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Integration of Cognitive and Physical Resources in Cognitive Development of Older Adults

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Abstract

Cognitive development in old age is characterized by a decline in many cognitive abilities such as speed of processing or working memory. In addition, different physical resources such as physical fitness or sensorimotor performance decrease as well during the aging process. Although some biological determinants may account for parts of the parallel development in both cognitive and physical resources, there is also a direct interaction between these resources, with abilities in both domains being able to affect performance in the other domain. An association between physical fitness and cognitive performance in old age has often been reported in both cross-sectional and longitudinal studies. This is in accord with the finding that as most physical activities involve cognitive processes, a decline in cognitive ability should be accompanied by declines in motor performance. In fact, a direct interaction between cognitive and physical resources can be observed during motor-cognitive dual-tasks requiring the integration and recruitment of both resources. In this regard, motor performance such as maintaining gait is usually impaired in the presence of an additional demanding cognitive task, and this effect is larger for older adults and in particular for older adults with cognitive impairments. The performance decrease in specific resources, thereby, represents an adaptation allowing the individuals to successfully perform the task when one or more resources are impaired. However, most studies so far have focused on motor performance and only little is known about the dual-task-related adaptation in cognitive performance of older adults.

Cognitive plasticity, which characterizes the individuals' potential for both compensation and change, persists up to extreme old age. This explains why, although a general average decline of cognitive abilities in old age is observed, there are a lot of inter-individual differences in cognitive performance of older adults. In fact, an active lifestyle with both cogni-

tive and physical stimulation is associated with higher cognitive functioning and specific training of both cognitive and physical resources has been shown to induce neuroplasticity and improve cognitive abilities of older adults. In this context, process-based training of working memory as well as cardiovascular training produces the most promising effects of specific training interventions. However, findings from both behavioral and brain imaging studies demonstrate overlapping as well as distinct effects of cognitive and physical training on cognitive abilities. Therefore, combining cognitive and physical training could be complementary and provide synergistic effects that go beyond the training effects of one or even two of the components alone. So far only a few studies have investigated the effect of combining cognitive and physical training, providing controversial results. As a consequence, there is still little knowledge about the integration of cognitive and physical resources in cognitive development of older adults with respect to both adaptation and potential for change.

This thesis provides two empirical studies that investigate the integration of cognitive and physical resources in old age. The first study aimed at investigating the adaptation to motor-cognitive dual-task conditions in terms of both motor and cognitive performance. In addition, adaptation was compared between cognitively healthy and impaired older adults. To that end, a representative sample of 711 participants performed two different dual-task conditions of walking and simultaneously performing either a working memory task or a semantic memory task. The same tasks were also conducted under single-task condition. For both cognitively healthy and impaired individuals, results showed a significant reduction of gait velocity during both dual-tasks and performance decrease in the working memory task but not in the semantic memory task. Dual-task-related reduction of gait velocity was larger for the cognitively impaired group, whereas reduction in the working memory task was even larger for the cognitively healthy group. In conclusion, adaptation to motor-cognitive dual-task situations depends on the type of the cognitive task and cognitively impaired individuals predominantly exhibited a reduction in motor performance. This unilateral dual-task adaptation of cognitively impaired individuals could, on the one hand, represent a less functional adaptation to complex task situations, but, on the other hand, also reflect a compensational strategy to maintain gait safety.

The second study in this thesis integrates cognitive and physical training within a new and functional training approach with the objective to improve cognitive performance and adaptation to motor-cognitive dual-tasks. Previous studies combining cognitive and physical training interventions only performed the cognitive and physical trainings separately. As a consequence, potentially positive effects of coordinating multiple training efforts simultaneously are neglected. The present study investigates the effects of simultaneous training of both cognitive and physical resources. Sixty-three healthy older adults either performed a simultaneous verbal working memory training and cardiovascular training on a treadmill, only performed the working memory training, or attended no training at all. Both the simultaneous and single cognitive training group showed similar improvements in the trained task and in the executive control transfer task as compared to the passive control group. In comparison, the simultaneous training group exhibited greater improvement in the paired-associates task than the single training group. In addition, the simultaneous training group also improved their performance in the motor-cognitive dual-task to a greater extent than the single cognitive and passive control group. In conclusion, the simultaneous training of cognitive and physical abilities presents a successful training concept improving cognitive as well as motor-cognitive performance. Moreover, the training is more efficient, as physical resources are trained in parallel, without impairing the training progress in the cognitive task. In conclusion, trainings integrating different abilities should have greater effects on daily life functioning, which usually involves the recruitment of multiple abilities and resources rather than a single one.

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1 Introduction [1]

The demographic trend of the next years and decades in the more developed regions of the world shows an increasing life expectancy with older adults being the fastest growing group of the population (Dlugosz, 2011; United Nations, 2009). Currently, one quarter of the population is aged 60 years and older, but estimations for the year 2050 assume that this ratio is almost going to double (United Nations, 2009). Therefore, investigation of development during the aging process becomes more important than ever. In particular, the development of cognitive and physical resources and the contributing factors to promote healthy aging are of great interest to society, the pension insurance, the health care systems, and not least to the aging population itself. Therefore, the present thesis focuses on the development of cognitive abilities in old age, and how the integration of cognitive and physical resources is associated with cognitive development. At the beginning, theories of cognitive development in old age are described, followed by theories of co-development and interaction of cognitive and physical resources. The subsequent chapter then relates to adaptation of older adults when different resources are impaired. Finally, the concept of cognitive plasticity and the potential of both cognitive and physical resources to affect plastic changes in old age are introduced. Based on these findings, two empirical studies are presented, which investigate the integration of cognitive and physical resources in old age. In the first study, the adaptation of older individuals to situations requiring the integration of both physical and cognitive resources depending on cognitive impairment is investigated. The second study integrates both cognitive and physical training into a new simultaneous training approach to promote cognitive development in old age. The thesis concludes with a general discussion of the findings and results of these studies and an outlook on future research, including an overview of promising methods to transfer measurement techniques out of the laboratory into real life settings.

[1] Parts of this chapter are published as book section in the book „Old Age in Europe: A Textbook of Gerontology“ (Martin, M. Theill, N., Schumacher, V., 2013).

1.1 Cognitive development in old age

Cognition is composed of multiple abilities, which demonstrate different developmental courses (multidimensionality), and the mean levels of most cognitive abilities decline differentially across adulthood (Park et al., 1996). Most theories provide a categorization of cognitive abilities into two types of intelligence. Age-related declines predominantly occur in measures of fluid intelligence such as speed of processing, working memory, cued and free recall, reasoning, or verbal fluency. Although the declines are much more evident for older adults, age-related effects can be observed across the entire adulthood (Verhaeghen & Salthouse, 1997). In contrast, performance in tests of crystallized intelligence (Horn & Cattell, 1967), i.e., experience- and culture-dependent non-speeded performances such as vocabulary normally increases quickly after mastering language and then more slowly across the lifespan well into very old age. That is, despite the general tendency of decreases in cognitive abilities, some individuals maintain or even increase their cognitive abilities in old age. More generally, cognitive aging can be characterized by inter-individual differences, generational differences, multidimensionality, and multidirectionality (Baltes & Schaie, 1976). Even though there are many differences in cognitive development, changes in a specific domain of measures of fluid intelligence have been shown to be related to changes in other cognitive domains (Wilson et al., 2002). This raises the question whether there is any common explanation for changes in cognitive abilities in old age that is able to differentiate between fluid and crystallized intelligence.

Currently, four main theories are used to explain the differential age-related changes in measures of fluid and crystallized intelligence. Salthouse (1991, 1996) proposed the processing speed theory, which assumes that the age-related differences in performance are the consequence of a general decrease in speed of performing mental operations. According to

Salthouse's theory, the slowing in processing speed is related to all aspects of cognition whether they have a speed component or not (Park, 1999). In a large meta-analysis, Verhaeghen and Salthouse (1997) demonstrated that processing speed has not only the largest cross-sectional correlation with age, it is a strong mediator for age-related differences in other cognitive measures such as episodic memory, reasoning, or spatial ability as well. A similar theory is the one developed by Craik and Byrd (1982). They argue that the age-related decline in cognitive functioning is due to reduced processing resources. Processing resources describe the ability to self-initiate processes and to manipulate and process information and are best measured by working memory tasks. The higher the resource demands of a task are, the more age differences become evident, whereas little or no age variance should occur in tasks requiring very low resource demands. Consequently, although both theories explain age differences in more complex cognitive performances requiring the integration of multiple elementary cognitive processes, it is only speed that accounts for the variance in less effortful memory tasks such as spatial memory (Park et al., 1996). Hasher and Zacks (1988) see the decline in inhibitory control, i.e., the ability to suppress currently irrelevant information or behaviors, as cause for cognitive deficits associated with age. According to this theory, older individuals have more problems to inhibit prior information from working memory, thus reducing the "work space" for new material (Glisky, 2007). Another approach is to relate changes in sensory functions such as visual and auditory acuity to age-associated changes in cognitive function. Lindenberger and Baltes (1997) found that both visual and auditory functions together can account for a large amount of the variation in intellectual functioning. These findings were the basis of the their "common cause hypothesis" (Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994), stating that sensory function, as a general marker of the intactness of the neurobiological architecture, is fundamental for all cognitive functions and has, when it declines, a generally negative effect on all cognitive abilities (Park, 1999). In particular, the studies of Baltes and Lindenberger (1997) and Lindenberger and Baltes (1994, 1997) revealed a higher correlation between these sensory functions and cognitive functions in older than in younger adults, as well as a higher inter-correlation between cognitive functions and a similar progress and decrease, respectively. These findings were also associated with the differentiation/dedifferentiation hypothesis of adult intellectual development (Baltes, 1997; Baltes, Staudinger, & Lindenberger, 1999), which describes a U-shaped development of cognitive abilities with a differentiation from childhood to adolescence and adulthood and a reversion of this process (dedifferentiation) from later adulthood to old age due to reduced physiological such as sensorimotor processes.

In recent years, a large field of research has further investigated potential correlates of cognitive decline with structural and functional brain changes. If biological determinants exist for cognitive development in old age, behaviorally relevant changes should be associated with brain changes. The role of specific brain regions being involved in certain cognitive abilities has been frequently reported, but the question is how aging affects global or specific changes in the brain and whether these changes are related to the age-related development of cognitive abilities. For example, prefrontal cortex (PFC), which is crucial for performing complex tasks involving planning and cognitive control (Miller, 2000; Miller & Cohen, 2001), undergoes the largest age-related volumetric change (Hedden & Gabrieli, 2004). Without going into too much detail, a recent review on this topic from Fjell and Walhovd (2010) describes a direct relationship of age-related structural differences in specific brain regions, such as for example PFC, frontal white matter, or cerebellum with age-related decline in specific abilities, such as for example working memory performance or executive functions. Moreover, a general mediating effect of white matter in age-related cognitive changes is assumed, which for example could account for the general slowing of processing speed with aging (Fjell & Walhovd, 2010). Although most of these findings rely on cross-sectional data, they still provide some insightful information about a potential age-related association between cognitive-behavioral and brain development. However, additional research is clearly needed to investigate this relationship in more detail, in particular incorporating the theories of cognitive aging mentioned above.

Although cognitive aging is typically associated with decline in a number of cognitive abilities, the previously described cognitive development has to be distinguished from pathological development and dementia such as Alzheimer, respectively, which is a disease that causes people to lose their cognitive ability faster than it would occur during the normal aging process and is associated with memory loss, confusion, and later also loss of physical functioning. However, as dementia is strongly age-related with an increasing prevalence with advancing age (Jorm & Jolley, 1998; Ritchie & Kildea, 1995), it has to be regarded as a part of the cognitive development in old age as well. Therefore, cognitive development in old age should always account for every cognitive aging progress that can be observed, including increase, maintenance, normal non-pathological decline, and pathological decline.

1.2 Co-development and interaction of cognitive and physical resources in old age

Development in old age is characterized by a decline in a number of different resources, whether they are specific cognitive abilities such as processing speed or working memory or physical resources, such as general physical health, physical fitness, or motor performance. In addition to an increased probability of occurrence for typical age-related diseases such as cardiovascular disease, there is a reduction in sensorimotor performance in the form of general slowing or decrements in balance or gait and physical fitness (Ketcham, 2001; Kraft, 2012). The co-development of different resources in the course of the aging process can be explained in different ways. Obviously, the decline of cognitive and physical resources could reflect the general aging of the body due to biological factors, which similarly affects both resources, as it corresponds to the aging theories of “common cause” or differentiation/dedifferentiation. In particular, the general slowing that is observed in both cognitive and physical performance could have a common origin. In addition, a highly correlated development of cognitive and physical resources is particularly evident in childhood and in old age, whereas developmental courses during adulthood are more differentiated.

However, although such biological determinants explaining some of the developmental courses of both resources certainly exist, there is strong evidence for a direct interaction between differences and changes in cognitive and differences and changes in physical resources, with abilities in both domains being able to affect performance in the other domain. A frequently reported physical resource supposed to influence cognitive abilities is physical fitness. A series of studies could demonstrate the association between fitness levels and cognitive performance of older adults, both on a cross-sectional and longitudinal basis (Barnes, Yaffe, Satariano, & Tager, 2003; Deary, Whalley, Batty, & Starr, 2006; Hillmann et al., 2006; Voelcker-Rehage, Godde, & Staudinger, 2010; Yaffe, Barnes, Nevitt, Lui, & Covinsky, 2001). In this regard, effects of physical fitness are observed on a global level of cognitive ability and especially in measures of executive functions (Barnes et al., 2003; Hillmann et al., 2006; Voelcker-Rehage et al., 2010).

Not only physical fitness but also motor fitness is related to cognitive ability in old age (Voelcker-Rehage et al., 2010). Moreover, different researchers have demonstrated declines in cognitive performance being accompanied by declines in motor performance (Kluger et al., 1997; Tabbarah, Crimmins, & Seeman, 2002). According to their findings from a longitudinal cohort study with healthy older adults, Tabbarah et al. (2002) conclude that physical tasks usually involve cognitive processes. For that reason, motor performance should always be affected by cognitive demand. An experimental evidence for this direct link between cognitive and motor performance comes from dual-task studies investigating motor performance such as balance or gait in the presence of additional cognitive task conditions. If motor processes were completely independent from cognitive processes, the performance of an additional cognitive task would not be able to affect the performance of the motor task. However, a series of studies demonstrated that integrating and simultaneously performing a cognitive and motor task such as walking is difficult for both cognitively healthy and impaired older individuals (Hausdorff, Schweiger, Herman, Yogev-Seligmann, & Giladi, 2008; Montero-Odasso et al., 2009; Priest, Salamon, & Hollman, 2008; Srygley, Mirelman, Herman, Giladi, & Hausdorff, 2009; van Iersel, Ribbers, Munneke, Borm, & Rikkert, 2007). In addition, cognitively impaired older individuals show additional problems during single as well as dual-task walking than those without impairment (Maquet et al., 2010; Sheridan, Solomont, Kowall, & Hausdorff, 2003). Typically, dual-task-related difficulties are reflected in a reduction of gait velocity or increased instability of gait and gait variability, respectively. What is more, both gait disturbances in the form of slowing and increased gait variability have been reported even for younger adults when simultaneously performing a cognitive task, albeit the effect was smaller (Priest et al., 2008). These results indicate that motor tasks such as gait are associated with cognitive abilities and this effect is more evident for older adults, in particular when cognitive ability is impaired. However, these findings only allow for a global perspective by distinguishing between age groups or healthy and clinical groups. For that reason, some studies aimed at a more accurate distinction between specific cognitive abilities in healthy older adults only. The role of executive functions was thereby emphasized for both single-task and dual-task gait (Ble et al., 2005; Coppin et al., 2006; Hausdorff et al., 2008; Springer et al., 2006; van Iersel et al., 2007), indicating at least some of the age-related declines in motor performance of gait being mediated by decline of executive functions associated with aging. Better performance in executive functions tasks was also reported for older individuals with higher motor fitness (Voelcker-Rehage et al., 2010). Therefore, global as well as specific cognitive abilities can be identified being involved in effective performance of a motor task during both single- and dual-task conditions.

These results clearly demonstrate the interdependence of cognitive and physical resources in the development of older adults. Therefore, cognitive development in old age both on an inter-individual and intra-individual level must not be addressed in isolation but rather should incorporate physical resources such as cardiovascular fitness or motor abilities.

1.3 Adaptation to reduced resources in old age

As development in old age is characterized by a decline of different resources, the aging individual has to make adaptations to still engage in his or her usual activities and to maintain his or her functional level. These adaptations usually meet the specific needs and goals of an individual and do not pursue the objective to keep a maximum functional level. This functional aspect demonstrates that adaptation can vary substantially depending on both the available resources and individual goals of an individual. Closely linked to this functional aspect is the model of functional quality of life (fQOL), which defines QOL as the integration of multiple subjective representations of the functionality of ones' resources (Martin, Schneider, Eicher, & Moor, 2012). That is, it assumes that QOL is higher, the more strongly individuals represent their resources as being principally functional to perform complex activities that serve individually central life or goal domains (Martin et al., 2012). Therefore, adaptations are made when the functionality of a specific resource or different resources is perceived as insufficient to achieve these goals. Adaptations can be done by reorganization of the environment, for instance by utilization of walking aids to account for motor decline, or of one's own behavior, for instance by allowing oneself more time to perform certain tasks to account for the general slowing.

One self-regulatory mechanism to achieve a successful and healthy personal development and adaption is the selective optimization with compensation (SOC) strategy (Baltes & Baltes, 1990). Selection refers to the process by which individuals choose tasks that are of high individual importance and that match their abilities. It is furthermore subdivided into elective selection (ES), which is guided by preference or social norms, and loss-based selection (LS), which refers to a shift in personal goals due to a loss of internal or external resources. This means that the process of selection leads to a narrowing of alternative options so that persons concentrate on a reduced range of achievable goals. Because of the loss of resources in old age the number of achievable goals usually decreases with increasing age (Baltes, 1997). To achieve a selected goal, individuals have to optimize their strategies by acquiring, refining and deploying resources. Optimization can be realized through training, learning new skills, and high motivation (Staudinger & Bowen, 2010). Compensation refers to acquisition and utilization of alternative means to reach given goals and keep performance at desired levels in face of actual or anticipated decreases in resources (Marcoen, Coleman, & O'Hanlon, 2007). A correct utilization of the SOC strategy should lead to better health, successful aging, and improved relationship quality (Freund & Baltes, 2002).

In the context of the SOC theory, both the utilization of a walking aid and allowing oneself more time is considered as compensation strategies. On the other hand, only to walk short distances or in a safe environment instead of using walking aids would represent an adaptation by selection, whereas doing strength training to maintain the ability to walk would be an adaptation by optimization. In old age, adaptations due to reduced resources are observed in many situations. The reduced gait velocity of older adults in particular under motor-cognitive dual-task conditions can also be interpreted as a compensation process. When confronted with a complex task requiring the integration and recruitment of different resources at the same time, a performance reduction in at least one of the underlying tasks can be regarded as a coping strategy to be able to successfully perform the task. The extent of this adaptation thereby depends on the available resources and occurs within the individuals' possibilities and the environmental demands. Depending on the demand of a situation, adaptations are made in different directions. Whereas walking and simultaneously talking to a person can be managed by reduction of motor performance in a simple walking condition, it is rather the conversation that is reduced when the walking condition is aggravated, so the motor task is prioritized to guarantee gait safety. With decreasing resources, resulting in higher requirements for the performance of each underlying task, the walking task is more preferred and the additional task performance is increasingly neglected. This prioritization of the motor has been shown in an experimental setting of dual-task walking with healthy older and younger adults, whereby dual-task costs for healthy older adults were higher for a cognitive task than for the walking condition (Li, Lindenberger, Freund, & Baltes, 2001). Additionally, older adults tended to optimize the walking performance when aids were offered, whereas the younger adults optimized cognitive performance. The authors interpret their findings in the context of the SOC theory, as the older adults were selecting the task that was more important to them as well as they rather chose a walking than the memory aid (Li et al., 2001). Accordingly, an adequate adaptation to different environmental demands denotes the successful coping with a complex task situation. Therefore, the inability to adequately adapt to a dual-task walking condition indicates an impaired functionality that further is supposed to be related to increased risk for falls in older adults (Bloem, Steijns, & Smits-Engelsman, 2003). As a consequence, the adaptation to reduced resources is an essential part of development in old age and the successful adaptation to situations requiring the integration of cognitive and physical resources is of particular relevance for an individuals' functional level, as many activities of daily life involve the simultaneous performance of cognitive and physical tasks.

1.4 Promoting cognitive development in old age

The process of normal aging generally involves a decline in cognitive abilities, but this does not imply that eventually everyone is going to lose his or her cognitive abilities or develop dementia. Whereas some individuals already show decline at an early age, others are able to maintain their abilities even up to a very old age. Accordingly, although age differences in cognitive abilities exist on an average level, both inter-individual as well as intra-individual variability increases with advancing age, indicating that there exists no predetermined decline of cognitive abilities after a certain point in time or state of development. To understand why some people show a decline in cognitive abilities or even suffer from dementia whereas others maintain their abilities to a large part or keep a functional level despite some losses, one must answer the question which individual or environmental resources may support successful cognitive aging or help to compensate in case some cognitive abilities decrease. The focus should, therefore, be on identifying these resources, the way they interact, and the factors that could contribute to strengthen them. Only this way is it possible to determine how the environment can be adapted to be adequate for different states of cognitive health or impairment. For that reason, the current chapter first introduces the concept of cognitive plasticity, which characterizes the individuals' potential for change and adaptation in cognitive performance, and provides an explanation for the observed variability in cognitive performance and the theoretical basis for any intervention that aims at improving cognitive abilities in old age. Subsequently, the potential for changes in cognitive development in old age through training of specific cognitive and physical resources is described. The chapter concludes with the consideration of integrating both cognitive and physical trainings.

1.4.1 Cognitive plasticity

One explanation to account for variability in cognitive ability of older adults is the concept of cognitive plasticity. Willis, Schaie, and Martin (2009) define cognitive plasticity as individuals' latent cognitive potential or individuals' cognitive capacity under certain specified conditions. On one hand, this can be understood as the existence of cognitive resources allowing the individuals to adapt and compensate for loss of certain abilities. In other words, the brain is able to utilize brain networks more efficiently or acquire new compensatory brain networks. In this case, cognitive plasticity can exist despite the fact that neuronal plasticity has been compromised (cognitive reserve) (Stern, 2002). In contrast to the passive models of brain reserve, which see reserve as the result of brain size and synapses, the theory of active cognitive reserve states that the brain actively copes with or compensates for pathology. This phenomenon has been observed in individuals with higher levels of intelligence and educational and occupational achievement. Whereas people with lower intelligence demonstrate functional deficits after brain damage, people in the same situation with a higher level of intelligence can maintain their performance level. Therefore, this cognitive reserve can be built up through an active lifestyle, which allows long-term plasticity even in old age (Stern, 2002). The large inter-individual variability of cognitive abilities in healthy older adults can be regarded as a result of different individual cognitive reserve, so the variability can particularly be observed when specific cognitive functions decline and the individual capacity to compensate becomes evident.

On the other hand, cognitive plasticity can be understood as the individuals' potential for change in cognitive ability and thus can result in both direction of increase and decrease.

In this case, the concept of plasticity is closely related to structural changes in the brain. In a positive direction, plasticity characterizes the individuals' capacity to improve, whereas an individually determined maximum limit exists at any age. Changes can be induced by the individuals' interaction with his or her environment, albeit the exact underlying mechanisms are still not well understood. According to the theoretical framework from Lovden, Backman, Lindenberger, Schaefer, and Schmiedek (2010), plastic changes are always triggered by a mismatch between the environmental demand and the individuals' supply in the form of functional capacity of the system. If the demand exceeds supply, adaptations are made to provide the necessary supply, for instance by developing new brain synapses, resulting in performance increase. Conversely, if the supply exceeds the demand, the same adaptations are made in the opposite direction, which leads to a decomposition of the brain and decrease of cognitive abilities. To allow for cognitive plasticity, this mismatch between demand and supply always has to be in the individual range of flexibility, so a highly demanding task might be able to induce changes in an individual with higher range of flexibility, whereas the same task fails to induce changes in an individual with a smaller range of flexibility (Lovden et al., 2010). Therefore, this framework explains both decrease and increase of cognitive abilities. It could also explain how the mentioned cognitive reserve can be realized through an active lifestyle, which provides the necessary demand for change. It further gives an indication how inter-individual variability can occur through the different demands of environments. The increased inter-individual variability observed with aging could reflect the fact that the demands of the environment become more different with increasing age. Whereas some individuals still attend an active lifestyle, others reduce their activities more and more, not at least due to reduction of their cognitive or physical resources. However, although plasticity in a positive sense persists up to a very old age, the relation between decline due to biologically determined decompositions and potential for increase of cognitive resources shifts to the disadvantage of the aging individual and the potential for increase is more limited than it is at a younger age (Baltes & Lindenberger, 1988; Baltes et al., 1999). Consequently, performance differences of cognitive abilities between younger and older adults rather become more evident when these specific abilities are improved through training (Kliegl, Smith, & Baltes, 1989). With respect to development in old age this means that cognitive plasticity not only denotes the potential for changes, but also the potential to maintain and stabilize cognitive abilities in the presence of age-related decline. Therefore, the target, at least on a long-term perspective, should not only be to improve but also to maintain and stabilize cognitive abilities in old age. However, from a subject's point of view, it is clearly more desirable to attend in activities aiming at improving rather than only maintaining abilities.

1.4.2 Factors promoting cognitive development

Based on these theoretical reflections on the individuals' ability to increase cognitive performance and build up cognitive reserve to compensate for loss, the question arises how cognitive abilities can be preserved up to an old age or even explicitly improved in old age. When inter-individual difference in old age are at least to some extent a result of different environmental conditions, conditions promoting cognitive development across adulthood and in old age should be able to be identified. Consequently, a number of factors have been investigated and identified which are associated with cognitive development of older adults. This clearly involves the active lifestyle mentioned above, including both cognitive and physical activities. In particular, engaging in cognitively and intellectually stimulating activities is often reported in association with higher cognitive abilities in old age (Ghisletta, Bickel, & Lovden, 2006; Hertzog, Kramer, Wilson, & Lindenberger, 2009). Moreover, cognitive and intellectual stimulation is one of the most reported protective factors related to dementia (Qiu et al. 2001; Wang et al. 2002; Wilson et al. 2002), for instance by providing the cognitive reserve needed to compensate for loss. As mentioned earlier, there is also an association between physical fitness and cognition in old age. In this regard, physical activity has not only been reported to be related to higher cognitive abilities in old age, but has also been found to act as a protective factor for cognitive decline and dementia as well (Larson et al., 2006; Laurin, Verreault, Lindsay, MacPherson, & Rockwood, 2001).

These findings raise the question whether attending cognitive and physical stimulating activities is able to directly improve cognitive abilities even in old age. Since plasticity in a positive sense still exists up to an old age, cognitive abilities of older adults should be able to be improved by training. Consequently, the discovered relation between cognitive and physical resources and cognitive development in older adults has initiated a number of intervention or training approaches that aimed at improving cognition of older adults. Both cognitive as well as physical training interventions thereby have been shown to induce neuroplasticity of the brain and successfully improve cognitive abilities of older adults, but the question is which cognitive abilities can be improved through strengthening of specific resources or abilities and whether training interventions exist that are able to improve general cognitive ability in old age. The following chapters thus address these questions by highlighting the most important findings in the field of cognitive and physical training interventions.

1.4.3 Training of cognitive resources

A large field of research has been concerned with improvement of cognitive abilities of healthy older adults through cognitive training interventions. So far, most cognitive training studies aimed at improving the general cognitive performance by training specific strategies or abilities. Although these trainings have been demonstrated to improve the targeted cognitive ability even over a long period of time (Ball et al., 2002; Willis et al., 2006), they have some deficiency generalizing to other task performances in older adults (Noack, Lovden, Schmiedek, & Lindenberger, 2009; Rebok, Carlson, & Langbaum, 2007). Moreover, even studies reporting on transfer to other task performances often involve only near transfer to similar tasks or abilities (Edwards et al., 2002; Li et al., 2008). One possible explanation for the lack of studies providing far transfer effects could be the type of the trainings, as trainings differ considerably in duration or frequency as well as in the tasks that are trained (Martin, Clare, Altgassen, Cameron, & Zehnder, 2011). With respect to the training tasks, cognitive trainings can be distinguished into strategy-based and process-based trainings. Whereas training gains of strategy-based trainings are rather task-specific, process-based trainings are more capable to produce transfer to other non-targeted performances (Lustig, Shah, Seidler, & Reuter-Lorenz, 2009; Zelinski, 2009). In particular, process-based training of working memory is promising, since working memory is closely connected with general intelligence (Conway, Kane, & Engle, 2003) and the capacity of working memory is an important component of cognitive plasticity (Verhaeghen, 2000). According to the described requirements for plasticity, a training task should always be within the individuals' range of flexibility to induce changes, so a successful training of working memory should provide a continuous adaptation of task difficulty or request (Lovden et al., 2010). Recently, a series of studies investigated the effect of such adaptive working memory trainings on cognitive performance in old age (Borella, Carretti, Riboldi, & De Beni, 2010; Brehmer, Westerberg, & Backman, 2012; Buschkuehl et al., 2008; Richmond, Morrison, Chein, & Olson, 2011). Buschkuehl et al. (2008) demonstrated that adaptive visual working memory training is able to improve not only visual working memory performance but also visual episodic memory of older adults. In their study, Richmond et al. (2011) found that participants attending an adaptive working memory span training with adjusting difficulty improved their reading span performance, as well as the performance in the California Verbal Learning Test and self-reported everyday attention. Borella et al. (2010) showed that verbal working memory training using alternating task requests is able to provide training gains in near and far transfer tasks of other domains such as visuospatial working memory, short-term memory, inhibition, processing speed, and even fluid intelligence. Performance increase of the latter task as well as working memory task even persisted after a period of eight months. Moreover, Brehmer et al. (2012) even compared adaptive working memory training with an active control group that performed the same working memory training without adjusted task difficulty. Although the active control group showed similar training gains to far transfer tasks of interference control and reasoning, they found larger performance gains to near transfer as a result of the adaptive working memory training as well as performance gains in sustained attention and less self-reported memory complaints in both younger and older adults compared to the active control group. This clearly demonstrates that plasticity of older adults allows for training gains through cognitive training especially of working memory process and that plasticity is modulated by the individually adjusted demand of the tasks. In addition, cognitive trainings are supposed to have a positive effect not only in cognitively healthy older adults but also in risk groups or individuals with mild cognitive impairment (Belleville, 2008; Mowszowski, Batchelor, & Naismith, 2010) and even in patients already suffering from dementia or Alzheimer's disease (Buschert, Bokde, & Hampel, 2010).

However, if there really are plastic changes induced by training, they should be reflected in neuronal changes as well. With regard to older adults, so far only few studies report on changes in brain functioning after cognitive training. Neuroplasticity resulting from working memory training in older adults is reflected in decreased task-related activation in neocortical regions, indicating increased neuronal efficiency (Brehmer et al., 2011). Contrariwise, Dahlin, Neely, Larsson, Backman, and Nyberg (2008) found different patterns of activation for younger and older adults, with older adults showing increased task-related activation in fronto-parietal areas and striatum after working memory training, which the authors explain by a lack of automatization of the task in older compared to younger adults (Dahlin, Backman, Neely, & Nyberg, 2009). Unfortunately, there is only little information about functional changes in older adults during rest or other tasks as well as about structural changes such as increased gray matter volume after cognitive training. In this context, increased cerebral blood flow in the PFC during rest was found in older adults following an attention training program (Mozolic, Hayasaka, & Laurienti, 2010), indicating the potential of training interventions to induce plastic changes independent of a specific task that is performed. However, due to this comparatively small number and somewhat controversial findings in older adults, it is difficult to get an accurate picture of the neuronal changes through cognitive training. Due to its involvement in complex task performance and typical age-related volume reduction, PFC could thereby play a key role in successful cognitive training interventions in particular but not exclusively of working memory process. Further research is clearly needed to investigate the effects of cognitive training on neuroplasticity in old age in more detail.

1.4.4 Training of physical resources

A series of studies have investigated the positive effects of physical training in general and, in particular, cardiovascular training, on cognitive performance of older adults. The findings indicate a substantial benefit of physical activity in healthy older adults (Angevaren, Aufdemkampe, Verhaar, Aleman, & Vanhees, 2008; Colcombe & Kramer, 2003; Kramer et al., 1999; Voelcker-Rehage, Godde, & Staudinger, 2011). Moreover, even in individuals with cognitive impairment or dementia physical training improves cognitive function (Heyn, Abreu, & Ottenbacher, 2004), and, therefore, may protect against cognitive decline and dementia (Rolland, Abellan van Kan, & Vellas, 2008). In a meta-analysis on 18 training studies with healthy older individuals, Colcombe and Kramer (2003) could demonstrate that physical training increases the performance of almost all cognitive abilities, regardless of the type of cognitive task (Colcombe & Kramer, 2003). Therefore, the effects of physical activity are rather broad compared to specific cognitive training interventions, but they are clearly smaller. However, the strongest effects of physical training on cognitive performance are observed in executive functions (Colcombe & Kramer, 2003; Kramer et al., 1999), as was already the case for the association between physical fitness and cognitive performance (Barnes et al., 2003; Hillmann et al., 2006; Voelcker-Rehage et al., 2010). Therefore, executive functions apparently show the highest association with both physical or motor fitness as well as motor performance.

With respect to plastic changes, it is important to investigate potential functional and structural changes of the brain resulting from physical training. In the recent years, a number of studies reported on neuroplasticity resulting from physical training. Global as well as localized changes in the brain are assumed (Thomas, Dennis, Bandettini, & Johansen-Berg, 2012). For instance, habitual physical exercise could offset some of the age-associated process of global cerebral atrophy by increasing cerebral blood flow (Ainslie et al., 2008). Moreover, physical exercise stimulates the release of brain-derived neutrophic factor (BDNF) as well as insulin growth factor (IGF-1), which are assumed to be involved in synaptogenesis, angiogenesis, and neurogenesis (Knaepen, Goekint, Heyman, & Meeusen, 2010; Lista & Sorrentino, 2010; Voss, Nagamatsu, Liu-Ambrose, & Kramer, 2011). Neuroplasticity associated with physical activity in older adults has been demonstrated in both increased and decreased task-related activation in regions of prefrontal and parietal cortices and decreased task-related activation of the anterior cingulate cortex brain regions during a flanker task (Colcombe et al., 2004; Voelcker-Rehage et al., 2011). In addition, a recent fMRI study found a behaviorally relevant increase of brain connectivity in networks associated with higher order cognitive functions after physical training (Voss et al., 2010). However, most of the findings on plastic changes in the brain following physical training involve structural changes such as increased gray or white matter volume. Structural changes can be observed in many regions such as in the hippocampus, motor cortex, PFC, temporal cortex or cerebellum (Colcombe et al., 2006; Erickson et al., 2011; Ruscheweyh et al., 2011; Thomas et al., 2012). These rather global and multi-layered effects of physical training reflect the broad effect of physical activity on cognition.

1.4.5 Combining training of cognitive and physical resources

Both cognitive and physical training are able improve cognitive abilities in old age. However, it has been shown that global cognitive stimulation is more effective than training of specific cognitive functions (Sitzer, Twamley, & Jeste, 2006) and that enriched environments allowing to engage in activities that activate different mental, physical or social skills are more beneficial than in one of those activities alone (Eskes et al., 2010; Karp et al., 2006). In line with this, findings from both behavioral and brain imaging studies demonstrate overlapping as well as distinct effects of cognitive and physical training on cognitive abilities. Therefore, combining cognitive and physical training could be complementary and provide synergistic effects that go beyond the training effects of one of the components alone. Moreover, strengthening of different resources could allow individuals to better adapt and compensate in case of losses in particular domains.

However, so far there exist only a few studies using a combination of both a cognitive and a physical training in the form of an aerobic, cardiovascular training. Fabre, Chamari, Mucci, Masse-Biron, and Prefaut (2002) for example compared three different types of training groups who either performed a single memory or physical training or a combination of both together. They found an improvement of cognitive performance for all trained groups compared to the control group, but the improvement was larger for the combined training group than the two training groups who only received either a mental or a physical training.

In a longitudinal study, Oswald, Gunzelmann, Rupprecht, and Hagen (2006) found similar results with larger improvements of the combined training group after a period of five years. Another study comparing two training groups, one receiving a combination of cognitive and physical training and one only attending a physical exercise training, with a control group found a general advantage of both training groups over the control group, but no superior effect of the combined training condition over the exercise condition (O'Dwyer, 2009). However, in this regard it has to be mentioned that the training conditions and durations of the trainings differ from study to study. In the training studies from Fabre et al. (2002) and Oswald et al. (2006), the participants in the combined training group attended more trainings than those of the other groups. Only in the study of O'Dwyer (2009) did all participants have the same amount of training sessions, but the participants of the combined training group alternately perform a physical or a cognitive training. Therefore, the results of these studies are hard to interpret and the reported training effects, especially of the combined training groups, could also appear to be a result of the different exposure to one of the training conditions rather than any superiority of the combined training. However, knowledge about combinational trainings of cognitive and physical resources is still low and this area of research is still in its infancy.

1.5 Research topics

The previous research of cognitive development and co-development as well as training of cognitive and physical resources in old age provides an abundance of enlightening information and important insights, but also leave many questions unanswered. This thesis presents two empirical studies taking up the previous findings and trying to answer some of these open questions.

The first study is aimed at investigating adaptation of older adults to situations requiring the integration of both cognitive and physical resources. Although so far a large number of studies have investigated adaptation to motor-cognitive conditions in both cognitively healthy and cognitively impaired older adults, most of the previous studies predominantly focused exclusively on motor performance such as gait parameter and ignored the performance in the cognitive tasks. In addition, adaptation has usually only been investigated in a specific population of either healthy older adults or clinical groups of patients with dementia or Parkinson's disease. For that reason, the first study in this thesis investigates adaptation of both cognitively healthy and cognitively impaired older adults to motor as well as cognitive performance. Gait velocity and cognitive performance in two distinct memory tasks were assessed during single and dual-task condition. The main objective of the study was to investigate differences in dual-task-related adaptation of motor and cognitive performance by comparing performance changes from single to dual-task condition. Additionally, adaptation strategies depending on cognitive ability were investigated.

The second empirical study integrates the training of cognitive and physical resources into a new and more functional training approach. Even though there are some additional benefits when training different resources, previous studies only performed the cognitive and physical trainings separately, so the combination of training did not include a simultaneous training. However, in addition to the reported plastic changes in the brain resulting from cognitive or physical training, acute effects of physical activity interacting with additional cognitive stimulation could also exist. These integrating effects are neglected when conducting the training separately. Moreover, multiple cognitive and motor resources are often engaged simultaneously in daily life and situations involving the simultaneous integration of cognitive and physical resources are usually more difficult to manage for older adults. Therefore, to maintain or even improve the global functional level, one would have to train different resources simultaneously for the training to correspond with demands in everyday life. The current training approach thus not only aims at improving cognitive performance but also motor-cognitive adaptation. For that reason, older adults simultaneously performed a verbal working memory and cardiovascular training on a treadmill. To evaluate the advantage of the simultaneous training, the training approach was further compared to an active control group that only performed the cognitive training, and a passive control group.

2 Simultaneously measuring gait and cognitive performance in cognitively healthy vs. cognitively impaired older adults [2]

2.1 Introduction

Many tasks of daily life require the simultaneous performance of multiple tasks, which often require both motor activity and memory. With advancing age, the ability to divide attention and to perform multiple tasks simultaneously seems to be impaired (Verhaeghen & Cerella, 2002; Verhaeghen, Steitz, Sliwinski, & Cerella, 2003). Particularly, when individuals have motor or cognitive impairments, it is more difficult for them to perform concurrent motor and cognitive tasks. Performance in one or both tasks may have to be adapted to execute both tasks simultaneously. Therefore, it is of great interest and importance to investigate motor activities such as gait in the presence of additional attention-demanding cognitive tasks. Gait is a process that requires attention, planning and memory (Hausdorff, Yogev, Springer, Simon, & Giladi, 2005; Mulder & Hochstenbach, 2003; Woollacott & Shumway-Cook, 2002), and hence attention-demanding tasks can affect it. According to previous research (Verhaeghen & Cerella, 2002), older adults require more attention to maintain stable gait. Usually, when older individuals are asked to walk and simultaneously perform another task, they walk more slowly (Beauchet, Dubost, Aminian, Gonthier, & Kressig, 2005; Beauchet, Dubost, Gonthier, & Kressig, 2005; Dubost et al., 2006; Hausdorff et al., 2008; Montero-Odasso et al., 2009; Priest et al., 2008; Sheridan et al., 2003; Springer et al., 2006; Srygley et

[2] A similar version of this chapter has been published in the "Journal of the American Geriatrics Society" (Theill, N., Martin, M., Schumacher, V., Bridenbaugh, S. A., Kressig, R. W., 2011).

al., 2009; van Iersel et al., 2007). Moreover, gait disturbances are especially common in individuals with cognitive impairment (Gillain et al., 2009; Maquet et al., 2010; Persad, Jones, Ashton-Miller, Alexander, & Giordani, 2008; Sheridan et al., 2003). These findings are of particular importance given that abnormal gait is a strong predictor of future falls, institutionalization, and even death (Bloem et al., 2003; Hausdorff, Rios, & Edelberg, 2001; Hausdorff et al., 2005; Springer et al., 2006; Verghese et al., 2006).

The current study investigated the interaction of gait and cognition in older individuals with and without cognitive impairment using a dual-task paradigm consisting of a working and a semantic memory task. Both tasks have already been used to demonstrate dual-task-related gait impairment in older adults with and without cognitive impairment (Beauchet et al., 2007; Beauchet, Dubost, Aminian, et al., 2005; Beauchet, Dubost, Gonthier, et al., 2005; Dubost et al., 2006; Hausdorff et al., 2008; Montero-Odasso et al., 2009; Priest et al., 2008; Sheridan et al., 2003; Springer et al., 2006; Srygley et al., 2009; van Iersel et al., 2007), but only few studies have investigated gait under dual-task conditions comparing older adults depending on their state of cognitive impairment (Gillain et al., 2009; Maquet et al., 2010; Sheridan et al., 2003). Cognitively impaired older adults seem to have a lower gait velocity than those who are cognitively less impaired or healthy (Gillain et al., 2009; Maquet et al., 2010; Sheridan et al., 2003).

Most previous studies on motor-cognition dual-task performance investigated only gait parameters such as velocity (Beauchet, Dubost, Aminian, et al., 2005; Beauchet, Dubost, Gonthier, et al., 2005; Dubost et al., 2006; Hausdorff et al., 2008; Montero-Odasso et al., 2009; Priest et al., 2008; Sheridan et al., 2003; Springer et al., 2006; Srygley et al., 2009; van Iersel et al., 2007). The current study additionally analyzed changes in cognitive performance between single and dual-task conditions, which to the knowledge of the authors has not been done before. By investigating both motor and cognitive performance, it is possible to evaluate whether and to what extent the individuals are able to walk and simultaneously perform an additional cognitive task, as well as which performance is more impaired in general and with increasing cognitive impairment. For example, some may adapt to the task and the single ability decrements by reducing gait velocity, some by reducing gait regularity, some by producing more cognitive errors, and some with a combination of the adaptive adjustments. With a working and a semantic memory task we used two different types of cognitive tasks to examine whether there are task-specific dual-task effects on gait and on cognitive performance. According to the literature, there seems to be no task-specific gait changes during dual-task walking, at least with regard to gait velocity (Beauchet, Dubost, Gonthier, et al., 2005; Bloem et al., 2003; Montero-Odasso et al., 2009; O'Shea, Morris, & Iansek, 2002), but little is known as to whether there are task-specific effects on cognitive performance during dual-tasks.

It was hypothesized that the participants would not only reduce their gait velocity, but also perform worse in both memory tasks during dual-task conditions and that such dual-task interference would be greater in those with cognitive impairments. Additionally, whether the performance changes during the dual-task condition were greater in gait or in cognitive performance and whether there were performance differences between the different memory tasks or between cognitively healthy and cognitively impaired older individuals were investigated.

2.2 Methods

Participants

Of the 894 older adults tested, 711 (mean age 77.22 ± 6.24, age range 65-97, 49.2% female) were included in this analysis. The sample consisted of 419 outpatients from the Basel Memory Clinic and 292 participants from the Basel Study on the Elderly (Project BASEL). The local Ethics Committee approved the project. Participants were excluded if they had severe medical, psychiatric or neurological conditions that could impair their cognitive ability or gait such as Parkinson's disease or major depression, or if they suffered from severe dementia (Mini-Mental State Examination (MMSE) score < 16 (Folstein, Folstein, & McHugh, 1975)). Participants with walking aids were excluded unless they were able to accomplish the task without using their walking aid. Furthermore, only participants were included whose answers were explicit without any interpretational bias such as translation problems or ambiguous corrections during the working memory task. Cognitive impairment was defined as a score of less than 25 points on the MMSE (Folstein et al., 1975). Of the sample, 548 (77.1%) participants had an MMSE score greater than 24 and were categorized as cognitively healthy, 163 (22.9%) participants had an MMSE score between 16 and 24, and were categorized as cognitively impaired. Mean MMSE score was 26.7 ± 3.1 (range 16 to 30). All group characteristics are listed in Table 1.

Table 1

Participant Characteristics of the Cognitively Healthy and Cognitively Impaired Groups

Characteristic	All (n = 711)	Cognitively healthy (n = 548)	Cognitively impaired (n = 163)	*p*
Gender, n (%)				.04
Male	361 (50.8)	290 (52.9)	71 (43.6)	
Female	350 (49.2)	258 (47.1)	92 (56.4)	
Age, mean ± SD	77.22 ± 6.24	76.56 ± 6.27	79.43 ± 5.58	< .001
MMSE, mean ± SD	26.66 ± 3.13	28.10 ± 1.63	21.84 ± 1.86	< .001
Number of drugs per day, mean ± SD	3.55 ± 2.45	3.54 ± 2.40	3.60 ± 2.56	.80
Number of psychoactive drugs per day, mean ± SD	0.29 ± 0.62	0.23 ± 0.59	0.47 ± 0.80	< .001
Education (years), mean ± SD	12.04 ± 2.82	12.30 ± 2.83	11.28 ± 2.70	< .001
Previous falls, n (%)				.71
Yes	288 (41.4)	219 (41)	69 (42.9)	
No	407 (58.6)	315 (59)	92 (57.1)	
Walking aid, n (%)				.07
Yes	46 (6.5)	30 (5.5)	16 (9.8)	
No	665 (93.5)	518 (94.5)	147 (91.2)	

SD = Standard deviation; MMSE = Mini Mental State Examination

Instruments For Gait

Gait analyses were performed according to the European guidelines for clinical applications of spatiotemporal gait analysis in older adults (Kressig & Beauchet, 2006) using the GAITRite® system (GAITRite® Gold, CIR Systems, Easton, PA). This system consists of a 972cm-long electronic walkway with integrated pressure sensors placed every 1.27cm over an active electronic surface area of 792 x 610cm, giving a total of 29,952 sensors. The scanning frequency was 60Hz. Onboard processors collect data from the mechanically activated sensors and then transferred through a cable and serial port to a computer and analyzed with the GAITRite® software version 3.8; 1.25m-long electronically inactive walkway sections flank the walkway at the beginning and the end. Acceleration and deceleration phases of gait occur on these electronically inactive sections, ensuring measurement of gait parameters under steady-state conditions.

Testing Procedure

Before each gait analysis, participants were asked about their medical conditions; medications; fall history; and the current use of walking, vision, or hearing aids. They were then verbally instructed regarding the gait analysis test procedure. A demonstration followed if the verbal instructions were not understood. No practice walks were performed before testing. Participants wore their normal shoes and a safety belt, and were accompanied by the test administrator for each walk.

Participants were instructed to complete one trial each of the following consecutive walking trials: self-selected speed ("normal walking"), self-selected speed while performing the working memory dual-task (counting backward out loud from 50 by 2s) and self-selected speed while performing the semantic memory dual-task (enumerating animals out loud). Previous studies have typically used rather demanding working memory tasks (Hausdorff et al., 2008; Priest et al., 2008; Springer et al., 2006; Srygley et al., 2009; van Iersel et al., 2007), but with increasing difficulty, even healthy older adults tend to either neglect the additional tasks or prioritize the walking task (Li et al., 2001; Salthouse, Hambrick, Lukas, & Dell, 1996), so a simple working memory task (serial subtraction by 2s) was used in the current study, which should allow even cognitively impaired individuals to divide their attention successfully to complete both tasks simultaneously.

For the dual-tasks, participants were instructed to perform both tasks simultaneously; no task priorities were given. The order of the dual-tasks was counterbalanced to avoid practice effects. Time needed for the dual-tasks was measured in seconds. This time was used for the same cognitive task performed while seated (cognitive single task). All participants of the current sample were able to perform the working memory as well as semantic memory dual-task independent of their cognitive status.

Analysis Procedures

Gait velocity was normalized with height (cm/sec divided by height in meters) because of the potential height-dependent differences. For the working memory task the correct calculations counting backward, as well as the number of calculation errors and repetitions were counted. For the semantic memory task, the total number of animals named, errors, and repetitions were counted, whit errors defined as any word that was not an animal. Because of the greater chance to produce more correct calculations, animal names, or errors and repetitions with more time, scores from the working and semantic memory tasks were normalized with the time required to complete the tasks (number of calculation, animal names and error/repetitions divided by time). Relative changes of the normalized scores represented decrements of performance from single to dual-task.

Statistical Analysis

Distribution assumption of the data was verified looking at distribution histograms and values of skewness or kurtosis. In cases in which approximate normal distribution was violated, nonparametric tests were used. The data from gait analysis as well as the performance of the working and semantic memory tasks underwent analysis of variance (ANOVA) or to analysis of covariance (ANCOVA) for repeated measures with the single- and dual-task performance as within-subject factors, the group variable as between-subject factor, and possible confounders as covariates. In cases in which normal distribution of data was violated, Mann Whitney *U* and Friedman test were used. MMSE scores, age, and number of psychoactive drugs per day were considered as confounding variables when analyzing gait velocity. Years of education were also considered when investigating the cognitive performance of the memory tasks, allowing better comparability between the cognitively healthy and the cognitively impaired individuals, because there was a significant difference between these two groups on these variables (Table 1). Significance values reported were based on effects before and after controlling for confounders, to allow an estimation of their influence on the findings.

For the comparison of the number of individuals reducing gait velocity or cognitive performance during dual-task between the cognitively impaired and the cognitively healthy group, participants were split into groups of those who decreased and those who increased their gait velocity or cognitive performance, which were then analyzed using chi square test.

To compare decrements of gait velocity and cognitive performance, relative performance changes in percentage from single to dual-task were calculated and subjected to ANOVA and ANCOVA for repeated measures, using the confounding variables mentioned above as covariates. The two-tailed level of significance was set at $p < .05$. All statistics were calculated using SPSS 18 for Macintosh (SPSS, Inc., Chicago, IL).

2.3 Results

Dual-Task Gait Velocity

Gait velocity was significantly lower under the working memory (F (1,704) = 725.75, $p <$ .001, $\eta^2 = .508$) and the semantic memory dual-task conditions (F (1,704) = 1080.13, $p <$ .001, $\eta^2 = .605$) than under the normal walking single condition (Table 2*)*, although 12.6% of the participants increased their gait velocity during the working memory dual-task condition and 6.2% during the semantic memory dual-task condition (defined as difference in velocity between dual and single task of < 0). Additionally, gait velocity during the semantic memory task was significantly lower than during the working memory task (F (1,704) = 162.47, $p <$ .001, $\eta^2 = .188$). The latter result was, however, no longer significant after adjustment for confounders.

Dual-Task Cognitive Performance of Working and Semantic Memory Tasks

Participants made fewer correct calculations counting backward during the working memory dual-task than under the single-task condition (F (1,691) = 518.10, $p < .001$, $\eta^2 = .428$). Overall, 76.4% of them made fewer correct calculations, 10.6% improved their performance and 13% of participants had no differences on their single- and dual-task performance. The effect was still significant after controlling for confounders ($p = .03$). During the semantic

Table 2

Mean Values (± SD) Relative Gait Velocity During Single Task (ST) and Dual-Task (DT)*

Group	Single task (ST)	Working memory dual-task (WM-DT)	*p* (ST vs. WM-DT)†	Semantic memory dual-task (SM-DT)	*p* (ST vs. SM-DT)†
All (n = 711)	68.4 (± 13.1)	55.5 (± 16.5)	< .001	50.6 (± 17.1)	< .001
Cognitively healthy (n = 548)	70.0 (± 12.6)	58.6 (± 15.6)	< .001	53.2 (± 16.2)	< .001
Cognitively impaired (n = 163)	62.6 (± 13.3)	44.9 (± 15.4)	< .001	41.7 (± 17.0)	< .001

* normalized with height (m)

† based on ANOVA for repeated measures

SD = Standard deviation

memory dual-task, the participants enumerated significantly fewer animal names (F (1,689) = 6.40, p = .01, η^2 = .009), but this effect disappeared after controlling for confounders. These results were reflected in 44.1% of the participants doing poorer in naming animals, whereas 34.4% doing better, and 21.5% being unchanged. The dual-task condition had no effect on error or repetition rate in both cognitive tasks (p > .10). Values of cognitive performance are displayed in Table 3.

Table 3

Mean Values (± SD) of Cognitive Performance During Working and Semantic Memory Single- and Dual-Task, Normalized Using Time Spent for Dual-Task

Cognitive Performance	Single task	Dual-Task	*p*
Working memory task			
Number of correct calculations per second			
All (n = 711)	0.76 (± 0.28)	0.63 (± 0.24)	< .001*
Cognitively healthy (n = 548)	0.83 (± 0.24)	0.67 (± 0.22)	< .001*
Cognitively impaired (n = 163)	0.53 (± 0.26)	0.44 (± 0.23)	< .001*
Working memory task			
Number of errors and repetitions per second			
All (n = 711)	0.026 (± 0.070)	0.029 (± 0.090)	.69†
Cognitively healthy (n = 548)	0.018 (± 0.058)	0.024 (± 0.088)	.92†
Cognitively impaired (n = 163)	0.052 (± 0.098)	0.046 (± 0.093)	.62†
Semantic memory task			
Number of animal names per second			
All (n = 711)	0.53 (± 0.22)	0.52 (± 0.22)	.01*
Cognitively healthy (n = 548)	0.58 (± 0.20)	0.57 (± 0.20)	.03*
Cognitively impaired (n = 163)	0.35 (± 0.18)	0.34 (± 0.17)	.21*
Semantic memory task			
Number of errors and repetitions per second			
All (n = 711)	0.010 (± 0.027)	0.011 (± 0.035)	.11†
Cognitively healthy (n = 548)	0.007 (± 0.024)	0.011 (± 0.035)	.02†
Cognitively impaired (n= 163)	0.016 (± 0.033)	0.014 (± 0.030)	.67†

* based on ANOVA for repeated measures

† based on Friedman Test

SD = Standard deviation

Comparison of Cognitively Healthy and Cognitively Impaired Individuals

Gait velocity of the cognitively impaired individuals was lower under the single walking condition and under both dual-task conditions ($p < .001$) than of cognitively healthy individuals (Figure 1). During the working memory task, significantly more cognitively impaired individuals (93.6%) reduced their gait velocity than those who were cognitively healthy (χ^2 (1) = 7.47, $p = .006$), of whom 85.5% walked slower. Furthermore, there was a significantly greater reduction of gait velocity during the working memory dual-task in cognitively impaired individuals (F (1,703) = 32.04, $p < .001$, $\eta^2 = .044$) with a main effect for dual-task condition (F (1,703) = 682.01, $p < .001$, $\eta^2 = .492$) and for group (F (1,703) = 83.90, $p < .001$, $\eta^2 = .107$). These effects remained significant after adjustment for the confounding variables mentioned above ($p < .01$). During the semantic memory dual-task, there was no difference between the two groups in the number of participants who walked slower or faster ($p = .47$), but the cognitively impaired individuals reduced their velocity more than cognitively healthy individuals (F (1,703) = 9.83, $p = .002$, $\eta^2 = .014$). Additionally, there was a main effect for the dual-task condition (F (1,703) = 862.24, $p < .001$, $\eta^2 = .551$) and for group (F (1,703) = 65.81, $p < .001$, $\eta^2 = .086$). Again, the results remained significant after controlling for confounders ($p < .01$).

Cognitively impaired individuals generally made fewer correct calculations and committed more errors and repetitions during both working memory single and dual-tasks than cognitively healthy individuals ($p < .001$). They also produced fewer animal names during the semantic memory single as well as dual-task ($p < .001$) and committed more errors and repetitions under both conditions ($p < .05$). As indicated in Figure 2, only the number of correct calculations counting backward significantly changed from single- to dual-task condition, at least when controlling for confounders. Cognitively healthy individuals showed a

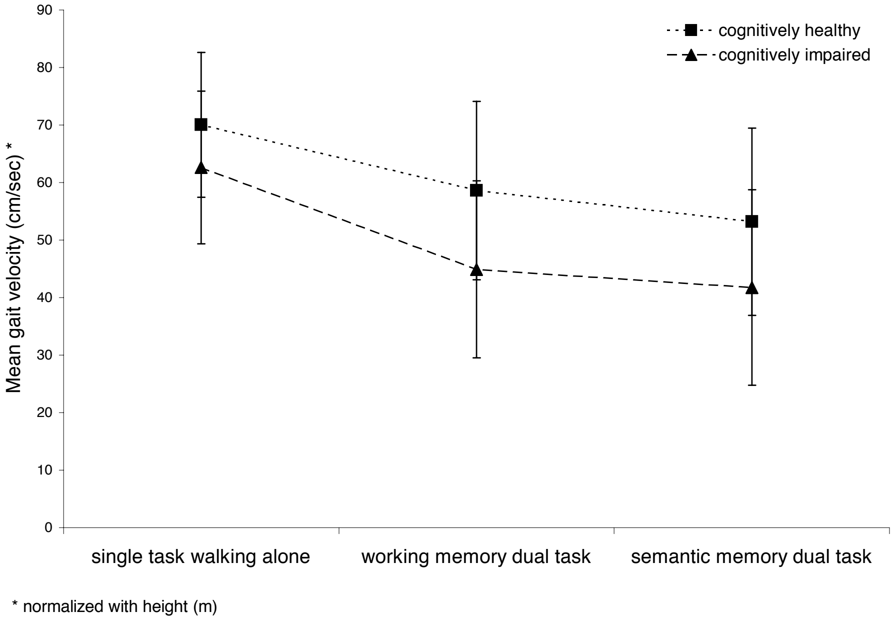

Figure 1. Mean gait velocity (normalized with height) of cognitively healthy (n= 548) and cognitively impaired individuals (n = 163) during single- and dual-tasks. Both groups decreased their gait velocity during the working and the semantic memory task (p < .001). Velocity of cognitively impaired individuals was lower under all the three conditions (p < .001). Cognitively impaired individuals decreased their velocity during both working and semantic memory tasks more than cognitively healthy individuals (p < .01). Error bars represent standard deviation.

greater decrease in their cognitive performance in the form of calculation backward than cognitively impaired individuals (F (1,690) = 20.84, $p < .001$, $\eta^2 = .029$), which was still significant after adjustment for confounders ($p < .001$). Only 66.2% of the cognitively impaired individuals decreased their cognitive performance during the working memory dual-task, compared with 79.3% of the cognitively healthy individuals. Moreover, 20.3% of the cognitively impaired individuals even increased their performance, compared with 7.9% of the cognitively healthy individuals, which represents a significant difference (χ^2 (1) = 19.31, $p < .001$).

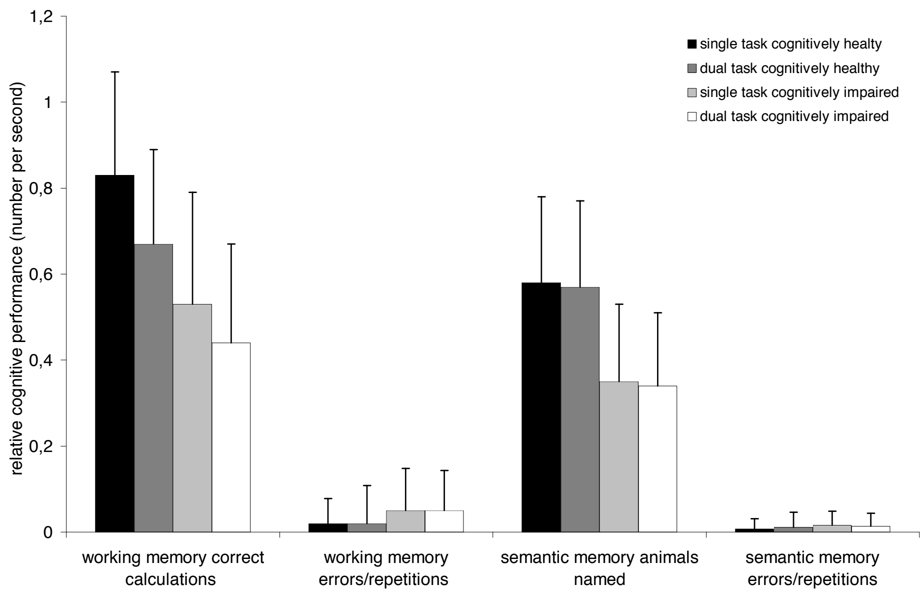

Figure 2. Single- and dual-task performance of cognitively healthy (n = 548) and cognitively impaired individuals (n = 163). Both groups produced significantly fewer correct calculations under dual- than single-task conditions ($p < .001$) but did not produce more animal names and did not make more errors or repetitions during both dual-tasks, at least when controlling for confounders ($p > .01$). Cognitively impaired individuals produced fewer correct calculations and animal names and made more errors and repetitions than cognitively healthy individuals ($p < .05$). Whereas the decrease in cognitive performance from semantic memory single- to dual-task did not differ between the two groups ($p = .84$), cognitively healthy individuals showed a greater decrease in cognitive performance on the working memory dual-task ($p < .001$). Error bars represent standard deviation.

There was no difference in improvement or decline between the two groups during the semantic memory task ($p = .61$) and no difference in reduction of number of animals named between the two groups ($p = .84$).

Gait Velocity and Memory Task Performance

Generally, 66.5 % of the participants walked slower and performed worse cognitively during the working memory dual-task, whereas only 0.9% increased their gait velocity and their cognitive performance. During the semantic memory dual-task, only 41.8% had worse gait and cognitive performance; 2.8% had better. One-third of the participants had worse gait velocity or cognitive performance while increasing the other performance at the same time, but there was no difference between those walking slower or faster and their direction of performance change during dual-task, independent of their cognitive status ($p > .10$).

Comparison Between Cognitive Performance on Working and Semantic Memory Task and Gait Velocity

Because there was no change in the number of errors and repetitions made during single versus dual-tasks, only decrements in gait velocity and cognitive performance in the form of correct calculations and number of animals named were compared. During the working memory dual-task, the relative reduction of gait velocity and the number of correct calculations counting backward did not differ ($p = .93$), but during the semantic memory dual-task, participants reduced their gait velocity more than their cognitive performance (F (1,673) = 357.75, $p < .001$, $\eta^2 = .347$). The reduction in gait velocity was greater during the semantic memory than the working memory dual-task (F (1,704) = 164.27, $p < .001$, $\eta^2 = .189$), whereas the decrease in cognitive performance was greater for the working memory than the semantic memory dual-task (F (1,635) = 165.32, $p < .001$, $\eta^2 = .207$). Only the reduction in gait velocity remained significant after adjustment for confounders ($p = .03$).

There was a significant interaction between performance change and group during the working memory dual-task (F (1,660) = 19.15, p < .001, η^2 = .028), with only a small main effect for the type of task performance (F (1,660) = 6.17, p = .013, η^2 = .009) and a main effect for group (F (1,660) = 16.32, p < .001, η^2 = .024). Cognitively healthy individuals therefore decreased their cognitive performance more than their gait velocity, whereas cognitively impaired individuals decreased their gait velocity more than their cognitive performance. The interaction was still significant after adjustment for confounding variables (p < .001). During the semantic memory dual-task, both groups showed a greater decline in gait velocity than in cognitive performance (F (1,672) = 312.68, p < .001, η^2 = .318).

2.4 Discussion

The goal of our study was to investigate motor-cognitive dual-task performance of older adults with and without cognitive impairment with regard to gait velocity as well as to task-specific cognitive performance.

During both dual-task conditions, participants reduced their gait velocity compared to their gait speed while walking alone under the single-task condition. These findings were consistent with results reported from previous studies investigating dual-task gait performance in older adults with and without cognitive impairment (Beauchet, Dubost, Aminian, et al., 2005; Beauchet, Dubost, Gonthier, et al., 2005; Dubost et al., 2006; Hausdorff et al., 2008; Montero-Odasso et al., 2009; Priest et al., 2008; Sheridan et al., 2003; Springer et al., 2006; Srygley et al., 2009; van Iersel et al., 2007). The reduction of gait velocity from single- to dual-task was greater during the semantic memory task than the working memory task, although previous studies did not find any difference in gait velocity or velocity change from single- to dual-task condition between different types of dual-tasks (Beauchet, Dubost, Gonthier, et al., 2005; Montero-Odasso et al., 2009; O'Shea et al., 2002).

The current study also investigated change in cognitive performance under dual-task condition. Whereas participants performed worse in the working memory task under dual-task condition, their performance in the semantic memory task remained stable regardless of single- or dual-task condition. One reason is that there were more individual differences during the semantic memory task with fewer than the half of the participants performing worse and at least one-third performing better during the dual compared to the single task. By way of comparison, only one in 10 performed better during working memory dual-task. Participants did not make more errors or repetitions under either of the cognitive dual-task conditions, indicating a negative impact of dual-tasking on productivity but not on error rate. The more demanding of executive functions the cognitive task was, the greater the productivity suffered.

Individuals with greater cognitive impairments had lower gait velocity and performed worse during the memory tasks, which is consistent with previous findings (Gillain et al., 2009; Maquet et al., 2010; Sheridan et al., 2003). Additionally, cognitively impaired individuals decreased their gait velocity more from single- to dual-task than cognitively healthy, which has not been reported before. The reduction in cognitive performance during the memory dual-tasks was equal to or even lower than that of the healthy group. Moreover, during the working memory dual-task, cognitively impaired individuals decreased their gait velocity more than their cognitive performance, which was contrary to cognitively healthy individuals, who decreased cognitive performance more than gait velocity. In both groups, there were no significant differences in semantic memory task performance between the single- and dual-task, and they both decreased their gait velocity more than their cognitive performance during semantic memory dual-task. One reason for the greater reduction of working memory performance in cognitively healthy older individuals could be their higher baseline performance, which could be more susceptible to an additional motor task than the already lower single-task baseline performance of cognitively impaired individuals. Additionally, the heterogeneity of working memory task performance seems to be greater in cognitively impaired individuals. Fewer individuals performed worse and almost three times as many performed even better during working memory dual-task compared to the cognitively healthy group, although some researchers have found that individuals with a better counting performance while walking than while sitting also have lower MMSE scores (Beauchet et al., 2007).

Under both dual-task conditions, cognitively impaired individuals reduced their gait velocity more than their cognitive performance and, at least during the semantic memory task, cognitively healthy individuals also reduced gait velocity more than cognitive performance. Nevertheless, the difficulty of the memory tasks was low, and only with increasing difficulty of the additional tasks, a prioritization of the walking task, or even neglect of the memory task performance would have been expected (Li et al., 2001; Salthouse et al., 1996). Especially in cognitively impaired individuals, a reduction in gait velocity may allow them to maintain gait safety in the presence of an additional attention-demanding task and to have enough attentional resources to manage both tasks without having to neglect one of the tasks.

Finally, some cognitively healthy and cognitively impaired individuals showed improvement of gait velocity or cognitive performance or both from single- to dual-task during both memory tasks. Fewer than two-thirds of participants decreased velocity and cognitive performance during the working memory dual-task and fewer than half during the semantic memory dual-task. Some individuals predominantly reduced motor performance, whereas others tended to reduce cognitive performance suggesting that the same person could potentially be stimulated to use either one of these strategies. Rather than assume that as individuals get older they increasingly and in a stable way tend to prioritize fall prevention over cognitive performance, the degree to which an individual may be able to do both, and to prioritize one or the other depending on the situation, needs to be determined. For example, this can be done by variation of cognitive task difficulty or by including obstacles such as steps into the motor task. This way, the approach to determine adaptive potentials in cognitively impaired individuals could be taken a step further, which could lead to a better understanding of adaptation processes to different tasks in everyday life including the consideration of potential dangerous situations.

There are some limitations of the current study. First, individuals with a score of less than 16 in the MMSE were not included, so the current findings cannot be generalized to patients with severe cognitive impairment. Additionally, the MMSE is only a screening questionnaire and has limitations detecting executive cognitive dysfunction (Juby, Tench, & Baker, 2002). The study did not specifically investigate dual-task performance depending on executive function, which indeed could be of particular interest with regard to the working memory task, which requires executive functions (Hittmair-Delazer, Semenza, & Denes, 1994).

Because of the large sample size, with its wide range of age and different states of cognitive impairment, the findings of the current study provide good representation of dual-task performance within the population of older adults. The study is therefore best qualified to characterize motor-cognition dual-task performance in cognitively healthy and cognitively impaired older individuals with regard to individual differences in gait and cognitive performance change depending on different dual-task conditions. Future research could investigate dual-task performance in clinical populations or in populations with different age ranges. It would be of particular interest to investigate cognitively healthy centenarians and their performance under dual-task condition. Because they are known to have fewer cognitive and physical resources, they might approach a dual-task situation differently than younger geriatric individuals.

3 Effects of Simultaneously Performed Cognitive and Physical Training in Older Adults [3]

3.1 Introduction

Both cognitive and physical trainings have been successfully applied to improve cognitive performances in old age. Although cognitive trainings typically improve the targeted ability (Ball et al., 2002; Willis et al., 2006) and have some deficiency generalizing to other task performances (Noack et al., 2009; Rebok et al., 2007), some of them are also able to transfer to abilities that are not explicitly trained (Lustig et al., 2009; Zelinski, 2009). In particular, training of working memory has been shown to be effective even in old age with respect to a series of abilities such as visuospatial working memory, block span or reading span tasks, inhibition, processing speed, fluid intelligence, visual episodic memory or verbal learning (Borella et al., 2010; Brehmer et al., 2012; Buschkuehl et al., 2008; Richmond et al., 2011). On the other hand, physical training, especially in the form of cardiovascular stimulating activity, increases cognitive performance in almost all abilities (Colcombe et al., 2003; Smith et al., 2010; Voelcker-Rehage et al., 2011).

Since both cognitive and physical training result in improvements in cognitive abilities, there might be some shared underlying mechanisms that lead to these changes in cognitive performance. Unfortunately, currently no common theory is known, which would explain the positive changes caused by cognitive and physical training. Neuroplasticity of the brain is supposed to provide the basis for any behaviorally relevant changes, so the question arises whether specific mechanisms exist that are essential for training effects going beyond the

[3] A similar version of this chapter is submitted for publication (Theill, N., Schumacher, V., Adelsberger, R., Martin, M., Jäncke, L., submitted).

specific task that is trained. In particular, training could be most effective if a task triggers as many different brain regions to induce functional or structural changes. On the other hand, brain regions known to be involved in higher-order cognition could promote interconnections with other regions that lead to the observable behavioral changes. It has to be determined how the specific effects of cognitive activities such as working memory and physical activities on brain functioning look like and what different or shared mechanisms and even complementary effects exist that result in improvements in cognitive performance. Actually, both working memory and physical training have been shown to induce functional changes in brain regions involved in higher-order cognition. In older adults, these changes are reflected once in decreased, once in increased task-related activation in neocortical regions such as PFC or parietal cortices (Brehmer et al., 2011; Colcombe et al., 2004; Dahlin et al., 2008; Voelcker-Rehage et al., 2011). Moreover, altered brain connectivity in areas of the PFC during rest has also been shown as a result of both trainings (Takeuchi et al., 2012; Voss et al., 2010), albeit the effects of working memory training only apply to younger adults. Therefore, regions of higher-order cognition such as the PFC, which is crucial for performing complex tasks involving planning and cognitive control (Miller, 2000; Miller & Cohen, 2001), seem to play a substantial role for training effects resulting from working memory as well as from physical training, whereas there is no consistent pattern of increase or decrease in brain activity.

However, whereas cognitive stimulation usually involves only localized effects, global as well as localized effects are assumed for physical stimulation (Thomas et al., 2012). Consequently, structural changes in the brain such as increased gray or white matter volume resulting from physical exercise can be observed in many different regions such as the PFC, hippocampus, motor cortex, temporal cortex or cerebellum (Colcombe et al., 2006; Erickson et al., 2011; Ruscheweyh et al., 2011; Thomas et al., 2012). Differences are also observed in acute effects of cognitive activity or physical activity on brain activation. During cognitive stimulation of working memory tasks, brain activation occurs in different specific brain regions, especially in regions of the PFC or cerebellum (Bluhm et al., 2011; Curtis & D'Esposito, 2003; Hautzel, Mottaghy, Specht, Muller, & Krause, 2009). Physical exercise, on the other hand, is associated with higher cerebral blood flow (Ainslie et al., 2008; Hellstrom, Fischer-Colbrie, Wahlgren, & Jogestrand, 1996; Timinkul et al., 2008). According to Ainslie et al. (2008), habitual physical exercise could thereby offset some of the age-associated process of global cerebral atrophy. In addition, physical exercise stimulates the release of brain-derived neurotrophic factor (BDNF) as well as insulin growth factor (IGF-1), which are assumed to be involved in synaptogenesis, angiogenesis, and neurogenesis, which are the main underlying mechanisms for neural plasticity (Knaepen et al., 2010; Lista & Sorrentino, 2010; Voss et al., 2011).

According to these findings, there are overlapping as well as distinct effects of cognitive physical training. As a result, cognitive and physical activities could have some complementary effects that are able to optimize training output on cognition. Consequently, combining cognitive and physical training should provide additional effects that go beyond the effects of the single underlying components. However, so far only a few studies have combined cognitive with physical training. Although they did not specifically focus on training of working memory, these studies still provide information about the effect of combining cognitive and physical training interventions in older adults. Two studies showed larger improvements for a combined cognitive and physical training compared to cognitive or physical training alone, although both single trainings were also able to improve cognition when compared to a control group (Fabre et al., 2002; Oswald et al., 2006). Another study comparing two training groups, one receiving a combination of cognitive and physical training and one only attending a physical exercise training, with a control group only found a general advantage of both training groups over the control group, but no superior effect of the combined training condition over the exercise condition (O'Dwyer, 2009).

One important limitation of previous training studies is that the trainings were conducted sequentially; the combination of training did not include a simultaneously performed training of cognitive and physical tasks. As a consequence, possible integrative effects are neglected. At least, it is imaginable that acute effects of physical activity such as increased cerebral blood flow boost the effect of an additional stimulation through a cognitive task and promote interconnections within and between different brain regions. Although there is so far no data confirming this theory, acute physical exercise in both younger and older adults has been shown to be associated with improved performance as well as enhanced PFC activity during a subsequent working memory or executive function task (Tsujii, Komatsu, & Sakatani, 2013; Yanagisawa et al., 2010), indicating increased task-related blood flow in corresponding brain areas during physical arousal.

In addition, physical activities are mostly performed in the context of specific perceptual and cognitive demands. During physical practice it is necessary to stay alert, focus one's attention onto the particular physical task, activate self-discipline and control emotion. Thus, the simultaneous performance of physical and cognitive tasks requires the integration of two different tasks, representing a kind of cognitively demanding dual task, activating not only those networks, which are involved in controlling each task, but also networks which are only active or show increased activity under demanding dual task conditions, e.g., PFC, inferior parietal cortex, dorsal PFC, and right inferior frontal gyrus (Collette et al., 2005; D'Esposito et al., 1995; Herath, Klingberg, Young, Amunts, & Roland, 2001; Klingberg, 1998). Moreover, additional brain regions within the cerebellum have been shown to be involved in motor-cognitive dual-tasking in younger adults that are supposed to integrate motor and cognitive networks (Wu, Liu, Hallett, Zheng, & Chan, 2012). Therefore, this integration is additionally trained. Consequently, training of the motor-cognitive dual-task resulted in higher accuracy, strengthened connectivity and neuronal efficiency when performing the dual-task (Wu et al., 2012). Increased neuronal efficiency has also been found following cognitive dual-task training (Erickson et al., 2007). Thus, dual-task performance can be specifically trained and has been shown to even transfer to other dual-task situations (Bherer et al., 2005, 2008).

As a conclusion, a substantial additional benefit is expected when performing a cognitive and a physical task simultaneously, both in terms of cognitive as well as motor-cognitive dual-task performance. In addition, the simultaneous training of different resources represents a more functional approach, as the simultaneous usage of different resources rather corresponds to the way they are required in everyday life. The current study is the first that provided such a simultaneous training. For that reason, older adults were trained using a verbal working memory training combined with a cardiovascular training performed on a treadmill. In line with previous research and in reference to the framework for plasticity from Lovden et al. (2010), the working memory training was adaptive with a continuously adjusted task difficulty as a function of the individual performance level. This has been shown to be more effective with regard to both behavioral as well as neuronal changes compared to non-adaptive working memory training (Brehmer et al., 2011; Brehmer et al., 2012; Takeuchi, Taki, & Kawashima, 2010). To evaluate the advantage of the combined training approach, the training was compared with a single cognitive training condition and a passive control group. The participants were tested with respect to their performance in selective attention, paired associates learning, executive control, reasoning, memory span, and information processing speed before, in the middle, and after the training. In addition, their adaptation to a motor-cognitive dual-task consisting of a walking and a working memory task was examined to account for transfer of the dual-tasking training. Older individuals usually adapt to a demanding motor-cognitive dual-task situation by reducing their performance of at least one of the underlying tasks, as they perform worse in the working memory task and walk slower and more unregularly compared to their performance of one of the tasks alone (Theill, Martin, Schumacher, Bridenbaugh, & Kressig, 2011; van Iersel et al., 2007). Therefore, the combined training in the current study was expected to improve the performance in the working memory task and gait parameters under dual-task, and to result in a lower reduction of gait parameters from single to dual-task walking. With respect to training progress in the verbal working memory tasks, both a boosting effect of acute physical activation and an interfering effect of simultaneous performance of two concurrent tasks were conceivable, so there was no clear expectation for either the simultaneous group or the single training group to improve more during training progress.

As a conclusion, this led to the following hypotheses: 1. Both training groups were expected to improve their performance in the two training tasks over the course of the training. 2. The participants of both training groups were expected to demonstrate training gains with regard to the cognitive transfer tasks, but with the combined training group demonstrating the larger improvements than the single training group. 3. The combined training group was expected to demonstrate improvements in their motor-cognitive performance, with no substantial differences between the single training and the control group.

3.2 Methods

Participants

Sixty-three healthy older adults with a mean age of 71.76 ± 4.92 (range 65 to 84) participated in the study, 46 (73%) of them were females. Participants were recruited through (a) advertisement in local newspapers, (b) a call at the senior University of Zurich, and (c) draws from

Table 4

Demographic Characteristics of Participants Included in the Study

	Simultaneous training (N = 18)	Single Cognitive training (N = 12)	Control group (N = 21)	
Variable	M (SD)	M (SD)	M (SD)	p
Age	72.39 (4.19)	73.33 (6.08)	70.90 (4.77)	.369
MMSE	28.94 (1.00)	29.25 (0.87)	29.24 (0.89)	.550
Education (years)	13.76 (2.95)	14.92 (4.93)	13.18 (2.87)	.394
Activity (MET)	112.10 (54.85)	159.57 (36.07)	147.02 (73.57)	.036

Notes. MMSE = Mini Mental State Examination, MET = Metabolic Equivalent.

the participant pool of the Division of Gerontopsychology of the Department of Psychology of the University of Zurich. They did not get any payment or refund of their travelling expenses but the prospect of detailed feedback at the end of the study. Participants signed up either for the combined training condition (N = 21), the single training condition (N = 16), or the passive control group (N = 26). At the beginning of the study, they were screened for cognitive impairment and medical conditions. One participant of the control group had to be excluded due to reading disability. Another eleven individuals did not complete the study mostly due to time constraints or illness during the course of the study, so there were 51 individuals left who fulfilled all inclusion criteria and completed the study. Characteristics of those participants are displayed on Table 4. However, each group was affected similarly with three individuals in the combined training group and four individuals in the single cognitive training and passive control group, respectively, who dropped out during the course of the study. Furthermore, there were no significant differences in demographic data, MMSE, baseline scores of cognitive tasks, and training progress between those who completed the study and those who dropped out (all $p > 0.05$).

Materials

Cognitive Transfer Tasks

The test battery consisted of six computer-based tests to assess the performance in the following domains: attention, paired-associates learning, executive control, reasoning, memory span, and information processing speed. Three parallel versions of the tests were programmed using E-Prime 2.0 Professional (Psychology Software Tools, Pittsburgh, PA), one for each test session. Due to the limited test material of the reasoning task, the posttest contained the same task as the pretest. The tests were always preceded by an instruction and either an example or trial. They were presented on a 24-inch monitor using a standard wireless keyboard as input device.

Selective Attention was measured using the continuous performance task (adapted from Ophir, Nass, & Wagner, 2009). At this task, letters were presented consecutively in the middle of the screen. The objective was to correctly identify if the letter X followed the letter A, which had to be signaled by pressing the button “2” on the keyboard. For all other characters or the letter X following another letter than the letter A, the participants had to press the button “1” on the keyboard. Each letter was presented for 300 milliseconds with an interval of 4.9 seconds between the probe and the target letter and 2 seconds between the target and the following probe letter. There was an exercise run followed by two consecutive trials, each consisting of 30 pairs of letters. The total number of correct answers as well as the number of correct answers depending on the combinations A-X (X following A), B-X (X following any other letter than A) or A-Y (any other letter than X followed A) were calculated for the analysis.

Paired-associates learning: At this test, the participants learned a sequence of seven combinations of shapes and colors (IGD see Gunzelmann, Brähler, & Daig, 2007). Each combination was presented in a random order for 4 seconds. Subsequently, the target shape was represented on the top of the screen with a choice of eight colors listed below. Participants had to press the button of the color that had been presented with the target shape during learning phase.

Executive control: During this test, up to nine pictures were presented with different numbers of circles and triangles on each picture. Participants were instructed to alternately count either the circles or the triangles (IGD see Gunzelmann et al., 2007). They had 60 seconds to consider as many pictures as possible and to learn the sequence of the numbers of the counted shapes, which made a total sequence of at most nine digits. Subsequently, the participants had 30 seconds to type in this sequence of numbers on the keyboard. The test consisted of three single trials each containing the same nine pictures in different order, so the participants could achieve a maximum score of 27.

Reasoning was measured with the Standard Progressive Matrices test (Raven, Raven, & Court, 1988). Matrices of different shapes or patterns were presented, in which a part was missing. The objective was to find out which piece of a given list could complete these matrices meaningfully. The participants had five minutes time to do as many matrices as possible out of a set of 27 pictures.

Memory span: Memory span was examined with the operation span test (adapted from Conway & Engle, 1996). During this test, the participants had to learn different sequences of words out of a pool of 100 words, varying between two and six words per trial. Participants were instructed to learn the words in the given order. Between these words, correct or incorrect mathematical operations were displayed and participants had to respond by pressing either the button “j” for correct or “n” for incorrect on the keyboard. After each trial, participants were requested to type in the word in the correct order. To make sure that the distraction task was done properly, only individuals who scored more than 85 % in the calculation task were included in the analysis. Of these, the number of correctly recalled words at correct serial position was calculated for all trials (see Conway & Engle, 1996).

Information processing speed was measured using a digit-letter task similar to the Digit Symbol Substitution Task from Wechsler (1981), except that participants were required to assign digits to letters instead of symbols to digits. At this task, five combinations of digits and letters were presented on the upper part of the screen, with one of the letters additionally being displayed as a probe on the lower part of the screen. The objective then was to type in the corresponding number as fast as possible. The task lasted 90 seconds and the total number of correct answers during this time was calculated.

Motor-cognitive dual-task

During the motor-cognitive dual-task, motor performance in the form of gait was investigated under single and dual-task conditions while performing a working memory task. The participants walked at their normal, self-selected speed over a distance of 20 meters, with a turning point at a cone after 10 meters. Under dual-task condition, they additionally performed a working memory task in the form of counting backwards in steps of seven, beginning alternately with either 501, 502, or 503. The correct steps of calculations and errors were noted. Time for walking was measured to determine gait velocity and gait patterns were assessed using four acceleration sensors located at upper and lower legs that communicate wireless to a computer via a portable device worn as a belt (for details see Adelsberger, Theill, Schumacher, Arnrich, & Tröster, 2012). Gait data were recorded with a scanning frequency of 25 Hz and gait parameters were reproduced in step duration. Gait variability then was calculated dividing the standard deviation of step duration with the mean time for step duration multiplied by hundred (step-to-step variability).

Verbal working memory training

The verbal working memory training session contained a computer-based n-back (adapted from Buerki, 2008) and serial position training, each of them lasting approximately 15 minutes. The training was programmed with E-Prime 2.0 Professional (Psychology Software Tools, Pittsburgh, PA) and was performed on a 24-inch monitor using a standard wireless mouse as input device. During the n-back training, the participants had to continuously respond to a series of letters appearing all three seconds on the computer screen, always comparing the subsequent letters with the letter in a given sequence before (n-back). The letters were presented for 500 milliseconds each and participants had to press the mouse button either once for any new letter or twice for any letter matching the one n positions before. One trial consisted of 30 letters and lasted 90 seconds. During the serial position training, participants had to learn a sequence of words in the correct order, each of them presented for three seconds. The learning phase was followed by a distraction phase in which participants had to decide if words out of a series of three words were meaningful or not. At the end, the words of the learning phase were presented in either the correct or incorrect word order. Again, they had to respond by pressing the mouse button either once if the sequence of the words had changed or twice if the sequence was the same.

Both tasks were adaptive, which means that the difficulty level rose with increasing performance. The n-back training started with 1-back and the serial position training started with a sequence of three words. The difficulty level gradually increased whenever participants achieved 80 percent within a level. As soon as the participants achieved level six for the first time, a new training session started with three levels below the level they achieved at the end of the last training session. During the n-back task, the participants also could fall back if their performance was less than 60 percent within a level. During the serial position task, they stayed at their latest level as long as they did not achieve at least 80 percent and a new training session started one level below the level they achieved during the last training session. Progress of training was determined by maximum level achieved during the training session.

Physical training

The participants walked quickly on a treadmill for about 40 minutes including a warm-up period at a self-selected speed. The treadmill training was pulse monitored to make sure that the pulse rate was in an aerobic range of at least 60 percent and at most 80 percent of their age-related maximum value (heart rate of 220 minus age) and the speed of the treadmill was adapted in case the heart rate went below or beyond this range. For safety reasons, the participants were fastened with a special safety belt that was ceiling-mounted above the treadmill to prevent them from falls in case they lost balance or stumbled.

Procedure

The participants of the training groups attended 20 training sessions and three test sessions overall, whereas the participants of the control group only took part in these test sessions. The tests were conducted before the training (pretest), in the middle of the training after five weeks (interim test), and after the completion of the training (posttest). The participants of the control group performed the tests at the same time intervals. The test sessions lasted between one and a half and two hours and started with the cognitive test battery, followed by the motor-cognitive dual-task. The participants received an introduction to the test process and conditions, and to the handling of the particular tests. They were allowed to ask questions during the cognitive tests in case they did not understand the instructions. During the motor-cognitive dual-task, the participants were first asked to walk at their normal, self-selected speed. Subsequently, they were asked to walk the same distance and count backward in steps of seven from either 501, 502 or 503. They were not instructed to prioritize any of the tasks.

At the first test session, the test procedure also involved a demographic and medical conditions questionnaire, and the screening for cognitive impairment (MMSE, (Folstein et al., 1975). In addition, the participants of the combined training condition walked on the treadmill for 10 minutes at the end of the first test session to habituate to the treadmill and to determine their optimal walking speed for the subsequent training sessions. After the test session, the German-PAQ-50+ (Huy & Schneider, 2008) was filled out at home to assess the physical activity of participants.

The trainings were conducted in two sequences of 10 training sessions held twice weekly over a period of 10 weeks. Both the single condition and combined training groups received a detailed instruction to the cognitive training program before the first training session, including a trial run of both cognitive trainings.

The participants of the combined group then performed the cognitive tasks on a computer screen located at eye level approximately one meter in front of them while simultaneously walking on the treadmill. The single-condition training group performed the cognitive training tasks while sitting at the table. Both training groups performed the training on the same type of computer and monitor using a wireless mouse as input device.

Statistical Analysis

Results of the metabolic equivalent (MET) score of the physical activity questionnaire and dual-task gait variability were transformed for calculations with natural logarithmic transformation to eliminate outliers.

Baseline performance and differences in demographic data between the groups were compared with Analysis of Variance (ANOVA) and motor-cognitive dual-task performance changes from single to dual-task were calculated using Analysis of Variance for Repeated Measures (ANOVAR). The training progress was analyzed with linear mixed-effects models (LMM). The random intercept model was calculated first as baseline model. Subsequently, the fixed and random factors for slope (training progress) were added, and eventually the fixed factor for group and the interaction between group and training. Goodness of fit indices between the models were compared using -2 restricted log likelihood (-2LL). The model with the optimal fit then was selected due to the adequate number of parameters estimated and co-variance structure. Training benefit to transfer tasks as well as gait analysis were analyzed using hierarchical multiple regression analysis with planned comparisons involving orthogonal contrast and polynomial trend coding (see Table 5 and 6). Contrast coding variables were created according to the hypotheses. For the transfer tasks, the control group was first contrasted against the average of both training groups with a subsequent comparison between the two training conditions to analyze the advantage of the combined training compared to the single training. For the motor-cognitive dual-task, the combined training group was contrasted against the average of the single training and the control group with a subsequent comparison between the single training and the control condition. Based on the study design with three points of measurement, polynomial trend coding variables were created for the linear and quadratic trend. To account for subject effects, effect code variables were defined for the individuals within each group. The planned comparison for the transfer tasks then was aimed at a significant interaction between both the first and the second contrasts and the linear trend in order to illustrate the expected linear training effects for the two training conditions. The planned comparison for the motor-cognitive dual-task was aimed at a significant interaction between the first contrast and the linear trend but no significant interaction between the

Table 5

Orthogonal Contrast and Polynomial Trend Coding for the Transfer Tasks

Factor		Factor G		Factor MT		Interaction			
G	MT	X_1	X_2	X_{lin}	X_{quad}	X_{1lin}	X_{2lin}	X_{1quad}	X_{2quad}
A	1	-2	0	-1	1	2	0	-2	0
B	1	1	-1	-1	1	-1	1	1	-1
C	1	1	1	-1	1	-1	-1	1	1
A	2	-2	0	0	-2	0	0	4	0
B	2	1	-1	0	-2	0	0	-2	2
C	2	1	1	0	-2	0	0	-2	-2
A	3	-2	0	1	1	-2	0	-2	0
B	3	1	-1	1	1	1	-1	1	-1
C	3	1	1	1	1	1	1	1	1

Notes. G = Group (A = contol group; B = single cognitive training group; C = simultaneous training group); MT = measurement time (1 = pretest; 2 = interimtest; 3 = posttest); lin = linear; quad = quadratic.

Table 6

Orthogonal Contrast and Polynomial Trend Coding for the Motor-Cognitive Dual-Task

Factor		Factor G		Factor MT		Interaction			
G	MT	X_1	X_2	X_{lin}	X_{quad}	X_{1lin}	X_{2lin}	X_{1quad}	X_{2quad}
A	1	-1	-1	-1	1	1	1	-1	-1
B	1	-1	1	-1	1	1	-1	-1	1
C	1	2	0	-1	1	-2	0	2	0
A	2	-1	-1	0	-2	0	0	2	2
B	2	-1	1	0	-2	0	0	2	-2
C	2	2	0	0	-2	0	0	-4	0
A	3	-1	-1	1	1	-1	-1	-1	-1
B	3	-1	1	1	1	-1	1	-1	1
C	3	2	0	1	1	2	0	2	0

Notes. G = Group (A = contol group; B = single cognitive training group; C = simultaneous training group); MT = measurement time (1 = pretest; 2 = interimtest; 3 = posttest); lin = linear; quad = quadratic.

second contrast and the linear trend to illustrate the advantage of the combined training compared to both the single training and the control condition. Statistics were calculated using SPSS 20 for Macintosh (SPSS Inc., Chicago, Il.) with a significance level of $\alpha = .05$.

3.3 Results

Due to technical problems, the results of the selective attention task of only 39 participants and gait variability of only 42 participants were analyzed. Data of the executive control and memory span task from two individuals had to be excluded due to note taking during the tests. In addition, gait parameters of one individual were excluded because of the large deviations in both gait velocity and variability.

Baseline characteristics and performance

The groups did not differ with respect to their demographic data such as age or education, as well as to their scores in the MMSE (all $p > .05$, Table 1). In addition, they did not show any differences in their baseline performance either in the cognitive test battery or in gait velocity, gait variability or working memory performance in the motor-cognitive dual-task (all $p > .05$). However, the groups differed in the metabolic equivalent (MET) score of the physical activity questionnaire ($p = .036$).

Training progress

For both trainings, the linear mixed model with the best fit was the model with fixed effects for intercept and training as well as random effects for intercept and slope (training) with a variance components covariance structure, but without fixed effects for group or interaction between group and training (Table 7 and 8). The participants of both training groups thus showed a significant increase in the n-back (F (1,34.08) = 22.53, $p < .001$) as well as the serial position training tasks (F (1,33.04) = 201.53, $p < .001$), with no group differences in

Table 7

Model Fit of The Linear Mixed-Effects Models For The Training Progress During N-Back Training

Model	*-2LL*	*Δdf*	*Δ2LL*	AIC	BIC
Model 0	2623.01		-	2627.01	2635.91
Model 1	2434.95	1	-188.06***	2438.95	2447.84
Model 2	2103.11	1	-331.84***	2109.11	2122.44
Model 3	2104.10	2	1.89	2110.10	2123.43

Notes. LL = Restricted Log Likelihoood, Δdf = Change of degrees of freedom between the models, Δ2LL = Change of Restricted Log Likelihood between the models, AIC = Akaike's information criterion, BIC = Bayesian information criterion of Schwarz. Model 0 = random intercept model, Model 1 = additional fixed effect für slope, Model 2 = additional random effect for slope, Model 3 = additional fixed effects for Group and Interaction between Group and Slope.

* < .05, ** < .01, *** < .001

Table 8

Model Fit Of The Linear Mixed-Effects Models For The Training Progress During Serial Position Training

Model	*-2LL*	*Δdf*	*Δ2LL*	AIC	BIC
Model 0	3537.46		-	3541.46	2550.35
Model 1	2498.48	1	-1038.98***	2502.48	2511.37
Model 2	1641.79	1	-856.69***	1647.79	1661.12
Model 3	1644.08	2	2.29	1650.08	1663.41

Notes. LL = Restricted Log Likelihoood, Δdf = Change of degrees of freedom between the models, Δ2LL = Change of Restricted Log Likelihood between the models, AIC = Akaike's information criterion, BIC = Bayesian information criterion of Schwarz. Model 0 = random intercept model, Model 1 = additional fixed effect für slope, Model 2 = additional random effect for slope, Model 3 = additional fixed effects for Group and Interaction between Group and Slope.

* < .05, ** < .01, *** < .001

terms of intercept and change over time, which means that the two training groups did not differ in their training progress either in the n-back or the serial position training. Training curves for both training groups are displayed in Figure 3.

Cognitive Transfer Tasks

Training gains on transfer task are displayed in Figure 4. Compared to the control group, there was a significant linear improvement in the executive control task (F (1,92) = 3.284, p = .037, R^2 = .011) as a result of the training, but with no differences between the two training conditions (F (1,92) = 0.178, p = .337, R^2 = .001). There was a positive but not significant trend for the training gain of both training groups (F (1,94) = 2.352, p = .064, R^2 = .003), with no differences between the two training conditions (F (1,94) = 0.194, p = .330, R^2 = .000). There was no significant improvement as a result of the two training groups in performance of the selective attention task (F (1,72) = 0.766, p = .192, R^2 = .006), the subscales of the selective attention task (p > .05), the paired association task (F (1,96) = 0.224, p = .319, R^2 = .001), the reasoning task (F (1,94) = 0.073, p = .394, R^2 = .000), and the memory span task (F (1,68) = 0.160, p = .346, R^2 = .001). In addition, the two training groups did not differ in their training gains in the selective attention task (F (1,72) = 0.501, p = .241, R^2 = .004), the subscales of the selective attention task (p > .05), the reasoning task (F (1,94) = 0.093, p = .382, R^2 = .000), and the memory span task (F (1,68) = 1.330, p = .127, R^2 = .004). However, the two training groups differed with respect to their paired associates task performance change (F (1,96) = 4.570, p = .018, R^2 = .015), indicating a larger training gain for the combined training group than the single training condition. Interactions between the two specific contrasts and linear trend are displayed in Table 9.

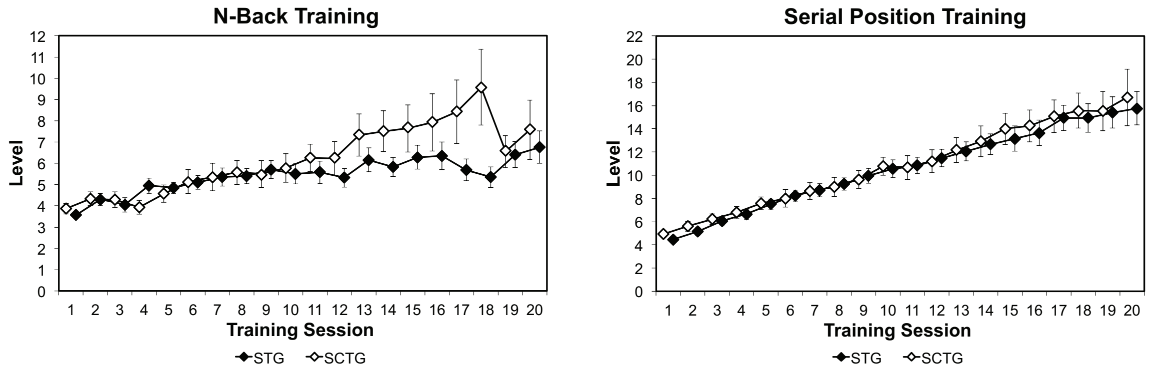

Figure 3. Training progress oft the simultaneous training group (STG) and single cognitive training group (SCTG) during the n-back and serial position training. During both trainings, participants showed improvements ($p < .001$), but with no significant differences in progress between the two training conditions. Bars represent ± standard error.

Motor-cognitive dual-task

At baseline, participants reduced gait velocity (F (1,58) = 82.469, $p < .001$, $R^2 = .587$) and increased step-to-step variability (F (1,53) = 10.417, $p = .002$, $R^2 = .164$) from single to dual-task condition. There was a significant difference between the groups in velocity reduction (F (1,58) = 3.165, $p = .05$, $R^2 = .098$) but not in step-to-step variability (F (1,53) = 2.541, $p = .088$, $R^2 = .087$). Both main effects for the factor group were not significant as well ($p > .05$). Considering the data of the interim test and posttest, participants still reduced gait velocity significantly but did not increase gait variability during dual-task, with no significant main effect for group or interaction ($p > .05$).

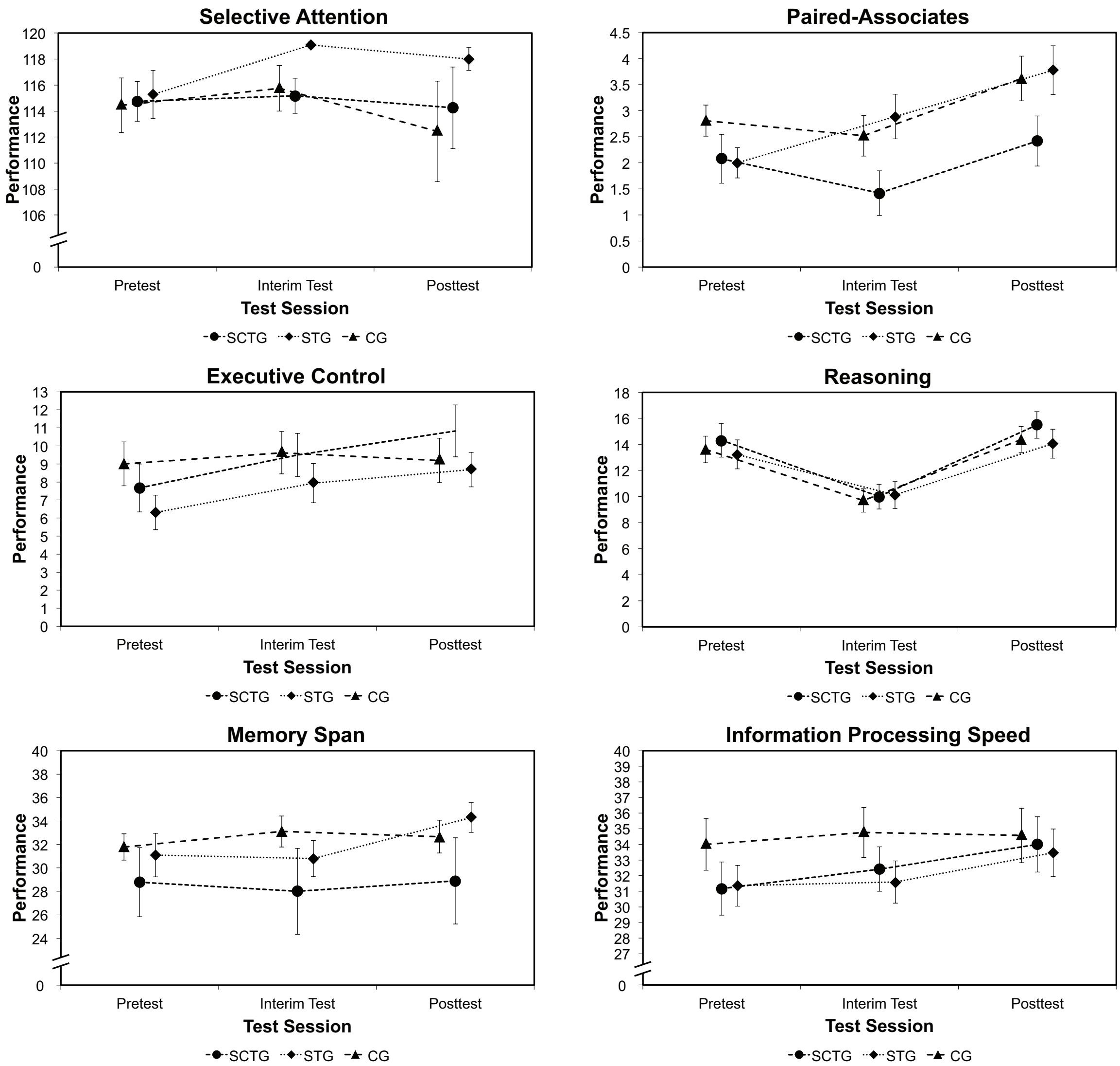

Figure 4. Performance of the simultaneous training group (STG), single cognitive training group (SCTG), and control group (CG) in the transfer tasks. The participants of both training groups showed a larger improvement in the executive control task compared to the control group (p = .037), with no differences between the two training conditions. In addition, the combined training group showed larger training gains in the paired association task compared to the single training group (p = .018), with no general training effect of both trainings compared to the passive control group. Bars represent ± standard error.

Table 9

Multiple Regression Analysis For The Interaction Between Orthogonal Contrasts And Linear Trend For The Transfer Tasks

Variable	*B*	*SE*	β
Selective attention			
Linear Interaction A x BC	0.52	0.59	0.08
Linear Interaction C x B	0.81	1.14	0.06
Paired associates			
Linear Interaction A x BC	0.04	0.09	0.03
Linear Interaction C x B	0.36	0.17	**0.13***
Executive Control			
Linear Interaction A x BC	0.43	0.24	**0.11***
Linear Interaction C x B	-0.20	0.47	-0.03
Reasoning			
Linear Interaction A x BC	0.04	0.14	0.01
Linear Interaction C x B	-0.09	0.28	-0.01
Memory Span			
Linear Interaction A x BC	-0.08	0.26	-0.02
Linear Interaction C x B	0.24	0.55	0.02
Processing Speed			
Linear Interaction A x BC	0.32	0.21	0.06
Linear Interaction C x B	-0.18	0.41	-0.02

Notes. A = Control Group; B = Single Cognitive Training Group; C= Simultaneous Training Group.

* < .05.

Interaction terms of the contrasts with the linear trend are displayed in Table 10. Compared with the single task training and control group, the combined training led to a significant reduction of the step-to-step variability during dual-task (F (1,78) = 2.958, p = .045, R^2 = .018) but not during single task walking (F (1,78) = 0.207, p = .326, R^2 = .001). There was no different change as a result of the training between the single training condition and the control group with regard to gait variability change during dual-task (F (1,78) = 0.073, p = .788, R^2 = .000) and single task condition (F (1,78) = 0.459, p = .500, R^2 = .003) or difference reduction (F (1,78) = 0.335, p = .564, R^2 = .003). Both gait velocities for single and dual-task walking as well as the difference between dual and single task velocity did not change over the three points of measurement either for the combined training compared to the single training and control group or the single training compared to the control group (p > .05). There also was

Table 10

Multiple Regression Analysis For The Interaction Between Orthogonal Contrasts And Linear Trend During Motor-Cognitive Dual-Task

Variable	*B*	*SE*	β
Gait Velocity ST			
Linear Interaction AB x C	0.09	0.09	0.05
Linear Interaction B x A	0.09	0.16	0.03
Gait Velocity DT			
Linear Interaction AB x C	0.04	0.14	0.02
Linear Interaction B x A	0.35	0.26	0.06
Gait Variability ST			
Linear Interaction AB x C	-0.04	0.09	-0.04
Linear Interaction B x A	0.11	0.16	0.06
Gait Variability DT			
Linear Interaction AB x C	-0.05	0.27	**-0.13***
Linear Interaction B x A	-0.01	0.49	-0.02
WM Correct Calculations			
Linear Interaction AB x C	-0.06	0.11	-0.03
Linear Interaction B x A	0.04	0.21	0.01
WM Errors			
Linear Interaction AB x C	0.14	0.12	0.09
Linear Interaction B x A	0.15	0.23	0.05

Notes. A = Control Group, B = Single Cognitive Training Group, C= Simultaneous Training Group; ST = Single Task; DT = Dual-Task, WM = Working Memory Task.

* < .05.

no larger improvement of the combined training group in the working memory task in terms of correct calculation backwards or errors, with no differences between the single training and the control group in correct calculation backwards and errors as well ($p > .05$). Motor-cognitive dual-task performance is displayed in Table 11.

Table 11

Performance of Motor-Cognitive Dual-Task During Pretest, Interim Test, and Posttest

	Simultaneous Training Group (*N* = 18)						Single Cognitive Training Group (*N* = 12)						Control Group (*N* = 21)					
	Pretest		Interim		Posttest		Pretest		Interim		Posttest		Pretest		Interim		Posttest	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
ST Gait Velocity (m/s)	1.21	0.20	1.24	0.20	1.22	0.19	1.18	0.15	1.17	0.13	1.21	0.17	1.18	0.16	1.17	0.17	1.23	0.15
DT Gait Velocity (m/s)	1.00	0.17	1.07	0.25	1.07	0.20	1.07	0.18	1.12	0.16	1.12	0.20	1.02	0.18	1.08	0.17	1.12	0.14
ST Gait Variability	3.23	1.17	3.23	1.22	3.34	1.40	3.08	0.94	3.12	0.64	3.63	2.13	3.04	0.81	3.17	1.16	3.16	1.17
DT Gait Variability	4.89	3.18	3.80	2.11	3.38	1.02	3.44	1.56	2.78	1.22	3.28	1.04	3.47	1.60	3.62	1.65	3.53	1.31
Correct Calculations	3.33	1.94	4.11	2.37	4.17	2.20	4.33	1.47	6.27	2.00	5.45	2.70	3.58	2.58	4.18	2.04	4.53	2.85
Errors	0.83	1.15	0.83	1.92	1.00	1.14	1.00	1.00	0.27	0.47	0.64	0.67	1.06	1.14	0.82	0.95	0.88	1.22

Notes. ST = Single Task, DT = Dual-task.

3.4 Discussion

The objective of the current study was to investigate training effects of a simultaneously performed working memory training and physical training on cognitive and motor-cognitive dual-task performance in older adults. It was hypothesized that the simultaneous performance of cognitive and physical training would lead to greater transfer effects in both single and dual-task performance than single-domain training. Therefore, a simultaneous training group was compared with an active control group (cognitive training only) and a passive control group. Results showed that the participants of both training groups improved their performance substantially and comparably in the trained tasks over the course of the training. While both training groups improved their performance in the executive control task significantly compared to the passive control group, only the simultaneous training group demonstrated a significant increase in the paired-associates task in the course of the training compared to the active control group. Furthermore, the simultaneous training group reduced its gait variability during dual-task in the motor-cognitive task compared to both the active and passive control group.

Although overall training progress was observed in both training tasks, it was larger for the serial position training than the n-back training. This might have been due to the training material. Since the serial position task consisted of meaningful words, this type of training is rather susceptible for the usage of strategies or mnemonics than the abstract n-back task with letters. However, there was no significant difference in the training progress between the two training groups. On the one hand, this is somewhat unexpected, as older adults usually adapt to a motor-cognitive dual task by reducing the performance of at least one of the underlying tasks (Theill et al., 2011) and typically tend to prioritize walking and balance maintenance rather than the cognitive task (Li et al., 2001). As a consequence, this should actually affect the cognitive performance. However, in this specific situation, the participants could also have focused on the cognitive task, since they were fastened with a safety belt and did not have to fear to fall. On the other hand, different studies have demonstrated the acute positive effect of moderate physical activity on cognitive performance (Kashihara, Maruyama, Murota, & Nakahara, 2009; Tsujii et al., 2013; Yanagisawa et al., 2010). Therefore, physical activation could counteract the dual-task related reduction of cognitive performance. Regardless of the exact mechanisms, the similar training progress of both training groups makes the simultaneous training more efficient, as physical resources can be trained in parallel without affecting the training progress in the cognitive task. However, even though the mean training progress did not differ between the two groups, the variance of the single cognitive training group during both training progress tended to be larger, so the training gain in the combined training group was more homogeneous. The physical activation could have helped to maintain concentration and attention during training, whereas individual difference became more evident during single cognitive training. In addition, the single cognitive training condition could have been perceived as more exhausting and less interesting and thus less motivating. In this case, the training potential of the single cognitive training actually would be greater at least for those who are motivated or able to keep focused, whereas the simultaneous physical activity is able to enhance motivation and promotes those who get unconcentrated or exhausted after a certain time. Moreover, Sibley and Beilock (2007) only found acute positive effects of physical activity on working memory performance for those with poor baseline performance. As a conclusion, the simultaneous performance of two concurrent tasks may impair maximum cognitive performance, whereas the physical activity helps to improve performance at least to a certain level. This could account for the smaller variance in the combined training group. A simultaneous cognitive and physical training then would be most indicated for those individuals with lower cognitive performance. In the theoretical framework for plasticity from Lovden et al. (2010), the acute physical activation may increase the range of flexibility for tasks that actually exceed the individual capacity limits.

Improvements in the cognitive tests from pre- to interim- and posttest were observed in executive control tasks for both training groups. Working memory capacity can be considered as an important component of executive functions and the constructs of working memory capacity and executive functions are highly correlated (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). Moreover, the current executive functions task was an updating task similar to the trained tasks, as the participants had to remember a series of numbers in the correct order. Therefore, the training gain in the executive control task can be interpreted as near transfer. However, there was no additional benefit of simultaneous training over the single cognitive training. This is rather unexpected, since physical activity intervention usually has the strongest effect on executive functions (Colcombe & Kramer, 2003). Due to the strong correlation between executive functions and working memory, the potential training effect of physical activity could be interfered by the effect of the cognitive training. In this case, there is no additive or integrative effect of a simultaneous training on performance in tasks requiring similar abilities as the trained tasks. On the other hand, a recent study could only find effects of physical activity on executive functions for inhibition, but not for updating and shifting (Boucard et al., 2012). In line with this, different studies reporting on effects of physical activity on executive functions have only used inhibition tasks (Colcombe et al., 2004; Voelcker-Rehage et al., 2011). Therefore, the missing additional effect of the combined training could also be the result of specific task characteristics.

However, both training groups did not improve their performance in the memory span task, when compared to the passive control group. This is surprising, since this task was very similar to the serial position task that was trained and thus was considered as near transfer. However, although the memory span task and the serial position training both aimed at remembering a series of words in the correct order, they still differed considerably. In particular, during the memory span task, the participants had to actively remember the words with a distraction task after each word, whereas during serial the position training, they had to recognize the correct order with only one distraction task after memorizing the entire word list. The similarity of those tasks with still different requirements could have caused interference.

Although there was no general training effect on the paired-associates task performance, the combined training group significantly improved their performance compared to the cognitive training group. This result is contrary to the results from the study from Fabre et al. (2002), who showed a general training effect for the combined and the mental raining on paired-associates learning, but without any additional effect of the combined training. Hence, our findings possibly reflect the additional effect of the simultaneous training compared to a separated combined training but also highlight the ineffectiveness of working memory training to improve paired associates learning performance. In the study from Fabre et al. (2002), the cognitive training includes a strategy learning of how to associate new information to a known reference point, which should definitively provide help in a following paired-associates learning task and can be considered as near transfer, whereas in our case the effect would represent far transfer. On the other side, physical training alone was also able to improve paired associates learning (Fabre et al., 2002). In this case, the significant effect in the current study could also result from physical activity alone. Since the study design did not involve a single physical training group, this question cannot be answered with any certainty.

Performance in the other far transfer tasks such as selective attention task, reasoning task, and information processing speed task was unaffected by training. These results did not confirm the findings of other adaptive working memory training studies in old age (Borella et al., 2010; Brehmer et al., 2012). On the other hand, training effects at least on reasoning ability in older adults are rather controversial. Whereas Jaeggi, Buschkuehl, Jonides, and Perrig

(2008) found effects of adaptive working memory on reasoning in younger adults, they only found near but no far transfer effects of adaptive working memory training in older adults (Buschkuehl et al., 2008). The missing additional effect of the combined training is more difficult to interpret, since previous studies with combined training approaches did not include similar tests or summarized the results of the separated tests (Fabre et al., 2002; Oswald et al., 2006). However, physical exercise alone has been shown to successfully improve at least attention and processing speed (Smith et al., 2010), but these results cannot be compared meaningfully, since we did not include a single physical exercise condition. As a consequence, different reasons could account for the missing training gain on the described tasks in our study. For instance, high baseline performance of the participants in our study at least in the attention and processing speed tasks could have prevented any training progress.

According to our hypothesis, only the participants of the simultaneous training group improved their performance in the motor-cognitive dual-task from pre- to interim- and post-test, at least with respect to gait variability under dual-task condition. The single cognitive training and passive control group did not significantly differ in their performance after training. Moreover, only gait variability under dual-task was affected, whereas variability under single task condition was not, indicating improved adaptation of the combined training group to the motor-cognitive dual-task condition. Specific training of dual-task gait has already been reported by previous studies, providing controversial results (Pichierri, Wolf, Murer, & de Bruin, 2011). In these studies, training was either very similar to the criterion or transfer task or the studies failed to show transfer to new dual task walking conditions. The training condition in the current study differed considerably from the transfer task condition, albeit both conditions include a walking and working memory task. One reason for the training effect could be the fact that the training was adaptive with continuously adjusted task difficulty, which keeps the training always demanding and should provide more training gains compared to non-adaptive trainings. As a result, this makes the simultaneous training of cognitive and motor components a more functional approach, as the simultaneous utilization of different resources often rather corresponds to the way they are required in daily life. Moreover, the current training approach could help to improve mobility and even prevent falls in older adults, as gait stability in the presence of an additional attentional demanding task is more impaired with increasing age and related to increased risk of falls (Bloem et al., 2003; Priest et al., 2008).

Although the findings of the current study are promising, one important limitation surely is the absence of a single physical training group that would allow for even more distinct comparisons. Ideally, the simultaneous training should additionally be directly compared to a combined training with separated training conditions. Moreover, the physical training was pulse-monitored and did not involve measures of individual fitness level before and after the training such as maximal O_2 uptake (VO_2max). Therefore, we could not determine whether participants' cardiovascular fitness was really increased. Nevertheless, it is not clear if an increase of fitness is required for effects on cognition or increased cerebral blood volume for instance might be sufficient (Thomas et al., 2012), which is already increased during moderate physical activity (Timinkul et al., 2008). At least with respect to synergistic effects of simultaneous cognitive and physical training, increase of cardiovascular fitness does not necessarily represent a precondition. Another limitation relates to the working memory training tasks, in particular to the serial position training, which could not have prevented the use of strategies with any certainty. Training progress could at least to some extent be explained by individual differences in the development of successful strategies. Therefore, the use of strategies could have weakened the potential of the working memory training to transfer to other abilities, as strategy training usually only show limited transfer (Lustig et al., 2009). Ideally, upcoming studies should regard adaptive cognitive training interventions not only with adjusting task difficulty but also alternating task requests to make the development of specific strategies even more difficult. Furthermore, the current participants have to be considered as a highly selective sample with an active lifestyle and thus not representative for the population at the same age. When training progress during cognitive task among those with low baseline performance is driven by additional physical activity, individuals with lower cognitive performance particularly should benefit from a simultaneous training, whereas those with already higher cognitive performance would not. Therefore, the effect of the simultaneous training in our study could have been underestimated. This factor could be addressed by investigating training progress depending on individual performance levels or among individuals with lower cognitive performance such as clinical subpopulations. Additionally, the current results also do not provide any information for maintenance of the training effects and whether there are differences between the training conditions in terms of long-term maintenance. Future research is clearly needed to determine long-term effects of simultaneous cognitive and physical training. Given the theoretical reflections of simultaneous training effects on neural activity and changes, it further would be of great importance to investigate neuronal changes associated with simultaneous cognitive and physical training. Only this way, potential for cognitive plasticity can be completely examined.

Despite the lack of these neuronal data in our study, which would have helped to understand the exact mechanisms of cognitive and physical training interventions in more detail, the present results clearly demonstrate the potential of integrating cognitive and physical training programs to improve cognition and adaptation to situations requiring both cognitive and physical resources. Hence, trainings integrating different abilities and resources definitely are the future, not least because their potential effect on daily life functioning, which usually involves the recruitment of multiple abilities and resources rather than a single one.

4 General Discussion

In the present chapter, the findings of the empirical studies in this thesis are summarized and discussed in view of the current research topics. Subsequently, limitations of the studies and implications for future research are discussed, including suggestions to transfer measurement out of the laboratory into daily life conditions.

4.1 Summary and discussion of results

4.1.1 Simultaneous measuring gait and cognitive performance in cognitively healthy vs. cognitively impaired older adults

The objective of the first empirical study was to investigate adaptation of cognitively healthy and cognitively impaired older adults to situations requiring the integration of cognitive and physical resources. For that reason, a representative sample of 711 individuals performed two different motor-cognitive dual-tasks of walking and simultaneously performing either a working memory task or a semantic memory task. A series of studies already has demonstrated that especially older adults adapt to this situation by decreasing their gait velocity and that this effect is larger for individuals with cognitive impairment. The current study extended this approach by additionally investigating adaptation in cognitive performance to determine age-related adaptation patterns or strategies depending on the individuals' cognitive ability.

Results revealed that both cognitively healthy and cognitively impaired older adults reduced their gait velocity during the working memory task as well as during the semantic memory task, whereas the cognitive performance was only decreased during working memory task. The capacity of working memory is closely related to executive functions, whose substantial involvement in motor tasks has been frequently described, so walking and additionally performing a working memory task should interfere more than walking and performing a semantic memory task. Furthermore, semantic memory rather belongs to the concept of crystallized intelligence, which is relatively stable up to an very old age, whereas working memory is part of the fluid intelligence, which shows substantial age-related decline. Therefore, adaptation to a semantic memory dual-task may reflect individual differences rather than a general age-related adaptation. In line with this, individual differences in adaptation to the semantic memory dual-task condition were much larger than to the working memory dual-task condition.

Baseline and dual-task performance of cognitively impaired individuals was lower for the motor task and both cognitive tasks, as it has already been reported by previous studies (Maquet et al., 2010; Sheridan et al., 2003). These finding reflect the previously reported impact of lower cognitive abilities on motor performance independent of any additional attentional demanding task (Kluger et al., 1997; Tabbarah et al., 2002). In addition, cognitively impaired individuals reduced their gait velocity from single- to dual-task more than cognitively healthy individuals, but they did not decrease working memory performance more than cognitively healthy individuals. On the contrary, the cognitively healthy older adults even showed a larger dual-task related performance decrease in the working memory task. Moreover, whereas both groups adapt to the semantic memory dual-task by decreasing only gait velocity, they showed different adaptation strategies during working memory dual-task. The cognitively healthy older adults reduced cognitive performance more than motor performance, so they prioritized the walking task, which is consistent with the findings from Li et al. (2001) who found that healthy older adults prioritize the walking task more than younger adults. The cognitively impaired individuals, however, reduced motor performance more than cognitive performance. These findings can be interpreted in different ways. On the one hand, as the performance in the working memory task was already low during baseline, the reduction of gait velocity may have allowed them to maintain gait safety and still be able to perform both tasks without having to neglect one of the tasks. On the other hand, the adaptation of the cognitively impaired group could reflect an inadequate or dysfunctional adaptation to a motor-cognitive dual-task situation. Whereas most healthy older adults were able to select the more important task, cognitively impaired older adults were not able to adequately adapt to the situation by prioritizing the more important task. In this case, the increased risk of falls associated with dual-task-related decrements in gait performance in particular of cognitively impaired older adults may reflect an inadequate or dysfunctional adaptation rather than only measures of gait parameters. Therefore, it is important to always look at every task that is involved, when interested in the functionality of older adults' resources. However, there were also large individual differences in the adaptation to the working memory dual-task condition in both cognitively healthy and cognitively impaired older adults, indicating different adaptation strategies independent of age or cognitive impairment. As a result, a more distinct investigation of adaptation to situations requiring the integration of cognitive and physical resources depending on both individual and environmental factors is needed.

The last paragraph highlights an obvious limitation of the first study in this thesis. Although the study included a large sample of older adults with an age range of 65 to 97 years, the analysis only relied on the global cognitive level, measured by the MMSE (Folstein et al., 1975). The results hence are only able to give a global picture of adaptation strategies to motor-cognitive dual-task conditions. Moreover, the MMSE is a simple screening instrument, which has limitations in detecting executive cognitive dysfunction (Juby et al., 2002). Due to the involvement of executive functions in motor tasks, a screening or test instrument for cognitive ability should at least account for executive functions when investigating motor performance. Consequently, future studies should include multi-layered measures of cognitive abilities and more distinct neuropsychological measures for cognitive impairment.

Another limitation is the cross-sectional design of the study. The results provide, therefore, only information about adaptation in older adults depending on their current cognitive impairment, but not about dynamical or developmental aspects. With regard to developmental aspects in old age, a longitudinal approach is needed. Only this way it is possible to determine how changes in cognitive, motor, or dual-task performance interact and contribute to maintain functional level in old age.

Future research

Ability to specifically adapt and self-evaluate performance levels

Future studies on the adaptation to situations requiring the integration of both cognitive and physical resources should investigate the factors affecting successful adaptation to motor-cognitive task conditions and how an inadequate or dysfunctional adaptation is characterized, for example by relating adaptation strategies to mobility decisions or tendencies to fall. It has to be clarified whether specific adaptation strategies are associated with lower mobility or insecurity during mobility decisions in daily life, and whether there are adaptation strategies that are related to a higher risk of falls. Furthermore, the ability to adapt to motor-cognitive dual-task conditions, i.e. lower performance costs in the underlying tasks when simultaneously performing a motor and cognitive task, should further be associated with the general ability to dynamically adapt performance levels and to switch focus as a function of environmental demands. On the one hand, this ability should be measurable through typical executive functions tasks such as task switching tasks. On the other hand, it would be interesting to investigate whether the ability to specifically adapt performance levels within a task particularly accounts for dual-task adaptation. The ability to specifically adapt performance even in more difficult tasks or two concurrent tasks could further be related to the ability to flexibly adapt to different environmental demands, indicating higher functionality of an individual. In an experimental design, this could be investigated using different task instructions. Instead of only testing the maximum performance in a given task, as it is usually done in most cognitive tests, the participants are instructed to specifically adapt their performance. For instance, the participants are instructed to perform exactly half, two-thirds, or a quarter of the maximum possible performance. In addition, task difficulty is adjusted either on a predetermined pattern or depending on the individuals' performance. With the former method, performance is investigated depending on difficulty levels and adaptation instruction. With the latter method, adaptation potential of individuals could be additionally trained. In a more complex design, this could also be investigated in dual-task conditions of either two concurrent cognitive tasks or both a motor and cognitive task. At least with two cognitive tasks, the instruction then could be adjusted in different ways, for example to always perform the same in both tasks, to perform twice as well in one of the tasks, or to adapt performance level of one task and to always maintain performance level of the other task. Again, task difficulty of the underlying tasks is adjusted to determine adaptation potential to more complex tasks. What is more, the individuals could be instructed to maintain at least a certain minimum level of one task independent of task difficulties. This approach could be further used to train successful adaptation to variable environmental demands.

In addition, individuals with an inadequate or dysfunctional adaptation could not only have lower cognitive abilities such as executive functions or the ability to specifically adapt performance levels, they may have difficulties to evaluate their performance in specific resources. In this case, the experimental design should involve self-evaluations of performance. With respect to cognitive performance, the participants should be asked how many percent of a task they think they have answered correctly or how much they think their performance has changed between different tasks. As gait is perceived less consciously, they could be asked if they think their gait velocity or regularity has changed, but they should be less able to quantify these estimations. To experimentally investigate self-evaluations during dual-task in both tasks, one could, therefore, alternatively investigate individuals' self-evaluations when performing two concurrent cognitive tasks. It would be of great interest to find out whether specific adaptation strategies or a possible tendency to fall are associated with an inability to specifically adapt or self-evaluate performance levels in different tasks, especially during dual-task conditions.

Adaptation in real life situations

Although the adaptation to different tasks requiting the integration of cognitive and physical tasks has frequently been investigated in experimental settings, little is known about adaptation in real life situations. Hence, a special concern of future studies should be to investigate adaptation during activities of daily life. For that reason, experimental designs have to incorporate different task settings that account for relevant daily life situations. This can be realized through virtual reality (VR) environments, as has been done for example by Neider et al. (2011) who investigated street-crossing behavior of older and younger adults depending on different dual-task conditions. The usage of VR technology in combination with multifunctional treadmills should at least allow the simulation of activities of daily life. An advantage of VR environment is that experimental settings can be completely standardized and manipulated for different situations of daily life, including variations of particular parameters such as traffic or visibility conditions. In addition, complex task conditions can be experimentally induced to specifically investigate limits in adaptation, without exposing the participants to a risk, and a large number of data can be collected easily, for example by using not only sensor technologies for motor performance but also eye-tracking technologies to investigate adaptation in visual attention to specific elements of the environment. Such VR environments coupled with multifunctional treadmills have already been applied to investigate gait adaptation in younger adults (Hak et al., 2012; McAndrew, Dingwell, & Wilken, 2010). Moreover, VR environment has been used to improve gait during single- and dual-task conditions in patients with Parkinson's disease, stroke patients, or idiopathic fallers (Mirelman, Maidan, et al., 2011; Mirelman, Patritti, Bonato, & Deutsch, 2010; Mirelman, Raphaely Beer, Dorffman, Brozgul, & Hausdorff, 2011). However, a disadvantage of such virtual environments is that the technology is still expensive and spacious, and providing dynamical task situations of daily life require a lot of technical knowledge and programming skills. In addition, even though VR environments become more and more realistic, they still provide an artificial environment and walking in virtual environments is even assumed to induce gait instability (Hollman, Brey, Bang, & Kaufman, 2007). In particular, so far even the most advanced treadmills are not able to simulate realistic conditions such as for example different surface properties. Therefore, adaptation to situations of daily life should be investigated in real life conditions. The technological progress provides different solutions to transfer measurements out of the laboratory into real life situations. In a recent study, we were able to show that it is feasible to measure gait performance of older adults with inertial measurement units (IMUs), allowing for a flexible and mobile usage (Adelsberger et al., 2012). Moreover, the technology is currently developed further as an insole with both acceleration and pressure sensors, enabling high-resolution balance measures. In addition, the system provides the possibility for real-time evaluation in association with a smartphone application. In a further study, we were able to measure cognitive load during daily life conditions in older adults using the same IMU technology to assess reaction times (Cinaz et al., in preparation). Both approaches could be combined to investigate cognitive load of different activities of daily life and its effects on motor performance such as balance or gait in real life settings. Field experiments could be realized under supervision of an investigator in controlled task settings or even completely unsupervised, as the connection to a smartphone enables to monitor individuals for example through GPS and to match these data with the data of the acceleration and pressure sensors. Theoretically, data acquisition could also be extended to individuals' feedback on activities, video recordings, mobile eye-tracking systems, and even physiological data using LifeShirt system (LifeShirt, Vivometrics, Ventura, CA, USA). To generate some standardized situations and to avoid too much data, the smartphone could be used to request individuals to perform specific tasks. But even without generating standardized situations, data could be subsequently used to investigate adaptation to different activities of daily life. Although adaptation in cognitive performance during activities of daily life cannot be directly observed or quantified in the same way as in an experimental task condition, the interplay between gait parameters and reaction time measures could provide information about adaptation in both cognitive and motor performance. For that reason, an individual baseline profile of gait behavior and reaction times has to be created initially. Subsequently, deviations from this profile denote adaptation to specific task conditions. Depending on the interaction in deviations of gait parameters and reaction times, different adaptation styles might be identified. Steady gait parameters coupled with lower reaction times for instance would indicate that the present walking condition is associated with higher cognitive load but adaptation is only made in the cognitive task or in the cognitive capacity for any further task. Lower gait parameter with steady reaction times would, however, indicate that the present walking condition is associated with higher cognitive load but adaptations are either only made in the motor task or in both the motor and the cognitive task, whereas cognitive capacity for any further task is still preserved. Lower performance in both gait parameters and reaction times would indicate that the cognitive load of a present task leads to adaptation in motor task as well as affects cognitive capacity for any further task. In this case, either the additional attentional demanding task is prioritized or the task condition is complex, so the individual has to adapt by decreasing performance in every underlying task. Therefore, large deviations in both gait parameters and reaction times could indicate excessive demand and potential dangerous situations. Additional data such as video recording or eye-tracking help to evaluate the situational conditions and demands. It would be further interesting to investigate how individual factors such as stress or fatigue influence adaptation styles to specific task conditions. In summary, adaptation styles as an interaction of different data could provide important information about adaptation to real life activities of older adults.

Identifying inadequate or dysfunctional adaptation

Eventually, data of laboratory experiments, VR environmental experiments, and real life situations should be brought together to identify potential dangerous situations in terms of falls. For that reason, complex task conditions should be simulated under safe conditions and adaptation should be matched subsequently with data from daily life conditions. The aim is to identify general or individual patterns signaling inadequate adaptation associated with increased risk to fall, so the individuals could be sensitized or warned. Subsequently, increased incidence of dangerous adaptation patterns could be used to induce treatment indications such as use of walking aids or training recommendations. This way, functional level and mobility of older adults could be longer maintained.

4.1.2 Effects of Simultaneously Performed Cognitive and Physical Training in Older Adults

The objective of the second study in the present thesis was to integrate cognitive and physical training to promote cognitive performance and motor-cognitive adaptation in older adults. A series of studies have already demonstrated the positive effects of cognitive and physical training interventions, some of them even by combining cognitive and physical training. However, the current study was the first providing a simultaneous cognitive training and physical training. For that reason, 63 older adults either performed 20 training sessions of verbal working memory training and simultaneous cardiovascular training on a treadmill, only performed the working memory training (active control group), or attended no training at all (passive control group). Cognitive performance and motor-cognitive adaptation was measured at the beginning, in the middle, and at the end of the training.

Results revealed that both the simultaneous training group and the cognitive training group showed similar progress in the trained task and improved in the executive control task compared to the passive control group. In comparison with the active control, the simultaneous training group also improved in the paired-associates task. In addition, the simultaneous training led to improvements in the motor-cognitive dual-task condition when compared to both the active and passive control group, indicated by decreased gait variability during dual-task. Although we expected larger transfer of simultaneous training to cognitive abilities or motor-cognitive adaptation, the expectations for training progress in the cognitive task were less conclusive, since both a boosting effect of acute physical activation and an interfering effect of simultaneous performance of two concurrent tasks were conceivable. According to the results, either the effects were only small and did not affect performance in the cognitive task or both effects balanced out. Regardless of the exact mechanisms, this makes the simultaneous more efficient, as in addition to the cognitive training physical resources are trained as well. However, the variance in training progress between participants of the simultaneous group was smaller for both training tasks, so the simultaneous physical activity could have helped to activate additional resources in those with lower potential, whereas the interfering effect of an additional motor task impeded those with larger potential to exploit their maximal capacity.

In our study, training effects to other cognitive abilities were restricted to near or middle transfer. In particular, both trainings were not able to improve performance in other tasks with typical age-related decline that were not trained, such as reasoning or speed of processing. However, evidence of working memory training to improve reasoning ability or speed of processing of older adults is rather small and is limited to few studies (Borella et al., 2010; Brehmer et al., 2012).

At least in our selective sample of cognitively healthy older adults with an already active lifestyle, simultaneous physical training could not produce larger effects in far transfer tasks except for the paired-associates task. There was also no additional effect of simultaneous physical training on executive functions, even though the largest effects of physical training and physical fitness are usually reported in executive functions. However, as we did not measure physical fitness in our study and the training was only twice a week for half an hour, we cannot be sure if the participants really increased their physical fitness. On one hand, to demonstrate effects of physical training on cognitive performance, the training possibly should take place more frequently and over a longer period of time. On the other hand, it is not clear whether increase of fitness is really needed for training effects on cognition (Thomas et al., 2012). At least the synergistic effects of simultaneous training should be independent of increases in fitness levels.

Furthermore, even though both training groups showed improvements in executive functions, it was only the simultaneous training group that improved during motor-cognitive dual-task. Therefore, increasing executive functions alone must not lead to better adaptation to tasks requiring the integration of both cognitive and physical resources, at leas not in high functioning healthy older adults. There was also no general training effect of treadmill walking on gait performance, as the motor performance of the simultaneous training group during single-task did not change. Hence, it is really the dual-task adaptation that was improved. As a consequence, the simultaneous training of different resources should in particular have a higher impact on daily life functioning, since the simultaneous usage of different resources rather corresponds the requirements of most daily life activities.

One of the greatest limitations of the current training study was the absence of an active control group that only performed the physical training and a combined group that performed both cognitive and physical training, but separately. It would be useful to compare training effects of simultaneous and separated training and the training of specific resources on both behavioral changes and plastic changes in the brain. Only this way, the exact mechanisms of physical stimulation and the interaction between cognitive and physical stimulation could be investigated in more detail, as the underlying mechanisms responsible for training gains are still not well understood. With respect to physical stimulation, the question must be allowed whether a direct effect of physical activity on cognition really exist or whether any of the reported training effects are only due to the fact that physical stimulation increases the physiological potential for cognitive stimulation to induce plastic changes. In fact, an individual is exposed to cognitive stimulation every single day and cognitive stimulation has an influence on cognitive abilities independent of physical activity. This makes it almost impossible to either confirm or reject this theory. Therefore, animal studies are used to better understand the specific mechanisms of physical activity and the interaction between cognitive and physical stimulation. In this regard, a series studies revealed different mechanisms of cognitive and physical stimulation. In an early study, Black, Isaacs, Anderson, Alcantara, and Greenough (1990) found that learning a complex motor task led to increased synaptogenesis, whereas physical exercise led to increased angiogenesis, but did not form any new synapses. More recently, physical exercise has been shown to be associated with increases proliferation of new neurons, whereas environmental enrichment increases the survival of new neurons (Kronenberg et al., 2003). Based on these observations, Fabel et al. (2009) were able to show that a combination of physical exercise and environmental enrichment led to larger neurogenesis, as physical exercise provides an increased potential for neurogenesis, which is used when additional cognitive stimulation follows the physical exercise. These results indicate that physical activity may provide the basis for any further cognitive stimulation to produce new synapses or even neurogenesis more efficiently. Future research is clearly needed to investigate this interaction between physical and cognitive stimulation in more detail.

Future research is also needed to determine whether combining cognitive and physical training should involve simultaneous training or whether a separated training is equally effective. In terms of transfer to cognitive performance in specific abilities, separated or simultaneous training of cognitive and physical resources could actually produce similar effects. However, results of the current study show that the simultaneous training should at least have two advantages. Since physical resources are simultaneously trained without affecting the training progress in the cognitive task, the simultaneous training is more efficient. In addition, as adaptation to motor-cognitive dual-tasks is additionally trained, the transfer to activities of daily life should be larger, as the simultaneous usage of different resources rather corresponds the way they are used in daily life.

Future research

Adaptive cognitive training through different task demands

Cognitive training interventions should always account for individual differences in performance levels. On one hand, this is important to maintain motivation of participants and to avoid excessive or too low demands. On the other hand, adaptive training has been shown to produce both more plastic changes as well as performance increase when compared to a non-adaptive training of the same task (Brehmer et al., 2011; Brehmer et al., 2012). Adaptive training allows for a continuous adjusted task demand and avoids use of strategies. However, only to adjust task difficulty could be insufficient to avoid strategies. In a future study, adaptive training of working memory should also include alternating task demands in the form of increased number of different tasks or different stimuli used in the task such as varying colors, images, or even auditory stimuli. When confronted with constantly changing conditions, participants should be less able to develop task-specific strategies. In addition, training progress is less susceptible to individual preferences of the task. Some individuals may prefer verbal stimuli such as words or letters, whereas others rather prefer figurative stimuli. Adaptive training with different task demands should hence be able to produce larger transfer to other tasks, as different aspects are trained.

Simultaneous training of different cognitive resources

Although adaptive training programs should be most appropriate to improve the performance in a specific task and to some extent also to transfer to other task performance, the question remains whether training of specific abilities is able to affect daily life functioning. Since most activities of daily life require the integration of different cognitive resources, future research should be more concerned with simultaneous training of different cognitive abilities. For that reason, multimodal or multidimensional training interventions that involve training of different cognitive processes such as working memory or spatial memory should be compared to trainings that only involve a single domain, but in particular to trainings that involve a separated training of all single domains. In the present case, a spatial component could be added to the n-back task, for example as the stimuli are no longer presented only in the middle of the screen. The stimulus then has to match with respect to characteristics as well as position. Simultaneous training of different cognitive resources should again include different task requests and difficulty levels to prevent the participants from building task-specific strategies.

Simultaneous training of different cognitive and physical resources

A further objective is to combine cognitive training programs with adjusting task demands and simultaneous training of different cognitive resources with training of physical resources. On one hand, this could be realized within the same conditions for physical training as in the present training study, by only changing the cognitive task demands. On the other hand, the physical training could also involve alternating task demands. Multifunctional treadmills can be used to produce variable conditions for the motor task, such as changing speed, angles, or suspension. Fixed or variable parameters could be applied to disrupt gait and to train appropriate motion sequences. As walking behavior in daily life is a dynamic process that depends on environmental demands, learning adaptation to different walking demands could provide a repertoire of operational resources that can be retrieved in complex task situations of daily life. In an experiment, changes of the treadmill could appear randomly or experimentally connected with task conditions of the cognitive task. In the former condition, individuals always have to be alert to sudden changes in walking demands. In the latter condition, specific changes in walking demands could be connected to a visual or auditory signal. For example, changes in walking demands could be signaled by different colors of the letters in the n-back task. A red letter could indicate a specific change or pattern of change in walking demands, whereas a blue letter indicates another pattern. Difficulty of walking task demands in the form of time delay or maximum angle is adjusted due to gait and balance performance of each participant. Frequency and number of different walking demands and colors, respectively, could be either adjusted due to gait and balance performance or due to performance in the cognitive task. With this flexibility to adjust task conditions in both the cognitive and the physical task, the training can be balanced out with optimal demands in each of the underlying tasks. In addition, the changing task demands in both tasks should induce larger transfer, and in particular improve flexible adaptation to tasks requiring the integration of cognitive and physical resources.

Measuring cognition during activities of daily life

Regardless of any training intervention, the question is how to objectively measure cognitive ability during activities of daily life. It is almost impossible to quantify effective task performance in activities of daily life, especially not on a group level. The same activities are perceived differently from different individuals, as the individuals not pursue the same goals. In particular, this could be a problem of self-rating questionnaires that aim at evaluating everyday functioning. An individual with already high functional level might perceive the cognitive training as not helpful for his or her functioning during activities of daily life, although from an objective point of view the training actually would have been effective to improve functioning, but outside any range of individual goals. A way to objectively evaluate functioning during activities of daily life could be to indirectly measure cognitive load through reaction times. In a recent study, we showed that individuals increase reaction times during different activities of daily life and additional cognitive load through an n-back task (Cinaz et al., in preparation). Therefore, if training of cognitive processes such as working memory successfully increases cognitive capacity to manage different types of activities of daily life, this should be reflected in lower reaction times or lower variability of reaction times during the tasks. This approach could help to investigate functioning during activities of daily life from a more objective point of view. As a result, both objective and subjective measures could be applied complementary to evaluate training effects on daily life functioning.

4.2 Conclusion

The studies of the present thesis provide further evidence for the interdependence of cognitive and physical resources and demonstrate that it is essential to integrate both cognitive and physical resources in cognitive development of older adults. On one hand, both physical resources and the ability to manage motor-cognitive dual-tasks are affected by cognitive ability in old age. Depending on the task that is solved, cognitively impaired older adults show different adaptation strategies to motor-cognitive dual-tasks than cognitively healthy older adults. They predominantly adapt by reducing gait velocity, whereas healthy older adults used different adaptation strategies depending on task situation. However, it remains open whether the adaptation strategy of the cognitively impaired older adults reflects the intention to maintain gait safety or indicates an inadequate or dysfunction adaptation to the task. For that reason, future research has to relate different adaptation styles to mobility decisions and tendencies to fall. In addition, future studies should also involve increased investigation of adaptation to activities of daily life, as it would be most predictive for functionality of older adults.

On the other hand, simultaneous cognitive and physical training was able to improve cognitive performance in the trained working memory task as well as in the executive control task, paired-associates task, and motor-cognitive dual-task, whereas a single cognitive training only increased performance in the trained working memory task and executive control task. Therefore, additional physical activity was able to increase training gains of a cognitive training. To promote cognitive development in old age, training programs should not only involve specific training of cognitive or physical resources, but in particular simultaneous training of both resources. The simultaneous training of cognitive and physical resources should be more relevant for daily life functioning and more efficient, as both cognitive and physical resources can be improved in parallel without affecting the training progress in the cognitive task. Future research should involve simultaneous training of different cognitive resources and adjusting task demands for both the cognitive training as well as the physical training.

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