Cognitive and Cognitive-Motor Interventions Affecting Motor Functioning of Older Adults: A Systematic Review

Giuseppe Pichierri, Peter Wolf, Kurt Murer, Eling D. de Bruin

1 Institute of Human Movement Sciences and Sport, ETH Zurich, Switzerland
2 Department of Mechanical and Process Engineering, ETH Zurich, Switzerland

§Corresponding author

Email addresses:

GP: pichierri@move.biol.ethz.ch
KM: murer@move.biol.ethz.ch
PW: wolf@mavt.ethz.ch
EDdB: debruin@move.biol.ethz.ch
Abstract

Background:
Several types of isolated 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 motor skills in older adults or people with cognitive impairments. 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 and adult patients with brain injuries or cognitive impairments. 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, mental imagery, virtual reality exercise, cognitive exercise, or a combination of these.

Results:

28 articles met our inclusion criteria. Three articles used an isolated cognitive intervention strategy, seven articles used a dual-task strategy and 19 applied a computerized game-like strategy. There is evidence to suggest that cognitive or motor-cognitive methods positively
affects motor functions, such as postural control, walking abilities and general functions of the upper respectively lower extremities. 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 motor-cognitive interventions to improve motor functions in older adults or people with cognitive 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.
Background

Health status is an important indicator of quality of life among older adults [1, 2]. Health-related fitness and functional performance, or chronic conditions and diseases that directly influence the components of fitness and performance, are related to perceived health among middle-aged and older adults [2-4]. Even in the absence of overt pathology, functional performance [cf. International Classification of Functioning (ICF) by the World Health Organisation, Geneva (see http://www.who.int/classification/icf)] can deteriorate, as is illustrated by the incidence and impact of falls in older adults [5]. Functional status is by far the most important factor affecting quality of life and healthcare utilization in old age [6].

An increased incidence of falls has a major impact on mobility impairment among older adults. A fall often causes hip fractures, head injuries, and fear of falling. Persons with a walking disability, e.g. due to impaired balance abilities, have an increased risk of repeated falls [7]. Disability and fear of falling both lead to the loss of independence [8]. The loss of independence, the reduction in the level of activity and a decrease in level of confidence constitute the major costs for the individual [9].

Age-related deteriorations in balance abilities have been attributed to decreases in sensory or motor system function [10]. Until recently gait was considered as being an automated motor activity requiring minimal higher-level cognitive input [11]. 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 [12]. 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 [13]. 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 [14]. Recent research indicates that the influence of motor and sensory impairments on falls is in part moderated by the executive functions [15] and, thus, some of the causes of gait disturbances might also be attributed to changes in the executive functions [11], e.g., changes in divided attention [16, 17]. These findings imply that in addition to physical forms of training, we should possibly also consider cognitive training strategies that aim to influence walking behavior of older adults.

Falls in balance-impaired older adults rarely occur during walking only, but rather during walking when simultaneously performing a second task, e.g. talking or manipulating an object [10, 18]. It seems that the higher the dual-task costs for task performance are, the higher the risk of falling. Critical dual-task costs can easily be observed: older adults who stop walking when starting a conversation are more susceptible to fall than those who do not stop [19]. This observation highlights the need of interventions that focus on the risk of falls among older adults by reducing the dual-task costs of walking. Effective interventions should theoretically focus on both physical and cognitive aspects [11]. The question remains, however, what the best strategies are, that can support achieving this aim.

Several types of isolated cognitive or combined cognitive-motor interventions that might be able to improve executive functioning have been proposed in the past: cognitive interventions,
improving cognitive function through the use of (virtual reality) computer games, training of
dual-tasking abilities, and pharmacological therapies [11, 20].

Cognitive interventions have been developed to ameliorate cognitive problems experienced by
healthy older adults [21, 22], and for adults suffering from traumatic brain injury [23-25], 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 motor
functioning. Specific motor imagery protocols seem to improve mobility in people with stroke
[26]. Playing of digital action games may also produce cognitive benefits for older adults [27]. It
is proposed as a training strategy that may transfer to physical activity related tasks, besides being
able to improve cognitive function [11]. Interventions using dual-tasking paradigms demonstrated
negative effects on postural control or gait while performing a concurrent cognitive task in older
adults, in patients with brain injury and Alzheimer’s disease. Several authors have suggested that
procedures to improve the dual-task performance of elderly should be included in fall prevention
programs [28]

The objective of this systematic review is to examine the literature regarding the use of cognitive
and cognitive-motor interventions to improve motor functioning. The aim is to identify strategies
that have the potential to affect motor functioning and that might be used in future intervention
type studies. The specific questions that we asked were: (1) what types of cognitive and
cognitive-motor interventions have been used to influence motor functioning of older adults or in
adults with impaired brain functioning (e.g., traumatic brain injury, stroke)? (2) What is the level
of evidence for cognitive and cognitive-motor interventions to influence motor 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 functions.
Methods

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 a second step, we developed an electronic search strategy. Individualized search strategies for the Medline/Premedline, PsycINFO, CINAHL and EMBASE databases were developed in collaboration with a librarian from the Medicinal Library of the University of Zurich. The search was focused on older adults and adult patients with brain injuries or cognitive impairments, since it has been shown that people with brain injuries show similar characteristics as older adults with an advanced aged-related cognitive decline. Like older adults, people with brain injuries show difficulties with postural balance or exhibit gait insecurities when performing dual-tasks [29, 30]. Older adults were people over the age of 65. The search was restricted to English, German and French language literature. There was no limitation of publication date or restriction by study design.

We used medical sub-headings as search terms, including terms for the population: *aged, elder, old, aging, brain/head/craniocerebral injury, trauma*; for cognitive aspects: *cognition, metacognition, learning, awareness, executive function*; for motor functions: *gait, walking, balance, movement, mobility, posture, motor function, accidental falls, training, exercise* and for the interventions of interest: *biofeedback, cognitive therapy, virtual reality, video game, action game, computerized, dual-task*. 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.

**Study collection**

After duplicate citations were removed, two reviewers (GP, EDbB) determined which articles should be included within the systematic review by scanning the titles, abstracts and keywords applying the inclusion and exclusion criteria (table 1). A study was considered eligible for inclusion in the review when it was examining the results of a cognitive or cognitive-motor intervention on motor functioning in people with traumatic brain injury and/or older adults. Cognitive or cognitive-motor interventions were defined as dual-tasking, mental imagery, virtual reality exercise, cognitive exercise, or a combination of these. Studies that evaluated 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.

Insert Table 1: “Inclusion and exclusion details”

**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 2 and 3).
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 of qualitative synthesis rather than meta-analysis.

**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 [31] 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 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 ($\beta = 70-80\% = 1$ 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 1.0 - 0.81 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 poor [32]. Disagreements were resolved by consensus.

The PRISMA-statement was followed for reporting items of this systematic review [33].
Results

Study selection

The search provided a total of 2349 references (figure 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. Thereafter 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 was representing an included article (n=1).

Insert Figure 1: ‘Flow diagram of study selection’

Characteristics of included studies

Of the 28 studies finally selected for the review 27 were published in English [34-61] and one in French [62]. The publication dates range from 1997 [58] to 2010 [39, 47, 60]. In 17 studies, participants were older adults partially with history of falls [38, 61], balance disorders [38, 53], with mild cognitive impairments [56] or osteoporosis [57]. Ten studies were concerned with patients after stroke [36, 40, 41, 45, 48, 54, 55, 59, 60, 62] and one study with traumatic brain injury patients [47].
From the 28 included articles three used an isolated cognitive intervention strategy [34, 41, 42], Seven articles used a dual-task strategy [49-53, 57, 61] and 19 applied a computerized game-like strategy [35-40, 43-48, 54-56, 58-60, 62]. From the seven articles concerning dual-tasking two articles arise from the same intervention [51, 52] leading us to regard it as one single study. In 22 studies, a cognitive intervention, dual-task training or a computerized game-like strategy were used as the only intervention for the participants [35-38, 40-43, 45-54, 57-61]. In six studies the interventions were applied as additional items to a traditional physical or balance training [34, 39, 44, 55, 56, 62]. The reported outcomes involved different assessments of balance, gait or functional mobility. Balance was assessed with the help of postural sway measurements [34, 35, 42, 43, 48, 53, 58, 62], with the Berg Balance Scale [34, 38, 40, 42, 44, 46, 51-55], with the Activities-specific Balance Confidence Scale [34, 38, 40, 42, 46, 51-53, 59], with the Functional Balance and Mobility test [35], with the Balance Index [54] and with one-leg-stance tests [50, 57]. Gait measurements included measurements of kinematic parameters [34, 39-41, 51, 52, 59, 61], the Timed Up & Go Test [34, 38-40, 53, 55, 57], the Dynamic Gait Index [38, 40, 53], or step-recording with pedometers [49]. Functional Mobility assessments were determined by manual ability measurements [36, 45], functional reach tests [55], the Physical Performance Test [56], the Rivermead Motor Assessment [48], The Nottingham 10 Point ADL Scale [48], the Box and Block Test [36, 45, 47] and the Fugl-Meyer Assessment of Upper Limb Motor Function [41, 45, 60, 62].

Insert Table 2 and 3 “Study characteristics”

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 4 summarizes the results of the quality assessment per training strategy: dual-tasking, behavioral interventions, and the use of (virtual reality) computer games.

**Insert Table 4 “Quality Assessment”**

**Strategies and their effects**

**A. Cognitive strategy**

From the three articles evaluating the effects of a cognitive intervention on motor outcomes, two examined the effects of mental imagery on motor functions of older adults aged between 65 and 90 years [34, 42]. In the third study, the participants were community-dwelling adults between 44 and 79 years of age suffering from hemiparetic stroke [41]. The three studies investigated the effect of mental imagery training on postural balance [34, 42] and on gait [34, 41]. 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 [42], twice weekly [34] to
three times weekly [41]. Two studies used a pure cognitive method [41, 42] whereas one study combined mental practice with additional physical exercise [34].

The studies show reduction of postural sway [42], and improvements in gait speed [34] and gait symmetry [41]. No improvements were shown for balance confidence [34].

Hamel and Lajoies’ [42] results show a significant reduction of antero-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. [34] 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 (TUG) 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. [41] 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.

B. Dual-task strategy

The methods varied from walking or balancing with a concurrent mental task like memorizing words, reciting poems, or computing mental arithmetic tasks [51-53, 57, 61] to a Square-Stepping
Exercise where participants executed forward, backward, lateral and oblique step patterns on a thin felt mat [49, 50]. The training lasted between 4 weeks [51-53], 6 weeks [61] or 12 weeks [49, 50, 57]. No dual-task study was found on stroke patients or people with traumatic brain injury. The study of Shigematsu et al. [49] showed improvements in functional fitness of lower extremities. The results on gait patterns and postural sway are controversial. Silsupadol et al. [51-53] showed improvement of gait speed under dual-task conditions and a reduction of body sway, whereas You et al. [61] and Vaillant et al. [57] 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. [51-53] 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 [61] 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 mediolateral and anteroposterior centre of pressure were found between the groups. Vaillant et al. [57] 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. [49, 50] developed an alternative approach to exercise for dual-task abilities in community-dwelling older adults. The 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 SSE-group showed a greater improvement in functional fitness of the lower-extremity.

C. Computerized game-like strategy

Nineteen studies investigated the effects of a computerized game-like strategy to improve motor functions. The studies were distributed over the populations of interest as follows: nine interventions treating older adults [35, 37-39, 43, 44, 46, 56, 58], nine interventions treating
patients with stroke [36, 40, 45, 48, 54, 55, 59, 60, 62] and one study treating young adults with traumatic brain injury [47]. Fifteen studies investigated the effects on lower extremities [35, 37-40, 43, 44, 46, 48, 54-56, 58, 59, 62], whereas four studies analyzed the effects on upper extremities [36, 45, 47, 60]. The interventions included various methods and ideas for the implementation of computers into a training session. Talassi et al. [56] used a computerized cognitive program [63, 64], 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. [37] 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 [37].

Seven studies used the method of computerized dynamic balance training with visual feedback technique [43, 44, 46, 48, 54, 58, 62]. The tasks required to move through weight-shifting a cursor on a screen representing the centre of pressure (COP) position to specified targets [35, 44, 46, 54, 58] or on a predefined sine wave trajectory [43]. In one study, the feedback signal displayed the weight distribution and weight shifting with moving columns, showing stance symmetry [48]. In another study researchers designed the task of visual feedback training in a more playful way, projecting the cursor for centre of pressure as a caterpillar moving on the screen [62].

A total of ten studies described an approach which included interactive virtual reality games or applications [35, 36, 38-40, 45, 47, 55, 59, 60]. Seven studies out of this ten were conducted on stroke patients [35, 36, 40, 45, 55, 59, 60], two studies on older adults [38, 39] and one on patients with traumatic brain injury [47]. 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 [35] or saving a ball as a soccer keeper.
Virtual devices consisting of a semi-immersive workbench with which participants were able to reach and interact with three-dimensional objects [36], a table-top virtual-reality based system requiring the patients to move an object to cued locations while receiving augmented movement feedback [47] and virtual-reality based treadmill training [59]. Furthermore, commercially available low-cost interactive video game console systems [38, 40, 55, 60] or dance simulation games [39] were applied.

The computerized cognitive training program proposed by Talassi et al. [56] produced an improvement in functional status, measured by the Physical Performance Test [65], 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. [37] 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 [35, 46] postural balance and stability [35, 46, 48, 54, 58, 62], gait speed [54], functional status, and performance [46, 48, 54, 62]. The intervention conducted by Hatzitaki et al. [43] revealed that weight-shifting training in antero/posterior direction only induces improvements in standing balance of older adults. In contrast, the studies of Lajoie et al. [46] and Bisson et al. [35] showed no improvements in postural sway after computerized balance training in older adults. Hinman and colleagues [44] 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. [62] 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 [45]. Older adults benefited from training in terms of improved functional abilities, postural control and simple auditory reaction times [35]. 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 [36].

A virtual reality-based treadmill intervention conducted by Yang et al. [59] 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 [38, 40, 55, 60]. Three of them were case studies and exemplified that a training with a commercially available computer game system can be applied for older adults [38] and for the treatment of balance problems after stroke [40, 55]. 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 [55]. The activities on the Nintendo Wii console were selected to practice balance, coordination, strengthening, endurance or bilateral upper extremity coordination [38, 40].
Subjects very much enjoyed the interventions resulting in better balance and mobility performance [38, 55], improvements in gait speed, gait endurance and balance [40]. A recently published study using the Nintendo Wii console [60] resulted in improvements in upper extremity functions in post stroke patients.

A study conducted by de Bruin et al. [39] 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.

**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 motor-cognitive strategies to improve motor skills of older adults and of adults with brain impairments.

Our search resulted in relatively few studies that evaluated a cognitive or a motor-cognitive approach. Twenty-eight articles were found including studies with older adults or patients with cognitive impairments. Our results show that the method of combining physical exercise with cognitive elements to improve motor skills is not yet systematically part of the current interventions for older adults or patients with cognitive 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 motor-cognitive interventions positively affect the motor functions, 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 strategies applied in more detail.

**Cognitive strategies**

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 [66]. Brain-imaging studies showed that comparable brain areas are activated during actual performance and during mental rehearsal of the same tasks [67, 68]. Hamel and Lajoie’s [42] 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 only that applied mental imagery. In one study [34] improvements of motor abilities were shown in both the intervention and the control group and in a second study [41], a missing control group made it impossible to assess whether improvements in motor function were attained through mental practice or not. Thus, as for now it is not possible to determine whether an isolated cognitive intervention based on mental imagery is able to improve motor functions in older adults. A narrative review concludes that several studies have demonstrated the effectiveness of mental imagery in improving motor performance of other populations than older adults [66]. 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.

**Dual-task strategies**

Research has shown that dual-task training 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 [35]. The included studies showed that it was generally feasible to apply dual-task training, 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 motor functions. Two studies included relatively simple cognitive tasks like computing or reciting poems. Both studies showed no improvements in motor functions that were clearly attributable to dual-task training.

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. [51-53] and Shigematsu et al. [49, 50] applied a more challenging way of attentional 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 [69].

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 strategy studies 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 training on motor functioning are controversial. In addition, analogue to the cognitive method, the limited number of studies performing dual-task training hampers a generalization of results.

**Computerized game-like strategies**

Computerized game-like methods varied from force platforms with visual biofeedback with relatively simple graphics [43, 44, 46, 48, 58, 62], 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 [35, 37, 45, 59]. 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 [38-40, 55, 60]. The study quality of the computerized game-like 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 studies, however, the results of the computerized game-like studies showed a consistent positive effect on various motor functions in older adults, patients with traumatic brain injury or stroke patients. Computerized game-like 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 game-like setting in comparison to conventional physical training programs. Computerized game-like 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 [27], 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 [60]. The visual aspect is crucial since with aging, vision remains important in maintaining postural control [70]. Virtual environments have also the potential to specifically include motor learning enhancing features that activate motor areas in the brain [71]. In addition You and colleagues suggest that virtual reality training could induce reorganization of the sensorimotor cortex in chronic patients [72].

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 game-like method constitutes a powerful tool to provide participant repetitive practice, feedback about performance and motivation to endure practice [73]. 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 [74] 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 [75]. 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 [76]. 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 [20].

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 [7]. 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 [77]. Interventions should, as previous research suggests, focus thereby on executive functioning processes [15], and in particular on the executive function component divided attention [17], 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 [78]. This review encourages the further development of VR interventions,
preferably with a randomized control design. Future research that aims to examine the relation
between VR 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
[17], and are dependent of the nature of the task investigated (preferred versus fast walking).

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 game-like design, does not specifically mention
or is even not aware of the potential cognitive aspects of their interventions.

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.

Conclusions

The current evidence on the effectiveness of cognitive or motor-cognitive interventions to improve motor functions 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 motor function. 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 game-like design, does not specifically mention or is even not aware of the potential cognitive aspects of their interventions.

Competing interests

The authors report no conflicts of interest.
Author’s contribution

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.

Acknowledgments

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.
References


Figures

Adobe PDF file:

Figure 1 – Study selection flow chart

Tables

MS Word files:

Table 1 – List of inclusion and exclusion details

Table 2 - Included studies reported by design and subject specifications

Additional files

MS Word files:

Table 3 - Included studies reported by subjects, outcome measures, intervention, control and results

Table 4 - Assessment of methodological quality
Figure 1 – Study selection flow chart

References identified through database searching (n = 2349)

Excluded duplicates (n = 652)

Articles screened on basis of title and abstract (n = 1697)

Excluded (n = 1671)
- Not outcome or population of interest (n = 89)
- Physical exercise (n = 129)
- Effects of physical exercise on cognition (n = 16)
- Reviews, discussions, no intervention etc. (n = 217)
- Tests (n = 246)
- Out of scope (n = 244)

Eligible for full-text reading (n = 26)

Additional records identified through citations and author tracking (n = 10)

Full-text reading and application of inclusion criteria

Excluded (n = 8)
- No mini (n = 4)
- Not outcome of interest (n = 1)
- Theoretical article (n = 2)
- Poster presentation of included article (n = 1)

Included (n = 28)

Dual-task strategy (n = 6)

Computerized game-like strategy (n = 19)

Cognitive strategy (n = 3)
Table 1 – List of inclusion and exclusion details

<table>
<thead>
<tr>
<th>Area</th>
<th>Inclusion details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>Any elderly subjects over 60 years, adult (aged &gt; 18 years) brain trauma patients</td>
</tr>
<tr>
<td>Study type</td>
<td>Intervention studies of any type, including case studies and non-randomized trials</td>
</tr>
<tr>
<td>Intervention</td>
<td>Cognitive or cognitive-physical intervention (physical exercise must include a cognitive strategy)</td>
</tr>
<tr>
<td>Outcomes</td>
<td>Outcomes focus on general motor function and mobility of upper or lower</td>
</tr>
</tbody>
</table>

**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
Table 2 - Included studies reported by design and subject specifications

<table>
<thead>
<tr>
<th>STUDY</th>
<th>DESIGN</th>
<th>N</th>
<th>SUBJECTS</th>
<th>AGE range or mean (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batson et al 2006</td>
<td>RCT</td>
<td>6</td>
<td>Community dwelling older adults</td>
<td>65 - 80</td>
</tr>
<tr>
<td>Dunsky et al 2008</td>
<td>Non-RCT</td>
<td>17</td>
<td>Community dwelling adults with hemiparetic stroke</td>
<td>44 - 79</td>
</tr>
<tr>
<td>Hamel &amp; Lajoie 2005</td>
<td>RCT</td>
<td>20</td>
<td>Older adults</td>
<td>65 - 90</td>
</tr>
<tr>
<td>Shigematsu et al 2008</td>
<td>RCT</td>
<td>63</td>
<td>Community dwelling older adults</td>
<td>65 - 74</td>
</tr>
<tr>
<td>Silsupadol et al 2008</td>
<td>RCT</td>
<td>21</td>
<td>Older adults</td>
<td>75.0 ± 6.1</td>
</tr>
<tr>
<td>Vaillant et al 2006</td>
<td>RCT</td>
<td>13</td>
<td>Older adults</td>
<td>68.3 ± 6.5</td>
</tr>
<tr>
<td>You et al 2009</td>
<td>Pre-Post</td>
<td>24</td>
<td>Community dwelling older adults</td>
<td>VR: 74.4±3.65; BF :74.4±4.92</td>
</tr>
<tr>
<td>Broeren et al 2008</td>
<td>Pre-Post</td>
<td>22</td>
<td>Community dwelling adults with stroke</td>
<td>67.0 ± 12.5</td>
</tr>
<tr>
<td>Buccello-Stout et al 2008</td>
<td>Pre-Post</td>
<td>16</td>
<td>Older adults</td>
<td>66 - 81</td>
</tr>
<tr>
<td>Clark et al 2009</td>
<td>Case study</td>
<td>1</td>
<td>Woman resident of a nursing home with unspecified balance disorders</td>
<td>89</td>
</tr>
<tr>
<td>de Bruin et al 2010</td>
<td>Two groups control</td>
<td>35</td>
<td>Older adults living in a residential care facility</td>
<td>IG: 85.2±5.5; CG: 86.8±8.1</td>
</tr>
<tr>
<td>Deutsch et al 2009</td>
<td>Case study</td>
<td>2</td>
<td>Chronic phase post-stroke</td>
<td>34 and 48</td>
</tr>
<tr>
<td>Hatzitaki et al 2009</td>
<td>RCT</td>
<td>48</td>
<td>Community-dwelling healthy older women</td>
<td>70.9±5.7</td>
</tr>
<tr>
<td>Hinman 2002</td>
<td>RCT</td>
<td>88</td>
<td>Community-dwelling older adults</td>
<td>63 – 87</td>
</tr>
<tr>
<td>Jang et al 2005</td>
<td>RCT</td>
<td>10</td>
<td>Patients with stroke</td>
<td>57.1±4.5</td>
</tr>
<tr>
<td>Kerdoncuff et al 2004</td>
<td>RCT</td>
<td>25</td>
<td>Patients with stroke</td>
<td>59.5±13.5</td>
</tr>
<tr>
<td>Lajoie 2003</td>
<td>Case study</td>
<td>24</td>
<td>Community-dwelling elderly</td>
<td>IG: 70.3; CG: 71.4</td>
</tr>
<tr>
<td>Mumford et al 2010</td>
<td>Pre-Post</td>
<td>42</td>
<td>Community dwelling older adults</td>
<td>42 - 91</td>
</tr>
<tr>
<td>Sackley et al 1997</td>
<td>Case study</td>
<td>20</td>
<td>Patients with stroke</td>
<td>77.7±6.5; TC: 77.7±5.6; CG: 75.2±4.9</td>
</tr>
<tr>
<td>Srivastava et al 2009</td>
<td>Pre-Post</td>
<td>45</td>
<td>Patients with stroke</td>
<td>45.5 ± 11.2</td>
</tr>
<tr>
<td>Sugarman et al 2009</td>
<td>Pre-Post</td>
<td>1</td>
<td>Patient with stroke</td>
<td>86</td>
</tr>
<tr>
<td>Talassi et al 2007</td>
<td>Pre-Post</td>
<td>16</td>
<td>Rehabilitation inpatients within 3 months post-stroke</td>
<td>64.5±9.6</td>
</tr>
<tr>
<td>Wolf et al 1997</td>
<td>Case study</td>
<td>3</td>
<td>Patients with stroke</td>
<td>20, 20 and 21</td>
</tr>
<tr>
<td>Yang et al 2008</td>
<td>RCT</td>
<td>20</td>
<td>Patients with stroke</td>
<td>30 - 74</td>
</tr>
<tr>
<td>Yong Joo et al 2010</td>
<td>Pre-Post</td>
<td>16</td>
<td>Rehabilitation inpatients within 3 months post-stroke</td>
<td>64.5±9.6</td>
</tr>
</tbody>
</table>

Abbreviations: CGL = Computerized game-like strategy; COG = Cognitive strategy; DT = Dual-task strategy; RCT = Randomized Controlled Trial; Non-RCT = Non-randomized Controlled Trial; TC = Tai Chi; VR = Virtual reality; BF = Biofeedback; IG = Intervention Group; CG = Control Group
CINAHL  
(n = 641)

EMBASE  
(n = 979)

Medline  
(n = 626)

PsychINFO  
(n = 103)

References identified through database searching  
(n = 2349)

Excluded duplicates (n = 652)

Excluded (n = 1671)  
- Not outcome or population of interest (n = 89)  
- Physical exercise: (n = 159)  
- Effects of physical exercise on cognition: (n = 16)  
- Reviews, discussions, no intervention etc.: (n = 217)  
  - Tests: (n = 246)  
  - Out of scope (n = 944)

Articles screened on basis of title and abstract (n = 1697)

Eligible for full-text reading (n = 26)

Additional records identified through citations and author tracking (n = 10)

Full-text reading and application of inclusion criteria

Included (n = 28)

Excluded (n = 8)  
- No training (n= 4)  
- Not outcome of interest (n=1)  
- Theoretical article (n = 2)  
- Poster presentation of included article (n=1)

Dual-task strategy  
(n = 6)

Computerized game-like strategy  
(n = 19)

Cognitive strategy  
(n = 3)

Figure 1
Additional files provided with this submission:

Additional file 1: Table 3_Oversview of Included Studies.doc, 108K  
http://www.biomedcentral.com/imedia/5169010044822449/supp1.doc  
Additional file 2: Table 4_Quality Assessment.doc, 141K  
http://www.biomedcentral.com/imedia/2083356103482244/supp2.doc