Full Review

The Contributions of Cognitive Trainings to the Stability of Cognitive, Everyday, and Brain Functioning across Adulthood

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Abstract. This review covers the contributions of cognitive trainings to stability in cognitive, everyday, and brain functioning across adulthood. For these functional domains, relevant types of empirical evidence were defined for training-induced enhancement in absolute, differential, and dimensional stability in the light of developmental decline. The state of research regarding these types of evidence is presented. Little data were generally available on the effects of cognitive trainings on the stability of everyday and brain functioning and across all covered domains for their contributions to differential stability. There was sound empirical support for training-induced enhancements of absolute and dimensional cognitive stability across adulthood. The theoretical, methodological, and practical implications of these findings are discussed.

Keywords: cognitive training, development, brain functioning, everyday functioning, stability

This paper examines whether there is evidence that cognitive trainings can stabilize cognitive, everyday, and brain functioning across adulthood. The purpose of the first section of the paper is three-fold: (1) To clarify conditions under which cognitive trainings may stabilize these three functional domains across adulthood and to demonstrate that these are fulfilled. (2) To introduce three types of stability that cognitive trainings may improve, to define which kind of studies can provide evidence for training-induced enhancement of these three types of stability in cognitive, everyday, and brain functioning across adulthood, and to establish criteria for the methodological quality of these studies. (3) To differentiate between three types of cognitive trainings that have previously been studied. In the second section of the paper, I review the current state of empirical evidence with regard to the proposed contributions of the major types of cognitive trainings to the three types of stability in cognitive, everyday, and brain functioning across adulthood. I conclude by summarizing the findings and discuss their theoretical, methodological, and practical implications.

Conditions for Training-Induced Stabilization of Cognitive, Everyday, and Brain Functioning across Adulthood

Cognitive trainings are defined as interventions that try to improve cognitive functioning through guided repeated practice of standardized cognitive tasks (Clare, 2003; Gates & Valenzuela, 2010). Because the goal of cognitive trainings is to achieve improvement only in cognitive functioning (i.e., change, and not stability), it might not be easy to comprehend how they can stabilize cognitive as well as everyday and brain functioning across adulthood. However, this is possible when following conditions are fulfilled: (1) The trajectory of normal development in these functional domains across adulthood includes periods of decline. (2) The decline in everyday and brain functioning is related to decline in cognitive functioning.

Declines in Cognitive, Everyday, and Brain Functioning across Adulthood

Longitudinal studies on cognitive development across adulthood show that cognitive functioning indeed starts to decline from 60 years on, albeit with a great variability in the onset and slope of decline between different cognitive abilities (e.g., Rönnlund, Nyberg, Bäckman, & Nilsson, 2005; Salthouse, 2010; Schaie, 2005).

Everyday functioning has been measured mainly by self-reported competence in basic and instrumental activities of daily living (BADL or IADL, respectively). BADL refer to fundamental self-care activities such as dressing or toileting, whereas more complex activities such as management of one's finances, transportation, or medication are regarded as IADL (Gold, 2012; Willis, 1996). The development of BADL/IADL competence has been studied only in old samples, pointing to a decline in IADL competency from around 75 years (Jagger, Arthur, Spiers, & Clarke, 2001; Sonn, Grimby, & Svanborg, 1996; Zuccolo et al., 2012). Another everyday ability that has often been assessed is driving. Driving records show that accident rate per distance travelled increases beyond the age of 70 (Bayam, Liebowitz, & Agresti, 2005; Kubitzki & Janitzek, 2009).

Functional neuroimaging studies also point to a decline in brain functioning in old age. Across a wide range of cognitive tasks, a reduced activation of posterior brain regions accompanied by the activation of additional prefrontal regions has been observed in older compared to young adults. Activation in these additional prefrontal areas often correlates positively with performance and negatively with activation in posterior brain regions. Therefore, it has been proposed that prefrontal regions are recruited to compensate for reduced functional efficiency of core brain regions in order to maintain performance (for reviews see Dennis & Cabeza, 2008; Park & Gutchess, 2005; Zöllig & Eschen, 2009). In young adults, recruitment of additional prefrontal regions is also observed along with performance maintenance under increasing task demands. However, in older adults the recruitment of additional prefrontal regions occurs at lower task demands and ceases at high task demands accompanied by performance decreases (Cappell, Gmeindl, & Reuter-Lorenz, 2010; Mattay et al., 2006), thus pointing to a reduced potential for the enhancement of brain functioning by the recruitment of additional brain regions in old age.

Relationships Between Declines in Cognitive, Everyday, and Brain Functioning

In older adults, cognitive functioning has been found to predict current and future performance in BADL/IADL competence (Gross, Rebok, Unverzagt, Willis, & Brandt, 2011; Royall et al., 2007; Willis, Jay, Diehl, & Marsiske,

1992). A wide variety of cognitive tests also predict driving performance among older drivers, as measured by accident records, on-road driving, or simulator driving (Mathias & Lucas, 2009). However, the magnitude of variance in BADL/IADL measures explained by cognitive tests is small and is further reduced when other variables enter the analyses (Gold, 2012). A multitude of other variables also predict current and future BADL/IADL competence in older adults, among them depression, disease burden, vision and motor impairments, or the use of assistive devices (McCurry et al., 2002; Sonn, 1996; Stuck et al., 1999). Similar variables have also been found to be predictors of driving performance (Bayam et al., 2005). Thus, other abilities or environmental resources (Kaiser, 2012) probably compensate for age-related cognitive deficits, which must accumulate before a decline in everyday functioning is directly observed (Gold, 2012). This is consistent with the later decline in everyday functioning compared to cognitive functioning in old age.

Although the significant relationships between activations in recruited brain areas and cognitive performance have generally been observed in older adults in imaging tasks, these are usually limited to only a subset of recruited brain regions and are far from consistent across studies (Eyler, Sherzai, Kaup, & Jeste, 2011; Spreng, Wojtowicz, & Grady, 2010). This is probably because declines in brain functioning can be buffered by the recruitment of additional brain regions and thus probably have to accumulate before they result in cognitive decline (Park & Reuter-Lorenz, 2009; Stern, 2009). Initial longitudinal data indicate that a decline in brain functioning indeed precedes a decline in cognitive functioning in old age (Beason-Held, Kraut, & Resnick, 2008).

Therefore, cognitive improvements induced by cognitive trainings in older adults may not improve everyday functioning immediately after training, but may delay or ameliorate its future decline. Similarly, cognitive trainings in older adults may improve brain functioning without changing cognitive functioning immediately after training, but may delay or ameliorate future cognitive decline. These proposals regarding time-lagged effects of cognitive trainings on everyday and cognitive functioning point to one of three different types of stability that cognitive trainings may enhance in the three functional domains of interest across adulthood and that will be considered in this review.

Types of Stability Enhanced by Cognitive Trainings

Stability can manifest itself in a constancy in the level of functioning over time, in a constancy in the slope of change over time, or in stability across different abilities within a functional domain. These manifestations of stability have been termed *absolute*, *differential*, or *dimensional stability*,

respectively (Martin & Zimprich, 2005; Willis, Schaie, & Martin, 2009).

Accordingly, cognitive trainings can enhance absolute stability in the three functional domains of interest across adulthood by increasing their level of functioning in older adults immediately after training, thus reversing previous declines. In addition, cognitive trainings can improve differential stability in cognitive, everyday, and brain functioning across adulthood by ameliorating the slope of their decline in older adults after training. Finally, cognitive trainings can increase dimensional stability in the three functional domains across adulthood by enhancing absolute or differential stability of several cognitive or everyday abilities or of brain functioning in several imaging tasks targeting different cognitive abilities in older adults.

Dimensional stability is similar to the concept of transfer, which is usually applied to classify the scope of cognitive training effects (Hertzog, Kramer, Wilson, & Lindenberger, 2008; Noack, Lövdén, Schmiedek, & Lindenberger, 2009; Zelinski, 2009). According to the concept of transfer, the scope of cognitive training effects is determined mainly by the similarity of the cognitive functions that have improved after a cognitive training to the cognitive functions targeted by this training. The less similar these are to the targeted cognitive functions, the wider the scope of cognitive training effects. Within the framework of dimensional stability, the scope of cognitive training effects is not defined with respect to the cognitive functions targeted by a cognitive training, but only by the similarity of cognitive functions positively affected by a cognitive training to one another. The less similar the positively affected cognitive functions are to one another, the wider the scope of cognitive training effects.

Studies Evaluating Training-Induced Enhancement of the Three Types of Stability

Training-induced enhancement of absolute stability in cognitive, everyday, or brain functioning across adulthood can be evaluated by studies in which older participants complete the same outcome measures for cognitive, everyday, or brain functioning immediately before and after a cognitive training. These two measurement points are usually referred to as *pretraining* and *posttraining*. Increases in the level of functioning immediately after training are indicated by improvements in outcome measures in the training participants from pre- to posttraining.

Training-induced improvement of differential stability in the three functional domains of interest across adulthood can be evaluated by studies in which older participants additionally complete the outcome measures used at pre- and posttraining some time after training termination. This additional measurement point is called *follow-up*. Declines in outcome measures from posttraining to follow-up in the training participants should be smaller than their declines in untrained older adults across this time period.

For the evaluation of the contributions of cognitive trainings to dimensional stability in cognitive, everyday, or brain functioning across adulthood, studies need to include outcome measures for at least two cognitive abilities, two everyday abilities, or two functional imaging task targeting different cognitive abilities at pre- and posttraining and at follow-up. These outcome measures should improve from pre- to posttraining in the trained older adults or decline milder than in untrained older adults from posttraining to follow-up.

Methodological Quality Criteria for the Studies

The methodological quality of studies evaluating training-induced enhancement of the three types of stability in cognitive, everyday, and brain functioning across adulthood can be improved by including a control group. A passive control group completes the same outcome measures as the training group at the same measurement points during the course of the study. This controls for improvements in outcome measures for cognitive, everyday, or brain functioning induced by their repeated completion. In contrast, an active control group is additionally engaged in a control training that differs as little as possible from the experimental training but does not target the same cognitive functions. It controls for unintended positive effects of training engagement on outcome measures for cognitive, everyday, or brain functioning such as practice of nontargeted cognitive, perceptual, or motor functions that are involved in both training tasks and outcome measures (Hager, 2000). There is intense discussion about what constitutes a good control training (Morrison & Chein, 2011; Shipstead, Redick, & Engle, 2012). Control trainings that have been employed so far range from noncognitive interventions over trainings of other cognitive functions to trainings targeting the same cognitive functions as the experimental training but not involving a performance-adaptive increase in task difficulty. For demonstrating training-induced enhancement in absolute stability, active control groups are regarded as methodologically superior (Hager, 2000). However, for demonstrating training-induced promotion of differential stability, the inclusion of a passive control group may be better since it is more representative for the normal course of development in cognitive, everyday, and brain functioning across the follow-up period.

The inclusion of a control group demands the application of further methodological measures to control for differences between the experimental groups or in experimenter behavior toward them: the randomized allocation of participants to experimental and control groups (Greenhalgh, 1997), blinding, and randomization concealment (Schulz & Grimes, 2002a, 2002b).

Table 1. Evaluation of training-induced enhancement of absolute, differential, and dimensional stability in cognitive, everyday, and brain functioning across adulthood

Stability type	Training-induced enhancement across adulthood	Design of studies evaluating training-induced enhancement	Methodological quality criteria of studies evaluating training-induced enhancement
Absolute stability	Increase in level of functioning immediately after training in older adults, thus reversing previous decline	Pre- and posttraining measurement of same outcome measures in older training participants	– control groups: at least passive, better active
Differential stability	Amelioration of slope of decline after training in older adults	Additional follow-up measurements of same outcome measures	– control groups: better passive than active – longer follow-up periods – several follow-up measurements
Dimensional stability	Training-induced enhancement of absolute or differential stability in several subfunctions of a functional domain in older adults at the same time	At all measurement points outcome measures for several subfunctions of a functional outcome domain	– outcome measures for a wide range of subfunctions of a functional outcome domain

In addition, the methodological quality of studies assessing training-induced enhancement of differential stability is better when more follow-ups are conducted over longer periods of time after training termination, which captures the trajectories of cognitive, everyday, and brain functioning in the experimental groups more precisely. If we take into account the normal course of development in the three functional domains of interest and their relationships with one another, follow-up periods of at least three years seem to be sensible (Salthouse, 2006).

Finally, the methodological quality of studies examining training-induced improvement of dimensional stability is higher when more outcome measures targeting very different cognitive or everyday abilities are applied.

Table 1 summarizes how cognitive trainings can enhance absolute, differential, and dimensional stability across adulthood in the three reviewed functional outcome domains, designs of studies for evaluating training-induced enhancements of the three stability types, and methodological quality criteria of these studies.

Types of Evaluated Cognitive Trainings

Three major types of cognitive trainings have been studied so far: strategy, process-based, and multidomain trainings. In strategy trainings, participants are instructed in and practice strategies on how to tackle cognitive tasks more successfully. Participants of process-based trainings extensively practice tasks targeting specific cognitive processes without instructions how to solve them. In multidomain trainings, participants are taught strategies for or practice complex cognitive tasks that require the successful combination of several different cognitive abilities.

Thus, the three training types differ in the complexity of their targeted cognitive functions. In process-based trainings very specific cognitive processes are trained, in strategy trainings cognitive abilities drawing on several cognitive processes, and in multidomain trainings several cognitive abilities (Eschen, Zöllig, & Martin, 2012; Lustig, Shah, Seidler, & Reuter-Lorenz, 2009; Noack et al., 2009; Zelinski, 2009).

The three training types are also supposed to differ in the mechanisms underlying training effects. In strategy trainings, cognitive processes used for task performance are changed, with more efficient or additional processes being recruited. In process-based trainings, the extensive practice of a cognitive process is thought to induce its automatization and thus improve its efficiency (Willis & Schaie, 2009). In multidomain trainings, more efficient combinations of cognitive processes are instructed or practiced.

Evidence for Training-Induced Stabilization across Adulthood

Below I review the current state of evidence with regard to the proposed contributions of the major types of cognitive trainings to absolute, differential, and dimensional stability of cognitive, everyday, and brain functioning across adulthood. Table 2 shows the resulting 27 combinations between the reviewed training types, stability types, and functional outcome domains and for which of these empirical evidence could be found and for which currently no data was available.

Evidence for Absolute Stability

Cognitive Functioning

In this section, I focus solely on pre- to posttraining improvements in trained cognitive functions, whereas training effects on other cognitive functions are discussed in the section concerning dimensional stability.

Table 2. Overview of the availability of data for the 27 combinations of reviewed training types, stability types, and functional outcome domains

Types of stability	Functional domains	Types of cognitive trainings		
Absolute stability	Cognitive functioning	Strategy trainings	Process-based trainings	Multidomain trainings
	Everyday functioning	Strategy trainings	Process-based trainings	Multidomain trainings
	Brain functioning	Strategy trainings	Process-based trainings	Multidomain trainings
Differential stability	Cognitive functioning	Strategy trainings	Process-based trainings	Multidomain trainings
	Everyday functioning	Strategy trainings	Process-based trainings	Multidomain trainings
	Brain functioning	Strategy trainings	Process-based trainings	Multidomain trainings
Dimensional stability	Cognitive functioning	Strategy trainings	Process-based trainings	Multidomain trainings
	Everyday functioning	Strategy trainings	Process-based trainings	Multidomain trainings
	Brain functioning	Strategy trainings	Process-based trainings	Multidomain trainings

Note. Gray fields = data was available; white fields = no data were available.

Strategy Trainings

Three meta-analyses (Gross et al., 2012; Martin, Clare, Altgassen, Cameron, & Zehnder, 2011; Verhaeghen, Marcoen, & Goossens, 1992) have summarized findings on pre- to posttraining gains in episodic memory for trainings teaching mnemonic strategies in older adults. They have been variously strict with regard to methodological quality of included analyzed studies, with Verhaeghen and colleagues also including studies without control groups, Gross and colleagues including only studies with control groups, and Martin and colleagues including only randomized controlled trials. Control groups in these studies were mainly passive or completed noncognitive interventions such as relaxation trainings or psychoeducation. The three meta-analyses found that these trainings lead to small to medium differential episodic memory improvements compared to both passive and active control groups from pre- to posttraining. For strategy trainings targeting reasoning in older adults, similar differential pre- to postperformance gains in this ability have been found (Ball et al., 2002; for a review see Baltes & Lindenberger, 1988).

Process-Based Trainings

Process-based trainings in older adults have concentrated mainly on executive processes such as updating (for reviews see Melby-Lervåg & Hulme, 2012; Morrison & Chein, 2011; Shipstead et al., 2012), multitasking (Bherer et al., 2006, 2008), focus-switching (Dorbath, Hasselhorn, & Titz, 2011), task-switching (Karbach & Kray, 2009), or processing speed (Ball et al., 2002). Most studies included passive control groups or active control groups among them those with control trainings that only differ in the performance-adaptive increase in task difficulty from the experimental trainings. Even with this stricter control, process-based trainings have proved to lead to medium to large differential performance gains in executive processes and large differential performance gains in processing speed.

Multidomain Trainings

Tasks of multidomain trainings have been modeled on cognitively demanding leisure activities. Examples are videogames (for a review, see Kueider, Parisi, Gross, & Rebok, 2012), group courses in acting (Noice & Noice, 2009), computer use (Klusmann et al., 2010), or problem solving (Stine-Morrow, Parisi, Morrow, Green, & Park, 2007), or volunteer work in elementary schools (Carlson et al., 2008). In line with the complexity of multidomain trainings, training effects on a wider range of cognitive abilities have been measured, mostly in comparison to passive control groups. Usually, significant differences in training effects between training and control groups were found for only a few of the tested cognitive abilities. For group courses and volunteer programs, small to medium differential performance gains in executive functions and episodic memory have been observed, whereas for videogames small to medium differential improvements in executive processes and processing speed have been demonstrated.

Everyday Functioning

Strategy Trainings

The well-known ACTIVE (Ball et al., 2002) and SimA studies (Oswald, Gunzelmann, Rupprecht, & Hagen, 2006) measured pre- to posttraining effects on self-reported BADL/IADL competence. In the ACTIVE study, about 2800 participants were randomized to a passive control, a strategy memory, a strategy reasoning, or a process-based speed training group. Among the experimental groups of the SimA study were an episodic memory strategy training group and a passive control group. In both studies, there were no significant differences between the passive control groups and the strategy training groups in pre- to posttraining BADL/IADL changes.

Process-Based Trainings

In the ACTIVE study, the process-based speed training also did not induce differential pre- to posttraining gains in BADL/IADL competence. In an independent study (Roenker, Cissell, Ball, Wadley, & Edwards, 2003), pre- to posttraining changes in driving induced by the speed training of the ACTIVE study were evaluated. From pre- to posttraining, the participants of the speed training group differentially improved compared to a passive control group in some driving simulator measures and undertook less dangerous manoeuvres in an on-road driving test.

Brain Functioning

I consider the following patterns of findings as supportive evidence for pre- to posttraining improvements in brain functioning: (1) activation decreases including the cessation of activation of brain regions recruited at pretraining and performance maintenance or performance gains in the imaging tasks or (2) activation increases in brain regions recruited at pretraining or recruitment of new brain regions and performance gains in the imaging tasks.

Strategy Trainings

Two studies investigated pre- to postchanges in brain functioning induced by strategy trainings in older adults. Both found activation increases in brain regions associated with cognitive processes that participants were instructed to use along with performance gains in the imaging tasks. Nyberg and colleagues (2003) found increases in occipito-temporal activations in an episodic memory task after practice of the method of loci. Occipito-temporal areas are known to be involved in visual imagery which the method of loci heavily relies on. Braver, Paxton, Locke, and Barch (2009) taught older adults to shift from proactive to retroactive control in a working memory task. Afterwards, they found an activation increase in the lateral prefrontal cortex earlier in the course of the trials.

Process-Based Trainings

Pre- to posttraining changes in brain functioning in older adults have so far been examined for two updating trainings (Brehmer et al., 2011; Dahlin, Stigsdotter Neely, Larsson, Bäckman, & Nyberg, 2008) and a dual-task training (Erickson et al., 2007). The first study included an active control group that completed an updating training without a performance-adaptive increase in task difficulty. The latter two studies included passive control groups. Brehmer and colleagues found differential prefrontal and parietal activation decreases and performance maintenance in an updating imaging task, while Dahlin and colleagues reported differential new recruitment of the striatum accompanied with differential performance gains in their updating imaging task. Erickson and colleagues found both prefrontal activa-

tion decreases and increases along with differential training improvements in a dual task conducted during scanning. In all studies, brain regions known to be involved in the trained processes were affected, which supports the assumption that process-based trainings increase efficiency of targeted processes.

Multidomain Trainings

Carlson and colleagues (2009) found differential pre- to posttraining activation increases in the left prefrontal and in the anterior cingulate cortices along with differential performance improvements in a flanker task for older participants of a volunteer program in elementary schools as compared to a passive control group. The affected brain regions are known to be involved in planning and coordination of cognitive processes, indicating that this multidomain training indeed practices finding and using new combinations of cognitive processes.

In sum, there is positive evidence that all types of cognitive trainings can stabilize cognitive and brain functioning across adulthood by reversing previous declines in older adults. In contrast, the few findings on everyday functioning indicate that cognitive trainings do not increase its level immediately after training.

Evidence for Differential Stability

Cognitive Functioning

Strategy Trainings

The SimA (Oswald et al., 2006) and the ACTIVE (Willis et al., 2006) studies followed their participants for 5 years after training termination. In the SimA study, large differential improvements in a cognitive composite measure derived from memory, attention, speed, and reasoning tests were found for the memory training group from pre- to posttraining compared to the passive control group. From posttraining to 5 years posttraining, the cognitive composite score of the control group remained stable, whereas it declined in the training group. However, their score was still higher than at pretraining. In the ACTIVE study, in all experimental groups episodic memory performance declined and reasoning performance improved from pretraining to 5-year follow-up. Compared to the other experimental groups, in the memory training group memory decline was milder and in the reasoning training group reasoning improved to a greater degree. However, from posttraining to follow-ups 1 and 2 years after training termination, in comparison to the other experimental groups the memory training group showed similar memory changes and the reasoning group a steeper reasoning decline (Ball et al., 2002). These findings can be regarded as proof of long-term maintenance of training-induced absolute cognitive

stability, but not as evidence for the enhancement of differential cognitive stability across adulthood (Salthouse, 2006).

Process-Based Trainings

For changes in speed from pretraining to 5-year follow-up (Willis et al., 2006) and from posttraining to 1- and 2-year follow-ups (Ball et al., 2002), a similar pattern of results as for changes in reasoning were found for the speed training group compared to the other experimental groups of the ACTIVE study, indicating only long-term maintenance of training-induced absolute stability by this cognitive training.

Everyday Functioning

Strategy Trainings

In all experimental groups of the ACTIVE study, BADL/IADL competence remained stable from pretraining to 2-year follow-up. Afterwards, up to the 5-year follow-up, it declined below the pretraining level in all experimental groups. Only the decline in the reasoning training group was significantly milder than that of the passive control group (Willis et al., 2006), indicating that only the reasoning training, but not the memory or the speed training, of the ACTIVE study enhances differential stability of BADL/IADL competence across adulthood. The following data also point to the promotion of differential stability in driving by this training. Car accident records across 6 years after training termination were acquired for the subsample of about 900 drivers of the ACTIVE study. Those drivers who had participated in the reasoning training were 50% less likely than drivers of the control group to experience a car crash across this period, whereas no significant differences between drivers of the memory training group and the control group were found (Ball, Edwards, Ross, & McGwin, 2010).

Process-Based Trainings

Ball and colleagues (2010) also reported that drivers of the speed training group of the ACTIVE study were 50% less likely than drivers of the control group to be involved in a car accident in the 6 years after training termination. Moreover, in other studies using this training in older adults, the speed training group reported less driving difficulty, more driving time, longer driving distances (Edwards, Myers et al., 2009), and less driving cessations in the 3-year follow-up period than a social and a computer contact control group (Edwards, Delahunt, & Mahncke, 2009). Thus, the process-based speed training of the ACTIVE study seems to enhance differential stability only in driving across adulthood.

In sum, for the evaluation of training-induced enhancement of differential stability, only data for the effects of four different trainings on cognitive and everyday functioning in older adults were available. The findings indicate that these trainings did not enhance differential cognitive stability, but a strategy reasoning training and a process-based speed training did ameliorate decline in everyday functioning for up to 6 years after training termination.

Evidence for Dimensional Stability

For the evaluation of the scope of cognitive training effects on dimensional stability in cognitive and brain functioning across adulthood, I adopt a recently proposed framework for classifying scope of training-induced cognitive transfer effects (Noack et al., 2009). This is based on the hierarchical model of human cognitive abilities by Carroll (1993) which differentiates between broad and narrow cognitive abilities. Thus, I categorize scope of training effects on dimensional stability as small, medium, or large according to whether training-induced enhancement of absolute or differential stability was demonstrated for outcome measures for the same narrow cognitive ability, for different narrow abilities from the same broad cognitive ability, or for different broad cognitive abilities, respectively.

Cognitive Functioning

Strategy Trainings

For the evaluation of effects of strategy trainings on cognitive functioning in older adults, so far mainly outcome measures for narrow cognitive abilities of the same broad cognitive ability have been employed. Mostly only improvements in the same narrow and seldom in other narrow cognitive abilities have been observed (Baltes & Lindenberger, 1988; Martin et al., 2011; Verhaeghen et al., 1992). The one exception is the ACTIVE study, in which outcome measures for the three broad cognitive abilities memory, speed, and reasoning were included. However, the memory and reasoning training groups only differentially improved from pre- to posttraining in their targeted cognitive abilities (Ball et al., 2002). Thus, only small to medium enhancement of dimensional stability in cognitive functioning by strategy trainings has to date been demonstrated.

Process-Based Trainings

Similarly, for the speed training of the ACTIVE study, only differential pre- to posttraining improvements in speed have been found (Ball et al., 2002), qualifying only for a small enhancement of dimensional cognitive stability. However, for process-based trainings of executive functions, differential pre- to posttraining improvements in executive functions and reasoning or memory have been demonstrated (Melby-Lervåg & Hulme, 2012; Morrison & Chein, 2011; Shipstead et al., 2012), meeting the require-

ments for a large improvement in dimensional cognitive stability across adulthood.

Multidomain Trainings

As described in the section on the effects of multidomain trainings on absolute cognitive stability across adulthood, differential pre- to posttraining improvements have been found for executive functions and episodic memory or processing speed. This can be regarded as evidence for a large enhancement of dimensional cognitive stability across adulthood by this training type.

Everyday Functioning

Strategy Trainings

For the reasoning training of the ACTIVE study, the enhancement of differential stability for both BADL/IADL competence (Willis et al., 2006) and driving (Ball et al., 2010) has been demonstrated in older adults. Since both everyday functions are quite different from each other, this indicates that this training improves dimensional stability of everyday functioning across adulthood.

Process-Based Trainings

In contrast, for the speed training of the ACTIVE study only enhancement of absolute (Roenker et al., 2003) and differential stability (Ball et al., 2010; Edwards, Delahunt et al., 2009; Edwards, Myers, et al., 2009) in driving across adulthood has been demonstrated. Thus, it may not increase dimensional stability in everyday functioning across adulthood.

Brain Functioning

Process-Based Trainings

Dahlin and colleagues (2008) investigated training-induced brain activation changes of their process-based updating training across two updating tasks in young and older adults. Compared to a passive control group, older training participants improved from pre- to posttraining in the updating task structurally similar to the training tasks, but not in the second updating task that was structurally dissimilar to the training tasks. In contrast to young adults, for whom a conjunction analysis across both tasks found a joint differential activation increase in the left striatum from pre- to posttraining along with differential performance increases in both tasks, in the older adults no common brain activation changes across both tasks were found. A differential left striatal activation increase was observed only in the first updating task. These findings indicate that this training cannot enhance dimensional stability in brain functioning across adulthood.

In sum, particularly process-based and multidomain trainings can reverse previous declines in several cognitive abilities in older adults at the same time. Among the four evaluated trainings for everyday functioning, only the strategy reasoning training ameliorates declines in two different everyday functions in older adults after training. One study indicated that a process-based updating training did not affect brain functioning across two updating imaging tasks.

Conclusions

A wealth of data are available on training-induced enhancement of cognitive functioning across adulthood but little data on everyday and brain functioning. Across the three reviewed functional domains, most studies evaluated training effects on absolute stability, but fewer studies their effects on dimensional stability and only a few studies their effects on differential stability. The latter studies had follow-up periods of maximal 6 years.

There is robust positive evidence that cognitive trainings enhance absolute and dimensional stability of cognitive functioning across adulthood. The few findings on the effects of cognitive trainings on differential stability in cognitive functioning across adulthood were negative, but they did indicate the maintenance of training effects on absolute cognitive stability up to 5 years after training termination. In contrast, the few data available on the contributions of cognitive trainings to stability of everyday functioning across adulthood were rather negative for absolute stability, but mostly positive for differential stability. One of the four evaluated cognitive trainings also enhanced dimensional stability of everyday functioning across adulthood. For brain functioning, findings of a few studies indicate that cognitive trainings enhance absolute stability in brain functioning across adulthood. No data were available to evaluate the effects of cognitive trainings on differential stability, and only one study (Dahlin et al., 2008) was available to evaluate their effect on dimensional stability. The findings of the latter study were negative.

All types of cognitive trainings enhanced absolute stability of cognitive functioning, but among them the greatest effects were reported for process-based trainings. The large effects of process-based trainings on absolute stability in cognitive functioning are probably caused by the high demands they pose on their targeted cognitive processes through their performance-adaptive increase in task difficulty. In addition, because strategy and multidomain trainings focus on several cognitive processes, they inflict smaller demands on each of their practiced processes. Moreover, strategy and multidomain trainings are usually conducted individually in a group and process-based training individually. Therefore, the participants of strategy and multidomain trainings may also have fewer opportunities for practice. Negative findings for the promotion of differential stability in cognitive functioning were limited to two

strategy memory trainings, a strategy reasoning, and a process-based speed training. Large effects on dimensional cognitive stability were demonstrated for a range of multi-domain trainings and process-based trainings targeting executive processes. In contrast, for many different strategy trainings only small to medium effects were reported. The large effects on dimensional cognitive stability of process-based trainings targeting executive processes may be surprising, because process-based trainings focus only on one cognitive process. However, this can be explained by the fact that executive processes are involved in a wide range of cognitive abilities (Kane et al., 2004; Unsworth, 2010).

For everyday functioning, only data on the same four cognitive trainings as investigated for training-induced enhancement of differential stability in cognitive functioning across adulthood were available. Only the strategy reasoning and the process-based speed training enhanced differential stability of everyday functioning. The reasoning training promoted differential stability in both BADL/IADL competence and driving, whereas the speed training affected only the slope of driving performance across the follow-up period. Thus, only the strategy reasoning training seems to promote dimensional stability in everyday functioning across adulthood.

For all types of trainings, also positive effects on absolute stability in brain functioning across adulthood have been demonstrated.

Consequently, all types of cognitive trainings can stabilize cognitive and brain functioning across adulthood by reversing their declines in older adults. Reversals of declines in cognitive functioning in older adults can be maintained up to 5 years after training termination. Process-based trainings targeting executive functions and multidomain trainings reverse declines not only in one but in several cognitive abilities in older adults. In addition, a strategy reasoning training and a process-based speed training also stabilize everyday functioning across adulthood by ameliorating decline in everyday functioning in older adults up to 6 years after training termination. Moreover, the reasoning training can ameliorate decline in two different everyday abilities in older adults after training termination. However, the current state of research calls for more studies on training-induced enhancement of stability of everyday and brain functioning across adulthood as well as on the training-induced differential stability in all three reviewed functional domains across adulthood.

With regard to studies on training-induced enhancement of differential stability of cognitive, everyday, and brain functioning across adulthood, follow-up periods of at least 10 years after training termination with several measurement points should be planned. In addition, contrary to the previous practice, not change in differential training gains for the training as compared to the control groups across the follow-up periods should be reported, but changes in outcome measures separately for both groups, so that the form and direction of change in these groups can be assessed.

It may be helpful to agree on a standard test battery that could be used across studies to evaluate the contributions of cognitive trainings to dimensional stability in cognitive functioning. The development of such a standard test battery could be oriented on the model about the structure of cognitive abilities of Carroll (1993) as Noack and colleagues (2009) suggested. However, executive functions are not well represented in this model. In addition, the current operationalization of the scope of cognitive training effects by the degree to which cognitive functions positively affected by a cognitive trainings are similar to those targeted in the training tasks should be changed. Instead, the scope of cognitive training effects should be defined by the degree to which cognitive functions enhanced by a cognitive training are similar to one another. This allows for a better evaluation of the scope of training effects of multidomain trainings for which it is otherwise hard to find any untrained cognitive abilities.

Better measures for everyday functioning need to be devised to study the effects of cognitive trainings on stability in everyday functioning across adulthood. However, a prerequisite for this is a clear definition of different everyday functions and their relations to one another.

Similarly, based on the little data available on the development of brain functioning and its relationship to cognitive development in old age, I have proposed preliminary definitions for positive evidence for training-induced enhancement of absolute and dimensional stability of brain functioning across adulthood. More longitudinal studies on the development of brain functioning across adulthood are needed to refine these definitions and provide a similar definition for differential stability.

Cognitive trainings studied so far in older adults differ significantly in their implementation characteristics such as duration, material, setting, or targeted cognitive abilities. There is a lack of studies systematically studying their influence on training-induced enhancement of stability in cognitive, everyday, or brain functioning across adulthood. In addition, very little is known about how different participant characteristics such as conscientiousness, self-efficacy, or health influence the effects of cognitive trainings on stability of cognitive, everyday, and brain functioning, and about how they might interact with training characteristics. This type of research is of great practical relevance since it generates information about which types of trainings can be recommended to which persons.

This review covers only how cognitive trainings can stabilize cognitive, everyday, and brain functioning in the face of developmental declines. Cognitive trainings could also enhance stability in these functional domains in the face of developmental increases, that is, by promoting their maturation across childhood and adolescence. In addition, other types of stability could also be enhanced by cognitive trainings such as intraindividual or divergent stability (Martin & Zimprich, 2005). The effects of cognitive trainings on absolute, differential, and dimensional stability in the three functional domains of interests have been reviewed sepa-

rately, but these three types of stability are probably related to one another. Furthermore, the classification of cognitive trainings into the three types presented here is indefinite. Thus, other authors may prefer other training classifications. The effects of cognitive trainings on stability in cognitive, everyday, and brain functioning across adulthood were not compared to those of other interventions. For example, physical fitness trainings seem to similarly enhance absolute stability of cognitive and brain functioning across adulthood (Kramer & Erickson, 2007).

Declaration of Conflicts of Interest

The authors declare that no conflicts of interest exist.

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