received twice weekly cognitive-motor exercise that included progressive strength and balance training supplemented by dance video gaming for 12 weeks (intervention group). The control group received no specific intervention. Voluntary step execution under single and dual task conditions was recorded at baseline and post intervention (Week 12).

*Results:* After intervention between-group comparison revealed significant differences for initiation time of forward steps under dual task conditions ( $U = 9, p = 0.034, r = 0.55$ ) and backward steps under dual task conditions ( $U = 10, p = 0.045, r = 0.52$ ) in favor of the intervention group, showing altered stepping levels in the intervention group compared to the control group.

*Conclusion:* A cognitive-motor intervention based on strength and balance exercises with additional dance video gaming is able to improve voluntary step execution under both single and dual task conditions in older adults.

**Keywords:** *fall prevention, exercise, dance, video game*



## 4.1. Introduction

Appropriate timing and execution of stepping responses is needed for the effective avoidance of falls [1]. With age, the speed of these responses inevitably declines due to changes in the sensory and motor systems [2,3]. Consequently, individuals who require more time to initiate and execute a step to avoid a threat or to recover postural balance, either during walking or performing postural transitions [4], may be at greater risk of falling [5].

Considerable evidence has been accumulated showing that an additional secondary cognitive dual task causes postural instability in older adults, and thus, a delay in step execution [6,7]. Postural balance control requires, among other things, the integration of visual, somatosensory, and vestibular inputs, as well as the adaptation of these inputs to changes in tasks and environmental context [6]. Maintenance and regulation of postural balance require a high information processing capacity, and a more difficult motor task may demand an amount that exceeds the capacity of the available resources [8].

Reduced step execution capabilities can be mitigated by exercise, and improvements in voluntary step execution after exercise interventions have been reported in older adults [5,9–11] and patients after stroke [12]. However, these improvements have been tested without any additional cognitive distraction, which questions the ecological validity of the findings; that is, it can be questioned whether the action within the test condition is equivalent to the motor performance requirements within the physical environment. Physical exercise alone does not contribute to an improvement of voluntary stepping performance under attention-demanding conditions [10].

A recently published systematic review supports the recommendation that a cognitive element should be part of an exercise program for older adults since falls often occur under attention-demanding circumstances [13]. A way to incorporate a cognitive element into an exercise program is the use of virtual reality techniques in the form of dance video gaming [14]. Games based on this technique require players to stand on a dance pad and make rapid step responses from either leg to a target location in response to a presented visual stimulus [15]. It involves controlled body weight transfer, which is similar to the step

responses required to cope with external threats in everyday life; thus, we hypothesized that the game has the potential to improve voluntary step execution under attention-demanding circumstances. Previous dance pad studies have shown the feasibility of this approach in the elderly and have reported positive contributions to self-reported balance confidence and mental health in older adults [15,16]. Furthermore, there are strong indications that the addition of dance video gaming has a positive effect on dual task walking in older adults [17].

New treatments usually have to go through a series of pilot studies to test whether they are safe and effective [18]. The aim of this pilot study was to perform a phase II trial according to the model for complex interventions, advocated by the British Medical Research Council [19] to test a traditional strength and balance training program that also includes dance video gaming in a group of elderly people in order to receive an estimation of the treatment effect and its variations. The study aimed to explore whether this cognitive-motor exercise program is able to improve the voluntary stepping responses of older adults under attention-demanding dual task conditions.

## **4.2. Material and methods**

### **4.2.1. Participants**

The study was designed as a prospective, randomized, controlled pilot trial and was carried out from October 2010 to January 2011 with participants recruited from two care homes in Zurich, Switzerland. The study protocol was approved by the local ethics committee (*KEK-ZH-NR 2010-0337/0*). The exercise intervention was conducted in suitable locations at the care homes. The measurements of voluntary step execution were performed in the laboratory of the Institute for Biomechanics of the ETH Zurich, Switzerland.

All residents of the care homes were invited to attend an information session in which the intervention was explained. Thirty-four persons attended the information session, and 30 were interested in participating in the study. Participants were included if they were older than 65 years, had a score of at least 22 points on the Mini-Mental State Examination [20], were able to stand upright for at least 5 minutes, and were free of rapidly progressive or

terminal illness, acute illness, or unstable chronic illness. If unsure, subjects were asked to consult their primary care physician for medical clearance. Interested individuals were contacted by the investigator seven days later for an individual appointment to clarify any remaining questions and to sign an informed consent statement.

Three persons refused to participate due to insufficient motivation. Two interested persons who used wheelchairs were excluded because they did not fulfill the inclusion criteria. A total of 25 eligible residents signed informed consent statements and were randomly assigned to either the usual care control group (CG) or the intervention group (IG). Eleven participants were allocated to the CG and 14 participants to the IG using a random numbers table. Blinding of investigators was not possible because the investigators supervised and conducted the training sessions.

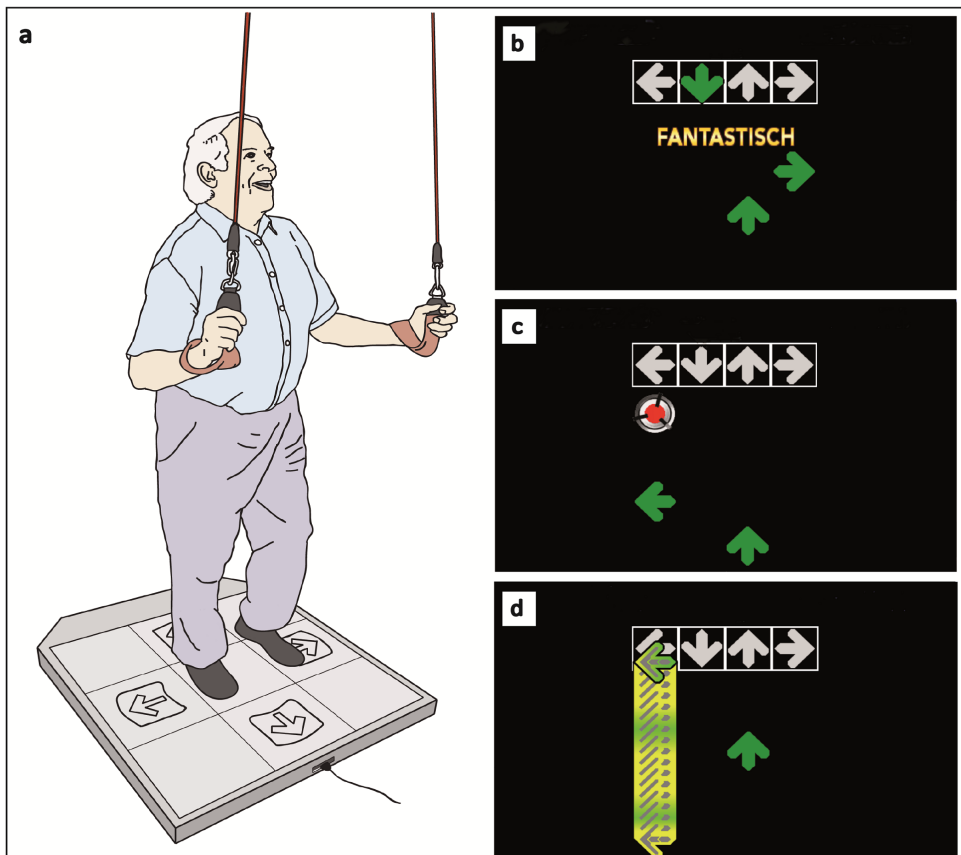
#### **4.2.2. Intervention**

The IG underwent a cognitive-motor intervention consisting of twice weekly progressive resistance training, progressive postural balance training, and progressive dance video gaming for twelve weeks. Intensity and duration of the program were chosen based on guidelines published by the American College of Sports Medicine [21,22] and on a review by Paterson et al describing exercise recommendations for older adults [23]. Training sessions were conducted in groups of three or four participants to form group cohesion and to encourage exercise class participation [24]. A training session lasted 60 minutes and consisted of a warm-up (5 minutes), resistance training (25 minutes), balance exercises (10 minutes), and the dance video gaming (20 minutes).

The progressive resistance training focused on the muscle groups of the core and lower extremities that are used in the functional activities of daily living, such as walking, standing up from a chair, sitting down, or stair climbing. The goal of each session was to perform two sets of ten to 15 repetitions of each exercise in a slow, controlled manner, with a one minute sitting break after each set and between the series. Training intensity was controlled by perceived exertion and intensity between "somewhat hard" and "hard (heavy)" on Borg's perceived exertion scale. This corresponds to a point of instantaneous

muscular fatigue at the end of a certain exercise [25]. To maintain the intensity of the stimulus during the training period, the number of repetitions and the load were progressively increased with weight vests (Kettler GmbH & Co KG, D-59469 Ense-Parsit), as tolerated by the participants. The weight of the vests was adjusted with single sand-filled elements of 1.125 kg each.

The progressive postural balance program consisted of static and dynamic functional balance exercises [26]. Participants' balance skills were challenged through a variety of activities performed with the help of air-filled balance cushions (diameter 32 cm and 16 cm) and grip balls (diameter 12 cm) (Ledraplastic S.p.a, I-33010 Osoppo).



**Figure 4.1** Dance video game: (a) participant on the dance pad secured by ropes fixed on the ceiling; (b–d) screenshots of the dance video game

The dance video game was performed on metal dance pads (*Figure 4.1 a*) (TX 6000

Metal DDR Platinum Pro, 93 × 14.7 × 109 cm, Mayflash Limited, Baoan Shenzhen, China) with a specially designed modification of the StepMania (Version 3.9) software [17]. The dance pad was connected to a desktop computer using USB. The video game was then projected on a white wall with a beamer. A scrolling display of arrows moving upwards across the screen cued each move, and the participants were asked to execute the indicated steps (forward, backward, right, or left) when the arrows reached the fixed raster graphic at the top of the screen (*Figure 4.1 b–d*) and in time with different songs (32 to 137 beats per minute). In the first training session, a tutorial sequence was provided to ensure understanding of the task. As the levels increased, additional distracting visual cues, e.g., "bombs," were presented (*Figure 4.1 c*). Participants had to ignore these cues and keep their attention focused on the arrows. Occasionally, some arrows were drawn-out on the target locations, indicating that the trainees should remain for a while on the dance pad button on one leg (*Figure 4.1 d*). The arrow sequences were generated using the Dancing Monkey MATLAB script [27]. Electronic sensors in the dance pad detected position and timing information that was then used to provide participants with real-time visual feedback. For each training session, the participants performed for four songs of 2 to 3 minutes length each, with a short break of 30 seconds after each song. Progression of performance was controlled through the beats per minute and the difficulty level.

When an exercise required the participants to stand, they were secured with ropes fixed on the ceiling, which they could hold on to (Redcord AS, Staubo, Norway).

#### **4.2.3. Usual care**

The participants in the CG did not participate in the cognitive-motor program, but were able to participate in the leisure time programs offered at the care homes at their own will. These programs were non-specific, not targeted toward specific exercise goals, and were representative of what is usually offered in assisted-living facilities [28]. Table 4.1 provides information regarding the physical activities of the CG during the intervention period.

**Table 4.1** Physical activities of the control group during intervention

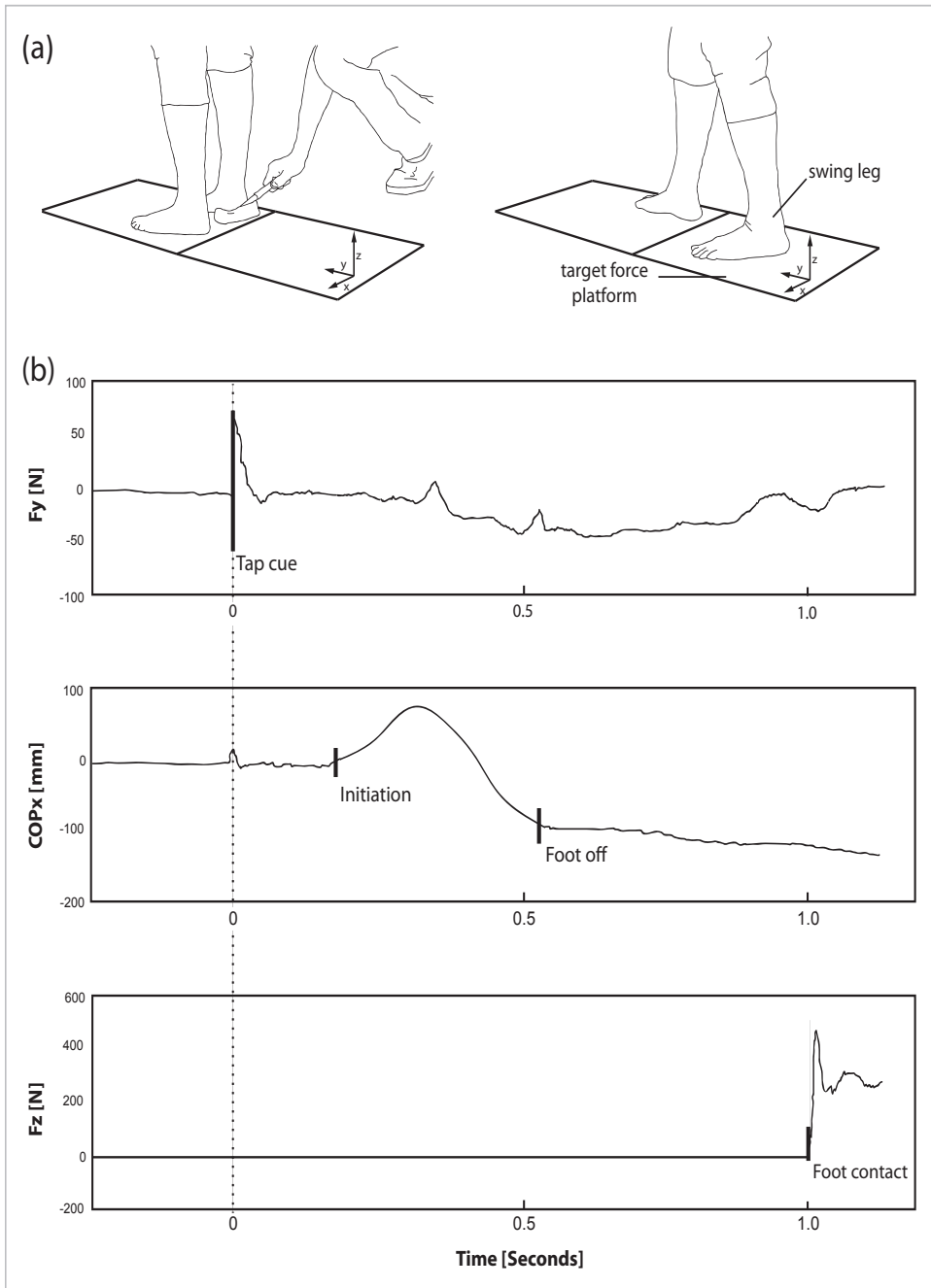
Participant	Activity	Duration (minutes)/frequency
1	Walking	30–60/daily
	Social dancing	120/weekly
2	Walking	60/daily
	Exercise program at care home*	45/irregularly
3	Walking	90/weekly
	Exercise program at care home*	45/irregularly
4	Walking	45/daily
	Aqua gym	45/weekly
5	Walking	90/daily
	Exercise program at care home*	45/weekly
6	No activities	-

Notes: \* Exercise program at the care home: Exercise is conducted seated or/and in a standing position. Trained factors are flexibility, coordination of movements, strength, endurance, fine and gross motor skills, posture and memory.

#### 4.2.4. Voluntary step execution

To estimate the performance of voluntary step execution, a test protocol was adopted that is able to identify elderly individuals at risk for falls under attention-demanding conditions [29,32]. The protocol assesses the change in the speed of voluntary step execution under the influence of a secondary distractive cognitive task and the time to initiate and complete a step [7,8,24]. The test was performed with all participants one week before and one week after the twelve-week training period.

For the test, subjects stood upright on a force platform with feet abducted 10°, barefoot, and heels separated medio-laterally by 6 cm. The stepping task required the execution of a step forward, backward, or to the side as quickly as possible after a tap cue on the heel, which was provided by the investigator with a cushioned hammer. The tap cue resembles the cutaneous stimulus experienced by the foot when hitting an object prior to stumbling or tripping [29]. Six trials for each step direction were recorded under single task and dual task conditions for a total of 36 trials. Step execution trials always occurred with the dominant leg, as chosen by the subject. Two target force platforms were used in front of (for forward steps) or behind (for backward steps) the main platform in order to register the data from the landing of the moving leg (*Figure 4.2 a*). The force platforms (Kistler AG,



**Figure 4.2** *Voluntary step execution test*: (a) participant standing on the force platform and executing a backward step after tap cue on the heel by the supervisor; (b) example of force platform data for a single step to determine the occurrence of the step parameters. *Abbreviations*: COPx, medio-lateral deviation of body's center of pressure in millimeters;  $F_y$ , anterior-posterior ground force in Newton;  $F_z$ , vertical ground force in Newton.

Switzerland, 400 × 600 mm) collected the ground reaction force data at a frequency of 2000 Hz.

In the single task condition, subjects focused on a white cross displayed at eye-level on a black screen at a distance of 4.60 meters in front of them. Under dual task conditions, a Stroop Color-Word task was displayed [30,31]. Participants were instructed to read the ink color of the displayed words out loud. The performance of the participants was controlled and corrected by the investigator if needed, but was not recorded as the Stroop Color-Word task was used only for distractive purposes.

#### 4.2.5. Data and statistical analysis

The criteria for success of this pilot was based on the primary feasibility objective (adherence to the exercise plan), and methodological standards for being adherent to training. A 75% attendance rate for the training sessions was set as the definition for being adherent to the training program [34]. A total of 24 training sessions was scheduled for each individual in the IG.

Force platform data was analyzed with a program written in MATLAB R2011a (Math Works Inc., Cambridge, MA) to identify the following time points for each trial: tap cue, response initiation (INI), foot off, and foot contact (*Figure 4.2 b*). These time points relate to the definitions provided by Melzer et al [32,35]. Tap cue on the heel was detected as a spike greater than three standard deviations from the average baseline noise in the anterior-posterior direction of the ground force data. INI was defined as the first medio-lateral deviation of center of pressure toward the stance leg (greater than 4 mm away from the average baseline noise after the tap cue). Foot off was defined as a sudden change of the center of pressure slope toward the stance leg in the medio-lateral direction. Foot contact corresponds to the time when loading of the vertical ground reaction force on the target force platform reaches more than 1% of a subject's body weight.

Statistical computations were carried out with SPSS 19 for a per-protocol strategy of analysis in which only those subjects who adhered to the training counted toward the final results. An average value for each temporal parameter in each stepping direction and for both task conditions (single task and dual task) was calculated. A comparison at baseline



was undertaken using a Mann-Whitney  $U$  test and a chi-squared test for dichotomous variables. Due to non-normality of the data, a Mann-Whitney  $U$  test was used to estimate group interaction effects in the form of between-groups differences, i.e., IG and CG after the twelve-week time period. For this purpose, the difference of the values pre and post intervention for each subject were calculated and then compared. The effect size,  $r$ , was calculated as  $r = Z/\sqrt{N}$  (where  $Z$  is the approximation of the observed difference in terms of the standard normal distribution and  $N$  is the total number of samples;  $r = 0.1$ , small effect;  $r = 0.3$ , medium effect; and  $r = 0.5$ , large effect). A Wilcoxon signed rank test was used to compare inner-group pre/post data. The significance level was set at  $p \leq 0.05$ . A trend to significance was defined as  $0.10 \leq p > 0.05$ .

**Table 4.2** Demographic baseline data of participants

Group	Intervention group	Control group
No of participants	9	6
Age (mean, SD)	83.6, 3.4	86.2, 4.8
Sex (female/male)	6/3	3/3
Height in cm (mean, SD)	160.3, 9.9	160.9, 9.4
Weight in kg (mean, SD)	68.0, 17.5	65.5, 9.4
Mini-mental status <sup>a</sup> (median, range)	28, 27–30	25.2, 22–29
Walking assistance		
None/cane or crutches	5/4	5/1
Number of falls in the last 6 months <sup>b</sup>		
None	7	4
One	1	1
>One	1	1
Diabetes	0	1
Hypertension	2	3
Cardiac insufficiency	3	1
Arthropathy	5	1
Osteoporosis	4	2

Notes: <sup>a</sup> Minimum score = 0, maximum score = 30 (higher scores indicate better functioning); <sup>b</sup> A fall was defined as an event, which results in a person coming to rest on the ground or other lower level [33]

Abbreviation: SD, standard deviation

### 4.3 Results

A flow chart (*Figure 4.3*) provides detailed information on the subjects included in this study and on the subjects lost during the intervention phase. Demographic data is summarized in Table 4.2. The participants were willing to be randomized. Neither subjective nor objective side effects related to the used intervention were reported. There were no significant differences at baseline in either demographic data or temporal measurements of the voluntary step execution test between the groups.

The average exercise program compliance was 86.9% (20.8 out of 24 sessions). Two participants achieved a compliance of only 71% (17 out of 24) and 42% (10 out of 24), respectively. As we expected the participants to attend at least 75% of the exercise sessions, they were not considered for the analyses.

Temporal data of the voluntary step execution task is summarized in Table 4.3. Compared to the baseline data, the IG showed an overall time reduction of -17.9% in all assessed temporal parameters after the training program (single task condition: -15.7%; dual task condition: -20.1%). In comparison, the CG showed an increase in time of +1.3% in all assessed temporal parameters (single task condition: +1.5%; dual task condition: -4.1%). Data for the dual task condition showed longer times for each of the three examined temporal parameters under dual task conditions compared to single task conditions for all step directions in both groups (IG: +42.7%; CG: +30.0%).

Between-group comparison revealed significant differences for INI of forward steps under dual task conditions ( $U = 9, p = 0.034, r = 0.55$ ) and for backward steps under dual task conditions ( $U = 10, p = 0.045, r = 0.52$ ) in favor of the IG.

Inner-group comparisons resulted in step directions with significance and step directions with a trend to significance in pre/post-differences in the IG for INI, foot off, and foot contact (*Table 4.3*). There were no changes detectable for the CG for the inner-group comparisons.

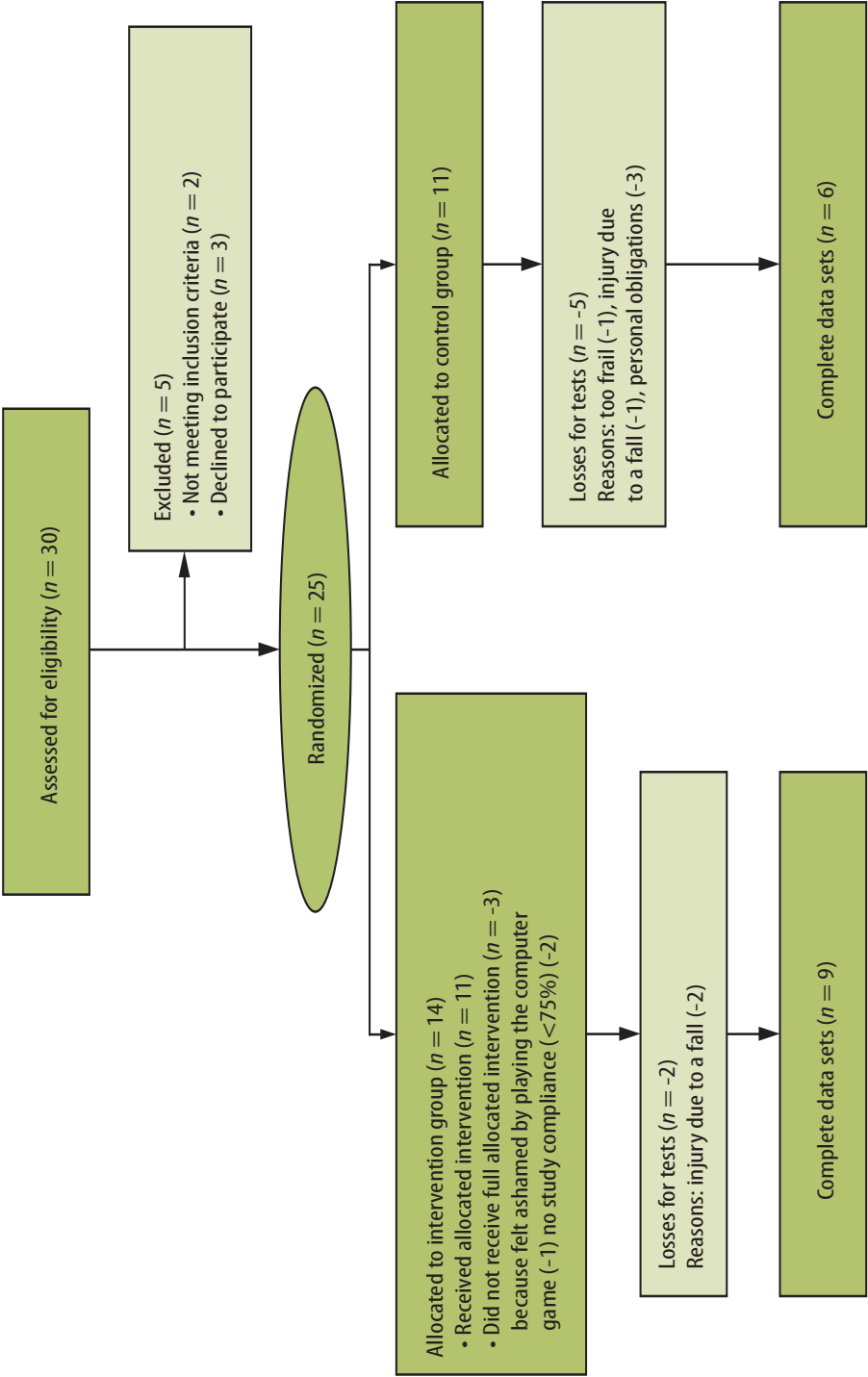


Figure 4.3 The study flow chart

Table 4.3 Temporal data in seconds and statistical evaluation of the voluntary step execution test

Temporal Parameters	Intervention group (n = 9)			Control group (n = 6)			$r$
	Pre	Post	$p_{\text{inner}}$	Pre	Post	$p_{\text{inner}}$	
<b>Initiation</b>							
Forward ST	0.162 (0.144; 0.253)	0.163 (0.143; 0.186)	0.260	0.190 (0.174; 0.213)	0.180 (0.166; 0.194)	0.249	0.906
Forward DT	0.301 (0.269; 0.496)	0.265 (0.195; 0.404)	0.051°	0.259 (0.196; 0.335)	0.291 (0.247; 0.355)	0.600	<b>0.034+</b>
Backward ST	0.197 (0.144; 0.208)	0.168 (0.138; 0.201)	0.066°	0.175 (0.174; 0.190)	0.170 (0.149; 0.185)	0.345	0.637
Backward DT	0.273 (0.219; 0.392)	0.265 (0.204; 0.323)	0.110	0.241 (0.214; 0.363)	0.248 (0.209; 0.359)	0.600	0.289
Sideway ST	0.179 (0.148; 0.197)	0.161 (0.147; 0.181)	0.173	0.187 (0.171; 0.198)	0.195 (0.173; 0.212)	0.463	0.289
Sideway DT	0.272 (0.192; 0.360)	0.261 (0.244; 0.282)	0.374	0.259 (0.205; 0.410)	0.278 (0.211; 0.413)	0.753	0.480
<b>Foot off</b>							
Forward ST	0.489 (0.438; 0.986)	0.437 (0.391; 0.618)	<b>0.015*</b>	0.602 (0.505; 0.777)	0.611 (0.483; 0.744)	0.345	0.239
Forward DT	0.716 (0.652; 0.879)	0.603 (0.530; 0.776)	<b>0.028*</b>	0.897 (0.586; 0.934)	0.709 (0.614; 0.890)	0.345	0.346
Backward ST	0.538 (0.409; 0.838)	0.445 (0.387; 0.605)	<b>0.028*</b>	0.629 (0.588; 0.661)	0.577 (0.487; 0.632)	0.345	0.724
Backward DT	0.723 (0.570; 1.155)	0.644 (0.556; 0.800)	0.066°	0.782 (0.583; 0.847)	0.683 (0.575; 0.830)	0.917	0.157
Sideway ST	0.431 (0.298; 0.645)	0.338 (0.289; 0.541)	0.051°	0.461 (0.396; 0.545)	0.468 (0.406; 0.522)	0.917	0.239
Sideway DT	0.615 (0.492; 0.879)	0.560 (0.506; 0.631)	0.260	0.733 (0.465; 0.852)	0.612 (0.504; 0.717)	0.249	1.000
<b>Foot contact</b>							
Forward ST	0.836 (0.674; 1.576)	0.676 (0.627; 1.057)	<b>0.015*</b>	0.906 (0.813; 1.122)	0.975 (0.717; 1.151)	0.600	0.157
Forward DT	1.163 (0.890; 1.245)	0.799 (0.765; 1.256)	<b>0.028*</b>	1.231 (0.899; 1.296)	0.989 (0.906; 1.195)	0.345	0.346
Backward ST	0.782 (0.662; 1.246)	0.738 (0.641; 1.056)	0.066°	0.966 (0.727; 1.083)	0.894 (0.789; 1.110)	0.917	0.480
Backward DT	1.045 (0.925; 1.523)	0.918 (0.843; 1.158)	0.086°	0.966 (0.727; 1.083)	1.113 (0.984; 1.360)	0.176	<b>0.045+</b>
Sideway ST	0.941 (0.510; 1.110)	0.619 (0.497; 0.911)	0.051°	0.820 (0.743; 0.901)	1.113 (0.984; 1.360)	0.917	0.556
Sideway DT	0.883 (0.685; 1.344)	0.989 (0.760; 1.058)	0.859	1.039 (0.786; 1.313)	0.991 (0.780; 1.101)	0.463	0.906

Notes: Values are in seconds and displayed as group medians with interquartile ranges (q1; q3) due to non-normal distribution of data. \* Significant inner-group differences pre-post ( $p_{\text{inner}} \leq 0.05$ ) calculated with Wilcoxon signed rank test; ° Trend to significance ( $p_{\text{inner}} \leq 0.10$ ); + Significant between-group differences after intervention phase ( $p_{\text{between}} \leq 0.05$ ) calculated with Mann-Whitney U test. Abbreviations:  $p_{\text{inner}}$ ,  $p$ -value for between-groups comparison;  $p_{\text{between}}$ ,  $p$ -value for inner-group comparison; DT, dual task;  $r$ , effect size ( $r = 0.1$ : small effect;  $r = 0.3$ : medium effect;  $r = 0.5$ : large effect); ST, single task.

#### 4.4 Discussion

The present pilot study aimed to develop and test a multimodal exercise intervention and to deliver it to individuals living in care homes. The main focus was to evaluate the feasibility of the multimodal intervention as a whole and the ability to recruit and retain elderly subjects, as well as to assess the effects of the intervention. This study showed that a cognitive-motor training program containing strength, balance, and computerized cognitive training components is feasible and is able to improve voluntary step execution under single task and dual task test conditions in older adults living in care homes. We demonstrated the feasibility of acquiring acceptable compliance rates for care home dwelling older people randomized to control and experimental training groups.

Our target of 75% compliance for this 12-week pilot project was attained. Two individuals had a less than 75% attendance rate and were considered non-compliant for the training. This non-compliance was mainly attributable to permanent sickness and low motivation that prevented program adherence. Thus, compliance with the exercise interventions and retesting was excellent. Adherence for group-based exercises could be expected to be between 72% and 88% [34]. Our intervention is in the higher range of adherence for group-based exercise. However, where we report on values after three training months, Nyman and Victor [34] report values that may be expected by 12 months. In a future phase III trial, the follow-up period for the assessment of adherence and attrition should, therefore, preferably be extended to a similar time frame to facilitate comparability of this future study with reference values.

To our knowledge this is the first intervention study that demonstrates temporal improvements in voluntary step execution under dual task conditions in older adults. This study confirms previous findings that showed improvements in dual task motor performance after an exercise program that included additional dance video gaming [17]. Although in previous literature, the deficiency of older adults in making rapid voluntary steps under dual task conditions is well documented, there is still a lack of studies aiming to improve the performance of voluntary step execution of older adults, specifically under attention-demanding circumstances. The deficiency of coping with attention-

demanding situations is well illustrated by the temporal delay of step execution in the dual task condition of the voluntary step execution test used in this study. In line with previous reports [29], we observed a temporal delay in step responses for all participants, regardless of group allocation, under the influence of a concurrent cognitive task.

In the dance video game, subjects were expected to observe the virtual environment for drifting arrows and initiate dance steps at the same time. When using an outward step, participants needed to rapidly unload the leg they were falling toward to allow them to take a step. This may be challenging from a cognitive, reaction time, and/or muscle power generation perspective [36]. The crucial point is that dance video gaming not only requires well-coordinated leg movements, but also requires cognitive work, e.g., sensing of stimuli, paying attention, and making quick decisions [14].

The fact that this intervention had an impact on the initiation of the step response is important since step or gait initiation is frequently repeated during daily activities, leading to accidental falls during the step initiation phase in people with deficits in balance control [37]. Important mechanisms for step initiation are the anticipatory postural adjustments (APAs). The function of APAs is to prepare the body for the imminent movement and possible changes in balance as a direct result of the movement caused by moving the body center of mass toward the stance limb [38]. Falls during initiation of a step could occur when the APAs are not performed efficiently enough prior to the unloading of the swing leg, causing an unstable postural condition [4]. These mechanisms are complex and require efficient peripheral sensory detection and afferent nerve conduction, followed by central neural processing and efferent nerve conduction [29,39]. It is hypothesized that these mechanisms are repeatedly trained by the use of a dance video game. Every step on a dance pad has to be planned and executed with the proper timing while focusing attention on the arrows on the screen.

Since our dance video game was based on the correct timing of the steps and not on the maximal speed generation of the leg, we hypothesized that improvements in step execution would be accountable in large part to the more efficient intramuscular interplay, induced as well by the strength and balance training. The finding that a large

part of the improvements in voluntary step execution seems to be attributable to the earlier execution of APA movements during the initiation phase was somewhat surprising.

This leads to the question of whether the improvements we observed are attributable to peripheral or to central adaptations. It is known that the supplementary motor area contributes to the timing of the APAs during step initiation [40]. It would be interesting to examine whether our cognitive-motor intervention has an influence on the activity of the supplementary motor area in a future study to clarify this observation.

#### **4.4.1. Related work**

There are some reports on the use and effects of similar virtual reality training in various populations. Methods using immersive computer technologies resulted in improved motor functions of the upper extremities and a cortical activation after virtual reality intervention in patients with chronic stroke [41]. Older adults benefited from training in terms of improved functional abilities, postural control, and simple auditory reaction times under dual task conditions [42]. Functional balance and dual task reaction times in older adults are improved by virtual reality and biofeedback training. A virtual rehabilitation program with the help of a semi-immersive virtual reality workbench, in a non-hospital environment, resulted in qualitatively improved manual trajectories and increased movement velocity of the trained upper extremities for patients with stroke, but without any transfer to real-life activities [43]. A virtual reality based treadmill intervention conducted by Yang et al [44] showed improved walking speed and walking ability at post-training in patients with stroke. Preliminary evidence for clinical effectiveness of virtual reality obstacle training post stroke has been reported by Jaffe et al [45].

Although it seems more intuitive that more immersive virtual environments are to be preferred for motor training, this may not actually be the case [46]. Less immersive desktop or wall screen displays can be used for this purpose as well [14] and have the advantage that no studies that used these two dimensional displays have been associated with incidence of cyber-sickness [46].

### **4.4.2. Limitations**

Several limitations of this work should be discussed. Surely the fact that step direction and the swing leg in the voluntary step execution test were known prior to the step execution could possibly have influenced the initiation of the step. An impact on the generation of APAs cannot be excluded since the subjects may try to lean on the supporting leg prior to the tap cue. However, the subjects of the CG had the same conditions and showed different reactions. Furthermore, we attempted to control for this potential disruptive factor through careful observation of the center of pressure on the verge of the tap cue. The point of application of the tap cue itself might be a limitation of the assessment protocol. A trip stimulus under real life conditions would be expected on the front of the foot and not the heel, and therefore, giving tap cues on the foot front might result in different reactions. Another limitation was the rather small sample size.

This pilot study, therefore, only reveals first estimates for the measures of a consecutive phase III study. This is an inherent property of a pilot study, and our findings warrant further research in a larger phase III main study that includes a larger sample and clinically relevant outcome measures. Differences regarding training intensities between the groups were another limitation. Future studies with larger sample sizes are needed, which compare training groups that achieve similar amounts of strength and balance training and where one group receives additional game-like training. For a more substantial study, monitoring the occurrence of falls post intervention is also recommended.

### **4.4.3. Future directions**

The IG trained 60 minutes twice weekly for 12 weeks and the CG received the usual care. It was thus expected that we would observe a difference in the development between the two groups since it seemed obvious that the difference in the amount of training would be the explanatory factor for the observed differences in the voluntary step execution test. We did not expect an effect for usual care because it did not comply with training recommendations to improve physical functions to prevent falls in the elderly [47]. Therefore, future studies should compare training groups that achieve similar amounts



of strength and balance training, where the intervention group receives an additional computerized cognitive component and the control group a placebo. In this case, we expect, however, only marginal effects on voluntary step performance under dual task conditions from the control group. The results of previous studies with similar groups that performed progressive, machine-driven, resistance training complemented with functional balance exercises revealed no improvement of performance under attention-demanding circumstances [48,49].

In future studies, to clarify the additional influence of the dance video game on the subjects in the IG, we should consider a study design with a control group that would perform the strength and balance exercises without the additional dance video gaming. Currently, we are performing such a trial registered under ISRCTN05350123 ([www.controlled-trials.com](http://www.controlled-trials.com)). In this study, however, we wanted to demonstrate the "proof of concept" of the effect of a cognitive-motor intervention compared to usual care in care homes in a pilot study.

#### **4.5. Conclusion**

We conclude that pilot studies with explicit feasibility objectives are important foundation steps in preparing for large trials. Ongoing formal review of the multifaceted issues inherent in the design and conduct of pilot studies can provide invaluable feasibility and scientific data for rehabilitation specialists, e.g., physiotherapists, and may also be highly relevant for furthering the development of theory based rehabilitation. For older adults, the ability to take a quick step to prevent a fall is crucial, especially under attention-demanding circumstances. We could demonstrate that a cognitive-motor intervention based on strength and balance exercises with the addition of dance video gaming is able to improve voluntary step execution under both single and dual task conditions in older adults. The trainees were able to quicken step initiation and total step completion time.

This study may constitute a reference for further studies in the topic of fall prevention in older adults with the aim to improve physical performance under dual

task conditions. This study encourages the further development of this intervention, preferably with a randomized control design and a larger sample. The application in a main study is deemed feasible with no need for protocol modifications.

### **Acknowledgments**

A special thank goes to Turgut Gülay, research assistant at the Institute of Biomechanics, for the assistance during the voluntary step execution test. We would also like to thank Angela Naegeli and Amos Coppe for supervising the training program and Eva van het Reve and Andrea Schärli for their help during the voluntary step execution test.

### **Authors' contributions**

Conception and design: GP, EDdB, AC; manuscript drafting: GP, EDdB; critical revision of manuscript for its content and approval of final version: GP, EDdB, AC, SL, KM.

### **Disclosure**

The authors report no conflicts of interest in this work.

## References

1. Maki BE, McIlroy WE. Control of rapid limb movements for balance recovery: age related changes and implications for fall prevention. *Age Ageing*. 2006;35 Suppl 2:ii12-ii18.
2. Inglin B, Woollacott M. Age-related changes in anticipatory postural adjustments associated with arm movements. *J Gerontol*. 1988;43(4): M105-M113.
3. Rogers MW, Kukulka CG, Brunt D, Cain TD, Hanke TA. The influence of stimulus cue on the initiation of stepping in young and older adults. *Arch Phys Med Rehabil*. 2001;82(5):619-624.
4. Rapp K, Becker C, Cameron ID, Konig HH, Buchele G. Epidemiology of falls in residential aged care: analysis of more than 70,000 falls from residents of bavarian nursing homes. *J Am Med Dir Assoc*. 2012;13(2): e181-e186.
5. Rogers MW, Johnson ME, Martinez KM, Mille ML, Hedman LD. Step training improves the speed of voluntary step initiation in aging. *J Gerontol A Biol Sci Med Sci*. 2003;58(1):46-51.
6. Shumway-Cook A, Woollacott M. Attentional demands and postural control: the effect of sensory context. *J Gerontol A Biol Sci Med Sci*. 2000;55(1):M10-M16.
7. Brauer SG, Woollacott M, Shumway-Cook A. The influence of a concurrent cognitive task on the compensatory stepping response to a perturbation in balance-impaired and healthy elders. *Gait Posture*. 2002;15(1):83-93.
8. Lajoie Y, Teasdale N, Bard C, Fleury M. Attentional demands for static and dynamic equilibrium. *Exp Brain Res*. 1993;97(1):139-144.
9. Nnodim JO, Strasburg D, Nabozny M, et al. Dynamic balance and stepping versus tai chi training to improve balance and stepping in at-risk older adults. *J Am Geriatr Soc*. 2006;54(12):1825-1831.
10. Melzer I, Marx R, Kurz I. Regular exercise in the elderly is effective to preserve the speed of voluntary stepping under single-task condition but not under dual-task condition. A case-control study. *Gerontology*. 2009;55(1):49-57.
11. Wong AMK, Pei Y-C, Lan C, Huang S-C, Lin Y-C, Chou S-W. Is Tai Chi Chuan effective

- in improving lower limb response time to prevent backward falls in the elderly? *Age (Dordr)*. 2009;31(2):163-170.
12. Marigold DS, Eng JJ, Dawson AS, Inglis JT, Harris JE, Gylfadottir S. Exercise leads to faster postural reflexes, improved balance and mobility, and fewer falls in older persons with chronic stroke. *J Am Geriatr Soc*. 2005;53(3):416-423.
  13. Pichierri G, Wolf P, Murer K, de Bruin ED. Cognitive and cognitive-motor interventions affecting physical functioning: a systematic review. *BMC Geriatr*. 2011;11:29.
  14. 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;43(4):229-234.
  15. Smith ST, Sherrington C, Studenski S, Schoene D, Lord SR. A novel Dance Dance Revolution (DDR) system for in-home training of stepping ability: basic parameters of system use by older adults. *Br J Sports Med*. 2011;45(5):441-445.
  16. Studenski S, Perera S, Hile E, Keller V, Spadola-Bogard J, Garcia J. Interactive video dance games for healthy older adults. *J Nutr Health Aging*. 2010;14(10):850-852.
  17. de Bruin ED, Reith A, Dörflinger M, Murer K (2011) Feasibility of Strength-Balance Training Extended with Computer Game Dancing in Older People; Does it Affect Dual Task Costs of Walking?. *J Nov Physiother* 1:104. Accessible at <http://www.omicsgroup.org/journals/2165-7025/2165-7025-1-104.php?aid=3350>
  18. Thabane L, Ma J, Chu R, et al. A tutorial on pilot studies: the what, why and how. *BMC Med Res Methodol*. 2010;10:1.
  19. Craig P, Dieppe P, Macintyre S, Michie S, Nazareth I, Petticrew M. Developing and evaluating complex interventions: the new Medical Research Council guidance. *BMJ*. 2008;337:a1655.
  20. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res*. 1975;12(3):189-198.
  21. Kraemer WJ, Adams K, Cafarelli E, et al. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc*. 2002;34(2):364-380.

22. Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, et al. American College of Sports Medicine position stand. Exercise and physical activity for older adults. *Med Sci Sports Exerc.* 2009;41(7):1510-1530.
23. Paterson DH, Jones GR, Rice CL. Ageing and physical activity: evidence to develop exercise recommendations for older adults. *Can J Public Health.* 2007;98 Suppl 2:S69-S108.
24. Estabrooks PA, Carron AV. Group cohesion in older adult exercisers: prediction and intervention effects. *J Behav Med.* 1999;22(6): 575-588.
25. Borg G. *Borg's Perceived Exertion and Pain Scales.* Champaign, IL: Human Kinetics; 1998.
26. de Bruin ED, Murer K. Effect of additional functional exercises on balance in elderly people. *Clin Rehabil.* 2007;21(2):112-121.
27. O'Keeffe K. *Dancing Monkeys (Automated creation of step files for Dance Dance Revolution).* <http://monket.net/files/dancingmonkeys/DancingMonkeys.pdf>. Accessed May 31, 2012. Imperial College London; 2003.
28. de Bruin E, Spence J, Hartman M, Murer K. Physical activity recommendations and programmes offered in Swiss residential settings. *Physio Science.* 2008;4(4):154-162.
29. Melzer I, Oddsson LIE. The effect of a cognitive task on voluntary step execution in healthy elderly and young individuals. *J Am Geriatr Soc.* 2004;52(8):1255-1262.
30. Stroop J. Studies of interference in serial verbal reactions. *Journal of Experimental Psychology.* 1935; 18: 643-662.
31. Van der Elst W, Van Boxtel M, Van Breukelen G, Jolles J. The Stroop Color-Word Test - Influence of Age, Sex, and Education; and Normative Data for a Large Sample Across the Adult Age Range. *Assessment.* 2006; 13: 62-79.
32. Melzer I, Kurz I, Shahar D, Levi M, Oddsson L. Application of the voluntary step execution test to identify elderly fallers. *Age Ageing.* 2007;36(5):532-537.
33. The Kellogg International Work Group on the Prevention of Falls by the Elderly. The prevention of falls in later life. A report. *Danish medical bulletin.* 1987; 34 Suppl 4: 1-24.
34. Nyman SR, Victor CR. Older people's recruitment, sustained participation, and adherence to falls prevention interventions in institutional settings: a supplement

- to the Cochrane systematic review. *Age Ageing*. 2011;40(4):430-436.
35. Melzer I, Shtilman I, Rosenblatt N, Oddsson LI. Reliability of voluntary step execution behavior under single and dual task conditions. *J Neuroeng Rehabil*. 2007;4:16.
  36. Egerton T, Brauer SG, Cresswell AG. Changes in stepping response to lateral perturbations immediately following a single bout of physical activity. *Physiother Res Int*. 2010 [epub ahead of print.]
  37. Uemura K, Yamada M, Nagai K, Tanaka B, Mori S, Ichihashi N. Fear of falling is associated with prolonged anticipatory postural adjustment during gait initiation under dual-task conditions in older adults. *Gait Posture*. 2012;35(2):282-286.
  38. Maki BE, McIlroy WE. The role of limb movements in maintaining upright stance: the "change-in-support" strategy. *Phys Ther*. 1997;77(5): 488-507.
  39. Goble DJ, Coxon JP, Van Impe A, et al. Brain activity during ankle proprioceptive stimulation predicts balance performance in young and older adults. *J Neurosci*. 2011;31(45):16344-16352.
  40. Jacobs JV, Lou JS, Kraakevik JA, Horak FB. The supplementary motor area contributes to the timing of the anticipatory postural adjustment during step initiation in participants with and without Parkinson's disease. *Neuroscience*. 2009;164(2):877-885.
  41. Jang SH, You SH, Hallett M, et al. Cortical reorganization and associated functional motor recovery after virtual reality in patients with chronic stroke: an experimenter-blind preliminary study. *Arch Phys Med Rehabil*. 2005;86(11):2218-2223.
  42. Bisson E, Contant B, Sveistrup H, Lajoie Y. Functional balance and dual-task reaction times in older adults are improved by virtual reality and biofeedback training. *Cyberpsychol Behav*. 2007;10(1):16-23.
  43. Broeren J, Claesson L, Goude D, Rydmark M, Sunnerhagen KS. Virtual rehabilitation in an activity centre for community-dwelling persons with stroke. The possibilities of 3-dimensional computer games. *Cerebrovasc Dis*. 2008;26(3):289-296.
  44. Yang YR, Tsai MP, Chuang TY, Sung WH, Wang RY. Virtual reality-based training improves community ambulation in individuals with stroke: a randomized controlled trial. *Gait Posture*. 2008;28(2): 201-206.

45. Jaffe DL, Brown DA, Pierson-Carey CD, Buckley EL, Lew HL. Stepping over obstacles to improve walking in individuals with poststroke hemiplegia. *J Rehabil Res Dev.* 2004;41(3A):283-292.
46. Holden MK. Virtual environments for motor rehabilitation: review. *Cyberpsychol Behav.* 2005;8(3):187-211; discussion 212-219.
47. Sherrington C, Whitney JC, Lord SR, Herbert RD, Cumming RG, Close JC. Effective exercise for the prevention of falls: a systematic review and meta-analysis. *J Am Geriatr Soc.* Dec 2008;56(12):2234-2243.
48. Hartmann A, Murer K, de Bie RA, de Bruin ED. The effect of a foot gymnastic exercise programme on gait performance in older adults: a randomised controlled trial. *Disabil Rehabil.* 2009;31(25): 2101-2110.
49. Hartmann A, Murer K, de Bie RA, de Bruin ED. The effect of a training program combined with augmented afferent feedback from the feet using shoe insoles on gait performance and muscle power in older adults: a randomised controlled trial. *Disabil Rehabil.* 2010;32(9):755-764.





## **A cognitive-motor intervention using a dance video game to enhance foot placement accuracy and gait under dual task conditions in older adults: a randomized controlled trial**

**Pichierri G<sup>1</sup>, Murer K<sup>1</sup>, de Bruin ED<sup>1</sup>**

<sup>1</sup>Department Health Sciences and Technology (D-HEST),

Institute of Human Movement Sciences and Sport, ETH Zurich, Switzerland

published in *BMC Geriatrics* 2012, 12:74 ([www.biomedcentral.com/1471-2318/12/74](http://www.biomedcentral.com/1471-2318/12/74))

## Abstract

*Background:* Computer-based interventions have demonstrated consistent positive effects on various physical abilities in older adults. This study aims to compare two training groups that achieve similar amounts of strength and balance exercise where one group receives an intervention that includes additional dance video gaming. The aim is to investigate the different effects of the training programs on physical and psychological parameters in older adults.

*Methods:* Thirty-one participants (mean age  $\pm$  SD:  $86.2 \pm 4.6$  years), residents of two Swiss hostels for the aged, were randomly assigned to either the dance group ( $n = 15$ ) or the control group ( $n = 16$ ). The dance group absolved a twelve-week cognitive-motor exercise program twice weekly that comprised progressive strength and balance training supplemented with additional dance video gaming. The control group performed only the strength and balance exercises during this period. Outcome measures were foot placement accuracy, gait performance under single and dual task conditions, and falls efficacy.

*Results:* After the intervention between-group comparison revealed significant differences for gait velocity ( $U = 26, p = 0.041, r = 0.45$ ) and for single support time ( $U = 24, p = 0.029, r = 0.48$ ) during the fast walking dual task condition in favor of the dance group. No significant between-group differences were observed either in the foot placement accuracy test or in falls efficacy.

*Conclusions:* There was a significant interaction in favor of the dance video game group for improvements in step time. Significant improved fast walking performance under dual task conditions (velocity, double support time, step length) was observed for the dance video game group only. These findings suggest that in older adults a cognitive-motor intervention may result in more improved gait under dual task conditions in comparison to a traditional strength and balance exercise program.

*Trial registration:* This trial has been registered under ISRCTN05350123 ([www.controlled-trials.com](http://www.controlled-trials.com))

**Keywords:** *dual task, dance video game, gait, older adults, cognitive-motor intervention*

## 5.1. Background

In the growing population of older people falling is a common problem. Approximately 30% of older adults over 65 years of age, experience a fall each year [1–3]. Fall incidence is even higher (50%) in women aged 85 and above [4]. Individuals who require more time to initiate and execute a step to avoid a threat or to recover postural balance, either during walking or performing postural transitions, may be at greater risk for falling [5]. Similarly, variable spatio-temporal gait characteristics may increase this risk [2]. For safe walking the accuracy with which one places the foot on the walking surface is essential, especially in challenging environments. Decreased foot placement accuracy [6,7] together with an increased variability in spatio-temporal gait characteristics [8], and dual task deficits [9] are typical symptoms of the ageing process and constitute critical factors that compromise safe walking [10].

Common tasks of daily life such as walking are dependent on both sensorimotor processes and higher-level cognitive functions [9]. Thus, the accurate foot placement onto a footpath for instance, requires not only the appropriate planning and execution of the movement. It also requires visual scanning, the extraction of visual information from the environment, and cognitive skills related to so-called executive functioning processes [7,11,12]. The term executive functioning processes refers to a group of cognitive actions that include: dealing with novelty, planning and implementing strategies for performance, using feedback to adjust future responding, vigilance, and inhibiting task-irrelevant information [13]. There also is increasing evidence that an age-related decline in visuo-motor control contributes to deficiencies in foot placement control [14]. Suboptimal visual sampling strategies have been observed in older adults prone to falling when taught to step into a target location [7,14,15].

Exercise interventions that incorporate exercises to improve muscle strength and postural control have been often recommended for older adults [16]. However, with physical exercise alone the additional cognitive requirements of safe walking cannot be addressed. Two recent reviews discussed the interplay between physical functions and cognition [17,18]. Both brought out the importance to combine physical and cognitive

training into clinical practice to enable older adults to move safer in their physical environment. Especially computerized interventions seem to be promising for this purpose [17]. Thus, cognitive elements should be taken into account when designing an exercise regimen with the aim to preserve or improve walking skills in older adults [19,20]. Interventions should thereby focus on executive functioning processes [19], in particular on divided attention [21], and should provide physical activities with decision-making opportunities because these are believed to be able to facilitate the development of both physical performance and brain functions [22].

A simple and motivating way to incorporate a cognitive element into a physical exercise program is the use of interactive video games. Interactive video games seem to have the potential to train cognitive functions [23] such as executive functioning processes [24]. An interactive dance video game for example [25–27], requires the player to observe the virtual environment for drifting cues and to concurrently execute well-coordinated body movements, thus, challenging in particular divided attention skills. Previous dance video games studies have shown the feasibility, defined through recruitment, attrition and adherence to the exercise intervention [28], of this approach. Dance video games studies in senior living settings [26,27,29,30] or with post-menopausal women [31] have also shown that this approach is a safe, low-cost and motivating way to activate and ensure continuation of physical exercise in middle-aged and older adults. Further, positive contributions to self-reported balance confidence and mental health were observed [26,29].

The results of two pilot studies conducted in care home settings, have shown that the addition of dance video gaming may have a positive effect on relative dual task costs of walking [30] and gait initiation under attention-demanding circumstances [27] even in the oldest old (85 years and beyond). These latter two findings, however, should be interpreted with caution. In both studies the control group did not train but rather underwent usual care. To clarify the additional influence of the dance video game we should consider a study design with a control group performing the same strength and balance exercises, however, without the additional dance video gaming [27].

This study compares two training groups that achieve similar amounts of physical strength and balance exercise, where one group additionally performs dance video game training. The aim is to investigate the additional effects of the dance video game training on foot placement accuracy [7,15], gait under single and dual task conditions, and on fear of falling.

## **5.2. Methods**

### **5.2.1. Participants**

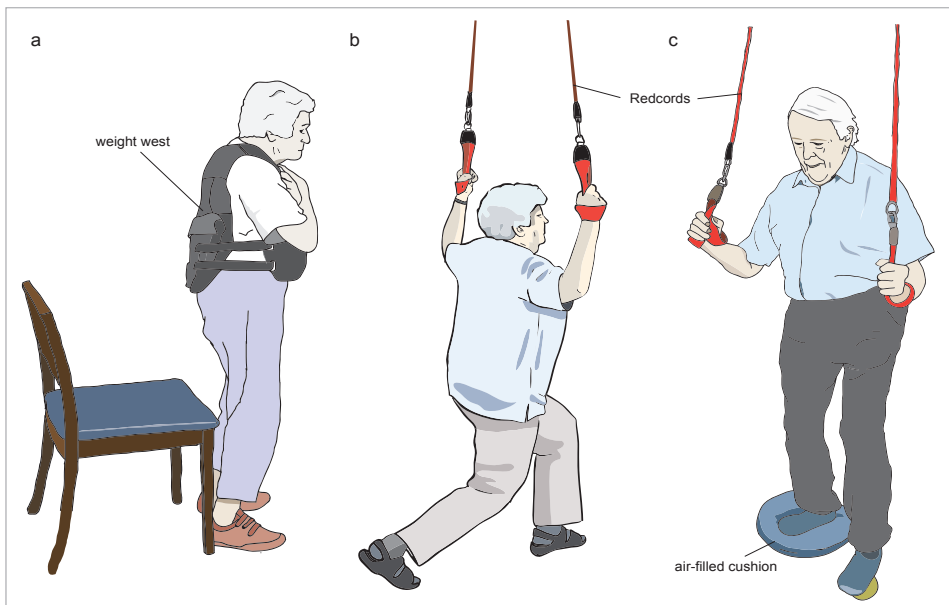
The study was designed as a prospective randomized controlled trial (*ISRCTN05350123*) and was carried out from June to September 2011. Participants were recruited from two hostels for the aged in the Canton of Zurich, Switzerland. The study protocol was approved by the local ethics committee (*KEK-ZH-NR 2011-0005/0*). All measurements and trainings were performed in suitable locations at the hostels.

The residents of both hostels were invited to attend an information session. Thirty-five (67.3%) out of 52 persons were interested in participating and were assessed for eligibility. Participants were included if they were older than 65 years, had a score of at least 22 points on the Mini-Mental State Examination (MMSE) [32], were able to walk for at least eight meters with or without the need for a walking aid, and were free of rapidly progressive or terminal illness, acute illness or unstable chronic illness. If unsure, subjects were asked to consult their primary care physician for medical clearance. They were excluded if a severe impairment of vision would impede to see projections on a wall screen as needed for the intervention.

Four interested persons were excluded from the study before the randomization process. One person changed his mind and declined to participate due to insufficient motivation. One person suffered from hernia inguinalis before the start of the study and two other persons were excluded for not fulfilling the inclusion criteria ( $MMSE < 22$ ). A total of 31 (59.6%) eligible residents signed informed consent statements and were randomly assigned to either the 'Dance group' (DG,  $n = 15$ ) or the 'Control group' (CG,  $n = 16$ ) using a random numbers table. Blinding of investigators was not possible because the investigators supervised and conducted the training sessions.

### 5.2.2. Intervention

The DG and the CG underwent a twice-weekly physical exercise program consisting of progressive resistance and postural balance training for twelve weeks. Intensity and duration of the program were chosen based on the guidelines published by the American College of Sports Medicine [33,34] and on a review by Paterson et al. describing exercise recommendations for older adults [35]. Training sessions were conducted in groups of three or four participants to form group cohesion and to encourage exercise class participation [36]. A training session lasted on average 40 minutes and consisted of a warm-up (5 minutes), resistance training (25 minutes), and balance exercises (10 minutes). In addition to the physical exercise program the DG performed a progressive video game dancing program for 10-15 minutes throughout the study ('cognitive-motor program'). When exercises required the participants to stand, they were requested to hold on to ropes fixed on the ceiling for safety reasons (*Figures 5.1 and 5.2*) (Redcord AS, Staubo, Norway).



**Figure 5. 1** Exercise examples from the physical exercise program: strength exercises (a) sit-to-stand, (b) squat; (c) balance exercise: subject rolls the ball back and forth or from the left to the right with the left foot while balancing on the air-filled cushion.

### 5.2.3. Physical exercise

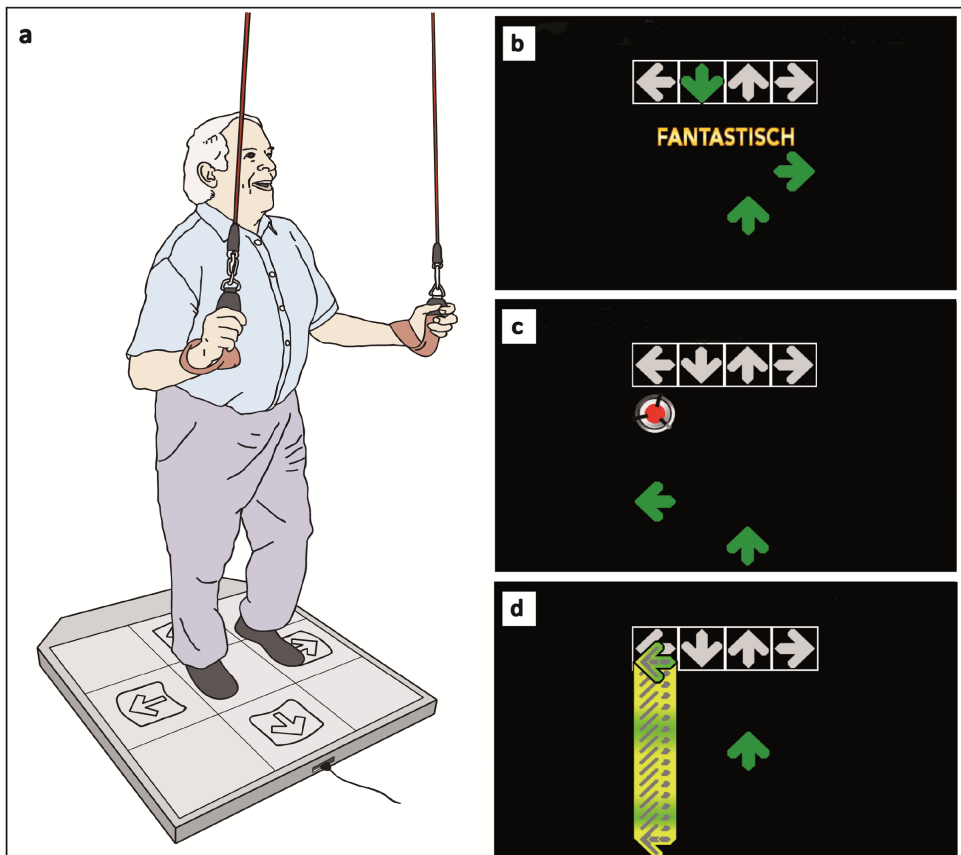
The progressive resistance training focused on the muscle groups of the core and lower extremities that are used in functional activities of daily living (*Figure 5.1 a–b*). Two sets of ten to 15 repetitions of each exercise in a slow, controlled manner were performed. One minute sitting breaks after each set and between the series were provided. Training intensity was controlled by perceived exertion and intensity between „somewhat hard“ and „hard (heavy)“ on Borg’s perceived exertion scale [37]. To maintain the intensity of the stimulus during the training period, the number of repetitions and the load were progressively increased with weight vests (Kettler GmbH & Co. KG, D-59469 Ense-Parsit), as tolerated by the participants.

The progressive postural balance program (*Figure 5.1 c*) consisted of static and dynamic functional balance exercises using air-filled cushions and grip balls (Ledraplastic S.p.a, I- 33010 Osoppo) [38]. A more detailed description of the program can be found elsewhere [38].

### 5.2.4. Cognitive-motor program

As an additional cognitive element the DG performed the dance video game after the physical exercise in every training session. The dance video game was performed on metal dance pads (*Figure 5.2 a*) (TX 6000 Metal DDR Platinum Pro, 93 x 14.7 x 109 cm, Mayflash Limited, Baoan Shenzhen, China) and with a specially designed modification of the StepMania (Version 3.9) free-ware [27,30]. The dance video game screen was projected on a white wall. A scrolling display of arrows moving upwards across the screen cued each move, and the participants were asked to execute the indicated steps (forward, backward, right, or left) when the arrows reached the fixed raster graphic at the top of the screen (*Figure 5.2 b–d*), and in time with different songs (32 to 137 beats per minute). In the first training session a tutorial sequence was provided to ensure understanding of the task. As the levels increased additional distracting visual cues, e.g., „bombs,“ were presented (*Figure 5.2 c*). Participants had to ignore these cues and keep their attention focused on the arrows. Occasionally,

some arrows were drawn-out on the target locations indicating that the trainees should remain for a while on the dance pad button on one leg (*Figure 5.2 d*). The arrow sequences were generated using the Dancing Monkey MATLAB script [39]. Electronic sensors in the dance pad detected position and timing information that was then used to provide participants with real-time visual feedback. For each training session, the participants performed for four songs of two to three minutes length each, with a short break of 30 seconds after each song. Progression of performance was controlled through the beats per minute and the difficulty level.



**Figure 5.2** Dance video game: (a) participant on the dance pad secured by ropes fixed on the ceiling; (b–d) screenshots of the dance video game



### 5.2.5. Baseline assessments of vision

To ensure that participants were free of vision impairments, which would have complicated the performance of the video game dancing part, participants' vision skills were assessed with the vision tests of the 'Physiological Profile Assessment' (PPA) [40,41]. Tests of edge contrast sensitivity ('Melbourne Edge Test'), and binocular dual-contrast visual acuity, were considered for assessing vision.

### 5.2.6. Test procedures and outcomes

The following tests were performed in the week before and in the week after the twelve weeks training period in suitable locations at the hostels.

#### 5.2.6.1. Foot placement accuracy test

Foot placement accuracy (FPA) was assessed with an adapted version of the protocol described by Chapman and Hollands in 2007 [7]. Subjects were instructed to walk at self-selected walking speed along a path with three different walking conditions: 'Condition 1' required placing the right foot into Target 1 (T1) (*Figure 5.3 a*); in 'Condition 2' subjects placed the right foot into T1 and the left foot into Target 2 (T2) (*Figure 5.3 b*); 'Condition 3' additionally required stepping over an obstacle placed between the two targets (*Figure 5.3 c*). The targets and the obstacle were made of soft foam material. The targets were rectangular (target area: 190 mm x 415 mm) and comprised a raised border (40 mm x 40 mm x 40 mm). Dimensions of the obstacle were 170 mm x 670 mm x 25 mm (height x length x depth). 170 mm corresponds to the ideal height of a staircase step as defined by the Federal Authorities of the Swiss Confederation. The subjects performed ten repetitions for each of the three walking conditions, resulting in a total of 30 trials per person. To prevent task familiarization within each condition, the target(s) appeared in two possible positions separated medio-laterally by 8 cm (*Figure 5.3 d*), an adaptation to the protocol based on the results of Young and Hollands [15]. Prior to the start of each trial subjects stood with their back against the walking path facing a wall to limit the amount of attention towards the pathway during the adjustments of the target position

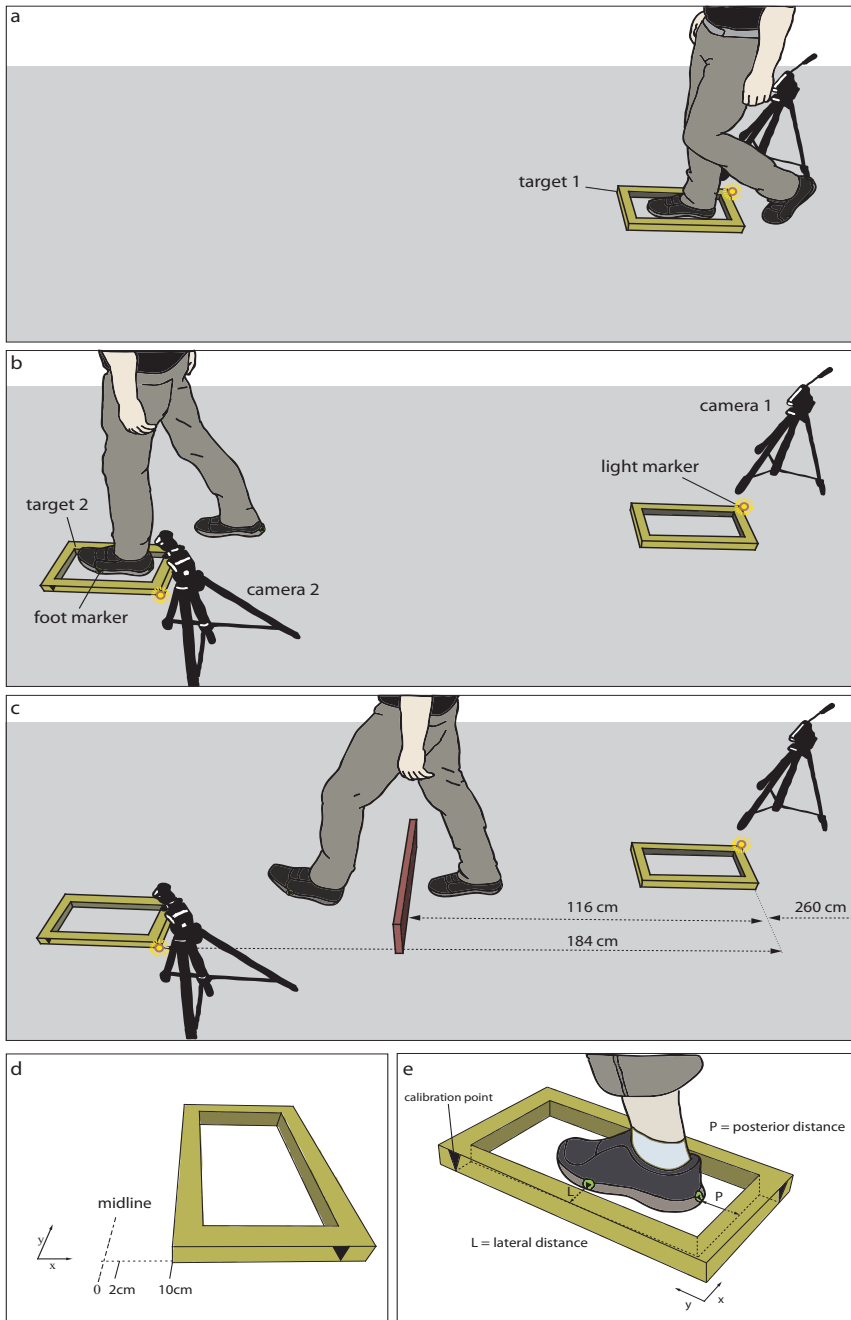
by the investigator. After a light cue, triggered by the investigator, subjects turned towards the walking path and began to walk from a labeled starting position over the path at a self-selected pace. Subjects were verbally instructed prior to each change of walking condition to place their foot as accurately as possible in the middle of the target area and were allowed to perform two rehearsal walks for each condition. The presentation of the target positions was randomized and of equal number for each condition. The presentation of the walking conditions was not randomized.

To assess participants' foot placement performance into the targets, adhesive labels were placed on both shoes on calcaneus level for anterior-posterior (A-P) distance assessment and on the level of the head of the fifth metatarsal for medio-lateral (M-L) assessment (*Figure 5.3 e*). During each trial the targets were recorded by two stationary video cameras (Contour HD 1080p) at a sampling rate of 30 Hz. A fixed image of the foot's stance phase into the target was then read into the analyzing software (Vicon Motus 9.2, Vicon Motion Systems, Oxford, UK). The foam targets were previously marked with two triangles (*Figure 5.3 e*), serving as calibration points to read in the dimensions and to determine spatial orientation of the target by the video analysis software.

The main outcome of the FPA test was the M-L and A-P deviation in mm of the foot center to the center of the foam target. Further, walking velocity between T1 and T2 and quality aspects of the performance during the FPA test were assessed. For the quality evaluation the number and percentage of contacts of the leading or the subsequent foot with the target, and the use of the wrong foot were assessed.

#### 5.2.6.2. Gait analysis

Spatio-temporal gait parameters were assessed with GAITRite® Platinum Version 4.0 software and the GAITRite® electronic walkway (CIR Systems, Havertown, USA) with a sampling rate of 60 Hz [42–44]. The GAITRite® with an active area of 7.92 meters length was extended with two 2.5 meters carpets at the beginning and at the end to eliminate the effects of acceleration or deceleration and to allow for steady state gait



**Figure 5.3** Set-up of the foot placement accuracy protocol. Subjects were required to walk along the pathway at self-selected pace and place the right foot into target 1 (Condition 1 (a)), place the right foot into target 1 and the left foot into target 2 (Condition 2 (b)), and additionally step over an obstacle lying between the two targets (Condition 3 (c)). The target(s) appeared in two possible positions separated medio-laterally by 8 cm to prevent task familiarization (d). Video still of camera 2 during stance phase used to evaluate the lateral and posterior distance error (e).

assessment. Subjects were instructed to walk over the electronic walkway under four different conditions: at self-selected comfortable walking speed (normal) and at a fast walking speed (fast, as fast as possible without running) each with or without a concurrent cognitive task (normalcog and fastcog), respectively. The additional cognitive task consisted in counting out loud backwards by steps of seven from a three-digit number given by the investigator at the start of each trial. For each walking condition three trials were collected, resulting in twelve walks per participant. Subjects were allowed to wear their everyday footwear.

The temporal-spatial parameters recorded were: velocity (cm/s), cadence (steps/min), step time (s), cycle time (s), stance time (s), single support time (s), double support time (s), and step length (cm). Relative dual task costs (DTC) of walking were calculated as percentage of loss relative to the single task walking performance, according to the formula  $DTC [\%] = 100 \times (\text{single task score} - \text{dual task score}) / \text{single task score}$  [45]. The effective DTC changes were defined as the mean difference between pre and post intervention ( $\Delta DTC$ ).

### *5.2.6.3. Gaze behavior*

ASL Mobile Eye, a head-mounted eye-tracking system (Applied Science Laboratories, Bedford, USA) was used to assess gaze behavior during the FPA test. Based on the observation that older adults prone to falling look away from a target location prior to heel contact on the floor [7], the temporal-spatial gaze parameters were defined as: a) location of gaze at heel contact (on/off target), b) the subsequent duration (milliseconds) of target fixation after heel contact, or in case of a premature gaze shift c) the time elapsed between the early gaze shift away from target and the heel contact (milliseconds). Gaze fixation was defined as a stabilization of gaze in the environment for longer than 120 milliseconds [7]. The light cue, serving as a start signal for the FPA test, was filmed by the eye-tracking camera and served as a marker for the synchronization of the eye-tracking camera with the stationary cameras pointed towards the targets.

### *5.2.6.4. Fear of falling*

The Falls Efficacy Scale International (FES-I) questionnaire was used as a measure of concern

about falling to determine the transfer effects of training to activities of daily living [46].

#### 5.2.6.5. Statistical methods

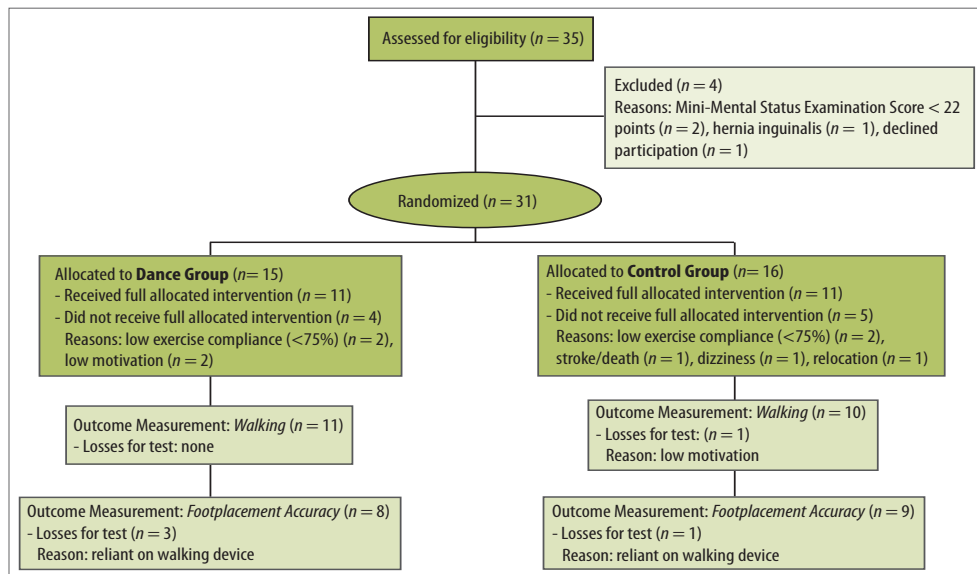
A 75% attendance rate for the training sessions was set as the definition for being adherent to the training program [47]. There were a total of 24 training sessions scheduled for each individual in the study. Only those subjects who adhered to the training counted towards the final results (per protocol analysis).

An average value of the M-L and A-P distance errors for each walking condition and target in the FPA test, as well as for each spatio-temporal gait parameter of the gait analysis for each walking condition, was calculated. Due to non-normality of the data a comparison at baseline was undertaken using a Mann-Whitney  $U$  test. The Mann-Whitney  $U$  test was also used to estimate group interaction effects (between-groups differences), after the twelve-week training period. For this purpose the difference of the values pre and post intervention for each subject were calculated and then compared. The effects size,  $r$ , was calculated as  $r = Z/\sqrt{N}$  (where  $Z$  is the approximation of the observed difference in terms of the standard normal distribution and  $N$  is the total number of samples;  $r = 0.1$ , small effect;  $r = 0.3$ , medium effect; and  $r = 0.5$ , large effect). A Wilcoxon signed rank test was used to compare within-group pre/post data. The significance level was set at  $p \leq 0.05$ . A trend to significance was defined as  $0.05 < p \leq 0.10$ . Statistical computations were carried out with SPSS 19.

### 5.3 Results

A total of 22 participants (mean  $\pm$  SD age:  $86.2 \pm 4.6$  years) received the full allocated intervention. Detailed information on subjects' recruitment and reasons for loss are presented in the flow chart (Figure 5.4). Table 5.1 shows demographic and clinical characteristics of the sample. Eleven (50%) subjects were classified as having a high risk for falling based on the presence of at least four of eight possible risk factors according to di Fabio et al. [48]. No significant differences at baseline, neither in demographic nor in the outcome measurements, were observed between the groups. No subject manifested a severe impairment of vision.

An average exercise compliance of 90.6% (21.7 out of 24 sessions) was observed. The DG showed a compliance of 94.7% (22.7 out of 24 sessions) whereas the CG visited 86.9% of the exercise sessions (20.8 out of 24 sessions).



**Figure 5.4** The Study Flow Chart

### 5.3.1 Foot placement accuracy

A summary of the FPA test is provided in Table 5.2. A more detailed illustration of the FPA test data with the single target locations and conditions is provided in Table 5.3. The data of 17 participants were collected.

Between-group comparisons (all conditions and targets) resulted in no significant differences of foot placement performance. Within-group comparison resulted in a significant improvement in M-L foot placement performance ( $Z = -1.960, p = 0.05$ ) in DG and no changes in the CG.

The detailed results of the FPA test performance in A-P directions demonstrate an increase in distance error for both the DG and CG. In Condition 3, for the CG even a significant increase in A-P distance error from 8.34 to 18.75 mm was observed ( $Z = -2.100, p = 0.036$ ).

Median walking velocity during the FPA test significantly increased in the DG in 'Condition 2' from 53.0 to 62.0 cm/s ( $Z = -2.371, p = 0.018$ ), and the between-group comparison revealed significant differences in favor of the DG ( $U = -2.122, p = 0.034, r = 0.51$ ).

**Table 5.1** Demographic baseline data of participants

Group	Dance group	Control group
No. of participants	11	11
Age (mean, SD)	86.9, 5.1	85.6, 4.2
Sex (female/male)	8/3	10/1
Height in cm (mean, SD)	159.1, 10.0	154.5, 10.1
Weight in kg (mean, SD)	68.3, 14.3	58.8, 13.1
Mini-Mental Status <sup>a</sup> (mean, SD)	27.2, 2.0	27.0, 2.6
<b>Vision</b>		
Vision aid (n / %)	5 / 45.4	4 / 36.4
Visual acuity <sup>b</sup> [MAR] (high / low contrast)	0.48 / 0.66	0.53 / 0.67
Melbourne Edge Test <sup>c</sup> [dB] (mode, range)	19, 9-21	19, 5-24
<b>Fall Risk factors<sup>d</sup> (n / %)</b>		
Low BMI (< 23)	1 / 9	5 / 4
Slow walking speed (< 1.22 m/s)	11 / 100	11 / 100
Previous falls requiring medical attention	none	none
Falls in the last 6 months	1 / 9	3 / 27
3 or more prescription medications	7 / 64	10 / 91
Cardiovascular medications	11 / 100	10 / 91
Anti-Anxiety medication or sedatives	3 / 27	3 / 27
Medication for dizziness	none	1 / 9
Categorized as 'Faller'	5 / 45	6 / 55

Notes: <sup>a</sup> Minimum score = 0, maximum score = 30 (higher scores indicate better cognitive functioning); <sup>b</sup>  $\log^{10}$  of the minimum angle resolvable (MAR) in minutes of arc ( $-\log^{10}$  (distance (3m)/lowest correct line)); <sup>c</sup> Minimum score = 1, maximum score = 24 (higher scores indicate better edge contrast sensitivity, 1dB =  $-10 \log^{10}$ ); <sup>d</sup> Di Fabio et al 2001 [48]; A fall was defined as an event, which results in a person coming to rest on the ground or other lower level.

Abbreviations: SD, standard deviation; arcmin, arcminute.

Table 5.2. Results of foot placement accuracy

	Dance group (n=8)		Control group (n=9)		$p_{\text{within}}$	$p_{\text{between}}$
	Pre	Post	Pre	Post		
<b>Distance errors [mm]</b>						
Medio-lateral error	13.4 (10.0; 15.3)	10.1 (8.8; 11.95)	<b>0.05*</b>	12.9 (9.9; 16.2)	10.1 (8.7; 15.7)	0.70
Anterior-posterior error	16.6 (14.9; 29.2)	21.2 (15.1; 28.7)	0.33	21.7 (17.2; 26.9)	24.4 (15.5; 30.7)	0.63
<b>Walking velocity [m/s]</b>						
Condition 2	0.53 (0.45; 0.67)	0.62 (0.57; 0.75)	<b>0.02*</b>	0.53 (0.41; 0.68)	0.49 (0.35; 0.58)	<b>0.03*</b>
Condition 3	0.42 (0.34; 0.43)	0.47 (0.45; 0.49)	0.37	0.33 (0.26; 0.60)	0.41 (0.24; 0.64)	1.00
<b>Quality evaluation (n, %)</b>						
Contact with leading foot						
medio-lateral	11 (2.8)	3 (0.8)		5 (1.1)	6 (1.3)	
anterior-posterior	17 (4.3)	8 (2.0)		21 (4.7)	10 (2.2)	
Contact with subsequent foot	16 (4.0)	14 (3.5)		14 (3.1)	16 (3.6)	
Wrong foot	2 (0.5)	2 (0.5)		5 (1.1)	2 (0.4)	

Notes: Distance error (absolute values) and walking velocity values are displayed as group medians with interquartile ranges (q1; q3) due to non-normal distribution of data. \* Significant within-group differences pre-post ( $p_{\text{within}} \leq 0.05$ ) calculated with Wilcoxon signed rank test. Percentage values are defined as the quotient between number of contacts or wrong foot, respectively, divided by the sum of trials of the whole group.

Abbreviations:  $p_{\text{within}}$ ,  $P$ -value for within-group comparison;  $p_{\text{between}}$ ,  $P$ -value for between-groups comparison.



Table 5.3 Detailed results of foot placement accuracy

Condition/Target	Dance group ( <i>n</i> =8)			Control group ( <i>n</i> =9)			
	Pre	Post	$p_{\text{within}}$	Pre	Post	$p_{\text{within}}$	$p_{\text{between}}$
Medio-lateral error [mm]							
C1/T1	15.00 (11.44; 17.33)	12.09 (8.95; 17.63)	0.48	12.96 (9.90; 16.71)	10.92 (8.72; 20.04)	0.86	0.77
C2/T1	12.27 (10.20; 14.74)	10.93 (8.92; 12.52)	0.21	11.72 (9.16; 16.69)	13.71 (10.20; 17.96)	0.31	0.15
C3/T1	10.42 (8.38; 15.20)	9.84 (8.50; 15.09)	0.58	11.00 (4.62; 17.86)	8.27 (6.78; 16.75)	1.00	1.00
C2/T2	13.51 (8.98; 20.10)	9.93 (5.65; 15.36)	0.07 <sup>a</sup>	12.52 (10.98; 20.16)	13.01 (8.37; 2.08)	0.72	0.39
C3/T2	12.97 (5.79; 16.00)	9.65 (6.78; 10.93)	0.16	9.62 (3.16; 17.14)	9.16 (6.78; 1.34)	0.48	0.29
Anterior-posterior error [mm]							
C1/T1	19.82 (12.78; 29.17)	19.59 (12.98; 26.44)	0.58	22.92 (17.22; 32.28)	21.40 (13.25; 34.01)	0.52	0.21
C2/T1	17.76 (12.77; 29.88)	22.32 (14.49; 31.21)	0.58	14.42 (10.21; 28.49)	23.55 (16.47; 30.18)	0.26	0.63
C3/T1	16.80 (14.88; 26.44)	27.86 (14.26; 39.72)	0.26	8.34 (3.58; 23.23)	18.75 (15.05; 26.88)	<b>0.04*</b>	0.77
C2/T2	22.85 (13.32; 28.90)	21.17 (15.15; 26.42)	0.67	18.60 (16.88; 34.12)	24.97 (18.37; 31.52)	0.86	0.63
C3/T2	16.56 (14.06; 27.15)	18.52 (13.49; 29.33)	0.40	19.84 (5.39; 21.51)	14.97 (11.53; 20.17)	0.89	0.56

Notes: Values are displayed as group medians with interquartile ranges (q1; q3) due to non-normal distribution of data. \* Significant within-group differences pre-post ( $p_{\text{within}} \leq 0.05$ ) calculated with Wilcoxon signed rank test; <sup>a</sup>Trend to significance ( $p_{\text{within}} \leq 0.10$ ).  
Abbreviations:  $p_{\text{within}}$ :  $p$ -value for within-group comparison;  $p_{\text{between}}$ :  $p$ -value for between-groups comparison; C1, C2, C3, Condition 1, 2, and 3; T1, T2, Target 1 and 2.

### 5.3.2 Gait analysis

The data of 21 subjects were collected for the gait analysis. The detailed results of the spatio-temporal gait analysis are summarized in Tables 5.4 and 5.5. Significant between-group differences were observed in the fastcog condition, where participants were required to walk as fast as possible with a concurrent cognitive task. The DG showed a significant increase in walking velocity ( $U = 26, p = 0.041, r = 0.45$ ), and a decrease in single support time ( $U = 24, p = 0.029, r = 0.48$ ) compared to the CG. The within-group comparison revealed significant walking performance improvements throughout all the walking conditions for the DG. In contrast, in the CG improvements in walking performance were only observable for the normal and normalcog conditions.

Table 5.5 summarizes the results of the DTC of walking analysis. Significant between-group differences for  $\Delta$ DTC were observed for the parameter single support time for both normal ( $U = 27, p = 0.049, r = 0.43$ ) and fast walking speed ( $U = 26, p = 0.041, r = 0.45$ ). Further, in the DG the  $\Delta$ DTC decreased throughout all parameters in both walking conditions from pre to post intervention. In contrast the CG demonstrated an increase in  $\Delta$ DTC values after the intervention when compared to baseline data.

### 5.3.3. Perceived fear of falling

The results of the FES-I questionnaire showed a reduction of concerns about falling in both groups. In the DG the mean value (mean, SD) was lowered from  $23.7 \pm 6.4$  to  $21.8 \pm 5.0$  and in the CG the mean value was reduced from  $24.5 \pm 4.2$  to  $19 \pm 4.1$ . Between-group comparison after the twelve-week regimen resulted in non-significant ( $U = 38, p = 0.134, r = 0.32$ ) differences.

### 5.3.4. Gaze behavior

Substantial losses of participants for the analysis of the eye-tracking data were documented. From the 17 participants who performed the FPA test only seven data sets were complete. Reasons for the losses were mainly attributable to problems with the handling of the eye tracking system. For the sake of completeness the gaze data is presented in Table 5.6 and not further referred to in the following section.

Table 5.4 Results of spatio-temporal gait analysis

Condition/Parameters	Dance Group (n=11)		Control Group (n=10)		$p_{\text{within}}$	$p_{\text{between}}$	$r$	
	Pre	Post	Pre	Post				
<b>normal</b>								
Velocity [cm/s]	80.4 (72.9; 89.1)	88.3 (69.2; 106.2)	0.248	69.0 (61.1; 82.7)	82.2 (73.8; 101.8)	0.059°	0.481	0.15
Cadence [steps/min]	95.5 (93.3; 102.5)	97.5 (96.0; 111.8)	<b>0.016*</b>	93.9 (80.2; 99.9)	104.2 (89.9; 112.3)	<b>0.022*</b>	0.260	0.25
Step time [s]	1.26 (1.17; 1.29)	0.62 (0.54; 0.63)	<b>0.016*</b>	0.64 (0.60; 0.75)	0.58 (0.54; 0.67)	<b>0.022*</b>	0.205	0.28
Cycle time [s]	0.63 (0.59; 0.64)	1.23 (1.07; 1.24)	<b>0.016*</b>	1.28 (1.20; 1.49)	1.15 (1.07; 1.34)	<b>0.022*</b>	0.217	0.27
Stance time [s]	0.82 (0.80; 0.86)	0.78 (0.72; 0.84)	<b>0.021*</b>	0.86 (0.78; 1.03)	0.75 (0.70; 0.92)	<b>0.037*</b>	0.191	0.29
Single support time [s]	0.42 (0.39; 0.44)	0.41 (0.36; 0.43)	<b>0.041*</b>	0.43 (0.41; 0.47)	0.39 (0.36; 0.43)	<b>0.013*</b>	0.095°	0.36°
Double support time [s]	0.41 (0.38; 0.43)	0.37 (0.31; 0.43)	0.062°	0.44 (0.37; 0.56)	0.36 (0.32; 0.49)	<b>0.047*</b>	0.259	0.25
Step length [cm]	50.7 (45.7; 53.0)	52.7 (42.6; 56.3)	0.477	46.6 (43.7; 52.2)	48.8 (46.0; 54.9)	0.203	0.725	0.08
<b>fast</b>								
Velocity [cm/s]	124.7 (89.9; 147.4)	132.7 (93.2; 149.8)	0.091°	112.1 (99.0; 124.0)	114.7 (99.6; 136.8)	0.285	0.778	0.06
Cadence [steps/min]	122.6 (113.8; 128.7)	127.1 (118.2; 134.5)	<b>0.033*</b>	118.2 (106.0; 129.1)	126.0 (105.7; 135.7)	0.203	0.888	0.03
Step time [s]	0.49 (0.47; 0.53)	0.47 (0.45; 0.51)	<b>0.050*</b>	0.51 (0.46; 0.57)	0.48 (0.44; 0.57)	0.139	0.972	0.01
Cycle time [s]	0.98 (0.93; 1.05)	0.94 (0.89; 1.02)	0.062	1.02 (0.93; 1.13)	0.96 (0.88; 1.13)	0.139	0.972	0.01
Stance time [s]	0.62 (0.58; 0.71)	0.60 (0.57; 0.66)	<b>0.041*</b>	0.65 (0.61; 0.72)	0.60 (0.55; 0.74)	0.169	0.944	0.02
Single support time [s]	0.37 (0.34; 0.38)	0.35 (0.32; 0.39)	0.170	0.38 (0.33; 0.39)	0.36 (0.33; 0.38)	0.169	0.669	0.09
Double support time [s]	0.25 (0.23; 0.33)	0.26 (0.22; 0.31)	0.131	0.30 (0.25; 0.32)	0.24 (0.22; 0.34)	0.203	0.804	0.05
Step length [cm]	58.4 (53.1; 66.7)	59.2 (50.5; 69.8)	0.594	56.0 (52.1; 61.0)	55.3 (50.4; 62.6)	0.575	0.549	0.13

Notes: Values are displayed as group medians with interquartile ranges (q1; q3) due to non-normal distribution of data. \* Significant within-group differences pre-post ( $p_{\text{within}} \leq 0.05$ ) calculated with Wilcoxon signed rank test; °Trend to significance ( $p_{\text{within}} \leq 0.10$ ). \* Significant between-group differences after intervention phase ( $p_{\text{between}} \leq 0.05$ ) calculated with Mann-Whitney U-test, °Trend to significance ( $p_{\text{between}} \leq 0.10$ ). Abbreviations:  $p_{\text{within}}$ ,  $p$ -value for inner-group comparison;  $p_{\text{between}}$ ,  $p$ -value for between-groups comparison;  $r$ , effect size ( $r = 0.1$ : small effect,  $r = 0.3$ : medium effect); normal, self-selected walking speed; fast, fast walking.

**Table 5.4** Results of spatio-temporal gait analysis (continued)

Condition/Parameters	Dance Group (n=11)			Control Group (n=10)			$p_{\text{between}}$	$r$
	Pre	Post	$p_{\text{within}}$	Pre	Post	$p_{\text{within}}$		
<b>normalcog</b>								
Velocity [cm/s]	65.4 (57.3; 87.4)	82.8 (60.0; 97.9)	<b>0.050*</b>	60.0 (51.7; 71.8)	63.2 (55.8; 84.4)	<b>0.028*</b>	0.673	0.09
Cadence [steps/min]	87.0 (82.4; 93.8)	101.0 (97.2; 103.3)	<b>0.026*</b>	82.7 (73.9; 100.9)	96.8 (74.5; 103.6)	0.139	0.481	0.15
Step time [s]	0.69 (0.64; 0.73)	0.60 (0.58; 0.62)	<b>0.013*</b>	0.73 (0.60; 0.84)	0.62 (0.58; 0.81)	0.074°	0.888	0.03
Cycle time [s]	1.39 (1.28; 1.45)	1.19 (1.17; 1.24)	<b>0.013*</b>	1.46 (1.19; 1.64)	1.24 (1.16; 1.61)	0.093°	0.573	0.12
Stance time [s]	0.94 (0.85; 0.99)	0.79 (0.75; 0.83)	<b>0.010*</b>	1.00 (0.78; 1.15)	0.81 (0.79; 1.08)	0.059°	0.672	0.09
Single support time [s]	0.45 (0.43; 0.47)	0.41 (0.39; 0.44)	<b>0.013*</b>	0.46 (0.40; 0.48)	0.43 (0.38; 0.50)	0.445	0.228	0.26
Double support time [s]	0.48 (0.41; 0.55)	0.39 (0.35; 0.41)	<b>0.016*</b>	0.55 (0.39; 0.67)	0.43 (0.39; 0.59)	0.059°	0.888	0.03
Step length [cm]	46.73 (40.3; 51.1)	50.5 (44.3; 56.6)	0.131	43.4 (37.5; 52.4)	46.3 (38.1; 54.6)	0.059°	0.751	0.07
<b>fastcog</b>								
Velocity [cm/s]	87.9 (68.6; 103.2)	107.5 (74.1; 115.6)	<b>0.013*</b>	80.1 (61.0; 100.0)	87.1 (59.0; 103.2)	0.386	<b>0.041*</b>	0.45+
Cadence [steps/min]	99.1 (94.8; 105.5)	109.7 (101.7; 117.4)	<b>0.006*</b>	91.8 (88.0; 108.8)	104.1 (76.7; 114.1)	0.445	0.057°	0.42+
Step time [s]	0.61 (0.57; 0.63)	0.55 (0.51; 0.59)	<b>0.006*</b>	0.65 (0.55; 0.68)	0.58 (0.53; 0.78)	0.799	0.062°	0.41+
Cycle time [s]	1.21 (1.14; 1.26)	1.09 (1.02; 1.19)	<b>0.006*</b>	1.31 (1.10; 1.37)	1.15 (1.05; 1.57)	0.799	0.091°	0.37+
Stance time [s]	0.78 (0.71; 0.84)	0.71 (0.64; 0.78)	<b>0.008*</b>	0.86 (0.72; 0.93)	0.76 (0.70; 1.03)	0.721	0.121	0.34+
Single support time [s]	0.43 (0.39; 0.43)	0.38 (0.37; 0.41)	<b>0.006*</b>	0.42 (0.38; 0.46)	0.39 (0.37; 0.50)	0.799	<b>0.029*</b>	0.48+
Double support time [s]	0.38 (0.32; 0.40)	0.32 (0.28; 0.37)	<b>0.013*</b>	0.39 (0.35; 0.51)	0.38 (0.31; 0.51)	0.646	0.260	0.25
Step length [cm]	53.0 (44.2; 58.8)	55.2 (44.8; 62.6)	0.170	50.7 (41.2; 57.8)	51.2 (38.6; 60.0)	0.333	0.324	0.22

Notes: Values are displayed as group medians with interquartile ranges (q1; q3) due to non-normal distribution of data. \* Significant within-group differences pre-post ( $p_{\text{within}} \leq 0.05$ ) calculated with Wilcoxon signed rank test; °Trend to significance ( $p_{\text{within}} \leq 0.10$ ). \* Significant between-group differences after intervention phase ( $p_{\text{between}} \leq 0.05$ ) calculated with Mann-Whitney U-test. ° Trend to significance ( $p_{\text{between}} \leq 0.10$ ). Abbreviations:  $p_{\text{within}}$ ,  $p$ -value for inner-group comparison;  $p_{\text{between}}$ ,  $p$ -value for between-groups comparison;  $r$ , effect size ( $r=0.1$ : small effect,  $r=0.3$ : medium effect); normal, self-selected walking speed; fast, fast walking; normal-cog, self-selected walking speed with additional cognitive task; fastcog, fast walking speed with additional cognitive task.

**Table 5.5** Results of dual task costs of walking analysis

Condition/Parameters	Dance Group (n=11)		Control Group (n=10)			r
	$\Delta$ DTC %	$p_{\text{within}}$	$\Delta$ DTC %	$p_{\text{within}}$	$p_{\text{between}}$	
<b>Normal walking speed</b>						
Velocity	- 8.22	0.16	+ 0.90	0.96	0.29	0.23
Cadence	- 4.92	0.13	+ 2.85	0.80	0.15	0.32 <sup>+</sup>
Step time	- 5.80	0.09 <sup>o</sup>	+ 2.00	0.88	0.25	0.27
Cycle time	- 5.68	0.09 <sup>o</sup>	+ 3.01	0.88	0.18	0.29
Stance time	- 6.69	0.11	+ 1.93	0.96	0.23	0.26
Single support time	- 3.60	0.06 <sup>o</sup>	+ 5.38	0.20	<b>0.05*</b>	0.43 <sup>+</sup>
Double support time	- 9.51	0.18	- 4.75	0.80	0.62	0.11
Step length	- 3.54	0.21	- 2.52	0.65	0.86	0.04
<b>Fast walking speed</b>						
Velocity	- 7.07	<b>0.04*</b>	- 3.05	0.88	0.29	0.23
Cadence	- 4.35	0.09 <sup>o</sup>	+ 0.62	0.72	0.16	0.31 <sup>+</sup>
Step time	- 6.27	0.08 <sup>o</sup>	+ 5.03	0.58	0.16	0.31 <sup>+</sup>
Cycle time	- 6.02	0.08 <sup>o</sup>	+ 4.74	0.58	0.16	0.31 <sup>+</sup>
Stance time	- 7.29	0.08 <sup>o</sup>	+ 5.36	0.58	0.16	0.31 <sup>+</sup>
Single support time	- 3.51	0.21	+ 4.18	0.51	<b>0.04*</b>	0.45 <sup>+</sup>
Double support time	- 13.42	<b>0.03*</b>	+ 9.23	0.33	0.18	0.29
Step length	- 3.73	<b>0.02*</b>	- 2.92	0.72	0.83	0.05

Notes: Dual task costs are illustrated as the percentage of the mean difference between pre and post intervention ( $\Delta$ DTC %), negative values represent a reduction of DTC, positive values represent an increase in DTC. \* Significant within-group differences pre-post ( $p_{\text{within}} \leq 0.05$ ) calculated with Wilcoxon signed rank test, <sup>o</sup> Trend to significance ( $p_{\text{within}} \leq 0.10$ ), \* Significant between-group differences after intervention phase ( $p_{\text{between}} \leq 0.05$ ) calculated with Mann-Whitney U-test, <sup>o</sup> Trend to significance ( $p_{\text{between}} \leq 0.10$ ). Abbreviations:  $p_{\text{within}}$ , p-value for within-group comparison;  $p_{\text{between}}$ , p-value for between-groups comparison; r, effect size ( $r = 0.1$ , small effect,  $r = 0.3$ , medium effect).

## 5.4. Discussion

This randomized controlled trial was designed to test whether a twelve-week strength and balance exercise regimen, that includes a dance video game as an additional cognitive element, would lead to greater changes in measures of gait performance and fear of falling, compared to strength and balance exercise alone. Although both groups attained improvements in gait performance and were able to reduce their concerns about falling, the results suggest positive interaction effects in favor of the dance video game group. The finding of this study supports the notion that it is advantageous to combine physical and cognitive training into clinical practice. The combination seems to have a positive

**Table 5.6** Results of gaze behavior assessment during FPA test

Subject	Group	Classification <sup>1</sup>	Gaze fixation [ms] Pre / Prost			Gaze on target at heel contact [%] Pre / Post				
			C1 - T1	C2 - T1	C3 - T1	C2 - T2	C3 - T2	C1	C2	C3
1	CG	faller	164 / -171	180 / 87	132 / 140	40 / 20	90 / 74	80 / 0	75 / 65	83 / 81
2	CG	faller	4 / 153	22 / 40	-72 / 24	472 / n.d.	416 / 232	50 / 63	70 / 73	55 / 64
3	DG	non-faller	-820 / 151	-675 / 124	-1005 / 188	-314 / 244	-510 / 292	0 / 100	0 / 95	0 / 100
4	DG	non-faller	228 / 380	240 / 102	148 / 52	320 / 188	276 / 132	80 / 100	100 / 85	85 / 75
5	DG	non-faller	-172 / 216	6 / 145	-1225 / 124	160 / 240	-780 / 220	30 / 100	59 / 90	38 / 95
6	DG	non-faller	-692 / 336	-395 / 87	-140 / 330	-293 / 248	-98 / 400	0 / 100	0 / 73	37 / 100
7	DG	faller	-347 / -613	84 / -18	216 / n.d.	449 / 260	369 / n.d.	13 / 11	100 / 60	100 / n.d.

Notes: <sup>1</sup> according to Di Fabio et al 2001 [48]; negative fixation values correspond to premature gaze shift from the target prior to heel contact, i.e. time from gaze shift to heel contact; positive fixation values correspond to the time of persistent fixation on target after heel contact; the values 'gaze on target' provide information on the location of gaze at heel contact (100% = gaze on target on every trial);

Abbreviations: CG, control group; DG, dance group; C1-3, Conditions 1-3; T1-2, Target 1-2; n.d., no data available.

influence on older adults walking abilities under dual task conditions in comparison to more traditional exercise forms [17,18].

The most prominent differences between the training groups were observable in the gait analysis. The CG demonstrated significant positive within-group changes of several spatio-temporal parameters, however, merely in the single task condition and at preferred gait speed (normal). Furthermore, this group exhibited a gain in velocity in the normalcog condition. This merely confirms findings from a systematic review that a strength and balance exercise regimen is able to preserve or improve walking abilities, even in advanced age [49]. The goal of this study, however, was to improve walking behavior under dual task conditions. The results of previous studies with similar groups, which were performing progressive machine-driven resistance training complemented with functional balance exercises, revealed no improvement of performance under attention-demanding circumstances; e.g. no changes in the dual task costs of walking [50,51]. Daily activities pose high cognitive demands and safe walking should be practicable also under cognitive distractive or otherwise challenging conditions. The results of the DG show significant positive within-group differences for most gait parameters also in the dual task conditions normalcog and fastcog, thus confirming findings from previous pilot studies with similar results for dual task related costs [27,30]. Furthermore, significant between-group differences in the dual task condition fastcog were observed for gait velocity and single support time in favor of the DG. Fastcog is the condition with the most challenging motor and cognitive demands. In the present study the positive effect on DTC of gait, represented by the decrease in  $\Delta$ DTC values in the DG (*Table 5.5*), may be attributed to the additional input provided by the dance video game. Thus, this substantiates the hypothesis that an additional cognitive challenge should be preferably part of a training program aiming to improve physical functioning in older adults, especially under dual task conditions. Unfortunately, how gait under these conditions should be improved has not yet been well-studied in general [52] and this study is one of the first that shows that an improvement in dual task walking with an exercise intervention supplemented by a video game is achievable.

In the FPA test both groups revealed a more accurate foot placement in M-L direction over all the walking conditions, however, only the DG manifested significant within-group differences after the intervention. The better performance may be in part attributable to improvements in walking and balance skills gained by the strength and balance exercises. A higher postural balance confidence during swing phase of the gait cycle has possibly enabled a more accurate targeting. However, a more efficient movement planning and a possible change in visual scanning of the walking path have possibly led to the better performance in the FPA test in favor of the DG. Interactive video games, like the dance video game used in this study, require precise visuo-motor control, that is to focus attention on the screen and the concurrent execution of controlled body movement and the regulation of postural control.

Interestingly in this context is that expert action video game players were found to have an improved spatial distribution and resolution of visual attention, a more efficient visual attention over time and were able to attend a higher number of objects simultaneously compared to non-players [53,54], thus allowing a better allocation of the attentional resources over a visuo-motor task.

Interestingly, in both exercise groups the mean distance error in A-P direction increased after the intervention. Participants were able to navigate quicker through the test path thereby controlling their M-L direction walking deviation, however, suffered the loss of accuracy in mean distance error in A-P direction. The higher inaccuracy in the A-P direction may be in part explained by the higher walking velocity in the second test. It can be suggested, that participants gave more priority to their walking performance (greater velocity, larger steps) and their navigation towards the target in M-L direction, so that their foot placement accuracy in A-P direction decreased (speed-accuracy tradeoff) [55]. The quality evaluation, however, shows in general a qualitative better performance in the second FPA test with less shoe contacts with the targets (*Table 5.2*).

The reason to use a dance video game or video games in general, is mainly based on the findings of a systematic review [17]. It is, however, also related to the numerous advantages attributed to such a tool [25]. As known from the principles of motor learning,



repetition is important for both motor learning and the cortical changes that initiate it [56]. The repeated practice must be linked to incremental success at some task or goal. A computerized intervention like the dance video game constitutes a powerful tool to provide participant repetitive practice, feedback about performance and motivation to endure practice [56]. In addition, it can be adapted based on the individual participant's baseline motor performance and be progressively augmented in task difficulty. Further, the addition of a challenging video game has the potential to engage people who otherwise would lack of interest to participate in a physical exercise regimen. Especially in the older population it is difficult to maintain high adherence to training programs [57]. The participants of the present study showed excellent compliance rates. The losses related to low exercise compliance or low motivation ( $n = 4$ ) in the DG were caused by animosities between the participants of one training group and in part by not perceiving any changes in performance level at the half of the study. The reasons for discontinuation of training were not because of rejection of the dance video game per se. The DG members were motivated by the additional playing of the video game at the end of every training session. The CG members were motivated by the assurance that after the end of the intervention they had the opportunity to include the dance video game in their exercise program as well. In both hostels, the training sessions with the additional dance video game were pursued also after the study ended.

The high acceptance of the dance video game used in our study seems at variance with reports of elderly being rather skeptical towards using commercially available games in a hospital setting [58]. We think that this is partly explainable due to the modifications made to the original dance video game free-ware StepMania. The information on the screen was reduced to a minimum and the music was chosen according participants' taste. In general, commercially available video games are often not adapted to the needs and preferences of older adults, since they are designed for children and young adults. The games are not easy to comprehend and the screens are flashing. This might be one of the reasons why some commercially available video games are rather disliked by older adults [58].

### 5.4.1. Limitations of the study

The present study contains some limitations that have to be discussed. A limitation of the FPA test is that different shoe sizes of the participants are not accounted for. The further development of the FPA test protocol should consider foot size by using different sized foam targets. We assume that a subject with small feet has more free space in the target area to place his/her foot before touching the border of the target resulting in a potentially higher risk of becoming variable in the accuracy performance. On the other hand the larger the foot the smaller the free space between foot and border of the target. A subject with large feet will not have a comparable amount of potential variability of distance errors as the person with small feet.

An obvious limitation of our study is the rather small sample size. This study, therefore, only reveals first estimates for these measures and warrants further research in larger populations. When evaluating the validity of a study it is important to consider both the clinical and statistical significance of the findings [59]. Studies that claim clinical relevance may lack sufficient statistical significance to make meaningful statements or, conversely, may lack practicality despite showing a statistically significant difference in treatment options. Researchers and clinicians should not focus on small  $p$ -values alone to decide whether a treatment is clinically useful; it is necessary to also consider the magnitude(s) of treatment differences and the power of the study [59]. Encouraging in this context is the observation that the majority of the between-groups comparisons show medium or medium-to-high magnitude(s) of treatment differences. This in mind, the relationship between physical and cognitive training research and its effect on gait in elderly individuals requires further exploration. Future adequately powered studies with similar populations should, therefore, be performed to substantiate our assumption and findings.

The suggested link between the observed improvement in the physical tests after the intervention and influences on cognitive processes in the brain is as of yet still speculative. A necessary next step would be to investigate the isolated effects of the video game on measures of cognitive functioning. Since improvements were observable in physical performance under attention-demanding circumstances it seems plausible to hypothesize that these changes

may rely, at least in part, on functional or even structural changes in the brain. A recently published study protocol [60] might be able to provide some insights on this topic.

## **5.5. Conclusions**

Our results support previous larger studies that strength and balance exercise may lead to better walking performance in older untrained subjects. Integrating a cognitive training component in addition, results in further improvements in those walking tasks that are related to cognitive functions. Enhancements in walking performance under dual task conditions were observed for the dance video game group only. Our findings suggest that the addition of this particular program to traditional strength and balance exercises may result in improved outcomes for older people. An exercise program that aims to improve physical functioning in older adults under dual task conditions should also consider a cognitive challenging element, preferably in form of an interactive video game adapted for older adults, in addition to strength and balance exercises.

## **Acknowledgements**

We would like to acknowledge Manuela Nötzli, Melanie Ramp, Rosina Landolt and Susan Brouwer for supervising the training sessions. We would also like to thank Marie-Louise Sarraj and Gerhard Ineichen for giving us the opportunity to conduct the study in their hostels in Stäfa and Rüti, Switzerland. Thanks also to Rolf van de Langenberg for his creative ideas in answering technical questions.

## **Authors' contribution**

Conception, design and manuscript drafting: GP, EDdB: Critical revision of manuscript for its content and approval of final version: GP, EDdB, KM. All authors read and approved the final manuscript.

## **Competing interests**

The authors declare that they have no competing interests.

## **References**

1. Berg WP, Alessio HM, Mills EM, Tong C: Circumstances and consequences of falls in independent community-dwelling older adults. *Age Ageing* 1997, 26(4):261-268.
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- 1056.
3. Gill T, Taylor AW, Pengelly A: A population-based survey of factors relating to the prevalence of falls in older people. *Gerontology* 2005, 51(5):340-345.
4. Blake AJ, Morgan K, Bendall MJ, Dallosso H, Ebrahim SB, Arie TH, Fentem PH, Bassey EJ: Falls by elderly people at home: prevalence and associated factors. *Age Ageing* 1988, 17(6):365-372.
5. Rapp K, Becker C, Cameron ID, Konig HH, Buchele G: Epidemiology of falls in residential aged care: analysis of more than 70,000 falls from residents of bavarian nursing homes. *J Am Med Dir Assoc* 2012, 13(2):187. e181-186.
6. Chapman GJ, Hollands MA: Evidence for a link between changes to gaze behaviour and risk of falling in older adults during adaptive locomotion. *Gait and Posture* 2006, 24(3):288-294.
7. Chapman GJ, Hollands MA: Evidence that older adult fallers prioritise the planning of future stepping actions over the accurate execution of ongoing steps during complex locomotor tasks. *Gait Posture* 2007, 26(1):59-67.
8. Hausdorff JM, Edelberg HK, Mitchell SL, Goldberger AL, Wei JY: Increased gait unsteadiness in community-dwelling elderly fallers. *Arch Phys Med Rehabil* 1997, 78(3):278-283.
9. Laessoe U, Hoeck HC, Simonsen O, Voigt M: Residual attentional capacity amongst young and elderly during dual and triple task walking. *Hum Mov Sci* 2008, 27(3):496- 512.
10. Chamberlin ME, Fulwider BD, Sanders SL, Medeiros JM: Does fear of falling influence spatial and temporal gait parameters in elderly persons beyond changes associated with normal aging? *J Gerontol A Biol Sci Med Sci* 2005, 60(9):1163-1167.
11. Alexander NB, Ashton-Miller JA, Giordani B, Guire K, Schultz AB: Age differences in timed accurate stepping with increasing cognitive and visual demand: a walking trail making test. *J Gerontol A Biol Sci Med Sci* 2005, 60(12):1558-1562.

12. Neider MB, Gaspar JG, McCarley JS, Crowell JA, Kaczmariski H, Kramer AF: Walking and talking: dual-task effects on street crossing behavior in older adults. *Psychol Aging* 2011, 26(2):260-268.
13. Bryan J, Luszcz MA: Measurement of executive function: considerations for detecting adult age differences. *J Clin Exp Neuropsychol* 2000, 22(1):40-55.
14. Chapman GJ, Hollands MA: Age-related differences in visual sampling requirements during adaptive locomotion. *Exp Brain Res* 2010, 204(3):467-78.
15. Young WR, Hollands MA: Can telling older adults where to look reduce falls? Evidence for a causal link between inappropriate visual sampling and suboptimal stepping performance. *Exp Brain Res* 2010, 204(1):103-113.
16. Anonymous: Guideline for the prevention of falls in older persons. American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention. *J Am Geriatr Soc* 2001, 49(5):664-672.
17. Pichierri G, Wolf P, Murer K, de Bruin ED: Cognitive and cognitive-motor interventions affecting physical functioning: a systematic review. *BMC Geriatr* 2011, 11:29.
18. Segev-Jacobovski O, Herman T, Yogev-Seligmann G, Mirelman A, Giladi N, Hausdorff JM: The interplay between gait, falls and cognition: can cognitive therapy reduce fall risk? *Expert Rev Neurother* 2011, 11(7):1057-1075.
19. Rapport LJ, Hanks RA, Millis SR, Deshpande SA: Executive functioning and predictors of falls in the rehabilitation setting. *Arch Phys Med Rehabil* 1998, 79(6):629- 633.
20. Scherder E, Eggermont L, Visscher C, Scheltens P, Swaab D: Understanding higher level gait disturbances in mild dementia in order to improve rehabilitation: 'Last in-first out'. *Neurosci Biobehav Rev* 2011, 35(3):699-714.
21. de Bruin ED, Schmidt A: Walking behaviour of healthy elderly: attention should be paid. *Behav Brain Funct* 2010, 6:59.
22. Yan J, Zhou C: Effects of motor practice on cognitive disorders in older adults. *Eur Rev Aging Phys Act* 2009, 6(2):67-74.
23. Zelinski EM, Reyes R: Cognitive benefits of computer games for older adults.

*Gerontechnology* 2009, 8(1):220-235.

24. Jobe JB, Smith DM, Ball K, Tennstedt SL, Marsiske M, Willis SL, Rebok GW, Morris JN, Helmers KF, Leveck MD, et al: ACTIVE: a cognitive intervention trial to promote independence in older adults. *Control Clin Trials* 2001, 22(4):453-479.
25. 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, 43(4):229-234.
26. Studenski S, Perera S, Hile E, Keller V, Spadola-Bogard J, Garcia J: Interactive video dance games for healthy older adults. *J Nutr Health Aging* 2010, 14(10):850-852.
27. Pichierri G, Coppe A, Lorenzetti S, Murer K, de Bruin ED: The effect of a cognitive-motor intervention on voluntary step execution under single and dual task conditions in older adults: a randomized controlled pilot study. *Clin Interv Aging* 2012, 7:175-184.
28. Thabane L, Ma J, Chu R, Cheng J, Ismaila A, Rios LP, Robson R, Thabane M, Giangregorio L, Goldsmith CH: A tutorial on pilot studies: the what, why and how. *BMC medical research methodology* 2010, 10:1.
29. Smith ST, Sherrington C, Studenski S, Schoene D, Lord SR: A novel Dance Dance Revolution (DDR) system for in-home training of stepping ability: basic parameters of system use by older adults. *Br J Sports Med* 2011, 45(5):441-445.
30. de Bruin ED, Reith A, Dörflinger M, Murer K: Feasibility of Strength-Balance Training Extended with Computer Game Dancing in Older People; Does it Affect Dual Task Costs of Walking? *J Nov Physiother* 2011, 1(104). Accessible at <http://www.omicsgroup.org/journals/2165-7025/2165-7025-2161-2104.php?aid=3350>.
31. Inzitari M, Greenlee A, Hess R, Perera S, Studenski SA: Attitudes of postmenopausal women toward interactive video dance for exercise. *J Womens Health (Larchmt)* 2009, 18(8):1239-1243.
32. Folstein MF, Folstein SE, McHugh PR: Mini-mental state. A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res* 1975, 12(3):189-198.
33. Kraemer WJ, Adams K, Cafarelli E, Dudley GA, Dooly C, Feigenbaum MS, Fleck SJ,

- Franklin B, Fry AC, Hoffman JR, et al: American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 2002, 34(2):364-380.
34. Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, Minson CT, Nigg CR, Salem GJ, Skinner JS: American College of Sports Medicine position stand. Exercise and physical activity for older adults. *Med Sci Sports Exerc* 2009, 41(7):1510-1530.
  35. Paterson DH, Jones GR, Rice CL: Ageing and physical activity: evidence to develop exercise recommendations for older adults. *Can J Public Health* 2007, 98 (Suppl 2):S69- S108.
  36. Estabrooks PA, Carron AV: Group cohesion in older adult exercisers: prediction and intervention effects. *J Behav Med* 1999, 22(6):575-588.
  37. Borg G: Borg's perceived exertion and pain scales. Champaign, IL: Human Kinetics; 1998.
  38. de Bruin ED, Murer K: Effect of additional functional exercises on balance in elderly people. *Clin Rehabil* 2007, 21(2):112-121.
  39. O'Keeffe K: Dancing Monkeys (Automated creation of step files for Dance Dance Revolution). London: Imperial College; 2003. <http://monketnet/files/dancingmonkeys/DancingMonkeys.pdf> Accessed May 31, 2012.
  40. Lord SR, Clark RD, Webster IW: Visual acuity and contrast sensitivity in relation to falls in an elderly population. *Age Ageing* 1991, 20(3):175-181.
  41. Lord SR, Menz HB, Tiedemann A: A physiological profile approach to falls risk assessment and prevention. *Phys Ther* 2003, 83(3):237-252.
  42. Menz HB, Latt MD, Tiedemann A, Mun San Kwan M, Lord SR: Reliability of the GAITRite walkway system for the quantification of temporo-spatial parameters of gait in young and older people. *Gait Posture* 2004, 20(1):20-25.
  43. Webster KE, Wittwer JE, Feller JA: Validity of the GAITRite walkway system for the measurement of averaged and individual step parameters of gait. *Gait Posture* 2005, 22(4):317-321.
  44. Kressig RW, Beauchet O: Guidelines for clinical applications of spatio-temporal gait analysis in older adults. *Aging Clin Exp Res* 2006, 18(2):174-176.
  45. Coppin AK, Shumway-Cook A, Saczynski JS, Patel KV, Ble A, Ferrucci L, Guralnik JM:

- Association of executive function and performance of dual-task physical tests among older adults: analyses from the InChianti study. *Age Ageing* 2006, 35(6):619-624.
46. Yardley L, Beyer N, Hauer K, Kempen G, Piot-Ziegler C, Todd C: Development and initial validation of the Falls Efficacy Scale-International (FES-I). *Age Ageing* 2005, 34(6):614-619.
  47. Nyman SR, Victor CR: Older people's recruitment, sustained participation, and adherence to falls prevention interventions in institutional settings: a supplement to the Cochrane systematic review. *Age Ageing* 2011, 40(4):430-436.
  48. Di Fabio RP, Emasithi A, Greany JF, Paul S: Suppression of the vertical vestibulo-ocular reflex in older persons at risk of falling. *Acta Otolaryngol* 2001, 121(6):707-714.
  49. Sherrington C, Whitney JC, Lord SR, Herbert RD, Cumming RG, Close JC: Effective exercise for the prevention of falls: a systematic review and meta-analysis. *J Am Geriatr Soc* 2008, 56(12):2234-2243.
  50. Hartmann A, Murer K, de Bie RA, de Bruin ED: The effect of a training program combined with augmented afferent feedback from the feet using shoe insoles on gait performance and muscle power in older adults: a randomised controlled trial. *Disabil Rehabil* 2010, 32(9):755-764.
  51. Hartmann A, Murer K, de Bie RA, de Bruin ED: The effect of a foot gymnastic exercise programme on gait performance in older adults: a randomised controlled trial. *Disabil Rehabil* 2009, 31(25):2101-2110.
  52. Yogev-Seligmann G, Hausdorff JM, Giladi N: The role of executive function and attention in gait. *Mov Disord* 2008, 23(3):329-342. quiz 472.
  53. Green CS, Bavelier D: Action video game modifies visual selective attention. *Nature* 2003, 423(6939):534-537.
  54. Achtman RL, Green CS, Bavelier D: Video games as a tool to train visual skills. *Restor Neurol Neurosci* 2008, 26(4-5):435-446.
  55. Fitts PM: The information capacity of the human motor system in controlling the amplitude of movement. *J Exp Psychol* 1954, 47(6):381-391.



56. Holden MK: Virtual Environments for Motor Rehabilitation: Review. *Cyberpsychol Behav* 2005, 8(3):187-211.
57. Yardley L, Donovan-Hall M, Francis K, Todd C: Attitudes and beliefs that predict older people's intention to undertake strength and balance training. *J Gerontol B Psychol Sci Soc Sci* 2007, 62(2):P119-P125.
58. Laver K, Ratcliffe J, George S, Burgess L, Crotty M: Is the Nintendo Wii Fit really acceptable to older people? A discrete choice experiment. *BMC Geriatr* 2011, 11:64.
59. Bhardwaj SS, Camacho F, Darrow A, Fleischer AB Jr, Feldman SR: Statistical significance and clinical relevance: the importance of power in clinical trials in dermatology. *Arch Dermatol* 2004, 140(12):1520-1523.
60. Jovancevic J, Rosano C, Perera S, Erickson KI, Studenski S: A protocol for a randomized clinical trial of interactive video dance: potential for effects on cognitive function. *BMC Geriatr* 2012, 12(1):23.



## Assessment of the test-retest reliability of a foot placement accuracy protocol in assisted-living older adults

**Pichierri G<sup>1</sup>**, Diener T<sup>1</sup>, Murer K<sup>1</sup>, de Bruin ED<sup>1</sup>

<sup>1</sup>Institute of Human Movement Sciences and Sport, ETH Zurich, Switzerland

published in *Gait & Posture* 38 (2013) 784–789.

## **Abstract**

*Introduction:* This study assessed the test-retest reliability of a foot placement accuracy protocol in assisted-living elderly. The goal is to evaluate the execution of foot placement performance with increasing complexity of the walking condition.

*Methods:* Twenty-five elderly (5 males, 20 females,  $80.4 \pm 8.6$  years) were assessed by one observer in two sessions with 48 hours as time interval between the measurements. Participants walked at self-selected pace along a pathway with three different walking conditions composed by two rectangular foam target locations and an obstacle on the walking surface. The main outcome measures were foot placement distance error, intraclass correlation coefficients (ICC), and the smallest detectable difference (SDD).

*Results:* Mean absolute values of the foot placement distance errors were  $14.0 \pm 4.5$  mm for medio-lateral deviation and  $27.2 \pm 2.1$  mm for anterior-posterior deviation, respectively. ICC values for test-retest reliability showed 'fair to good' to 'excellent' reliability across all conditions with values ranging from 0.63 to 0.94. SDD values lie between 3.6 and 37.3 mm.

*Conclusion:* The protocol showed good reliability for test-retest measurements of foot placement accuracy, thus making this protocol a reliable and location-independent tool to assess performance of foot placement in elderly in assisted-living settings. In the future, measurements with elderly fallers and non-fallers should be conducted to assess validity of the protocol.

**Keywords:** *test-retest, reliability, foot placement, elderly, video analysis*

The majority of falls in the elderly occur during activities of postural transition such as walking [1]. Controlled placement of the foot on the walking surface is essential for safe walking, especially in challenging environments. Because increased stride- to-stride variability [2] and decreased foot placement accuracy [3,4] are typical features of the aging process, the elderly are at greater risk of tripping or falling.

Accurate positioning of the foot requires appropriate planning and execution of the movement, as well as cognitive skills such as visual scanning, attention and problem solving [5]. It has been demonstrated that elderly people that are prone to falling generally show greater foot placement variability compared to younger adults [3]. The elderly apparently need more time to plan accurate steps into a target due to longer eye fixation times on the target compared to younger adults [4]. In the past there have been some attempts to assess foot placement accuracy in elderly populations [5–8], however these have not included quantification of the performance. Foot placement accuracy performance was defined by whether or not the participant stepped onto a target area on the floor [5–7], or by measuring the foot placement accuracy error in the anterior-posterior (A-P) direction only [8].

Chapman and Hollands [3,4] in contrast, designed a protocol that enabled the assessment of foot placement accuracy in both A-P and medio-lateral (M-L) directions. The goal of their protocol was to evaluate the planning and execution of foot placement with increasing complexity of the walking condition. This foot placement protocol proved to be able to discriminate between elderly with a low-risk and a high-risk for falling. However, the use of this protocol is dependent on dedicated gait analysis infrastructure and, therefore, restricted to gait analysis laboratories. Further, the time required to complete the protocol limits the use of this protocol in clinical practice [9].

Critical to the further development of therapies and interventions are easy-to-use devices that can be applied in clinical and (care) home settings [10]. Compared to other motion measurement devices, digital cameras have the advantage of being lightweight and portable, thus permitting data collection in a home environment. Consequently, they seem ideal for extending our understanding of foot placement and gait, and the causes

of elderly gait problems in real-life conditions, and ultimately facilitate the choice or the development of appropriate physical treatment.

To be clinically useful, an assessment procedure must have a small measurement error to detect a real change in an individual. A test-retest difference in a patient with a value smaller than the standard error of the measurement (SEM) is likely to be the result of measurement noise and is unlikely to be detected reliably in practice; a difference greater than the smallest detectable difference (SDD) is highly likely (with 95% confidence) to be a real difference [11].

We conducted this study to investigate the reliability of a foot placement accuracy protocol in an assisted-living elderly population with mobile equipment, to identify the SEM, and the SDD. To the best of our knowledge no evaluation of reliability of the foot placement protocol in assisted-living settings has been published so far.

## **6.2. Methods**

### **6.2.1. Study design**

This study was designed as a test-retest study where all subjects were tested by the same observer. Two trials were executed on two different days with 48 h between the measurements. The study protocol was approved by the local ethics committee. All participants received written and oral information and were requested to sign an informed consent statement.

### **6.2.2. Subjects recruitment**

Letters with an explanation of the study process and its aims were sent to the residents of two senior hostels (total: 155). 31 residents (20%) evinced interest and were assessed for eligibility. Inclusion criteria were age over 65 years, residential status, the ability to walk independently for at least 10 m. Exclusion criteria were severe cognitive impairments (Mini-Mental Status Examination Score (MMSE) < 22 points), rapidly progressive or terminal illness, acute illness or presence of an unstable chronic illness.

### **6.2.3. Test procedures**

The protocol used to assess foot placement accuracy was a modification of a previously described protocol [4,12]. Subjects were instructed to walk at self-selected pace along a path with three different obstacle conditions (*Figure 6.1 a–c*): ‘Condition 1’ (C1) required subjects to place their right foot onto target 1 (T1); in ‘Condition 2’ (C2) subjects were required to place their right foot onto T1 and the left foot onto target 2 (T2); ‘Condition 3’ (C3) additionally required stepping over an obstacle placed between the two targets. The targets and the obstacle were made of soft foam material. The targets were rectangular (target area (TA): 190 mm × 415 mm) and comprised a raised border (40 mm × 40 mm × 40 mm). Dimensions of the obstacle were 170 mm × 670 mm × 25 mm. 170 mm corresponds to the ideal height of a staircase step as defined by the Federal Authorities of the Swiss Confederation. Subjects performed ten repetitions for each walking condition, resulting in a total of 30 trials per person. Compared to the original protocol the number of trials was halved since we expected to have older participants with on average less optimal physical abilities compared to the elderly in the reference studies [4,12].

Prior to the start of each trial subjects stood with their back to the walking path, facing a wall, to limit knowledge of the pathway during adjustments of the target position by the investigator. The target(s) appeared in two possible positions (A or B) separated medio-laterally by 8 cm (*Figure 6.1 d*), an adaptation to the protocol based on the results of Young and Hollands [12]. The presentation of the target positions was randomized and of equal number for each condition. The presentation of the walking conditions was not randomized.

After a verbal signal by the supervisor, subjects turned toward the pathway. From a labeled starting position they began to walk over the path at a self-selected pace. Subjects were verbally instructed prior to each change of walking condition to place their foot as accurately as possible in the middle of the TA and were allowed to perform two rehearsal walks for each condition.

#### 6.2.4. Data acquisition

To assess participants' foot placement performance on the targets, adhesive labels were placed on both shoes at calcaneus level for A-P estimation and on the level of the head of the fifth metatarsal for M-L estimation (*Figure 6.1 e*). During each trial, the targets were recorded by two stationary video cameras (Contour HD 1080p, chosen for shooting sharp, high resolution 1080p HD video) at a sampling rate of 30 Hz. Video data was analyzed with Vicon Motus (Version 9.2) with an accuracy of 4.30 mm (A-P)/ 1.12 mm (M-L), and a precision of 3.39 mm (A-P)/0.87 mm (M-L), respectively. Short video sequences (4 to 5 frames) of the heel strike moment onto the target were imported into the software (*Figure 6.1 e*).

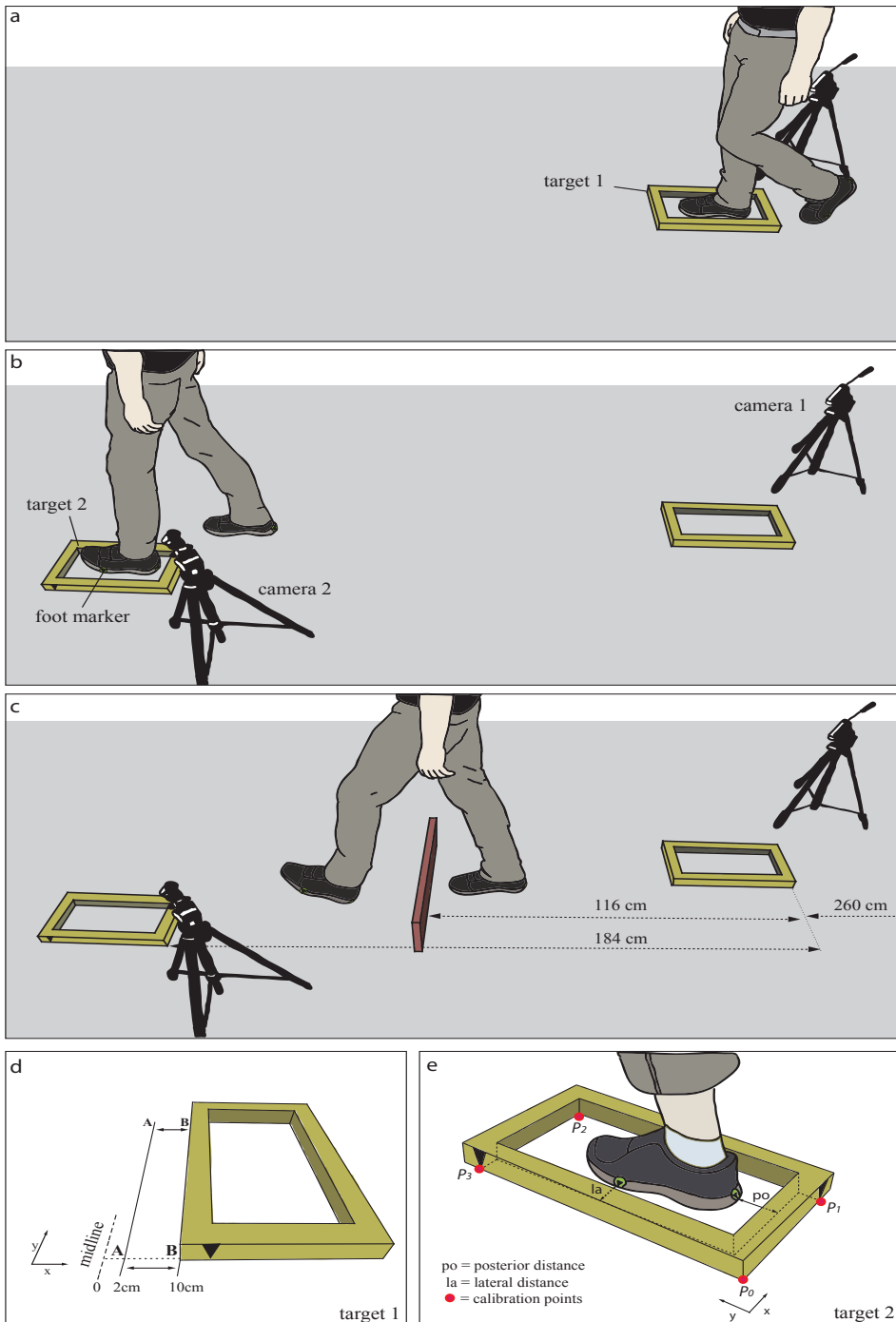
First, the spatial coordinates of the TA were determined for spatial calibration. Following this, four reference points ( $P_0$ - $P_3$ ) were selected, where  $P_0$  represents the point of origin.  $P_1$  and  $P_3$  represent the extension of the medial and frontal boarder of the target, respectively.

Second, the M-L and A-P distance of the foot markers to the previously defined coordinates of the TA were calculated by the software. Finally, for the assessment of foot placement performance, the M-L and A-P deviation of the foot center to the center of the foam target was determined. For this purpose, the contour of the participants' shoe sole were traced on a sheet of paper, thus allowing identification of the foot center, which was defined as the midpoint between heel and toe for A-P error and the midpoint between the lateral marker and the proximal shoe border for M-L error. The foam targets were marked with two black triangles (*Figure 6.1 e*), serving as calibration points to read in the dimensions and to determine spatial orientation of the target by the video analysis software. The shape of a triangle was chosen to facilitate identification and marking of the calibration points on the video file.

#### 6.2.5. Statistical analysis

The mean M-L and A-P absolute distance errors of the foot center to the target center were calculated for each target under each condition. Normality of the data was analyzed with the one sample Kolmogorov-Smirnov test.





**Figure 6.1.** Set-up of the foot placement accuracy protocol. Subjects were required to walk along the pathway at self-selected pace and place the right foot into target 1 (Condition 1 (a)), place the right foot into target 1 and the left foot into target 2 (Condition 2 (b)), and additionally step over an obstacle lying between the two targets (Condition 3 (c)). The target(s) appeared in two possible positions (A or B) separated medio-laterally by 8 cm to prevent task familiarization (d). Video still of camera 2 during stance phase used to evaluate the lateral ( $la$ ) and posterior ( $po$ ) distance error (e).

Heteroscedasticity of the data was assessed by calculating the square value of Pearson's correlation coefficient ( $r^2$ ) between the absolute measurement differences (measurement 1 – measurement 2) and the respective means. Values of  $r^2$  above 0.1 indicate heteroscedasticity. Negative values or values below 0.1 indicate homoscedasticity.

Bland-Altman plots were created for the visual inspection of heteroscedasticity [13,14]. If heteroscedasticity was present, data was transformed to the logarithms of base 10 for the calculation of the reliability parameters [15]. For the relative measures of test-retest reliability the two-way random intraclass correlation coefficients ( $ICC_{2,k}$ ) with absolute agreement were calculated. 95% confidence intervals (95% CI) for each target and condition were determined. The interpretation of the  $ICC_{2,k}$  values was based on the benchmarks suggested by Shrout and Fleiss (>0.75 excellent reliability, 0.4–0.75 fair to good reliability, <0.4 poor reliability) [16].

To examine if a significant systematic bias existed between the test and retest and as needed for the subsequent calculation of the absolute indices of reliability a two-way analysis of variance (ANOVA) was performed [17]. SEM was estimated with:  $SEM = SD\sqrt{1 - ICC_{2,k}}$  where SD is the standard deviation of the scores from all subjects (determined from the ANOVA:  $\sqrt{SS_{total}/(n - 1)}$ ) and  $ICC_{2,k}$  is the reliability coefficient.  $SS_{total}$  is the total sum of squares derived from the ANOVA. SDD was calculated with the formula  $SDD = SEM \times 1.96 \times \sqrt{2}$  [18]. All statistical analyses were performed with SPSS Statistics 19. Significance level was set at  $\alpha = 0.05$  (2-tailed).

### 6.3. Results

25 subjects were recruited and signed informed consent statements. The participants' characteristics are summarized in Table 6.1. 25 subjects, with a mean age of 80.4 years (range 66 to 94 years), completed both measurements. From the thirty subjects who evinced interest to participate, four were excluded for not meeting the inclusion criteria (walking device ( $n = 2$ ), MMSE score < 22 ( $n = 1$ ) or too frail ( $n = 1$ )) and one person declined to participate after the first measurement.

Data sets for A-P distance error for T1 in C1, M-L distance error for T1 in C3, and A-P

distance error for T2 in C2 were heteroscedastic and were log-transformed to base 10 for calculation of the reliability parameters.

Mean absolute values and ranges of both measurements, their mean difference with corresponding limits of agreement and 95% CI, and the results of the ANOVA are reported in Table 6.2. Data for A-P distance error for T1 in C3 ( $p = 0.04$ ) and for M-L distance errors for T2 in C2 ( $p = 0.05$ ) revealed significant differences between the measurements. Mean absolute values of the foot placement distance errors combining all experimental conditions and both measurements were  $14.0 \pm 4.5$  mm for M-L deviation and  $27.2 \pm 2.1$  mm for A-P deviation, respectively.

The results of the reliability measures and agreement parameters are shown in Table 6.3.  $ICC_{2,k}$  values show 'fair to good' to 'excellent' reliability results across all conditions with values ranging from  $ICC_{2,k}$  0.63 to 0.94. SDD values lie between 3.6 and 37.3 mm. In proportion to the size of the TA, the SDD values range from 1.9% (3.6 mm) to 7.0% (13.3 mm) for M-L distance error, and from 0.87% (3.6 mm) to 9.0% (37.3 mm) for A-P distance error. The Bland-Altman plots are presented in Figure 6.2.

**Table 6.1** Demographic data of participants

No. of participants	25
Age (mean, range)	80.4, 66–94
Sex (female/male)	20/5
Height (m) (mean, range)	1.61, 1.37–1.78
Weight (kg) (mean, range)	67.0, 47.1–92.7
Mini-Mental status <sup>a</sup> (median, range)	28, 24–30
FES-I <sup>b</sup> (median, range)	17, 16–24
Walking assistance (cane) <i>n</i> (%)	3 (12%)
Falls <sup>c</sup> in the last 6 months <i>n</i> (%)	
One	7 (28%)
More than one	2 (8%)
Previous falls requiring medical attention	1
Hypertension <i>n</i> (%)	13 (52%)
Arthropathy <i>n</i> (%)	8 (32%)
Osteoporosis <i>n</i> (%)	4 (16%)
Diabetes <i>n</i> (%)	4 (16%)
Cardiac insufficiency <i>n</i> (%)	3 (12%)

<sup>a</sup> Minimum score = 0, maximum score = 30; higher scores indicate better cognitive functioning.

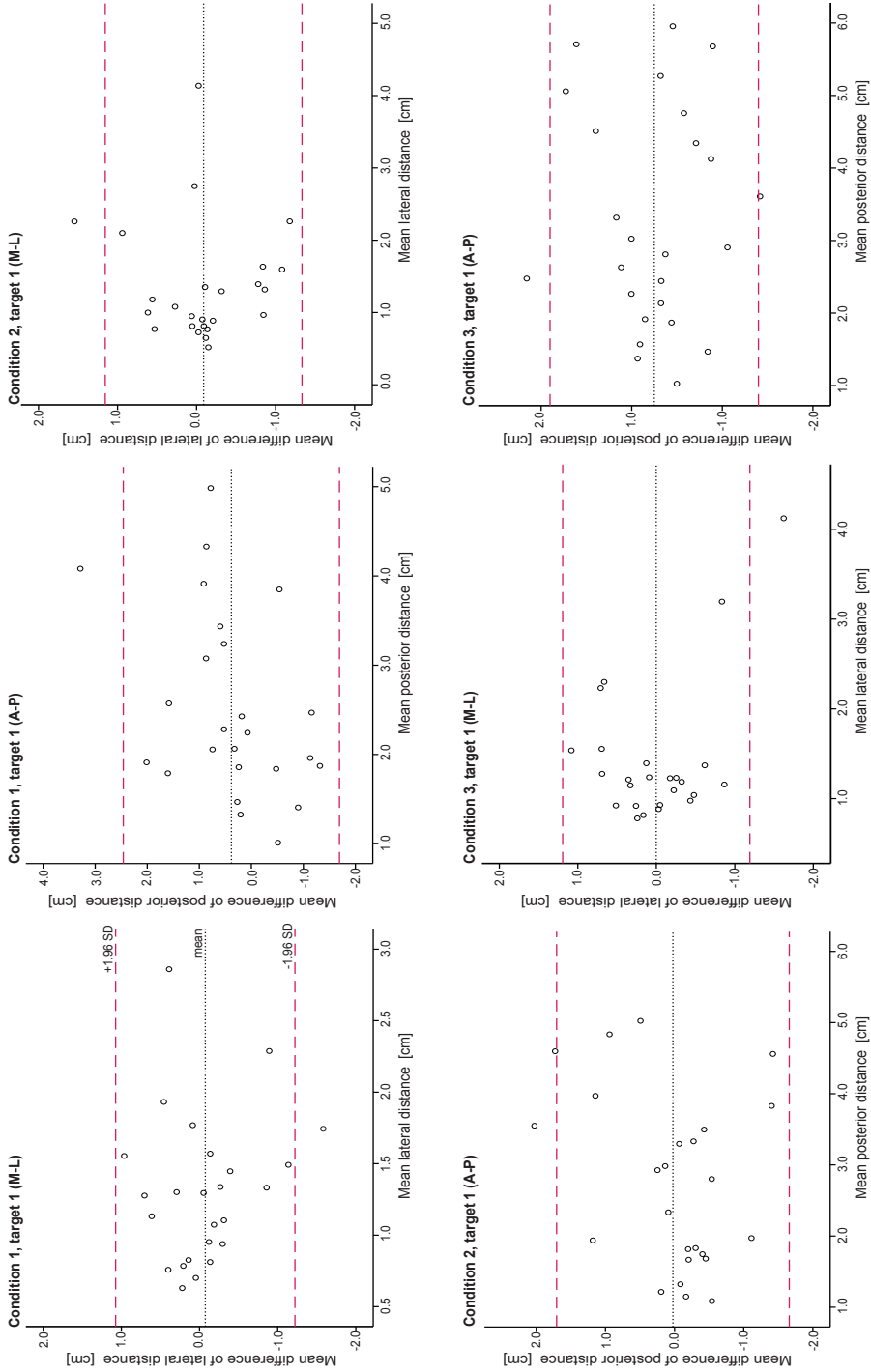
<sup>b</sup> FES-I: falls efficacy scale-international; minimum score = 16, maximum score = 64; lower scores indicate less fear of falling.

<sup>c</sup> A fall was defined as an event, which results in a person coming to rest on the ground or other lower level.

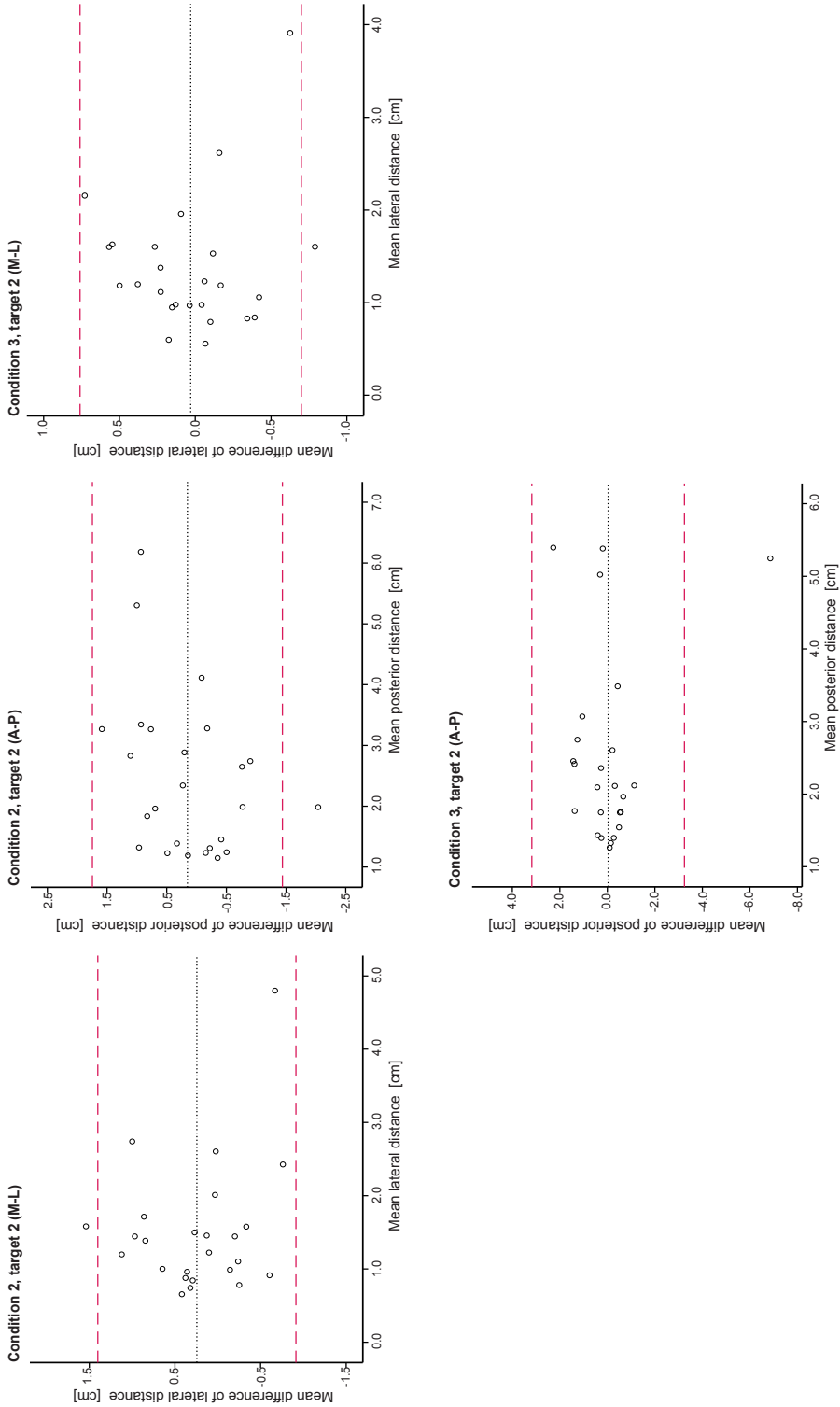
**Table 6.2** Distance errors (foot center to target center), mean difference  $d$ , and ANOVA values (sample size  $n = 25$ )

Condition	Target	Direction	Measurement 1		Measurement 2		Difference $d$		ANOVA	
			Mean (range) (mm)	Mean (range) (mm)	Mean (LoA) (mm)	95% CI of $d$ (mm)	$F$	$p$		
1	T1	M-L	12.8 (7.3, 30.6)	13.5 (5.2, 27.3)	-0.7 (-12.2, 10.7)	-3.2, 1.7	0.401	0.53		
1	T1	A-P	27.3 (7.6, 57.3)	23.5 (9.0, 45.9)	3.8 (-16.9, 24.6)	-0.5, 8.2	1.333	0.26		
2	T1	M-L	13.2 (4.4, 41.2)	14.1 (5.1, 41.5)	-0.9 (-13.3, 11.6)	-3.5, 1.7	0.494	0.49		
2	T1	A-P	27.7 (8.2, 54.6)	27.5 (1.2, 52.7)	0.2 (-16.6, 17.1)	-3.3, 3.8	0.019	0.89		
2	T2	M-L	16.4 (6.1, 44.7)	14.0 (4.5, 51.3)	2.4 (-9.1, 14.0)	0.0, 4.9	4.272	<b>0.05*</b>		
2	T2	A-P	25.4 (9.7, 66.5)	23.8 (8.4, 57.2)	1.5 (-14.4, 17.5)	-1.8, 4.9	0.139	0.71		
3	T1	M-L	14.3 (7.2, 33.1)	14.3 (6.6, 49.3)	0.0 (-11.9, 11.9)	-2.5, 2.5	0.145	0.71		
3	T1	A-P	35.4 (0.3, 68.2)	30.4 (8.2, 60.7)	5.0 (-18.0, 28.0)	0.2, 9.9	4.583	<b>0.04*</b>		
3	T2	M-L	13.9 (5.2, 36.0)	13.6 (5.1, 42.2)	0.3 (-7.0, 7.6)	-1.4, 1.8	0.162	0.69		
3	T2	A-P	25.4 (2.1, 65.3)	25.7 (0.8, 86.8)	-0.3 (-32.4, 31.8)	-7.1, 6.4	0.010	0.92		

*Abbreviations:* Condition 1: one target; Condition 2: two targets plus obstacle; T1, T2: target 1 or 2; M-L, A-P: medio-lateral or anterior-posterior distance error of center foot to target center;  $d$ : difference between the value of measurement one minus measurement two; LoA: lower and upper limit of agreement ( $d \pm 1.96$  stand deviation of  $d$ ); 95% CI: 95% confidence interval (lower limit, upper limit).



**Figure 6. 2** Bland-Altman plots with the mean lateral / posterior distance [cm] plotted against the corresponding mean difference between measurement 1 and measurement 2 [cm]. Mean difference (dotted lines) and upper and lower limits of agreement (dashed lines) are shown.



**Figure 6. 2 (continued)** Bland-Altman plots with the mean lateral / posterior distance [cm] plotted against the corresponding mean difference between measurement 1 and measurement 2 [cm]. Mean difference (dotted lines) and upper and lower limits of agreement (dashed lines) are shown.

**Table 6.3** Reliability measures and agreement parameters (sample size  $n = 25$ )

Condition	Target	Direction	Reliability measures		Agreement parameters	
			ICC <sub>2,k</sub>	95% CI for ICC <sub>2,k</sub>	SEM (mm)	SDD (mm)
1	T1	M-L	0.70	0.31, 0.87	4.7	13.0
1	T1	A-P	0.66	0.24, 0.85	1.7	4.8
2	T1	M-L	0.85	0.66, 0.93	4.8	13.3
2	T1	A-P	0.89	0.74, 0.95	6.3	17.5
2	T2	M-L	0.88	0.71, 0.95	4.7	13.0
2	T2	A-P	0.85	0.65, 0.93	1.3	3.6
3	T1	M-L	0.78	0.50, 0.90	1.3	3.6
3	T1	A-P	0.83	0.61, 0.93	9.5	26.4
3	T2	M-L	0.94	0.85, 0.97	2.7	7.4
3	T2	A-P	0.63	0.14, 0.84	13.4	37.3

*Abbreviations:* Condition 1: one target; Condition 2: two targets; Condition 3: two targets plus obstacle; T1 & T2: target 1 or 2; M-L & A-P: medio-lateral or anterior-posterior distance error of foot center to target center; ICC<sub>2,k</sub>: intraclass correlation coefficient (two-way random with absolute agreement); SEM: standard error of measurements in mm; SDD: smallest detectable difference in mm.

## 6.4. Discussion

The purpose of this study was to determine the test–retest reliability of the modified foot placement accuracy test with mobile equipment applied with a healthy elderly population in assisted-living settings. The results show ‘fair to good’ to ‘excellent’ reliability parameters, thus making this protocol a reliable tool to assess performance of foot placement in healthy elderly people in assisted-living settings.

Our study population was representative of a typical population in senior care homes when the demographic variables are considered. A wide age range (66–94 years), high percentage of women (80%), and MMSE scores ranging from 24 to 30 points, that is from the edge to mild cognitive impairments to no cognitive impairments. This indicates our results can be generalized to comparable populations of elderly people in clinical settings.

In this study we used the  $ICC_{2,k}$  with corresponding 95% CI to estimate relative reliability. We observed prevalently 'excellent'  $ICC_{2,k}$  values for C2 ( $ICC_{2,k} = 0.85-0.89$ ) with narrow 95% CI values ranging from 0.65 to 0.95. In contrast C1 and C3 showed  $ICC_{2,k}$  values between 'fair to good' and 'excellent' ( $ICC_{2,k} = 0.63-0.94$ ) but wider ranges of corresponding 95% CI (range from 0.14 to 0.97). Therefore it seems plausible to assume that C2 is the more reproducible condition for elderly people.

The reason for these results could be that participants made use of C1 to acclimatize to the test. This could be interpreted as a need for more rehearsal trials ahead of the actual testing. C3 was more complex than C2 since participants were required to decelerate, take a step over the obstacle and accelerate toward T2. Since the mean age of our participants was 80.4 years it is plausible to think that C3 posed a more challenging condition for some of the participants compared to others, explaining the high variability of the results and the low reproducibility of the performance. It could also be argued that some participants, especially the older ones, felt tired after the first two conditions, which may have caused inaccuracies during walking. C2 on the other hand, represented a more constant and rhythmical condition since it did not require any changes in pace.

To detect relevant changes in performance of foot placement accuracy on an individual level in clinical practice, the changes should exceed the SDD values presented in Table 6.3. However, it is difficult to say whether the SDD values are adequate to detect clinically meaningful differences on an individual level following an intervention. At present the data used to categorize individuals as being at high-risk for falls based on their foot placement accuracy, is poor and reported somewhat contradictorily. Chapman and Hollands observed similar high values for foot placement distance errors for both young adults and for elderly people prone to falling [3]. Their values are in line with the values in our study over all test conditions. Interestingly, elderly people with a low-risk for falls manifested lower values for distance errors, which could be interpreted as a more accurate performance. In contrast, in the study published in 2007, high-risk elderly people showed lower values for distance error



compared to both the low-risk and the young group [4]. This is one of the reasons why further research should aim to acquire a broader collection of data in clinical settings.

One limitation of the protocol was that participants' different foot sizes were not accounted for. We assumed that a subject with smaller feet had more free space in the TA to place his foot before touching the border, resulting in a potentially higher risk of becoming variable in accuracy performance. On the other hand the larger the foot, the smaller the free space between the foot and the border of the target. Therefore, a subject with large feet may not have a comparable amount of variability in distance errors as a person with smaller feet. A further development of the test protocol should consider foot size by using different sized foam targets for instance. The small bias from test to retest suggests learning effects of the protocol and can therefore be considered as another limitation. Learning effects negatively influence reliability and might be prevented by increasing the number of practice trials [19]. In frail elderly people however, extensive testing might also cause systematic bias. A solution for this problem might be the performance of several trials taken over several days in order to control for learning effects. Furthermore, the occurrence of trial-to-trial learning effects should be limited by a randomized presentation of the walking conditions.

## **6.5. Conclusion**

This study showed good reliability for test–retest measurements of the foot placement accuracy protocol, thus making this protocol a reliable and location-independent tool to assess performance of foot placement in groups of elderly people in assisted-living settings. However, the study should be repeated, taking into account the improvements of the protocol as suggested in the limitations, and preferably with a sample of non-fallers and frequent fallers to assess the ability to differentiate between these groups.

### **Funding**

No external funding.

### **Acknowledgements**

Special thanks go to Gerhard Ineichen and Hans van het Reve for giving us the opportunity to conduct this study in their hostels in Rüti and Feusisberg, Switzerland. We also acknowledge Eva van het Reve's and Rosina Landolt's efforts for organizing the measurements and for motivating the participants for this study.

### **Conflict of interest statement**

The authors declare that they have no competing interests.

## References

- 1 Berg WP, Alessio HM, Mills EM, Tong C. Circumstances and consequences of falls in independent community-dwelling older adults. *Age & Ageing*. 1997; 26: 261-8.
- 2 Hausdorff JM, Edelberg HK, Mitchell SL, Goldberger AL, Wei JY. Increased gait unsteadiness in community-dwelling elderly fallers. *Archives of Physical Medicine & Rehabilitation*. 1997; 78: 278-83.
- 3 Chapman GJ and Hollands MA. Evidence for a link between changes to gaze behaviour and risk of falling in older adults during adaptive locomotion. *Gait & Posture*. 2006; 24: 288-294.
- 4 Chapman GJ and Hollands MA. Evidence that older adult fallers prioritise the planning of future stepping actions over the accurate execution of ongoing steps during complex locomotor tasks. *Gait & Posture*. 2007; 26: 59-67.
- 5 Alexander NB, Ashton-Miller JA, Giordani B, Guire K, Schultz AB. Age differences in timed accurate stepping with increasing cognitive and visual demand: a walking trail making test. *Journals of Gerontology Series A-Biological Sciences & Medical Sciences*. 2005; 60: 1558-62.
- 6 Yamada M, Higuchi T, Tanaka B, Nagai K, Uemura K, Aoyama T, Ichihashi N. Measurements of stepping accuracy in a multitarget stepping task as a potential indicator of fall risk in elderly individuals. *Journals of Gerontology Series A-Biological Sciences & Medical Sciences*. 2011; 66: 994-1000.
- 7 Yamada M, Higuchi T, Mori S, Uemura K, Nagai K, Aoyama T, Ichihashi N. Maladaptive turning and gaze behavior induces impaired stepping on multiple footfall targets during gait in older individuals who are at high risk of falling. *Archives of Gerontology & Geriatrics*. 2012; 54: e102-8.
- 8 Berg WP and Murdock LA. Age-related differences in locomotor targeting performance under structural interference. *Age & Ageing*. 2011; 40: 324-9.
- 9 Simon SR. Quantification of human motion: gait analysis-benefits and limitations to its application to clinical problems. *J Biomech*. 2004; 37: 1869-80.

- 10 Wade E and Mataric MJ. Design and testing of lightweight inexpensive motion-capture devices with application to clinical gait analysis in *Pervasive Computing Technologies for Healthcare, 2009. 3rd International Conference on PervasiveHealth 2009*. p. 1-7.
- 11 Hartmann A, Knols R, Murer K, de Bruin ED. Reproducibility of an isokinetic strength-testing protocol of the knee and ankle in older adults. *Gerontology*. 2009; 55: 259-68.
- 12 Young WR and Hollands MA. Can telling older adults where to look reduce falls? Evidence for a causal link between inappropriate visual sampling and suboptimal stepping performance. *Experimental Brain Research*. 2010; 204: 103-13.
- 13 Bland JM and Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986; 1: 307-10.
- 14 Ageberg E, Flenhagen J, Ljung J. Test-retest reliability of knee kinesthesia in healthy adults. *BMC Musculoskeletal Disorders*. 2007; 8: 57.
- 15 Tabachnick BG and Fidell LS. *Using multivariate statistics*. California State University, Northridge: Harper Collins College Publishers; 1996.
- 16 Shrout PE and Fleiss JL. Intraclass correlations: uses in assessing rater reliability. *Psychol Bull*. 1979; 86: 420-8.
- 17 Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *Journal of Strength & Conditioning Research*. 2005; 19: 231-40.
- 18 de Bruin ED, Rozendal RH, Stussi E. Reliability of phase-velocity measurements of tibial bone. *Physical Therapy*. 1998; 78: 1166-74.
- 19 Atkinson G and Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med*. 1998; 26: 217-38.





# Seven

Chapter

## General Discussion

Physical and cognitive decline are amongst the many factors that are thought to be responsible for the increased fall risk in the older population. In the last few years the awareness of the link between cognitive decline and the decline of physical functioning, i.e. the decrease of walking abilities or impaired postural control, has given rise to novel approaches for the prevention or reduction of the occurrence of falls in older adults. In particular, cognitive decline that affects complex cognitive structures such as the executive functions has been made responsible for the higher fall rate in older adults. The many observations made in dual task experiments comparing younger with older adults has led to the suggestion that a cognitive-motor approach should preferably be part of an effective fall prevention training program.

This doctoral thesis discusses approaches that require consideration with a view to including a stimulating cognitive factor to fall prevention training programs. Further, this thesis aims to investigate the current state of research into using cognitive elements in fall prevention or interventions with the aim of improving physical functioning in older adults. Based on these findings, two intervention trials with a randomized controlled study design that used a cognitive-motor approach with residents of four senior hostels in Switzerland were performed. The objective of these studies was to examine the feasibility and acceptance of the cognitive-motor approach, and to assess the benefits to the participants of the cognitive-motor training program of including additional computer game dancing in progressive strength and balance exercises, compared with those who only received usual care or performed only strength and balance exercises. In this chapter the main findings of the literature investigation and of the experiments are summarized and discussed. In a second step methodological issues and clinical implications are addressed. To conclude, future perspectives and conclusions are presented.

### **7.1. Main findings**

#### **7.1.1. The current use of cognitive-motor techniques for rehabilitation (Chapter 2 & 3)**

There is limited current evidence on the effectiveness of cognitive or cognitive-motor approaches on physical functioning with the objective of reducing the occurrence



of falls in older adults. The many pilot or case studies traced by the systematic review (**Chapter 3**) clearly indicate that the use of cognitive or cognitive-motor approaches to influence physical functioning in older adults is still in its fledgling state. Although numerous studies have detected the dual task performance deficiency of older adults in the past, surprisingly, there seems to be an inexistent practical use of dual task methods in the context of intervention studies for rehabilitation purposes. The systematic review, together with the conclusions of the theoretical discussion offered in **Chapter 2**, conclude that approaches using computerized gaming techniques are the most convenient methods to be used for the implementation of cognitive elements in a training program with the aim of simulating a dual task condition. As early as the late 1990s, computerized gaming techniques had begun to be developed and to be considered as a potential tool for physical rehabilitation. Computerized gaming techniques were suggested to be able to enhance the way older adults perceive their bodies within their environment, due to the concordance of visual and proprioceptive information during training [1].

Computer games offer almost unlimited possibilities to implement into a training program challenges that are close to reality. They provide scenarios that stimulate and induce naturalistic movement and behaviors in a safe manner and they can be easily shaped and adapted to the individual needs of the target subjects. Further, they provide sufficient gaming experience to distract the subject's attention from motor insecurities or pain. To date the majority of the computer games for motor rehabilitation purposes are found in the treatment and care of stroke patients, people with acquired brain injury, and Parkinson's disease sufferers [2, 3]. The aim of these studies in general is to rehabilitate movements of upper and lower extremities that are important for activities of daily life. With the help of computerized interventions the therapy sessions are motivating, improvements in performance can be easily recorded and the level of difficulty can be adjusted individually. The main finding of the systematic review is that to date there is an insufficient application of cognitive or cognitive-motor interventions with the aim of improving physical functioning. Further, computerized interventions for older adults have to date seldom been applied or reported. Thus, the performance of experiments

and interventions using a cognitive or a cognitive-motor approach that uses interactive computerized technologies is a justifiable and desirable objective.

### **7.1.2. The effects of a cognitive-motor intervention on voluntary step execution in older adults (Chapter 4)**

The execution of a timed voluntary stepping response is essential for tasks that demand avoidance of a threat or recovery of balance during walking or whilst performing postural transitions. It has been observed that individuals who require more time to initiate and execute a step are at greater risk of falling [4–6]. In older adults the ability to execute a quick step response further decreases in attention-demanding situations [7, 8].

The randomized controlled pilot study presented in **Chapter 4** focused on the evaluation of the effects of a twice-weekly exercise program enhanced by supplemental computer game dancing for 12 weeks ( $n = 9$ ) in comparison to usual care ( $n = 6$ ) in older adult residents of two senior hostels in the city of Zurich. Furthermore, the study examined the feasibility and the potential to recruit and retain elderly subjects.

For the first time this intervention study revealed temporal improvements in voluntary step execution under dual task conditions in older adults. The between-group comparison resulted in a significant decrease of step initiation time ( $U = 9, p = 0.034, r = 0.55$ ) and step completion time ( $U = 10, p = 0.045, r = 0.52$ ) in favor of the cognitive-motor group. Additionally, the study participants showed an excellent mean compliance rate of approximately 87%, thus substantiating the suggestion that a cognitive-motor intervention that includes progressive strength and balance exercises supplemented by an interactive dance video game is feasible and appreciated by older adults.

### **7.1.3. The effects of a cognitive-motor intervention on foot placement accuracy and gait under dual task conditions and falls efficacy in older adults (Chapter 5)**

Intact walking abilities are certainly one of the most important factors for the preservation of autonomy and independence in everyday life. The accurate positioning of the foot onto a footpath, for instance, is a crucial ability to ensure safe walking. It enables the avoidance of

missteps and the handling of potential threats to postural stability. Furthermore, reduced gait abilities under attention-demanding conditions, and the slowing of usual gait velocity are associated with a higher risk of falls and with a decline in attention and psychomotor speed [9, 10]. It has even been suggested that improvements in usual gait velocity predict a substantial reduction in mortality [11]. Both the decreased foot placement accuracy and the general reduced walking abilities are often reported as common symptoms of the natural aging process. In this regard, fear of falling is a frequently reported concern in older adults, especially in individuals who have already experienced a fall, and can lead to a further decrease in activity of daily life, a further decline in physical functioning and to a general decrease in quality of life [12, 13].

**Chapter 5** highlights the effects of a 12-week randomized controlled intervention study of residents of two senior hostels regarding foot placement accuracy and gait under dual task conditions, coupled with fear of falling. The participants either performed a cognitive-motor program that comprised twice-weekly progressive strength and balance exercises with supplemental computer game dancing ( $n = 15$ ) or progressive strength and balance exercises alone ( $n = 16$ ). Although both groups attained improvements in foot placement and gait performance and both were able to reduce their concerns about falling, the results of this study suggest positive interaction effects in favor of the cognitive-motor group. The cognitive-motor group achieved significant positive within-group differences for most gait parameters assessed under both single and dual task conditions. Furthermore, significant between-group differences for gait velocity ( $U = 26, p = 0.041, r = 0.45$ ) and single support time ( $U = 24, p = 0.029, r = 0.48$ ) under dual task conditions in favor of the cognitive-motor group were observed. However no significant between-group differences were found for foot placement accuracy after the intervention – only the cognitive-motor group exhibited significant positive within-group differences after 12 weeks. The results suggest that a cognitive-motor intervention may have a positive influence on dual task walking abilities in older adults compared to a traditional exercises regimen. The addition of a cognitive training component results in further improvements in those walking tasks that are related to cognitive functions.

#### **7.1.4. The test-retest reliability of the foot placement accuracy test (Chapter 6)**

Knowledge of data reliability allows the use of a system in observational and interventional type studies. The study presented in **Chapter 6** assessed the test-retest reliability of a foot placement accuracy protocol performed with mobile equipment in assisted-living elderly. One observer assessed twenty-five elderly residents of two senior hostels in two sessions with a 48-hour time interval between measurements. Participants walked at a self-selected pace along a pathway with three different walking conditions composed of two rectangular foam target locations and an obstacle on the walking surface. The analysis of the foot placement performance was performed by the help of commercially available digital video cameras and software able to identify the spatial position of objects and to calculate relative distances to other objects based on video data. The results show 'fair to good' to 'excellent' reliability parameters and SDD values in a small range, thus making the foot placement accuracy test protocol a reliable tool to assess performance of foot placement in healthy elderly in assisted-living settings.

However, it is difficult to say whether the SDD values are adequate to detect clinically meaningful differences on an individual level following an intervention. Therefore, further research should aim to acquire a broader collection of data, especially with groups of non-fallers and frequent fallers, in clinical settings.

## **7.2. Methodological issues**

### **7.2.1. Systematic review (Chapter 3)**

Although the primary objective of the review was to identify intervention studies using cognitive or cognitive-motor interventions affecting physical functioning in an older population, studies including people with neurological deficits were considered as a methodological supplement with the intention of receiving useful inputs for the application in studies with older adults. People with neurological deficits as a cause of brain dysfunctions behave very similarly to older adults, although the causes of the deficits are different. Whether brain functions are lost through a sudden accident or through slow and gradual decline, as it is in older adults, both result in more or less the same behavioral

symptoms and deficits, that is slowing of gait together with variability of temporal and spatial gait parameters under single and dual task situations. The consideration of other groups for the systematic literature search turned out to be fundamental for the methodological content and the completeness of the review, since a majority of the studies were conducted with older adults not in full health.

### **8.2.2. Randomized controlled pilot study (Chapter 4)**

The small sample size definitely hinders the generalization of the results reported for the pilot study presented in **Chapter 4**. Presumably, a larger sample size in both the cognitive-motor and usual care group would have led to different results. The rationale for the performance of this pilot study was purely scientific. Besides estimating possible effects on physical functioning and the feasibility of a cognitive-motor approach the study was concerned with the assessment of treatment safety, the determination of dose levels and response. As Thabane, L. et al., stated [14]: “Pilot studies can be very informative, not only to the researchers conducting them but also to others doing similar work. However, many of them never get published, often because of the way the results are presented. Quite often the emphasis is wrongly placed on statistical significance, not on feasibility – which is the main focus of the pilot study.”

Certainly, an effective replication of the study should not only consider a larger number of participants but also additional clinical meaningful measures of physical performance such as the Expanded Timed Get-Up-and-Go test (ETGUG) [15], the Berg Balance Scale [16], or the Activities-specific Balance Confidence Scale (ABC) [17]. These assessments may contribute to a better and more comprehensible estimation of the effects observed on the voluntary step execution task.

The comparison of the cognitive-motor group with a control group that received only usual care is not recommendable by implication. It remains unclear whether the positive results were a consequence of the additional dance computer game alone, or of the cognitive-motor intervention as a whole. Therefore, the randomized controlled study presented in Chapter 5 focused on separating the contribution of

the isolated training parameters, i.e. progressive strength and balance exercise and interactive computer game dancing.

Nevertheless, the comparison reveals obvious deficiencies in the usual care management in senior hostels. The two hostels considered for this pilot study lacked a systematic physical exercise program as well as appropriate infrastructures to perform physical activity for the resident older adults. This is a common problem in Swiss residential settings [18].

### 7.2.3. Randomized controlled study (Chapter 5)

From the viewpoint of the assessments performed in the context of the study presented in **Chapter 5**, some methodological issues need to be discussed. One major limitation of the study is the absence of complete gaze behavior data during the foot placement accuracy test. This substantial data deficiency makes it impossible to draw a relationship between the improvements in the foot placement accuracy task and a possibly changed gaze behavior as suggested by the reference studies [19–21]. Not only were technical problems experienced, but also several age-related difficulties (vision problems) that hampered the use of the eye-tracking system, thus bringing up the question whether such an eye-tracking system is suitable for adults in this age category. In a future study subjects who are not able to walk without glasses, subjects suffering from head tremor, or those who have hanging eyelids should be excluded from the measurements.

Furthermore, some modifications in the foot placement accuracy test are necessary. Participants were told to face a wall prior to the start of the test to prevent pre-walking adjustments when aware of the targets' medio-lateral position. After the visual start signal appeared they performed a body turn of 180° towards the walking path. This body turn could have been the origin of unwanted vestibular effects and may have influenced the performance of the foot placement accuracy test. Nonetheless, as the time needed to perform the body turn and perform the first step was not limited, the occurrence of unwanted vestibular effects and its influence on performance can be disregarded. In contrast, the participants in the reference studies [19–21] were told to close their eyes to

prevent catching a premature view of the walking path. Closing and opening the eyes may also have an influence on the vestibular system, since participants begin to walk during the light adaptation phase of the eye. A possible method of avoiding both unwanted pre-start effects is the use of an easily removable wall on wheels between the participant and the walking path.

From the viewpoint of the exercise program there is no need to change the design of the cognitive-motor intervention used in this study. Participants very much enjoyed the physical exercise as well as playing the dance video game. Some participants involved in the performance of the dance video game suggested that the music could have been more diversified, but this was reported as a minor issue. However, suggestions of this kind should be taken seriously, since they may influence adherence to the training program and the results of the study.

As in the pilot study offered in **Chapter 4** the randomized controlled trial presented in **Chapter 5** showed small sample sizes although numerous residents attended the recruitment events. For future studies the participant recruitment process should be more focused on establishing a personal relationship between the investigators and the residents of the senior hostels, right from the start. The support of the hostel staff is therefore crucial, as they know the residents and are able to convince potential participants in case of concerns about the participation to the study. The presentation of videos and pictures of previous studies showing participants during the performance of the training program is definitely helpful to provide confidence and assure that the study is safe and especially designed for the older population. Having been more conscious of these aspects possibly would have resulted in a larger study population.

#### **7.2.4. The test-retest reliability study (Chapter 6)**

The study that examined the test-retest reliability of the foot placement accuracy test (**Chapter 6**) did not account for test to retest learning effects. To control for these learning effects, the performance of several trials taken over several days is recommended. Further, the trial-to-trial learning effects should be limited by a randomized presentation of the

walking conditions. As a matter of convenience the walking conditions were presented in order of their complexity, i.e. one target, two targets, two targets with the obstacle.

### **7.2.5. Falls ascertainment**

The fact that we did not ascertain falls after the intervention periods of both studies is a point that needs to be discussed. Participants should be followed up for a certain period, preferably 12 months, in order to assess the incidence of falls. In both intervention studies only a retrospective data assemblage of falls data was performed. Participants were asked how many times they had fallen in the last year or the last six months. Such an approach is misleading because of failings in a participant's memory of fall events over such a long period of time. For future studies a prospective report of falls experiences should be considered. This can be done by a self-reported bi-weekly or monthly falls diary, where the participants report a fall event, its cause, and can note the environmental conditions in which the fall happened. The accuracy of the fall reports increases when staff in senior hostels are involved in the collection of falls data. Information on prospective falls data is important to evaluate the long-term effects of an intervention.

### **7.3. Using computer games for older adults**

The dance video game setting used in the context of this thesis is one possible approach to using computerized methods. The advantage of using dance pads is that stepping on the pad requires repetitive, well-coordinated leg movements and the regulation of postural balance during the course of the training. The motivating component 'music' and the performance of a step choreography on the dance pad in synchronization with music is a complex sensorimotor action. Further, the continuous feedback on performance of the dance computer game is very important for the participants since older adults may show age-related deficits in self-monitoring [22, 23]. The feedback encourages the participants to persevere with the game.

The most important aspect when using computer games for older adults is the consideration of their preferences and needs for an aged-based adaptation of these games



[24]. This was shown by a recent study from Australia that investigated the acceptability of a commercially available interactive video games as a therapeutic tool in health and aged care settings [25]. The conclusion was that the usefulness of a commercially interactive mainstream video game, in their case the Nintendo Wii Fit, is limited. Although the Nintendo Wii Fit has become a popular tool in rehabilitation settings the applicability to the older population is not warranted. Contemporary mainstream computer games are designed for children or younger adults, they do not cope with the needs, interests and abilities of older adults. The animation on the screen is colorful, blinking and overloaded with information.

Computer games for older adults with the aim of improving physical functioning under dual task conditions should focus on the stimulation of executive functions, especially on divided attention and should preferably implement strength and balance exercises.

#### **7.4. Clinical implications**

Cognitive impairment should be regarded as one important point of future fall prevention programs. Actual guidelines that prescribe adequate fall risk assessments still do not propose the assessment of cognitive impairments for fall prevention. The guidelines for the prevention of falls published by the American Geriatrics Society, the British Geriatrics Society, and the American Academy of Orthopedic Surgeons Panel on Falls Prevention propose the assessment of fall history, medication, vision, gait and balance, lower limb joints, neurological (sensory neuron and motor responses) and cardiovascular factors [26]. Although these assessments cover a diversified list of potential fall risk factors, cognitive impairments such as impaired executive functions, dementia, cognitive dysfunctions following traumatic brain injuries or stroke are not considered. A complete fall risk assessment should consider the cognitive domain. Cognitive tests for executive functions and the assessment of physical performance, e.g. gait under dual task conditions, should be considered in routine assessments for older adults. Many other researchers support this suggestion [11, 27–29].

Progressive physical activity that comprises strength exercises focusing on muscle groups that are used in everyday situations and the improvement of postural balance enriched with a cognitive element should be part of any training program for older adults. Thereby the aspect of group exercise is very important, especially in institutionalized older adults where people tend to live their own lives regardless of the cohabitants. An exercise program should be considered as a regular social event where people meet and enjoy the common activity. The addition of a computer game such as the dance video game used in the experiments in the context of this doctoral thesis integrates not only physical activity and cognitive challenges but also offers emotional inputs to support social cohesion between the inhabitants of a senior hostel.

When planning intervention studies for improving physical functioning in older adults one should not be too cautious or blinded by too many prejudices. The perception that computer games in general cannot be adapted to older adults' abilities and needs is fatal, since aged people can be young at heart. Introducing a gaming effect and a healthy portion of competition is important also in the old age. This could possibly be an argument for higher participation rates in future studies. Low participation rates are a big problem in exercise studies with older adults.

Further, the adequate design of computerized gaming techniques that focus on improving physical functioning in older adults should be easily and economically incorporated into home-based training programs without the need of any expensive and unfamiliar settings.

### **7.5. Suggestions for future research**

In a next step the effective contribution of the computer dance game on the observed improvements in physical performance under dual task conditions should be evaluated. The study would thus compare one group that performs physical exercise alone, one group that performs the cognitive-motor program, and a third group that performs only the computer dance game during the whole study period of twelve weeks. Main outcome measures would be the assessment

of gait and of other relevant fall-related physical performances under dual task conditions.

A model where cognitive stimuli are suggested to have an impact on physical functioning could be examined. The question would be whether improvements in gait under dual task conditions can be observed when the dance computer game is played with a hand-held controller

(HC) only (Figure 7.1) instead of whole-body step training (WBT) on the original dance pad. The HC- and WBT-group would exercise twice weekly or more for 12 weeks. Main outcome measures would be pre- and post-tests of gait performance or of other relevant fall-related



**Figure 7. 1** Hand-held controller ( 20 x 20 x 60 cm)

physical performances under dual task conditions. The hypothesis is that the WBT-group will show better performances in dual task walking compared to the HC-group. This would speak in favor of the suggestion that the cognitive and the motor element have to be performed together. In case of improvements in dual task performance of the HC-group after the purely cognitive training, such a design could possibly be applied in the workout of rather frail older adults, who are not yet able to take part in a WBT-training.

In fact, the dance computer game implies that participants are standing on the dance pad for several minutes. Even with the help of the hanging ropes, this is an ability that cannot be taken for granted for a great part of institutionalized older adults. Unfortunately, some individuals interested in participating had to be excluded from the training program, including those who required the use of a wheelchair, or suffered from muscle weakness that restricted the ability to stand for such a long time, or who just felt too insecure while standing without device support. An adaptation of the training program specifically for this group of older adults that are overlooked

in the majority of training studies should be designed. Strength and balance exercises that can be performed in a seated position should be implemented. The dance computer game could be performed by stepping on the dance pad in a sitting position or by performing the game with the hands using an appropriately designed hand controller constituting a miniature dance pad (*Figure 7.1*). This approach would constitute a valuable opportunity for weaker and physically impaired older adults to start with physical exercise in a safe manner. As main outcome measures in these groups simple or choice reaction time of upper and lower extremities under dual task conditions are suggested.

The next step should be the investigation of the dance computer game on a neuropsychological level. It is still unclear what the underlying factors are that lead to the improvements in physical functioning under dual task conditions in older adults. We can only speculate that the dance computer game has an influence on executive functions. However, first pilot findings suggest that interactive computer dance gaming is associated with increased fronto-parietal network activation [30]. The further investigation of the dance computer game should focus on whether and how the game stimulates and affects brain activity, with a focus on prefrontal brain structures. Measurement of brain activity with electroencephalography (EEG) during the performance of the computer task or functional magnetic resonance imaging (fMRI) before and after the cognitive-motor intervention could reveal which and to what extent specific brain functions are active or affected during and after the performance of the dance computer game. An interesting point would be to explore whether the possibly observed changes in brain activity are achieved by structural and/or functional changes in the brain. Three groups would be tested after a training regimen of either computer game dancing, computer game dancing with a hand-held controller (*Figure 7.1*), traditional stepping exercises and compared to a non-intervention group.

In addition, with the integration of the possibly new insights regarding the effect of an interactive dance video game on brain level, new types of interactive computer games especially designed and adapted for older adults should be developed.

## **7.6. Conclusions**

This doctoral thesis highlights the fact that the use of cognitive-motor approaches is still in its fledgling state, thus justifying the need for further research in the use of cognitive-motor approaches for the improvement of physical functioning and fall prevention in older adults. The suggested link between cognitive functions and physical functioning should be taken into account in future studies aiming to improve the ability of older adults to counteract threats to their postural stability. Furthermore, cognitive impairments and decreased dual task performances in older adults should be considered in routine assessments to identify at an early stage dysfunctions in this context. The findings arising from the interventions performed in the experimental context of this thesis substantiate the hypothesis that physical exercise enriched by supplemental cognitive stimuli, in the form an interactive and attention-demanding computer game, has an essential positive benefit on the physical performance of older adults under attention-demanding circumstances when compared to previously applied physical exercise regimen. However, it remains unclear to what extent the additional cognitive input is responsible for the observed improvements of performance.

To conclude, the design of future training approaches and interventional studies should consider the needs, interests and abilities of the older population to ensure adherence and persistence.

## References

1. Bisson E, Contant B, Sveistrup H, Lajoie Y: Functional balance and dual-task reaction times in older adults are improved by virtual reality and biofeedback training. *Cyberpsychol Behav* 2007, 10(1):16-23.
2. Holden MK: Virtual environments for motor rehabilitation: review. *Cyberpsychol Behav* 2005, 8(3):187-211; discussion 212-189.
3. Sveistrup H: Motor rehabilitation using virtual reality. *J Neuroeng Rehabil* 2004, 1(1):10.
4. Maki BE, McIlroy WE: Control of rapid limb movements for balance recovery: age-related changes and implications for fall prevention. *Age Ageing* 2006, 35 Suppl 2:ii12-ii18.
5. Rapp K, Becker C, Cameron ID, Konig HH, Buchele G: Epidemiology of falls in residential aged care: analysis of more than 70,000 falls from residents of bavarian nursing homes. *J Am Med Dir Assoc* 2012, 13(2):187 e181-186.
6. Rogers MW, Kukulka CG, Brunt D, Cain TD, Hanke TA: The influence of stimulus cue on the initiation of stepping in young and older adults. *Arch Phys Med Rehabil* 2001, 82(5):619-624.
7. Brauer SG, Woollacott M, Shumway-Cook A: The influence of a concurrent cognitive task on the compensatory stepping response to a perturbation in balance-impaired and healthy elders. *Gait Posture* 2002, 15(1):83-93.
8. Shumway-Cook A, Woollacott M: Attentional demands and postural control: the effect of sensory context. *J Gerontol A Biol Sci Med Sci* 2000, 55(1):M10-16.
9. 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):2127-2136.
10. Inzitari M, Newman AB, Yaffe K, Boudreau R, de Rekeneire N, Shorr R, Harris TB, Rosano C: Gait speed predicts decline in attention and psychomotor speed in older adults: the health aging and body composition study. *Neuroepidemiology* 2007, 29(3-4):156-162.
11. Hardy SE, Perera S, Roumani YF, Chandler JM, Studenski SA: Improvement in

- usual gait speed predicts better survival in older adults. *J Am Geriatr Soc* 2007, 55(11):1727-1734.
12. Howland J, Peterson EW, Levin WC, Fried L, Pordon D, Bak S: Fear of falling among the community-dwelling elderly. *J Aging Health* 1993, 5(2):229-243.
  13. Yardley L, Beyer N, Hauer K, Kempen G, Piot-Ziegler C, Todd C: Development and initial validation of the Falls Efficacy Scale-International (FES-I). *Age Ageing* 2005, 34(6):614-619.
  14. Thabane L, Ma J, Chu R, Cheng J, Ismaila A, Rios LP, Robson R, Thabane M, Giangregorio L, Goldsmith CH: A tutorial on pilot studies: the what, why and how. *BMC Med Res Methodol* 2010, 10:1.
  15. Wall JC, Bell C, Campbell S, Davis J: The Timed Get-up-and-Go test revisited: measurement of the component tasks. *J Rehabil Res Dev* 2000, 37(1):109-113.
  16. Berg K, Wood-Dauphinee S, Williams JI: The Balance Scale: reliability assessment with elderly residents and patients with an acute stroke. *Scand J Rehabil Med* 1995, 27(1):27-36.
  17. Schott N: [German adaptation of the „Activities-Specific Balance Confidence (ABC) scale“ for the assessment of falls-related self-efficacy. *Z Gerontol Geriatr* 2008, 41(6):475-485.
  18. de Bruin ED, Spence JC, Hartmann M, Murer K: Physical Activity Recommendations and Programmes Offered in Swiss Residential Settings. *physioscience* 2008, 4:154-162.
  19. Chapman GJ, Hollands MA: Evidence for a link between changes to gaze behaviour and risk of falling in older adults during adaptive locomotion. *Gait Posture* 2006, 24(3):288-294.
  20. Chapman GJ, Hollands MA: Evidence that older adult fallers prioritise the planning of future stepping actions over the accurate execution of ongoing steps during complex locomotor tasks. *Gait Posture* 2007, 26(1):59-67.
  21. Young WR, Hollands MA: Can telling older adults where to look reduce falls? Evidence for a causal link between inappropriate visual sampling and suboptimal stepping performance. *Exp Brain Res* 2010, 204(1):103-113.

22. Dunlosky J, Kubat-Silman AK, Hertzog C: Training monitoring skills improves older adults' self-paced associative learning. *Psychol Aging* 2003, 18(2):340-345.
23. Studer M: Rehabilitation of executive function: to err is human, to be aware-divine. *J Neurol Phys Ther* 2007, 31(3):128-134.
24. Herman H, de Kort YAW, Ijsselsteijn WA: Senior gamers: Preferences, motivations and needs. *Gerontotechnology* 2009, 8(4):247-262.
25. Laver K, Ratcliffe J, George S, Burgess L, Crotty M: Is the Nintendo Wii Fit really acceptable to older people? A discrete choice experiment. *BMC Geriatr* 2011, 11:64.
26. Guideline for the prevention of falls in older persons. American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention. *J Am Geriatr Soc* 2001, 49(5):664-672.
27. Allali G, van der Meulen M, Assal F: Gait and cognition: the impact of executive function. *Schweizer Archiv für Neurologie und Psychiatrie* 2010, 161(6):195-199.
28. Mirelman A, Herman T, Brozgol M, Dorfman M, Sprecher E, Schweiger A, Giladi N, Hausdorff JM: 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.
29. 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.
30. Jovancevic J, Rosano C, Perera S, Erickson KI, Studenski S: A protocol for a randomized clinical trial of interactive video dance: potential for effects on cognitive function. *BMC Geriatr* 2012, 12:23.







# Eight Chapter

**Summary / Zusammenfassung**

**Danksagungen**

**PhD Curriculum**

**Curriculum Vitae**



# Summary / Zusammenfassung

## Summary

Our body is constantly challenged not only by different internal influences (muscle weakness, illness, fatigue, mood, cognitive impairments, vision problems) but also by external ones (obstacles, crowds, traffic, weather) all of which constitute a potential threat to our postural stability. These demand intact cognitive functions to register potentially threatening situations at an early stage, to plan and execute the correct motor response to the special circumstance in order to avoid a misstep or a fall. Besides the decline of physical functions, a decline of cognitive functions that regulate these abilities has been suggested as a major cause for falls in the older population. It has been extensively observed that older adults show poorer performances in dual task situations compared to younger adults, and this deficiency is thought to be in part attributable to declines in executive functioning.

The thesis aims to answer the question of whether effective fall prevention programs for older adults should implement approaches that address the cognitive decline and the dysfunctions in cognitive processes, especially of the executive functions. The assumption is based on the growing evidence that rather than isolated physical or cognitive activity, the combination of both better supports the healthy functions of executive function, working memory, and the ability to divide and select attention. The results of a systematic review of literature (**Chapter 3**) reveal that the current evidence on the effectiveness of such approaches on physical functioning under single and dual task conditions in older adults is still limited, thus warranting the performance of experiments and interventions using such a cognitive-motor approach for this population.

The thesis proposes the use of interactive computer games as a supplement to traditional physical exercise procedures, that is strength and/or balance exercise. The special value of interactive computer game training paradigms is believed to be due to the concordance of visual and proprioceptive information during training. Further, interactive computer games provide salient feedback about the movement performance and the task difficulty can be easily adapted according to the subject's ability and needs. The computer game used in the experiments is an interactive dance game (a specially designed modification of StepMania, Version 3.9) based on the performance of precise and timed steps on a metal

pad in response to visual and acoustic stimuli. Subjects are expected to observe the virtual environment on a screen indicating moving arrows and concurrently initiate appropriate dance steps (forwards, backwards and to the side, respectively). The dance game challenges body coordination and attention at the same time.

In two intervention studies (**Chapter 4** and **5**) older adults in care home settings in Switzerland performed for twelve weeks either a cognitive-motor program that comprised twice-weekly progressive strength and balance exercises with supplemental interactive computer game dancing (dance group) or twice-weekly strength and balance exercise alone (**Chapter 5**) or usual care offered at their homes (**Chapter 4**), respectively (control groups). At baseline and after the intervention period of twelve weeks the groups were compared in reference to their performance on walking (**Chapter 4** and **5**), their voluntary step execution under single and dual task conditions (**Chapter 4**), and on their foot placement accuracy during walking (**Chapter 5**). In both experiments the results revealed positive effects on the performance of the tasks in favor of the dance group: a significant decrease of step initiation time and step completion time in a voluntary step execution test under dual task conditions (**Chapter 4**), a significant increase of gait velocity under dual task conditions, and a significant positive within-group difference for foot placement accuracy in the dance group (**Chapter 5**).

The findings arising from the interventions substantiate the hypothesis that physical exercise enriched by an interactive and attention-demanding computer game can lead to essential positive benefits in the physical performance of older adults under dual task conditions when compared to traditional physical exercise. An exercise program that aims to improve the physical performance under attention demanding circumstances should consider a cognitively challenging element in addition to strength and balance exercise, preferably in the form of an interactive computer game that is adapted to the participants' abilities and needs. However, it still remains unclear to what extent the additional cognitive input is responsible for the observed positive changes in physical performance in the presented studies, which offers an incentive for further research on this topic.

## Zusammenfassung

Unser Körper ist ständig sowohl mit inneren (Muskelschwäche, Erkrankungen, Müdigkeit, Gemütslage, kognitive Beeinträchtigungen, Sehschwächen) als auch mit äusseren Einflussfaktoren (Hindernisse, Menschenmassen, Strassenverkehr, Wetter) konfrontiert. Diese Faktoren stellen eine potentielle Gefahr für die Erhaltung des Körpergleichgewichts dar. Der Einfluss dieser Faktoren verlangt von unserem Körper intakte kognitive Funktionen um so potentielle Gefahrensituationen frühzeitig erkennen und eine angemessene motorische Antwort auf die speziellen Gegebenheiten planen und auszuführen zu können. Nur so ist es möglich einen Fehltritt oder gar einen Sturz zu verhindern. Nebst dem Rückgang der körperlichen Funktionen wird ein Rückgang der kognitiven Funktionen, welche diese Fähigkeiten steuern, als eines der Hauptgründe für Stürze bei älteren Menschen vermutet. Es wurde bereits nachgewiesen, dass ältere Menschen im Vergleich zu jüngeren Erwachsenen eine beeinträchtigte Leistungsfähigkeit unter Dual-Task-Situationen aufweisen. Es wird vermutet, dass diese Beeinträchtigung teilweise einem Rückgang der exekutiven Funktionen zuzuschreiben ist.

Ziel dieser Dissertation ist es herauszufinden, ob effektive Programme zur Sturzprävention bei älteren Menschen Methoden einsetzen sollten, welche den kognitiven Rückgang aufhalten und auf die Beeinträchtigungen der kognitiven Prozesse, mit Schwerpunkt auf den exekutiven Funktionen, eingehen. Diese Frage basiert auf die wachsende Anzahl der Studienergebnisse, die darauf hinweisen, dass die Kombination von kognitiver und motorischer Aktivität, gegenüber der rein isolierten Ausübung der beiden Aktivitäten die exekutiven Funktionen, insbesondere das Arbeitsgedächtnis und die Fähigkeit der geteilten und selektiven Aufmerksamkeit, stärker fördern. Die Ergebnisse der Literaturübersicht (**Kapitel 3**) machen deutlich, dass das Wissen über die Wirkung der kognitiv-motorischen Methoden auf die körperliche Leistungsfähigkeit unter Single- und Dual-Task-Bedingungen bei älteren Menschen noch sehr gering ist, was die Durchführung von Experimenten und Interventionen mit einem kognitiv-motorischen Charakter in dieser Population rechtfertigt.

Zur Ergänzung des traditionellen körperlichen Trainings (Kraft- und Gleichgewichtsübungen) wird in dieser Dissertation der Einsatz von interaktiven



Computerspielen vorgeschlagen. Der Einsatz dieser Spiele ist aufgrund des Zusammenspiels zwischen visuellen und propriozeptiven Informationen während des Trainings äusserst wertvoll. Die Spieler erhalten wertvolle Rückmeldungen zur Qualität der Bewegungsausführung und der Schwierigkeitsgrad kann relativ einfach an die Fähigkeiten und Bedürfnisse der Trainierende angepasst werden. Das Computerspiel, welches in den Interventionen dieser Dissertation zu Verwendung kam, ist ein interaktives Computer-Tanzspiel (eine speziell modifizierte Version von StepMania, Version 3.9), welches auf die Ausführung von präzisen und zeitlich getimten Schrittfolgen auf einer metallischen Tanzplatte, aufgrund visueller und akustischer Reize basiert. Der Spieler beobachtet die virtuelle Umgebung auf einem Bildschirm, auf welchem sich Pfeile vom unteren zum oberen Ende bewegen und führt gemäss der angezeigten Pfeilrichtung Tanzschritte aus (vorwärts, rückwärts oder zur Seite). Das Computer-Tanzspiel fördert die Koordination der Körperbewegungen und schult gleichzeitig aber auch die Fähigkeit der geteilten Aufmerksamkeit.

In zwei Interventionsstudien (**Kapitel 4** und **5**) absolvierten Senioren aus Schweizer Altersheimen ein 12-wöchiges kognitiv-motorisches Trainingsprogramm, welches zweimal pro Woche progressives Kraft- und Gleichgewichtsübungen und zusätzlich interaktives Computer-Tanztraining beinhaltete (Tanzgruppe). Die Senioren der Kontrollgruppen hingegen, absolvierten entweder ein rein motorisches Programm mit Kraft- und Gleichgewichtsübungen zweimal pro Woche (**Kapitel 5**) oder besuchten weiterhin die in den Altersheimen angebotenen Aktivitätsprogramme (**Kapitel 4**). Vor Beginn und nach Beendigung der 12-wöchigen Trainingsphase wurden die Gruppen jeweils auf ihre Gehleistung (**Kapitel 4** und **5**), ihre Fähigkeit der willentlichen Ausführung eines Schrittes unter Single- und Dual-Task-Bedingungen (**Kapitel 4**) und die Genauigkeit ihrer Fussplatzierung beim Gehen (**Kapitel 5**) getestet und miteinander verglichen.

Die Resultate beider Interventionsstudien zeigten positive Effekte in der Ausführung der körperlichen Tests zugunsten der Tanzgruppe. Es resultierten eine signifikante Verminderung der Schrittnitierungs- und Schrittausführungszeit bei der willentlichen Ausführung eines Schrittes unter Dual-Task-Bedingungen (**Kapitel 4**), eine signifikante

Zunahme der Gehgeschwindigkeit unter Dual-Task-Bedingungen und eine signifikant positive Veränderung der Genauigkeit der Fussplatzierung innerhalb der Tanzgruppe **(Kapitel 5)**.

Die Beobachtungen aus den beiden Interventionen bekräftigen die Hypothese, dass ein körperliches Trainingsprogramm, welches durch ein interaktives und Aufmerksamkeit förderndes Computerspiel im Vergleich zu traditionellem Training zu einem wichtigen positiven Nutzen für die körperliche Leistungsfähigkeit von älteren Menschen unter Dual-Task-Bedingungen führen kann. Ein Trainingsprogramm, welches zum Ziel hat die körperliche Leistungsfähigkeit unter Aufmerksamkeit fördernden Bedingungen zu verbessern, sollte ein zusätzliches kognitiv anspruchsvolles Element in die Kraft- und Gleichgewichtsübungen integrieren. Dies idealerweise in Form eines interaktiven Computerspiels, welches auf die Fähigkeiten und Bedürfnisse der älteren Menschen zugeschnitten ist. Allerdings bleibt noch unklar in welchem Ausmass der zusätzliche kognitive Input für die beobachteten positiven Veränderungen der körperlichen Leistungsfähigkeit der Teilnehmer in den vorgestellten Studien verantwortlich ist, was eine Legitimation für weitere Forschung in diesem Themengebiet ist.





# Danksagungen



Viele Leute haben zum Gelingen dieser Dissertation beigetragen. Im Folgenden möchte ich mich bei denjenigen Leuten bedanken, die mich während der Zeit meines Doktorats am Institut für Bewegungswissenschaften und Sport der ETH Zürich begleitet, unterstützt und die Zeit so angenehm gestaltet haben.

Ein besonderer Dank gilt meinem Betreuer **PD Dr. Eling de Bruin**. Ich möchte mich bei Dir für die einzigartige Unterstützung bedanken. Du hattest immer ein offenes Ohr für alle Arten von Fragen und Problemen, ganz besonders auch in der letzten Phase meiner Arbeit, in der ich nicht mehr am Institut anwesend war. Auch hast Du mich immer wieder mit Deinem unerschöpflichen Optimismus angesteckt wenn es darum ging schwierigen Reviewern entgegenzutreten und eine passende Lösung zu finden. Danke für die Ermöglichung an zahlreichen internationalen Kongressen teilzunehmen und die Einbindung in das alljährliche MOBEX Meeting, welches mir ermöglicht hat, meine ersten Schritte in der Präsentation der eigenen Resultate vor einem fachkundigen, aber toleranten und hilfsbereiten Publikum zu vollführen. Danke auch für Deine unkomplizierte Art, die es einem ermöglicht auch bei der Arbeit viel Spass zu haben und nicht immer alles so ernst zu nehmen.

Beim Institutsleiter und meinem Co-Referenten **Prof. Dr. Kurt Murer** möchte ich mich dafür bedanken, dass er mir die Möglichkeit gegeben hat, am IBWS meine Doktorarbeit zu schreiben. Kurt, insbesondere möchte ich mich bei Dir bedanken, dass Du am IBWS eine lockere, freundschaftliche und verständnisvolle Atmosphäre unter allen Mitarbeitern ermöglichst, wa ich sehr schätze.

Herr **Prof. Dr. David P. Wolfer**, bei Ihnen bedanke ich mich, dass Sie sich bereit erklärt haben als Co-Referent für meine Doktorarbeit zu fungieren. Danke für Ihre Offenheit sich auch mit Themen, welche ausserhalb Ihres Fachgebietes liegen zu begeistern.

Ohne die Mitarbeiter des IBWS wären die letzten vier Jahre nur halb so angenehm gewesen:

**Regula und Yvonne:** Danke für die tolle Administrationsarbeit und eure Hilfsbereitschaft – auch schon in den guten 'alten' Zeit im Kellersekretariat im ETH-Hauptgebäude.

**Rolf:** Danke für Deine Unterstützung bei technischen und statistischen Fragen im Rahmen meiner Studien. Ich bewundere Dich für Deine kreative Herangehensweise bei solchen Dingen. **Laura:** Danke für Deine Gastfreundschaft und den vielen selbstgemachten Leckereien mit denen Du uns regelmässig verwöhnt hast. **Brigitte:** Danke für Deine Unterstützung bei wissenschaftlichen Fragen und Dein leckeres Johannisbeerkuchen-Rezept. **Jessica:** Danke, dass ich Dir gleich am ersten Arbeitstag den Fensterplatz „klauen“ durfte. Danke für die gute Zeit als Nachbarn und auch für die Zeit, in der uns ein hohes Bücherregal trennte. **Simon:** Danke für unsere manchmal sinnvolle, aber auch sinnlose Diskussionen über Gott und die Welt. Dank Dir werde ich nie mehr vergessen die Hintergrundebene im Photoshop zu duplizieren. Der Dank geht auch an **Sara, Monika, Roger, Roli und Oli**, die zum guten Arbeitsklima am IBWS beigetragen haben.

Ganz besonders möchte ich mich bei meinen 'Doktoratsgspänlis' bedanken:

**Andrea** wir haben die Hochs und Tiefs des 'Doktorandendaseins' fast vom selben Tag an zusammen durchlebt. Wir haben immer versucht, uns gegenseitig so gut es ging zu helfen. Ich danke Dir für die tolle Zeit, die wir miteinander am Institut erleben durften. Dank für Deine Hilfsbereitschaft, Deine Echtheit und Dein Vertrauen Sam während Deinen Experimenten hüten zu dürfen und Deine Offenheit während unseren Gesprächen über Dinge, die das Leben so mit sich bringt. Ich hoffe Du konntest von mir eine kleine Portion 'Ironie' mit auf den Weg nehmen. Liebe **Eva**, heute denke ich nicht mehr, dass wir als die 'dümmsten' Doktoranden in der Geschichte der ETH eingehen werden, denn wir haben in den gemeinsamen Jahren am IBWS viel erarbeitet und geleistet. Bewundert habe ich dabei immer Deine Zielstrebigkeit und Dein Organisationstalent. Ein grosses Dankeschön für Deine Mithilfe bei den Tests und für das Einspringen beim Leiten von Trainingslektionen. Danke für Deine Mithilfe in der Organisation der Probanden und Räumlichkeiten für die Durchführung der Reliabilitätsstudie in Feusisberg, das weiss ich sehr zu schätzen. Ich wünsche Dir für Deine Zukunft als Mami und Geschäftsfrau von Herzen alles Gute. **Rahel** Du warst der sichere Wert am IBWS. Wenn alle schon den Feierabend genossen oder frei machten, warst Du noch mit mir im Büro. In der Zeit am Institut haben wir viele



Gemeinsamkeiten entdeckt, z. B. das Ärgernis von 'Nespresso-Kapseln-stecken-lassen-bis-sie-so-fest-kleben-dass-sie-nicht-mehr-von-alleine-runterfallen'. Du hattest in Deinem ersten Jahr leider etwas Pech mit Deinem Thema, ich wünsche Dir für Deinen zweiten Anlauf alles Gute und viel Erfolg. Danke auch Dir **Seline** für die gemeinsame Zeit am IBWS. In der kurzen Zeit konnte ich Dich als eine warmherzige, aufgestellte und fleissige Person kennenlernen. Unsere Aufenthalte in Trondheim und Manchester und unseren Ghetto-Gruss am Morgen und am Abend werde ich in guter Erinnerung behalten. Auch Dir viel Erfolg bei Deiner Arbeit und 'keep on running'. Lieber **Patrick**, leider hatten wir nicht oft die Gelegenheit uns besser kennenzulernen. Ich wünsche Dir alles Gute für Deine Doktorarbeit und danke, dass Du meine Arbeit mit den Tanzplatten am Institut weiterverfolgst.

Ein spezieller Dank geht auch an **Andrew Fraser**. Ich bin Dir sehr dankbar für das englische 'proof-reading' des Manuskripts dieser Doktorarbeit. Bleibe weiterhin so interessiert und begeistert für neue Themen.

Danke auch an alle, die im Rahmen der Studien mitgeholfen haben, sei es bei der Mithilfe bei der Durchführung der Tests, bei der Leitung der Trainingsstunden oder bei der Bereitstellung der Räumlichkeiten: **Amos Coppe, Angela Nägeli, Tatjana Diener, Simone Karmann, Turgut Gülay, Manuela Nötzli, Melanie Ramp, Rosina Landolt, Susan Brouwer, Gerhard Ineichen, Marie-Louise Sarraj, Hans van het Reve** und danke allen Teilnehmern und Mitarbeitern des Alterszentrum am Etzel in Feusisberg, des Zentrum Breitenhof in Rüti, des Alterszentrum Lanzeln in Stäfa, der Altersheime Limmat und Stampfenbach in der Stadt Zürich.



# PhD Curriculum



## PhD Curriculum

### Peer-reviewed publications:

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.

Pichierri G, Wolf P, Murer K, de Bruin ED. **Cognitive and cognitive-motor interventions affecting physical functioning: A systematic review.** *BMC Geriatrics* 2011,11:29.

Pichierri G, Coppe A, Lorenzetti S, Murer K, de Bruin ED. **The effect of a cognitive-motor intervention on voluntary step execution under single and dual task conditions in older adults: a randomized controlled pilot study.** *Clinical Interventions in Aging,* 2012:175–184.

Pichierri G, Murer K, de Bruin ED. **A cognitive-motor intervention using a dance video game to enhance foot placement accuracy and gait under dual task conditions in older adults: a randomized controlled trial.** *BMC Geriatrics* 2012,12:74.

Pichierri G, Diener T, Murer K, de Bruin ED. **Assessment of the test-retest reliability of a foot placement accuracy protocol in assisted-living older adults.** *Gait & Posture* 38 (2013) 784–789.

### Other publications:

Slavko R, Pichierri G, de Bruin ED. **Denk-Sport – Dual-Tasking-Training mindert Sturzrisiko.** *Physiopraxis* 2011, 10:34-37 & *Ergopraxis* 2012, 3/12.

**Presentations:**

**Oral presentation** at the *1<sup>st</sup> Joint World Congress ISPGR and GMF* in Trondheim (Norway), June 28<sup>th</sup>, 2012: "The effects of computer game dancing on voluntary step execution in older adults".

**Oral presentation** at the *15<sup>th</sup> MOBEX Meeting 2012* in Zurich, Switzerland, January 13<sup>th</sup>, 2012: "The effects of a cognitive motor exercise intervention on voluntary step execution and step accuracy in older adults".

**Oral presentation** at the *14<sup>th</sup> MOBEX Meeting 2011* in Glasgow, Scotland UK, January 14<sup>th</sup>, 2011: "Cognitive and cognitive-motor interventions affecting motor functioning of older adults: a systematic review".

**Poster presentation** at the *16<sup>th</sup> annual Congress of the European College of Sport Science (ECSS)* in Liverpool UK, July 7<sup>th</sup>, 2011: "Cognitive and cognitive-motor interventions affecting motor functioning of older adults: a systematic review".

**Poster presentation** at the *4. Jahrestagung der Sportwissenschaftlichen Gesellschaft der Schweiz (SGSS)* in Magglingen, Switzerland, March 1–2, 2012: "The effect of a cognitive-motor intervention on voluntary step execution under single and dual task conditions in older adults: a randomized controlled pilot study".

**Visited congresses:**

**3<sup>rd</sup> International Congress on Gait & Mental Function** – The interplay between walking, behavior and cognition. Washington D.C., USA, February 26–28, 2010.

**14<sup>th</sup> MOBEX Meeting 2011** in Glasgow, Scotland UK, January 14–15, 2011.

**16<sup>th</sup> annual Congress of the European College of Sport Science (ECSS)**, Liverpool, England UK, July 6–9, 2011.

**15<sup>th</sup> MOBEX Meeting 2012** in Zurich, Switzerland, January 13–14, 2012.

**1<sup>st</sup> Joint World Congress ISPGR and GMF** in Trondheim (Norway), June 24–28, 2012.

**16<sup>th</sup> MOBEX Meeting 2013** in Manchester, England UK, January 13–14, 2013.







# Curriculum vitae



## About the author

<b>Name</b>	Giuseppe Pichierra
<b>Date of birth</b>	July 6 <sup>th</sup> 1979 in Bülach, Switzerland
<b>Citizen of</b>	Niederglatt, Zurich, Switzerland Sava, Taranto, Italy

### Education

2009 – 2014	<b>PhD in Science</b> at the Institute of Human Movement Sciences and Sport, ETH Zurich, Switzerland
2006 – 2008	<b>Master of Science Degree</b> in Human Movement Sciences and Sport ETH Zurich with Major in Motor Control and Motor Learning
2002 – 2006	<b>Bachelor of Science Degree</b> in Human Movement Sciences and Sport, ETH Zurich
1995 – 2000	<b>Academic Upper Secondary School</b> , Matura Type D (modern languages)

### Master thesis and academic internships

01 – 07/2008	<b>Master thesis</b> ETH Zurich, Switzerland “Factors related to the reduced physical activity in patients with hematological malignancies” In collaboration with the University Hospital Zurich
09 – 12/2007	<b>Academic internship II</b> in oncological rehabilitation in the Clinic for Rheumatic Diseases and Physical Medicine at the University Hospital Zurich, Switzerland
03 – 06/2007	<b>Academic internship I</b> in neuropsychology at the Institute for Neuropsychology of the University of Zurich, Switzerland