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The Interplay between Cognitive and Motor Functioning in Healthy Older Adults: Findings from Dual-Task Studies and Suggestions for Intervention

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Key Words

Cognition · Motor functioning · Exercise · Intervention · Dual tasks

Abstract

Reaching late adulthood is accompanied by losses in physical and mental resources, but lifestyle choices seem to have a considerable influence on the aging trajectory. This review deals with the interplay between cognitive and motor functioning in old age, focusing on two different lines of research, namely (a) dual-task studies requiring participants to perform a cognitive and a motor task simultaneously, and (b) intervention studies investigating whether increases in physical fitness also lead to improvements in cognitive performance. Dual-task studies indicate that healthy older adults show greater performance reductions in both domains than young adults when performing a cognitive and a motor task simultaneously. In addition, older adults often tend to protect their motor functioning at the expense of the cognitive task when the situation involves a threat to balance. This can be considered an adaptive behavior since fall-related injuries can have severe consequences. Fitness intervention studies which increased the aerobic fitness of previously sedentary older adults have demonstrated impressive performance improvements in the cognitive domain, espe-

cially for tasks involving executive control processes. These findings are interesting in light of cognitive intervention studies, which often fail to find significant transfer effects to tasks that have not been trained directly. The authors argue that future research should compare the effects of cognitive and aerobic fitness interventions in older adults, and they present a study design in which cognition and fitness are trained sequentially as well as simultaneously. Finally, methodological issues involved in this type of research and potential applications to applied settings are discussed.

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Introduction

Due to demographical changes in industrialized countries around the world, an increasing proportion of the population reaches late adulthood. Aging successfully, however, not only entails reaching a very old age, but also being able to live independently and to actively follow one's interests. To achieve this, it is necessary to remain 'fit', both physically as well as mentally.

This paper deals with the interplay between cognitive and motor functioning in old age, focusing on two different lines of research, namely (a) dual-task studies which require participants to perform a cognitive and a motor

task simultaneously, and (b) intervention studies which investigate whether increases in physical fitness also lead to improvements in cognitive performance. The literature review in the section on cognitive-motor dual tasks primarily focuses on studies which have been conducted in the Sensorimotor-Cognitive Couplings project at the Max Planck Institute for Human Development in Berlin. The interested reader is referred to Wollacott and Shumway-Cook [1] and Schaefer et al. [2] for more comprehensive reviews of the literature. The section on intervention studies includes a newly developed study design to be implemented by the Gerontopsychology Research Unit at the University of Zurich. The final section discusses some methodological problems encountered in this type of research and suggests future directions as well as potential practical implications.

Simultaneous Performance of Cognitive and Motor Tasks in Late Adulthood

To remain mobile and functionally independent in old age is not a trivial task, given that aging is accompanied by decline in mental [3], physical [4] and sensory abilities [5]. Such decline leads to performance decrements in many different cognitive tasks, with fluid intellectual abilities like cognitive speed, memory, reasoning abilities and executive control tasks showing a steeper age-related decline than crystallized abilities like knowledge of vocabulary or word fluency [6]. In addition, seemingly automatized motor tasks like walking or keeping one's balance require more cognitive resources in late adulthood than at younger ages due to declining visual and auditory acuity and reduced muscle strength and joint flexibility. This aging-induced merging of motor functioning with cognition [7] makes it particularly difficult for older adults to master situations in which a cognitive and a motor task must be performed concurrently. For example, an 80-year-old might refrain from keeping up a conversation while crossing a busy street in order to pay attention to the traffic and any potential obstacles on the way.

Dual-task studies are often interpreted in relation to the concept of 'resources' [8], which can be conceptualized as general information processing abilities, like for example cognitive speed, working memory capacity or attention span [9]. Resources are expected to be limited, and when they have to be shared between two concurrent tasks, performance in one or both tasks can deteriorate. For the assessment of cognitive-motor dual-task situations in different age groups, Li et al. [10] recommend us-

ing laboratory settings similar to everyday life situations, assessing single- and dual-task performances for both tasks involved, and using difficulty levels of the two component tasks which do not lead to floor or ceiling effects in the age groups under investigation. The following studies took these considerations into account. In addition, they all compared a group of healthy young adults, aged between 20 and 30 years, to a group of healthy older adults, aged between 60 and 75 years, concerning their ability to perform a cognitive and a motor task simultaneously. The central assumption was that older adults should show more pronounced performance decrements than young adults in the dual-task situation since their motor functioning requires more attentional resources than in young adulthood. Furthermore, in situations in which neglecting the motor performance might lead to harmful consequences (e.g. a fall), older adults were predicted to prioritize their motor functioning at the expense of cognitive performance.

Lindenberger et al. [7] trained young (20–30 years), middle-aged (40–50 years) and old (60–70 years) adults to encode word lists using a particular memory strategy until each individual reached a prespecified criterion. The motor task consisted of walking on two narrow tracks which differed in complexity (one oval track and one with a more complex path) as fast and accurately as possible. Participants were asked to encode the word lists while sitting, standing and walking on the two tracks. Walking speed and accuracy were measured under single-task conditions (walking with no concurrent tasks) and while encoding the word lists. A proportional measure for dual-task costs was used, expressing performance reductions under dual-task conditions in relation to each individual's single-task performance. In general, dual-task costs were larger with increasing age, indicating that motor tasks such as walking require increased cognitive control with advancing age. When the difficulty of the motor task was increased, performance of the concurrent cognitive task deteriorated, with greater dual-task memory loss on the complex track than on the oval track.

Using a similar combination of tasks, Li et al. [11] also had younger and older adults walk on an oval track while encoding word lists. The authors extended the paradigm by introducing difficulty manipulations of the two tasks as well as by offering compensation opportunities for the increased task difficulties under some conditions. In the more difficult version of the tasks, participants were asked to walk over obstacles on the track, and the inter-stimulus intervals for encoding individual words were shortened. The task difficulty was adjusted individually

for each participant under single-task conditions. Compensatory external aids were provided for some trials in the form of (a) a button which could be pressed to prolong encoding times and (b) a handrail which could be used while walking on the track. There were pronounced age differences in the dual-task costs for memory, with older adults showing greater losses than younger adults. For the walking task, however, losses were comparably high for both age groups. This was interpreted as an adaptive allocation of resources in the elderly since prioritizing the motor domain in demanding dual-task situations might protect them from falls. In addition, when given a choice of which external aid to use, older adults optimized walking, whereas younger adults optimized memory performance. This pattern of adaptive resource allocation, shifting attention to the motor task when the situation becomes challenging, has also been demonstrated by children [12], and it seems to be preserved in older adults suffering from Alzheimer's disease as well [13].

To investigate performance tradeoffs in the domain of spatial navigation, Lövdén et al. [14] asked younger and older men to walk on a treadmill while navigating through a virtual museum projected onto a screen in front of them. Their task was to reach the museum's bistro twice in a row via the shortest possible route. In order to do this, they had to explore the museum and create a mental map of the shortest route once they had found it. In some conditions, participants were allowed to use a handrail while walking on the treadmill. The path-finding performance of the younger adults was superior to that of the older adults. Furthermore, the older men demonstrated increased body sway while walking under cognitive load as compared to walking with no navigation task, whereas there were no differences in body sway for younger men under either set of conditions. In addition, handrail use increased navigational performance in older but not in younger men, indicating that lowering the attentional demands of walking by providing a handrail helps older adults, who must concentrate more on the motor task.

However, cognitive-motor dual-task situations do not always lead to performance decrements. A study by Huxhold et al. [15] required younger and older adults to sway as little as possible while standing on a force plate. The dependent measure for balance performance was the area covered by the center of body pressure (COP) over time, with smaller areas representing a better balance performance (less body sway). Various cognitive tasks were assessed under single- and dual-task conditions, namely a two-choice reaction time task, a 2-back working memory task with digits, and a spatial 2-back working memory

task. Participants performed the cognitive tasks while sitting on a chair (single-task condition) and while standing on the force plate (dual-task condition). There was also a condition in which participants were instructed to sway as little as possible while simply watching a series of digits presented on the screen in front of them. Cognitive performances did not differ between sitting and standing. For the balance task, older adults showed larger COP areas than younger adults, but both age groups reduced their body sway when watching digits on the screen as compared to balancing with no cognitive task. This indicates that focusing one's attention exclusively on a motor task which is usually performed automatically can lead to performance decrements. When the cognitive load was increased by presenting more difficult cognitive tasks, older adults increased their body sway again. This resulted in an inverted U-shaped relationship between the efficacy of postural control and concurrent cognitive demands, and it supports the notion that older adults have to invest more attention into their motor functioning than young adults, who continued to show reduced levels of body sway even when the difficulty of the concurrent cognitive task was high.

Similar findings were obtained in a study by Lövdén et al. [16], in which younger and older adults were asked to walk on a treadmill while performing a working memory task with four difficulty levels. For the n-back task, participants were presented with a series of digits via loudspeaker. In the easiest version, n-back 1, the participants were asked to compare the digit they heard to the previous one, whereas in the most difficult condition, n-back 4, they were required to compare the current digit to the one 4 back in the sequence. The regularity of their gait was measured by the variability of different spatio-temporal gait parameters such as stride length, stride time and walking velocity. Similar to the findings by Huxhold et al. [15], both younger and older adults showed less gait variability when walking with an easy cognitive task, as compared to walking with no cognitive task. Younger adults decreased their gait variability further with increasing cognitive load (n-back 2–4), while older adults showed stability or increases in gait variability under these conditions. These findings were substantiated by Verrel et al. [17], who used a different measure of gait stability, principal component analysis, which separates regular from irregular components of whole-body motion.

Altogether, cognitive-motor dual-task studies comparing young and old adults support the assumption that older adults need to concentrate more on their motor

functions, leading to more pronounced performance decrements in a dual-task situation than in young adulthood. In addition, the elderly tend to focus their attention on motor tasks in demanding dual-task situations which involve a risk to physical balance, possibly to avoid falls ('posture first' hypothesis) [18].

Positive Influence of Fitness Interventions on Cognitive Functioning in Late Adulthood

Fitness intervention studies also investigate the interplay between cognitive and motor functioning, with the underlying assumption that increases in physical fitness also lead to beneficial effects on cognitive functioning. As opposed to the dual-task studies investigating performance changes in both task domains, the fitness intervention studies assume that increases in motor performance (physical fitness) will increase cognitive performance, and not vice versa. In these studies, previously sedentary elderly participants take part in an exercise training regime that enhances their aerobic fitness (e.g. via walking, swimming or cycling). The control group also exercises but follows a training regime which does not lead to increases in aerobic fitness (e.g. stretching, toning or strength training). Following the intervention, cognitive performances are compared to the baseline performances before training. Colcombe and Kramer [19] conducted a metaanalysis based on 18 such studies in older adults. They reported impressive improvement in cognitive performance via aerobic fitness training (0.5 standard deviations on average). The benefits of aerobic fitness training were greatest for rather difficult cognitive tasks involving executive control processes, but fitness-related benefits were reliable for visuospatial tasks and tasks involving controlled processes as well. Benefits were also greater for training regimes which lasted for more than 6 months and for longer than 30 min in each individual training session, for those which combined aerobic and strength training, for samples which included more female than male participants, and for participants aged 66–70 years as compared to younger or older participants.

These results indicate that aerobic fitness training can enhance the cognitive vitality of older adults. This is supported by animal studies showing that aerobic fitness positively influences brain metabolism and neurogenesis in mice and rats [20–23], and by human brain imaging data indicating that aging-related declines of neural tissue can be counteracted by a high level of aerobic fitness

[24, 25]. Apparently, training regimes which increase the physical fitness of older adults can, at least to a certain extent, 'turn back the clock' and reverse some of the negative effects of biological aging, and they may also lead to an increase in cognitive performance.

These findings are especially interesting in light of cognitive intervention studies with older adults, which often demonstrate impressive improvements in the trained cognitive task but little transfer to untrained tasks [26]. For example, old and very old adults show substantial performance improvement in remembering word lists after practicing a memory strategy to encode word lists [27–29], but their performances in other cognitive tasks do not improve reliably. It is therefore of great importance to the field of aging research to conduct studies which directly compare the effects of cognitive and aerobic fitness training in order to determine which training regime is most helpful for various kinds of cognitive performances and specific populations.

To our knowledge, there are three studies which have integrated cognitive and cardiovascular training tasks into one training for combining the positive aspects of both types of training tasks [30–32]. In the study by Fabre et al. [30], for example, participants aged 60–76 years attended 1 or 3 (subject to group membership) training sessions per week over a period of 2 months. Participants either participated in aerobic training, memory training, combined aerobic and memory training or a passive control group. The aerobic training session consisted of 60 min of brisk walking and/or jogging, and memory training entailed 90 min of mental training conducted on the basis of Israel's method [33]. Participants in the aerobic training attended 2 training sessions per week, whereas participants in the memory training group trained only once a week. The combined training group participated in all the aerobic as well as memory training sessions. All three training groups demonstrated a significant improvement in total Wechsler Scale score in contrast to the control group. Moreover, the combined training group demonstrated greater improvement in cognitive function on the memory quotient than the other two training groups.

Oswald et al. [32] obtained similar results. Although their physical and cognitive training as well as the age of their participants (75- to 93-year-olds as compared to 60- to 76-year-olds in the study by Fabre et al. [30]) and the amount of training differed from Fabre et al. [30], the findings were almost the same. They found that especially the combined physical and cognitive training group outperformed their counterparts in the control group

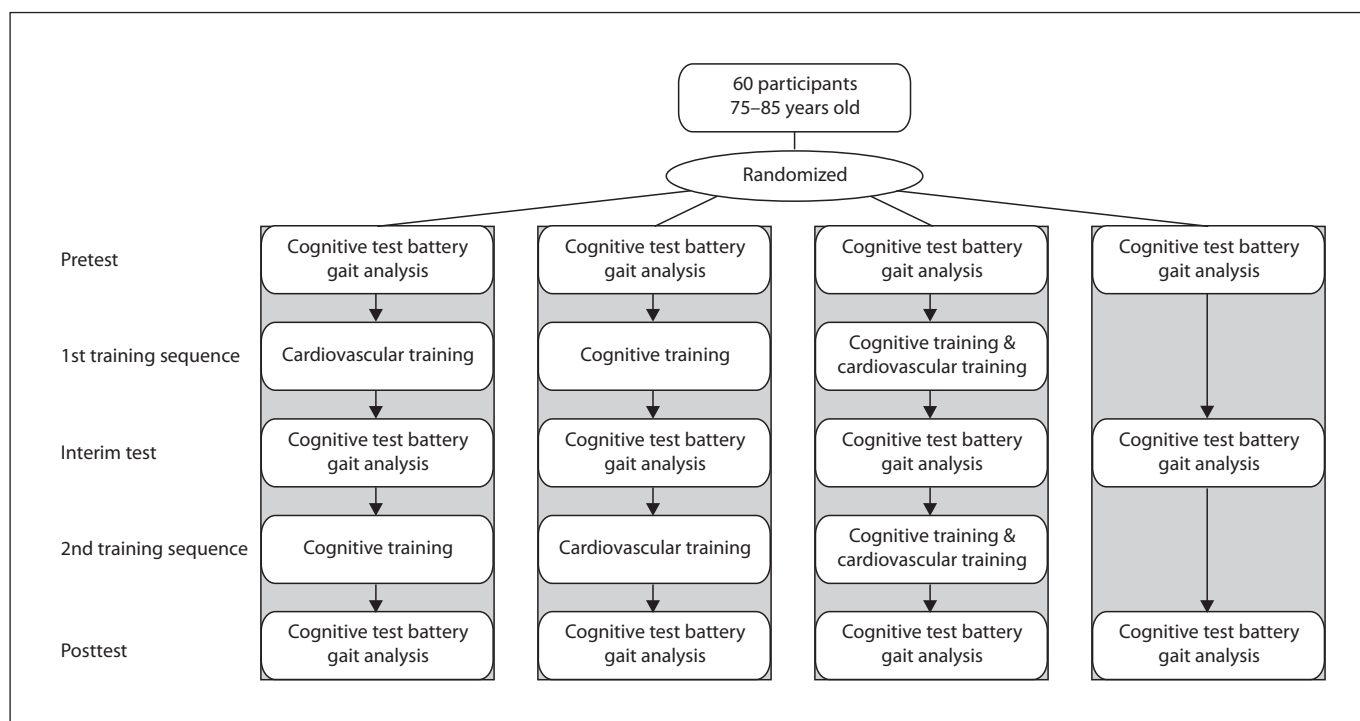


Fig. 1. Model of an intervention study combining motor and cognitive training [38].

over the long term. While these findings demonstrate a clear advantage of combined training over single-task training, this is not the case for the results found in the training study by O'Dwyer [31]. Although the exercise group taken together with the combined exercise and cognitive training group displayed significant improvements in memory compared to the control group, the performance of the two training groups did not differ significantly. The differences in findings should not be overinterpreted due to differences in the variables investigated. The different training groups are hardly comparable with each other since the duration of the various training sessions vary considerably. In the study by Fabre et al. [30], for example, the mental training group attended 1 training session per week in contrast to the physical training group and the combined training group, who attended 2 and 3 training sessions per week, respectively. The training study by Oswald et al. [32] was conducted using the same approach. However, in contrast to the Fabre study, the participants were required to perform the physical and cognitive training in the same training session. In the study by O'Dwyer [31], the participants of both the exercise and the combined exercise and cognitive training groups received 3 training sessions per week.

Whereas the exercise group attended 3 physical training sessions per week, the combined training group only participated in 2 physical training sessions with an additional cognitive training session per week. Therefore, it is not clear how strongly the different outcomes of the studies have been influenced by unequal exposure to physical and cognitive training tasks, and the positive effect of combining both trainings cannot be separated from these unequal exposure times.

Design of an Intervention Study Combining Cognitive and Fitness Training in Older Adults

In order to get a clearer picture of the effects of combined cognitive and motor interventions in late adulthood, the Gerontopsychology Research Unit of the University of Zurich is currently planning an intervention study in which subjects participate in combined training. Both training tasks, cognitive and motor, are designed to activate the same brain region, namely the cerebellum [34–36]. Cognitive training consists of verbal working memory tasks, and motor training consists of treadmill walking. In the cognitive training, participants are re-

quired to perform an adaptive n-back task [37] as well as an adaptive verbal serial position task. Both of these cognitive training tasks are designed in a way that they can be performed either in single-task as well as in dual-task conditions. As for the motor training, participants must walk on a treadmill at a speed which will lead to improvements in cardiovascular fitness. The goal of this study is to train the oldest old. However, since the cognitive as well as the motor trainings are highly demanding, an age limit of 85 years is envisaged. In order to obtain a preferably homogenous age group, an age range of 10 years is defined. Participants will be randomly assigned to 1 of 4 groups: one group must perform the treadmill training sessions first and then the verbal working memory training sessions, the second group must do the verbal working memory training sessions first and then the treadmill training sessions, the third group performs the verbal working memory training simultaneously with the treadmill training in all training sessions, while the fourth group acts as the control group (fig. 1). In this way, it should be possible to measure the effect of the training sequence as well as of the training condition, single versus dual task. While the variation of the training sequence allows identifying the effect of cognitive activation on motor training and the other way round, the dual-task condition gives insight into a new training approach (simultaneous training). It is assumed that by performing the two tasks simultaneously, brain activity of and around the cerebellum should be stronger and therefore should lead to a greater training benefit in the learned task as well as in near and far transfer tasks. To examine the effect of the different types of training on different cognitive abilities, participants are tested before, during and after the training program with regard to the following age-sensitive variables: processing speed, working memory, executive control, episodic memory and fluid intelligence. In contrast to the previously mentioned studies [30–32], in this study all three training groups are exposed to the same amount of cognitive and motor training, which allows for a distinct differentiation between the training effects in all three training groups, eliminating the confounding variable of ‘training exposure’.

Methodological Issues and Ideas for Future Research

The methodological considerations by Li et al. [10] concerning the assessment of cognitive-motor dual-task performances in age-comparative settings have been pre-

sented above. In the following section, we outline several methodological issues that we consider important for future intervention studies.

Concerning intervention studies that include a fitness training regime, the fitness training should tax the cardiovascular system to the extent that aerobic fitness is likely to improve [19], e.g. by using walking, jogging, swimming or cycling as an intervention. The heart rate should be monitored and controlled during exercise to adjust exercise intensity for each individual. Furthermore, positive outcomes are likely to increase if participants in fitness interventions have led sedentary lives in the months and years prior to the intervention since people who engage in regular physical activity are less likely to profit from additional training. Training regimes should be long and intense enough to lead to measurable improvements in aerobic fitness (e.g. lasting for several months, with 3 or more training sessions per week), and those fitness improvements should be documented by performances on standardized tests before and after the intervention (e.g. estimating maximum oxygen consumption while cycling to exhaustion).

If the study design includes a comparison of fitness with cognitive interventions, the specific type of cognitive training administered should fulfill several requirements to enhance transfer to other tasks. As has previously been shown, transfer is more likely to occur if task difficulties are adjusted adaptively in the course of training, and if individual feedback is offered after each trial [26]. Furthermore, if combined training regimes are included in the study design, i.e. if there are participants who take part in both the cognitive and the fitness trainings, either sequentially or simultaneously, it is important that equal time is given to both. If aerobic fitness training requires individual training sessions to last for at least half an hour in order to achieve any effect, then a cognitive training session should be given about the same amount of time. In addition, if there is a group doing both types of training simultaneously, it is of course necessary to find cognitive and motor tasks which can actually be administered that way (e.g. it is simply not possible to perform a word fluency task with verbal responses while swimming). In the same way, based on the findings from cognitive-motor dual-task research in older adults, the balance requirements of the motor task should be minimized so as not to create an additional problem for this age group. Pre- and posttest assessments including cognitive-motor dual-task situations which have not directly been trained would indicate whether the ability to perform such tasks has also improved by the combined train-

ing, and whether it can be transferred to other more or less similar task combinations. As in any study focusing on intervention effects, it is important to consider issues such as selective dropout rates (e.g. one of the training regimes is more likely to lead to high dropout rates) and the identification of suitable transfer tasks.

Conclusions and Implications for Applied Settings

We have presented two lines of evidence for a close interrelationship of cognition and motor functioning in late adulthood, namely dual-task studies combining a motor and a cognitive task, and fitness intervention studies reporting cognitive performance improvements following an aerobic fitness training in late adulthood. Older adults often show more pronounced performance decrements than younger adults in demanding cognitive-motor dual-task situations (e.g. walking on a narrow track while memorizing word lists [7, 11]) and tend to protect their motor functioning by showing greater dual-task costs in the cognitive domain when balance and physical integrity are at stake [11, 13, 14, 18]. This can be considered an adaptive behavior according to the theory of selection, optimization and compensation [11] since it protects from fall-related injury and harmful consequences.

In applied settings, cognitive-motor dual-task situations might be used with healthy older adults as diagnostic tools to assess limits of performance [39] and to identify situations that might involve a risk to balance. How-

ever, it should be kept in mind that dual-task situations do not necessarily lead to performance decrements [15–17] and that there might be situations in which healthy older adults even profit from the concurrent performance of an easy cognitive task. Identifying dual-task situations which are particularly problematic or particularly advantageous for elderly individuals may be of help to those who design interventions adjusted to individual needs.

From the authors' point of view, the positive influences of aerobic fitness interventions on cognitive functioning in late adulthood have great potential for improving the lives of older adults in modern societies. In the face of physical and mental decline with advancing age, leading a more active life might help to optimize an individual's aging trajectory [26], not only by improving health and physical wellbeing, but also by slowing down or even reversing some of the biological effects of the aging process [24, 25] and their negative consequences on cognition. This should be taken into account not only by therapists working with elderly populations, but also by the interested layperson with the goal of 'aging gracefully'. Future research should aim at elucidating the mechanisms responsible for favorable outcomes.

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