CHAPTER

12

Cognitive Training in Later Adulthood

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INTRODUCTION

This chapter is a selective review of the literature on behavioral-based cognitive training with a focus on midlife and later adulthood. Neural outcomes and correlates associated with behavioral-based interventions are reviewed. We first discuss differing perspectives on interventions with older adults, and the key questions addressed by those with a magnification versus compensatory orientation. We begin the review with more traditional approaches that involve single cognitive domains and focus on strategy or component training. We then discuss practice-based approaches including variable priority, whole-task (full emphasis) training, and multi-domain studies involving a combination of these approaches. Multi-domain studies focusing on activity engagement are also considered. We then review the burgeoning literature on computer- or mobile-based interventions, including both computerized training and casual gaming approaches. In a final section we discuss the emerging study of neural correlates and outcomes of behavioral interventions and consider the important contributions made by neuroimaging. We consider issues and debates on transfer with regard to each of these approaches, as well as factors, such as maintenance or durability of training effects, use of adaptive training techniques, and the role of control groups.

Theoretical Perspectives and Assumptions on Training

Intervention studies differ not only in the training protocol but also in theoretical perspective and key questions addressed regarding cognitive aging (Lövden, Bodammer, & Kuhn, 2010; Reuter-Lorenz & Park, 2014). A major question underlying most cognitive intervention studies has focused on the range of plasticity or modifiability of cognitive functioning and interindividual differences in training effectiveness (Lövden, Brehmer, Li, & Lindenberger, 2012).

Magnification Perspective

Age, given the predominance of cross-sectional studies in cognitive aging, has been the most common individual difference variable examined, with early training studies involving primarily extreme age group (young–old) comparisons of training effects (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Li et al., 2008). Age groups were said to differ in baseline level of cognitive resources or reserve and the initially more able were hypothesized to show greater training gain. The assumption is that there would be a positive association between baseline performance and magnitude of training gain.

Thus, interindividual differences (e.g., age) in training gains were expected to be magnified and to increase with training (Lövden et al., 2012). This approach to intervention has recently been described as *magnification* (Lövden et al., 2012), or as *testing the limits* in earlier formulations (Baltes, 1987). Plasticity in this view represented the capacity for change not only in the target cognitive domain, but particularly in transfer to other domains. The intervention focuses primarily on *practice* on one or multiple tasks, with no strategy or instructional training; the initially more able, having greater cognitive resources, should need only practice to reach the highest levels of performance. More recently, intervention studies with this orientation have also been concerned with neural plasticity and assumed that cerebral change or plasticity precedes or accompanies behavioral plasticity (Lustig, Shah, Seidler, & Reuter-Lorenz, 2009). Neural plasticity is often referenced as an alteration in processing efficiency, often associated with broader frontal brain activation.

Compensatory Perspective

A second major perspective toward intervention developed early in cognitive training research with older adults and has been described as *compensatory* or *remedial* in nature (Brom & Kliegl, 2014; Craik et al., 2007). This approach acknowledges the increasing likelihood of cognitive deficits associated with normal aging and focuses on compensating for less efficient functioning, particularly in less able older adults, via strategy or component training approaches (Belleville et al., 2006; Belleville, Clement, & Mellah, 2011; Schaie & Willis, 1986). Interindividual differences are also of concern within a compensatory perspective, but focus often on differences *among* older individuals within the same age range, rather than groups differing widely in age/cohort. In contrast to findings based on a magnification approach, individual differences are *reduced* as a function of training; and the less able elderly often demonstrate the largest training gains; baseline performance is negatively related to training gain (Schaie & Willis, 1986).

Some researchers have adopted the term *flexibility*, rather than plasticity, to describe the compensatory mechanism—flexibility indicates the capacity to optimize performance within the constraints of the aging process, with some researchers assuming that these constraints lie primarily in neural structural constraints. Malleability of cognitive performance in training results from the support provided by strategy use and instruction to restore or compensate for effects of cognitive aging. Neural functioning is also of concern within a compensatory approach, but often addresses interindividual differences in neural function among individuals varying in baseline cognitive performance and differential neural outcomes. For example, low functioning elderly, as a result of training, may show an increase in activation, rather than decreased activation (increased efficiency) shown by more able elderly and younger adults in the magnification approach.

COGNITIVE TRAINING: BEHAVIORAL INTERVENTIONS AND BEHAVIORAL OUTCOMES

Strategy Training

Strategy-based studies involve the *compensatory* perspective described above, focus on strategies aimed at compensating for aging-related cognitive deficits (Brom & Kliegl, 2014; Verhaeghen, Marcoen, & Goossens, 1992). They typically focus on a single complex mental ability, such as episodic memory or reasoning (also mental rotation), and involve training on strategies that are specific to the target ability. Thus, strategies differ markedly by the ability trained. Memory strategies are quite different, for example, to reasoning strategies (Jobe et al., 2001). Usually multiple strategies, specific to the ability, are trained. Strategies often reduce the complexity and attentional/memory demands for a given ability. Training items have traditionally closely resembled the format of measures and items employed in assessing the ability, although a variety of stimuli (numbers, letters, shapes) are employed and are not identical to test items. Recent strategy training protocols have increasingly emphasized subjects using the strategies in everyday activities and naturalistic settings (e.g., remembering a grocery list, remembering names at a party, etc.).

Episodic Memory

Memory programs typically rely on the teaching of mnemonics or strategies that provide rich and distinctive encoding (Craik et al., 2007). These include strategies that promote semantic elaboration, organization of material or strategies based on visual and interactive imagery (Rebok et al., 2013). For instance, in the method of loci participants learn to associate items to be remembered to a sequence of loci in a familiar environment (Gross et al., 2014). The technique is useful in learning sequences of items (e.g., word list) or temporally organized items. Interactive imagery is used to remember pairs or groups of items that are not easy to associate otherwise. Participants learn to pair the items in a vivid and interactive image. This technique has been used to learn the names of people. In this case, participants are taught to identify a salient feature in the person's face and to make an interactive image with a meaning given to the name of the person. Verbal strategies have also been frequently used. Categorical grouping, semantic elaboration, and organization of material have been proposed as ways to memorize lists of words or complex material such as texts or conversations.

There is an extensive literature that has examined the efficacy of those types of mnemonic strategies using experimental designs (Craik et al., 2007; Kueider, Parisi, Gross, & Rebok, 2012; Rebok et al., 2013). These studies examined whether various strategies showed differential levels of efficacy and whether their effect was durable and transferred to non-practiced tasks. Verhaeghen et al. (1992) performed a meta-analysis of 33 studies on memory training that comprised a total sample of 1539 healthy older adults. They reported that memory training that promoted encoding enhanced memory performance by approximately 0.7 standard deviations (SD) in healthy older adults. They also examined whether the characteristics of the training program determined efficacy. This provided critical information on the active ingredients that should be included in memory interventions designed for older adults. The findings that there were no differences in training efficacy as a function of the different types of mnemonics trained suggested that perhaps older adults with different learning styles and preferences are likely to benefit from different strategies and that efficacy is not restricted to a single type of strategy or mnemonic. However, efficacy of mnemonics may vary by type of material to be learned and recalled (Belleville et al., 2006). Method of loci may be particularly useful when words in a list belong to no common categories; whereas, strategies involving associations or organization (chunking) may be more useful when words in a list can be organized into superordinate categories, thus reducing the number of items to be remembered.

Moreover, reviews of memory training suggest that differences in efficacy occurred as a function of whether memory was trained in isolation (uni-factorial) or whether it was embedded in a multifactorial program (Belleville et al., 2006; Bier et al., 2015). For instance, programs that included attentional training, relaxation training or training meant to increase the ability to create interactive images have sometimes been found to improve memory more than programs focusing solely on memory strategies (e.g., method of loci). It was also found that shorter training sessions were more efficient than longer ones, perhaps because they reduced the negative effect of fatigue and attentional load on older adults' capacity to benefit from learning. Finally, there were clear indications that social interactions and mutual support are often important components of effective memory training as some authors reported better efficacy for group than individual training and for training involving a trainer, rather than self-directed training provided through instructional materials, such as a print manual.

Note that the meta-analysis published by Verhaeghen et al. (1992) was mostly based on small-scale non-randomized experimental studies, which limits conclusions regarding the specificity of the type of memory training program most effective and durable for promoting cognition and quality of life in healthy older adults. The Advanced Cognitive Training in Vital Elderly (ACTIVE) study was a large-scale randomized single-blind trial involving 2832 community-dwelling healthy older adults, which compared three different training programs. one of which targeted memory (Ball et al., 2002; Jobe et al., 2001). The 10-session memory program included training on a variety of mnemonics (e.g., categorization, semantic elaboration, visualization) and was unifactorial in that it did not include specifically training on non-memory dimensions, such as relaxation or imagery per se. Booster sessions were provided in a subset of participants 11 months following the end of the primary training and at 3 years follow-up; and efficacy was measured on a number of proximal and distal composite measures. Persons randomized to memory training were compared to those randomized to training on processing speed, reasoning or to a no-training condition. Memory training was found to selectively improve the memory composite measure (Ball et al., 2002; Jones et al., 2012; Rebok et al., 2013). The effect was still significant 5 years after the end of the training (Willis et al., 2006) but maintenance of training effects was not found at the 10-year follow-up (Rebok et al., 2014). Far transfer was examined to both self-reported and performance-based tasks of complex activities of daily living. At 10-year follow-up, memory-trained subjects reported less difficulty performing daily activities compared to controls.

There has been the suggestion that broader training transfer might occur when memory training is embedded in a multifactorial or multidomain program, involving such components as relaxation, imagery training, and socialization (see discussion of multidomain interventions below). Another possibility is that the activity outcome measures were not sensitive or specific enough to capture the type of daily activities that rely on episodic memory capacities or fail to reflect situations when mnemonics were used by trained participants. Use of journals or logs to record use of memory strategies may provide more sensitive and direct assessments of memory use in daily life, or new technologies (e.g., mobile devices) to test memory in real-life environments (Greenaway, Duncan & Smith, 2012).

Inductive Reasoning

Reasoning training has focused on improving the ability to solve problems that require linear thinking, involve rule-based problem-solving, and that follow a series pattern or sequence (Blieszner, Willis, & Baltes, 1981; Schaie & Willis, 1986; Willis & Nesselroade, 1990). Such problems, for example, involve identifying the pattern in a series of letters or numbers, or understanding the pattern in an everyday activity such as the dosing for a prescription drug or travel schedule. Participants were taught strategies to identify the pattern or sequence required to solve the problem and how to apply these strategies to determine the next item in the pattern. Participants were given an opportunity to practice the strategies in both individual and group exercises. The exercises involved abstract reasoning tasks as well as reasoning problems that related to activities of daily living (e.g., identifying medication dosing pattern and filling a pill reminder case).

The reasoning training program has been implemented with a trainer in small group settings in the ADEPT (Blieszner et al., 1981) and ACTIVE (Jobe et al., 2001; Willis & Caskie, 2013; Willis et al., 2006) studies and in one-on-one training sessions within the Seattle Longitudinal Study (SLS) training study (Schaie & Willis, 1986). Self-directed, at-home training has also been conducted with couples, compared to a single-subject condition (Margrett & Willis, 2006). Inductive training was employed as a comparison treatment at-home condition within the Senior Odyssey trial (Stine-Morrow, Pairsi, Morrow, Green, & Park, 2007; Stine-Morrow, Parisi, Morrow, & Park, 2008). Within the ADEPT and ACTIVE trials (Jones et al., 2013), significant training effects were found at immediate posttest and up to 10-year follow-up. For the ACTIVE trial, 68% of reason trainees experience reliable training improvement; effect size for reasoning training was 0.48 SD improvement at immediate posttest. In ACTIVE, booster training at 3-year follow-up demonstrated significantly enhanced effects beyond initial training. Significant near transfer effects to multiple measures of reasoning ability, measured as a latent construct, were reported in ADEPT and ACTIVE studies.

Within the SLS training study (Schaie & Willis, 1986), subjects' longitudinal cognitive trajectories prior to training were classified as exhibiting stability or decline on reasoning ability; training effects were compared for subjects showing prior decline or stability on the reasoning ability. Significant training effects occurred for both SLS subjects demonstrating prior stability or decline, with decline subjects showing somewhat greater effects. Training effects were maintained; baseline level and longitudinal training trajectories were found to be predictive of future cognitive impairment (Boron, Turiano, Willis, & Schaie, 2007; Boron, Willis, & Schaie, 2007).

Moderators of training improvement and transfer of training to non-cognitive factors were examined within the ACTIVE trial (Willis & Caskie, 2013). Different factors were related to the reason score at baseline compared with the magnitude of training gain (Willis & Caskie, 2013). Higher education, MMSE, better health, and younger age were related to higher baseline score. In contrast, larger training gain was related to training adherence and MMSE. Subjects who at baseline were retrospectively classified as at risk for memory impairment and did not show improvement in memory training nevertheless showed improvement in both reasoning and speed of processing training, suggesting that normal elderly with memory deficits may still profit from training on alternative abilities, such as speed or reasoning. There was no transfer from reasoning training to other abilities (memory, speed) trained in ACTIVE. At 5-year and 10-year follow-up, reason-trained subjects reported less difficulty carrying out daily activities compared to the control group.

While no cross-ability for transfer was found, transfer to other domains was found in ACTIVE. Significant improvement in internal locus of control beliefs was found between baseline and 5-year follow-up for the reasoning group, compared to a no-contact control (Wolinsky et al., 2010). Also, at 5- and 10-year follow-up, the reasoning and speed of processing training groups had lower rates of at-fault collision involvement than controls based on motor vehicle records; training participants had an approximately 50% lower rate (per person-mile) of at-fault motor vehicle crashes.

The reasoning training condition within the Senior Odyssey program exhibited significant training effects on reasoning measures, compared to a gain in divergent thinking for the Odyssey condition (Stine-Morrow et al., 2014). In addition, reasoning participants exhibited a significant increase on the personality trait of openness to experience, compared to a waitlist control group (Jackson, Hill, Payne, Roberts, & Stine-Morrow, 2012). Memory self-efficacy beliefs at baseline were found to predict reasoning training gain within the Senior Odyssey program; self-efficacy had effects on how trainees allocated time to training materials over the course of the intervention (Payne et al., 2012).

Component-Specific and Variable Priority Training

Training studies involving a component (part-task) and/or a variable priority approach may more closely resemble a compensatory perspective to training than the magnification approach (Boot et al., 2010; Kramer, Larish, & Strayer, 1995). While these studies do not specifically involve use of strategies, they do reduce the complexity of the task by focusing successively on different components of a task and increasing the task demands across training sessions. In variable priority training skills are practiced alternately or successively in an integrated context. Adaptive training, often employed in these approaches, involves individualized training, calibrating and changing item difficulty, speed of responding, and/or sequencing of task components to the performance level of the subject.

Variable Priority Training: Attention

Numerous studies have reported that variable priority training reduces dual-task cost in healthy older adults (Bherer et al., 2005, 2008; Bier, de Boysson, & Belleville, 2014; Boot, Blakely, & Simons, 2011; Kramer et al., 1995). Variable priority was also found to increase attentional dual-tasking capacities in persons with mild cognitive impairment who experience executive control deficits (Gagnon & Belleville, 2012). In variable priority training, individuals are asked to complete a divided attention task but are instructed to emphasize one task over the other across different blocks of dual tasking. It has been argued that variable priority training may be more effective to improve dual-task coordination than fixed priority training, where participants perform the two tasks simultaneously by allocating the same amount of attention to each task (Bier et al., 2014; Gagnon & Belleville, 2011; Lee et al., 2012; Voss et al., 2012). Studies that have compared the two training types reported larger dual-task coordination gain following variable priority than fixed priority training.

There are many reasons why the variable priority approach might be more favorable than fixed priority training. One possibility comes from the fact that divided attention costs depend on both the ability to carry out each individual task and the ability to coordinate or divide attention. Because variable priority contains trials where each task is practiced with full attention, it would involve both training of the individual component tasks and training of the coordination component (Kramer et al., 1995). One other possibility is that variable priority training is more powerful because it increases the participant's ability to exercise self-control over the locus of attention. In support of this later hypothesis, Bier et al. (2014) have found that participants who practice each task individually in full attention did not improve their ability to divide attention among tasks, in contrast to those who were provided with variable priority and fixed priority training. This suggests that it is not the greater practice on the individual tasks afforded by variable priority training which is responsible for its larger efficacy but the fact that it promotes an active control of attentional resources. This could also explain the results obtained by Bherer et al. (2005, 2008) who failed to find larger gain following variable than fixed priority training. One possible explanation is that in this study, the divided attention task involved discretely presented trials and response timing was fixed and pre-determined by the investigator, in contrast to the previous studies where the two tasks had to be monitored simultaneously. This suggests that variable training increases self-regulation and top-down regulatory control capacities and has its strongest effect when the conditions require that participants control and monitor their response strategies.

Speed of Processing

The protocol utilized in speed of processing training suggests similarities to the variable priority approach. Speed of processing training has focused on improving speed of visual search and ability to perform an increasing number of attentional tasks quickly, as assessed on the useful field of view (UFOV) task (Edwards, Wadley, Vance, Roenker, & Ball, 2005; Roenker et al., 2003). Speed of processing is trained by systematically reducing the stimulus duration in a series of progressively more difficult information-processing tasks presented via computer. In the simplest UFOV task (Task 1) participants were asked to identify objects at increasingly brief exposures. Once this ability was mastered at the shortest possible stimulus duration, participants were asked to divide their attention between two tasks: stimulus identification in the center of a computer monitor and localization of another target presented somewhere in the peripheral vision (Task 2). Again task difficulty was increased by either decreasing stimulus duration, expanding the area within which targets can be localized or increasing the difficulty of the central identification task. Once this task was mastered for the most difficult condition and minimum stimulus exposure, Task 3 added visual distractors to the stimulus display. Stimulus duration was then reduced systematically once again in response to improving performance, alternating with increasing task difficulty as in Task 2. Finally in the most difficult training conditions (Task 4) task demand was increased even further by superimposing an auditory identification component over the visual tasks.

This training has been presented in a variety of formats, including a one-on-one condition with a trainer, in small groups, and currently in a gaming format for at-home self-directed administration (Edwards, Valdes et al., 2013; Roenker et al., 2003). For the ACTIVE trial, 87% of speed trainees experience reliable training improvement; effect size for speed of process training was 1.46 SD improvement at immediate posttest (Ball et al., 2002). Factors associated with baseline speed performance included older age, poorer health. and MMSE. Booster training at both 1-year and 3-year follow-up enhanced performance. Subjects, who at baseline were retrospectively classified as at risk for memory impairment and did not show improvement in memory training, nevertheless showed improvement in both reasoning and speed of processing training. Significant improvement in internal locus of control beliefs was found between baseline and 5-year follow-up for the speed group, compared to a no-contact control (Wolinsky et al., 2010).

Several studies in the Ball laboratory have demonstrated the effects of speed of processing on various driving behaviors, particularly for older adults with significantly slower speed of processing (Ball et al., 2002). Prior studies indicated that lower-functioning older adults not only profited from speed training but also demonstrated better on-road driving safety (Roenker et al., 2003). Specifically, older adults demonstrated significantly fewer dangerous on-road maneuvers after training—an improvement that endured 18 months later, as compared to a control group of older drivers who received traditional driver education and simulator training. In addition, low-functioning adults receiving speed training reported no more difficulty in driving situations (high traffic, driving in rain, merging traffic) than did normal-functioning adults receiving training (Edwards, Myers, Ross, Roenker, Cissell, Mclaughlin, et al., 2009). In the ACTIVE trial, it was first demonstrated that speed of processing training was associated with reduced motor vehicle crashes at 5 and 10 years following training (Ball, Edwards, & McGwin, 2010). ACTIVE trainees on speed also showed immediate improvements in performance of the Timed IADL Test, a performance-based assessment measuring speed and accuracy across four IADL domains (Edwards et al., 2005; Edwards, Ruva, O'Brien, Haley & Lister, 2013).

Effects of speed of processing training have also been examined in studies by Wolinsky, Vander Weg, Howren, Jones, and Dotson (2013) and others. Wolinsky compared 10 and 14 h of laboratory-based training and 10-h at-home training with an attention control group in midlife and older adults.. All speed training groups showed moderate training effects on the UFOV test with no age differences (midlife, older adult) in effect size. Also, small significant effects on Trials A & B, and Symbol Digit test were found; improvement on Stroop color test was not significant.

Whole Task Practice Training

Studies from a magnification perspective have often focused on the whole task (in contrast to a component or variable priority approach) and involved practice (in contrast to an instructional approach). The studies often involve age group comparisons assuming that older versus younger age groups differ in baseline resources and thus those with greater resources should exhibit the greatest training improvement—magnifying interindividual differences. Adaptive training techniques are often employed to maximize individual differences in training outcomes.

N-Back (Working Memory) Training

Perhaps the most frequently employed training task in magnification studies has been the n-back task, assumed to be a strong marker of working memory (WM) (Au et al., 2015). WM, considered to be a key determinant of many higher-order cognitive functions, is thus of much interest in studies from a magnification perspective. Training seeks to develop process-specific WM outcomes which some expect to lead to general, broader training transfer. Jaeggi et al. (2008) carried out one of the early n-back training studies reporting what was described as far transfer to one measure (Raven matrices) of fluid intelligence (Gf). Given that these findings on Gf transfer were not replicated in other labs (Chooi & Thompson, 2012; Shipstead, Redick, & Engle, 2012; Redick et al., 2013), much debate has ensued on both the construct represented by the n-back task and the potential of magnification (whole task practice) studies to demonstrate broad transfer.

Jaeggi and colleagues (Au et al., 2015) recently reported on a meta-analysis of n-back training research, but unfortunately limited studies reviewed young and midlife samples (18–50 years). They concluded that studies support the finding that various components of WM are modifiable, but that findings regarding broader transfer are equivocable. Thus, broad transfer effects (to Gf) were found to show modest or small effects, equivalent to a few test points. Generally transfer effects were assessed with only one Gf measure, often matrix reasoning. Similar limited transfer effects were reported in a meta-analysis by Melby-Lervag and Hulme (2013).

WM as a Multidimensional Construct: Implications for Training

There has been growing recognition of the limitations of using a single measure as either the training task or as a transfer measure (Au et al., 2015; Banqued et al., 2013; Schaie, Willis, Hertzog, & Schulenberg, 1987). Discussion of the limitations of a single measure outcome has focused on WM; however, the limitation holds for all cognitive training studies, including both compensation and magnification approaches. WM has been shown to involve multiple sub-processes including updating, inhibition, and maintenance. These sub-processes may all influence or be differentially represented in various WM measures. For example, capacity may vary for span measures involving only maintenance versus also including sub-processes related to updating and inhibition. Since WM represents a construct of multiple sub-processes, assessment of training effects and transfer effects need to assess multiple sub-processes. Similarly, fluid intelligence is conceived as a second-order factor involving multiple abilities (e.g., inductive reasoning, configural relations). A single measure (Raven matrices) of a single ability (reason) is an inadequate marker of transfer to fluid intelligence.

Jaeggi and colleagues (Jaeggi, Buschkuehl, Perrig, & Meier, 2010) have also reported other issues with use of the n-back test as a training measure and as a marker of WM. Less difficult versions of the n-back task have been found to have poor reliability and thus inadequate measures of individual differences, due to low test reliability. Assessing the relationship of the n-back test to other cognitive domains is, thus, problematic. Of major concern are findings regarding the construct validity of the n-back test with other more complex WM measures.

The n-back task appears to be more related to simple span measures than more complex WM measures. Moreover, in relation to training transfer, the n-back measure appears related to Gf only at higher levels of load and to represent primarily attentional control within the Gf construct, thus not representing the multiple abilities included in the second-order factor of Gf (Baniqued et al., 2013).

Training Involving Multiple WM Subprocesses or Tasks

Other WM training studies have focused on a variety of WM tasks, rather than solely on the n-back task (Brehmer, Westerberg, & Bäckman, 2012; Li et al., 2008). Training involving multiple WM tasks increases the likelihood of involving multiple components of WM. Some training and transfer effects have been observed in studies using multiple tasks/processes. Zinke, Zeintl, Rose, Putzmann, and Pydde (2014) trained on multiple aspects of WM, involving verbal, visuospatial WM and executive control, using an adaptive training technique; transfer to one measure of matrix reason was reported, but not maintained at follow-up. In an elderly sample, Brehmer et al. (2012) compared young and older adults in practice on spatial and verbal WM tasks with one condition receiving adaptive training and another condition receiving the same tasks under a non-adaptive, low-difficulty protocol. Greater gains occurred for adaptive training. Older and younger subjects did not differ in training and transfer effects on verbal WM, but older adults did less well than young adults on spatial WM tasks.

Multi-Domain Training

Multi-Domain: Combined Strategy and Component Training

Historically, a large number of training studies have focused on a single cognitive ability or process. However, given that many factors are contributing to cognitive decline and functional loss in aging, this might not be the most sensible approach if the goal is greater transfer or generalization/application of training to everyday activities, leading to independence and quality of life (Park et al., 2014).

MEMO

Belleville and collaborators have developed a multifactorial approach for use with healthy older adults and persons with mild cognitive impairment (Méthode d'entraînement pour une mémoire optimale, MEMO; Belleville et al., 2006; Bier et al., 2015). The program involves small groups (4–8 individuals) and teaches a variety of mnemonics (method of loci, face-name association, interactive imagery, text hierarchization, semantic elaboration). It is multifactorial as it includes pre-training on attention and visual imagery abilities as well as general psychoeducational information on cognitive aging and lifestyle factors. In addition to training different cognitive components, the program includes a number of features to promote self-efficacy and generalization, for instance, homework exercises, instructions on how to implement the strategies in real-life situations, discussion about the difficulties encountered while using strategies at home, class demonstrations by the instructor, gradual decrease in support and cues while participants learn to apply the strategy; peer support facilitated by numerous occasions for participants to share strategies and discuss their challenges. These elements were meant to increase engagement and motivation and provide psychosocial stimulation in addition to cognitive training.

In a preliminary pilot study (Bier et al., 2015), positive training effects were found on word-list and face-name association tasks with a comparable magnitude of effects found in groups of healthy older adults and persons with mild cognitive impairment. The authors measured generalization using the self-evaluation complaint questionnaire (van der Linden et al., 1989). In this questionnaire, participants rate the frequency with which they encounter memory difficulties in different areas of their daily life, for instance difficulties in remembering political events or not being sure of whether one had already bought an item or not. Following training, participants reported fewer complaints regarding their memory. They also improved on a measure of general well-being. These two results suggest that the effect of the training might have generalized to concrete dimensions of their life. However, this study needs replication as it included only a small number of participants and did not involve a randomized design.

ACTIVITY ENGAGEMENT INTERVENTIONS

Computer- and Mobile-Based Training and Gaming

Computerized Training

One of the fast-growing and most controversial approaches to cognitive intervention involves the use of computers as the delivery mechanism for the intervention (Boot, 2015; Boot et al., 2011). It is important to distinguish two domains of computer-based interventions, although there is some overlap between the two.

One approach was developed largely by researchers in cognition, including cognitive aging, many of whom had conducted trainer-based intervention studies and sought to enhance training by utilizing technological resources, such as adaptive training, graphics, and use of latencies as either individualizing training or as a primary outcome (Kueider et al., 2012; Lampit, Hallock, & Valenzuela, 2014). In addition, computer-based training expanded the training context and scheduling beyond the laboratory and facilitated an individualized, more self-directed approach to intervention. These computer-based training studies focused on similar cognitive abilities and process to those discussed in earlier sections.

The second approach has involved cognitive researchers exploring the efficacy of commercial products, often described as casual video games, for enhancing cognitive functioning (Boot et al., 2011). Casual video games are highly popular, involve simple rules, can be completed in a short time period, requiring less rigor and skill than those played by serious gamers. It is estimated that 200 million people worldwide play casual video games.

COMPUTERIZED-COGNITIVE TRAINING

The effort to develop computer-based training, especially for older adults, evolved both from recognition of the potential for technology to enhance the training process, and the need for a more cost-efficient alternative to the trainer-based approach (Kueider et al., 2012). In addition, in the past decade the computer literacy of older adult cohorts has significantly increased; older adults are now the fastest-growing segment of internet uses with 42% of 65+ and 78% of 50–64-year-old adults using the internet (Pew Internet & American Life Project, 2010). Kueider et al. (2012) recently reviewed the cognitive focus and efficacy of computerized training studies with cognitively normal older adults over the period 1984 to 2011. The 21 classical cognitive training studies reviewed trained on seven aspects of cognition and used guided practice on standardized tasks, with half of the studies focused on processing speed with generally positive effects (five) or memory (five; including episodic, WM and spatial memory) with studies varying in efficacy. The studies met rigorous standards of randomized designs and pre-posttest assessment. They found effect sizes, in general, to be comparable to those reported in non-computerized training studies. Of the seven types of cognitive process included in studies, the effect sizes for studies varied from 1.3 for processing speed to 0.39 for visuospatial abilities, with the highest effect sizes for processing speed, reaction time, and WM. Reports from older adults who completed the computerized training were positive with high satisfaction ratings. Kueider et al. (2012) urge some caution in interpreting findings due to the wide variety of training approaches and cognitive processes involved in studies. Lampit et al. (2014) also reviewed 52 studies of computerized training with healthy older adults (60–82 years) with 32 group versus 19 home training contexts, from 1992 to 2014. Studies reviewed were limited to randomized controlled trials with training duration of at least 4 h, with focus on an active control. Training domains included speed of processing, WM attention, with approximately half of studies multidomain. Their conclusion was somewhat less positive, describing effects as small and significant, with generally less effect for WM and executive domains.

Casual Gaming Interventions

A more controversial domain in computerized training for older adults has focused on casual video games as the training approach (Boot et al., 2011). There have been two recent consensus statements from cognitive researchers on commercial gaming approaches for enhancing cognitive functioning in older adults (Max Planck Institute for Human Development and Stanford Center on Longevity, 2014). Both statements express concern regarding the limited reliable scientific research reported in high-impact, peer-reviewed scientific journals for claims made by some commercial promoters on the efficacy of "brain games" particularly for the elderly. The brain-training industry is unregulated and quasi-scientific claims are not vetted by any regulatory group, leaving prospective consumers to face the challenge of separating wild claims from serious science. Both consensus statements agree on optimism for the plasticity of cognitive and brain functioning into old age, acknowledging that training can improve performance on trained tasks, but few training programs have shown evidence for transfer to improved performance on everyday tasks and importantly no interventions have been shown to prevent or cure dementias such as AD. It is important to note that the concern for promoting video games as brain games is not inherent to the use of computers or mobile devices to deliver the tasks; it is that most commercial companies making unsubstantiated claims are providing their programs via computers and mobile devices.

ASSOCIATION OF COGNITIVE ABILITIES AND CASUAL VIDEO GAMES

One of the most basic and largely unexamined hypotheses underlying casual gaming is that these games do involve exercise of the basic cognitive abilities and processes shown to decline with age and thus have potential as a training tool (Boot, 2015; Boot et al., 2011). Recent research findings (Baniqued et al., 2013) question the strength and specificity of the association between key cognitive constructs (fluid intelligence, perceptual speed, episodic memory, WM, and attention) and 20 web-based games.

CHALLENGE OF CLASSIFYING GAMES BY COGNITIVE DOMAIN An a priori task analysis by game developers (Militello & Hutton, 1998; and subsequently by the study co-authors Baniqued et al., 2013) for grouping the 20 games by cognitive construct presumably tapped by each game was not substantiated. CPA analyses suggested that many games could be grouped into multiple categories; reasoning games often also loaded highly on WM and spatial reasoning game categories. Perceptual speed games also were heterogeneous and did not form a single group. These results indicate that intuitive task-based analyses of games may be insufficient when selecting games for interventions and required empirical validation. A series of factor analytic procedures resulted in five broad and over-lapping game groups: Reasoning-WM; spatial reasoning; attention tracking; and perceptual-visual-motor-speed games.

ASSOCIATION BETWEEN COGNITIVE ABILITIES AND GAME GROUPS A series of factor analyses resulted in identifying seven cognitive ability/process domains: fluid reasoning, speed, episodic memory, WM, general attention, shifting, inhibition. Correlations between game groups and cognitive constructs were examined. Most game scores, regardless of game group, were highly related to WM, fluid intelligence, and perceptual speed. The authors conclude that demonstrating the relationship between games and cognitive abilities is a critical first step if games are to be useful for training—a step often neglected in gaming research.

In a second study, Baniqued et al. (2014) conducted a training study with young adults to examine the ability–game associations found in Baniqued et al. (2013). Subjects were randomized to 15-h of practice on four memory-reasoning games with and without an adaptive training approach or to an active control. Although there was improvement on the games, transfer to the target abilities or untrained tasks was minimal.

One of the most successful studies of casual gaming with older adults focused on executive functions required in the Rise of Nations game (Basak, Boot, Voss, & Kramer, 2008). Training for 23.5 h involved multiple strategies including a variable priority approach. There was improvement both on game performance and on task switching, WM, and visual short-term memory. Individual differences in game performance were correlated with an improvement in task switching.

Research by Boot and colleagues (Boot, 2015; Boot et al., 2013) compared efficacy of an action game versus "brain fitness" game to improve abilities in older adults. Neither group showed significant improvement in cognitive abilities. However, there were important group differences in training adherence and enjoyment of training. The action game has lower adherence and was reported by older adults to be less enjoyable. Trainees perceived fewer benefits from playing the action game and more difficulties in game-playing associated with eyesight and arthritis, supporting prior research that older adults preferred games involving an intellectual challenge over fast-paced action games (McKay & Maki, 2010).

MCI Training

In recent years, there has been tremendous interest in the development of intervention programs focusing on age-related neurodegenerative diseases. The term mild cognitive impairment (MCI) has been proposed to identify the prodromal phase of Alzheimer's disease (AD). Persons with amnestic MCI have memory complaints and impaired performance on memory tasks, but they do not meet the criteria for dementia (Gauthier et al., 2006). Many of these individuals are in a transitional phase between normal aging and dementia and they have a ten-fold larger risk than non-MCI to progress to dementia. This phase has been identified as a strategic target for the provision of non-pharmacological preventive and/or clinical interventions, as during this phase, compensatory processes including neuroplasticity are still active and could be enhanced to delay expression of dementia symptoms (Clement & Belleville, 2010, 2012). In addition, cognition interventions are particularly appealing as a way to address cognitive problems in MCI because these persons still have the capabilities to learn compensatory strategies and these can have a tremendous impact on their quality of life (Clare, van Paasschen & Evans, 2009).

A large number of studies have examined whether cognitive training can improve performance in persons with MCI. Some of them relied on computerized training of multiple cognitive components (Cipriani, Bianchetti, & Trabucchi, 2006; Gunther, Schafer, Holzner,

& Kemmler, 2003; Rozzini, et al., 2007; Talassi, et al., 2007). Other interventions focused on structured group training in which participants were taught different memory strategies (Belleville et al., 2006; Kinsella et al., 2009; Kurz, Pohl, Ramsenthaler, & Sorg, 2009; Olazaran et al., 2004; Rapp, Brenes, & Marsh, 2002; Troyer, Murphy, Anderson, Moscovitch, & Craik, 2008; Wenisch et al., 2007; Olchik et al., 2013). Group interventions most often included education on memory, ways of coping with stress, and the teaching and practice of the learned strategies.

Overall, the results of these techniques have been mixed. Some studies reported improvement in participants' perception of their memory capacities (Rapp et al., 2002) or in strategic knowledge and self-reported used strategies (Troyer et al., 2008), but no difference in objective memory tasks. By contrast, a number of more recent studies have reported positive results on objective cognitive measures (Belleville et al., 2006; Kinsella et al., 2009; Kurz et al., 2009; Olazaran et al., 2004; Wenisch et al., 2007). For example, Belleville et al. (2006) found training-related improvement in objective memory outcomes, well-being, and subjective appraisal of memory in daily life situations. The program employed was a multifactorial intervention that included the explicit learning of memory strategies as well as training in non-memory capacities (attention, visual imagery) and non-cognitive (stress, self-efficacy, empowerment) strategies that were considered important factors in promoting the learning and proper use of the memory strategies. Multifactorial interventions that implicate extended practice and explicit generalization strategies may be the most effective way of improving memory performance in MCI, as they are likely best suited to the range of problems encountered in MCI. Similar results were reported by Kinsella et al. (2009), who found a significant effect of a multifactorial intervention involving family members that focused on prospective memory tasks, knowledge, and the use of memory strategies. Colleagues at the Mayo Clinic (Greenaway, Duncan, & Smith, 2012) have examined training with a memory support system (MSS) involving training in use of notebooks and calendars and including family members. Functional ability and memory self-efficacy improved with MSS training and functional ability improvement was maintained at 8-week follow-up. Care partners demonstrated improved mood at 8-week and 6-month follow-up. Wenisch et al. (2007) also found significant results on memory measures.

Note, however, that these studies have relied on small sample sizes and many of them did not compare their intervention to an active control group condition or randomized participants. Two studies that have involved well-controlled designs have reported fairly disappointing findings. The PACE study is a randomized control trial of cognitive activity in persons with MCI. One hundred and sixty participants enrolled in 90-min sessions twice per week for 5 weeks. A short booster session was provided by phone after 6 months and in a longer face-to-face booster after a year. The cognitive training program provided participants with a range of techniques to help manage their difficulties and participants were compared to a psychoeducational program that provided healthy lifestyle guidelines (Vidovich et al., 2009). Results (Vidovich et al., 2015) indicated no effect of the cognitive intervention relative to the control intervention on the primary outcomes, though some effects were found on secondary cognitive measures and on measures of quality of life.

Similar results were reported by Unverzagt et al. (2007) based on the results from the ACTIVE study. Though the study did not have access to clinically identified MCI, the authors examined whether performing below average on memory tasks at baseline predicted efficacy of the memory training program. They found that persons with a reduced memory score did not benefit as much as those with normal or above-average memory performance from memory training but benefit was equivalent for the processing speed and reasoning training.

These two studies suggest that persons with amnestic MCI might require intervention strategies that differ from the ones typically designed for healthy older adults. It is possible that this population requires interventions that are more intensive and multifactorial in nature, similar to the one that was proposed in the MEMO program (Bier et al., 2015). Another important issue is the identification of the most sensitive and valid outcome measures, given that this is a population likely to experience cognitive decline over the course of the study. Interindividual variability is also a challenge in this quite variable population. Interindividual differences can, of course, interfere with the ability to identify training effect because they have an impact on the effect size. It can also have tremendous consequences on the training approach to be selected. Within an individualized perspective, interindividual differences in disease etiology and brain characteristics as well as in psychological, motivational and lifestyle characteristics should be used to shape an appropriate intervention strategy. While this comes with methodological challenges, individualized approaches are likely to be the most beneficial in persons with prodromal AD because interdifferences are likely to have their largest effect in populations with mild clinical symptoms.

COGNITIVE TRAINING: NEURAL MECHANISMS AND OUTCOMES

Brain imaging techniques are powerful tools to better understand the impact and mechanisms by which cognitive training exerts its effect. Brain imaging can reflect the impact of training on the structure of the brain or on its function. Structural brain imaging provides information on the brain anatomy, including whole-brain volume, regional gray matter volumes, cortical thickness, and white matter integrity. In turn, functional brain imaging provides information on the regions or networks that are active when at rest or when performing a task, and can be used to identify the neurocognitive effects of the intervention. Functional brain imaging can provide critical information on the mechanisms through which an intervention enhances cognition. For instance, the patterns of change in brain activation can reveal whether the cognitive improvement has occurred through compensatory use of alternative regions/processes or whether it results from increased efficiency of specialized regions. Structural and functional brain changes can precede behavioral changes, and functional brain imaging can reveal changes that are not detectable at the structural level due to technical constraints. For this reason, these various neuroimaging domains or markers are likely to provide complimentary information.

Brain Imaging as a Surrogate Biomarker

These techniques can be used as “surrogate biomarkers” of training efficacy or to reveal the neurobiological mechanisms supporting the effect of cognitive training. The training-induced brain changes revealed by those techniques can also inform lifespan models of brain reorganization and compensation because they provide direct information regarding the impact that environmental stimulation exerts on brain structure and function.

In therapeutic trials, surrogate markers are used as clinically meaningful measures of the effect of a therapy (Fleming & DeMets, 1996; Katz, 2004), when assessment of the primary outcome is methodologically unfeasible. For instance, dementia, such as AD, is a clinically valid outcome when designing a study to measure whether cognitive training can prevent the progression of AD in pre-symptomatic individuals. However, detecting the progression of dementia may require too long a follow-up, or necessitate too large a sample to be used as a critical outcome in dementia prevention-delay studies. In turn, a biomarker which reflects the underlying neuropathology, for instance measures of hippocampal volume, neuronal injury, or amyloid deposition, can be used to assess the effect of training on the neuropathology of the disease (dementia) or on its progression (Rosen, Sugiura & Kramer, 2011; Valenzuela, Jones & Wen, 2003). For instance, reduced PET uptake at rest of [^{18}F]fluorodeoxyglucose (FDG) was suggested as a valid biomarker of neuronal injury in early AD and MCI (Albert, DeKosky, & Dickson, 2011; McKhann, Knopman, & Chertkow, 2011). A 6-month multicomponent cognitive training program was found to reduce decline in brain glucose metabolism in MCI and early AD participants (Forster, Buschert, & Teipel, 2011) suggesting that the program had an impact on some of the neuronal injuries that underlie AD. Some of the work by Hampstead and colleagues also exemplifies this approach. The authors found that training memory strategies in persons with MCI increased activation in the right hippocampus, hence partially restorating hippocampal function (Hampstead, Stringer, & Stilla, 2012). In both cases, neuroimaging was used as a surrogate marker to indicate that cognitive training could have an impact on the early biological expression of AD.

Brain Imaging to Identify Structural Plasticity

There is evidence that cognitive training has direct effects on brain structure. Boyke, Driemeyer, and Gaser (2008) examined the effect of a 3-month three-ball juggling learning program on gray-matter volume measured with voxel-based morphometry in younger and older adults. Following the learning phase, older adults showed increased volume in the visual cortex, in the left hippocampus and in the nucleus accumbens bilaterally. Overall, younger adults showed slightly larger volume increases than older adults, but it was only older adults who showed training-related changes in the hippocampus and nucleus accumbens.

Engvig, Fjell, and Westlye (2010, 2012a) examined the effects of an 8-week method of loci memory training on cortical thickness in middle-aged and older adults and on the white matter microstructure, using diffusion tensor imaging (DTI). Training was found to increase cortical thickness in the lateral orbitofrontal cortex bilaterally and right fusiform cortex; and these changes correlated positively with memory improvement. The authors also reported a non-significant increase in fractional anisotropy (FA) in the frontal areas of trained older adults and a significant decrease in those who received no training. These findings suggested that training might reduce white-matter degradation associated with aging. There were similar findings by Lovden et al., who reported increased FA (and decreased mean diffusivity) in older adults, following a multidimensional program in which participants practiced WM, episodic memory, and perceptual speed tasks. Overall the studies investigating the effect of training on the structure of the brain indicate that behavioral training can induce considerable structural plasticity in older adults.

Effects on Training for Brain Activation

Nyberg, Sandblom, and Jones (2003) were among the first to assess the effect of training with a task-related activation paradigm. They reported increased occipitoparietal PET-related activity in older adults trained successfully with the method of loci. Younger adults showed a similar pattern of brain changes following training with an additional increase in the prefrontal cortex. Belleville et al. (2011) used fMRI to assess memory-related activation following a 6-week multifactorial memory-strategy training program. In their program, participants were trained on a range of memory strategies including semantic elaboration, face-name association, and the method of loci. They assessed whether training would be found in specialized brain regions that are typically involved in verbal memory, or in alternative areas, that is, regions not typically involved in word memory. They found increased post-training activation in specialized brain regions as well as new areas of activation. These additional activations, they argue, would reflect the implication of alternative compensatory strategies. For instance, activation of the right inferior parietal lobe found following training might reflect the fact that participants applied the visual imagery techniques as a strategy to encode words. Interestingly, activation of the right inferior parietal lobe was found to correlate with the efficacy of memory training in persons with MCI, hence suggesting that this brain region might support successful compensation. Note that training in this study did not modify activation of the hippocampus, which is surprising given that the goal was to improve episodic memory and hippocampal function is thought to be impaired in MCI. This lack of hippocampal activation might be explained by the fact that the program used in this study relies heavily on the teaching of visual-based mnemonics and hence might promote recruitment of prefrontal and posterior brain regions rather than the hippocampus.

In a set of more recent studies, Hampstead et al. (2012) used a memory training method that relied on associative memory (relying on mental imagery to learn object–location associations). They found that hippocampal activation increased significantly in MCI following training compared to an exposure-control condition. Hence, enhanced hippocampal activation might be favored by the use of a more focused approach that targets associative memory. Overall, studies of memory training that have induced brain changes have mostly reported increased activation either in specialized regions or in alternative regions that are required by the mnemonics taught.

A few studies have assessed the neurofunctional basis of attention-executive training in older adults and while some have reported increased post-training activation, others indicated a mix of increased and decreased activation. Rosen and colleagues reported increased left hippocampal activation in MCI persons who were assigned to a computerized program designed to improve speed and temporal auditory processing (Rosen et al., 2011). Disadvantaged older adults participating in Experience Corps, a program promoting social engagement, also showed increased post-training activation in the left dorsolateral prefrontal cortex and anterior cingulate gyrus when performing the flanker-task (Carlson, Erickson, & Kramer 2009). Erickson, Colcombe, and Wadhwa (2007) and Erickson, Boot, and Basak (2010) measured changes in the pattern of fMRI activation during dual-task performance following attentional training in healthy older adults. They reported increased activity in the left VLPFC region (near Broca's area), which could reflect an increased reliance on verbal or inner speech strategies. They also observed decreased activity in the right VLPFC, suggesting a reduced dependence on response selection strategies or a more efficient stimulus–response–stimulus association. Brehmer et al. (2012) reported decreased post-training brain activity following a 5-week WM adaptive (individualized) training, a result which they interpret as reflecting improved neural efficiency. Braver and colleagues reported a combination of increased activation in response to the cue and reduced activation in response to the probe, following strategy training on task maintenance and updating.

Models of Training-Induced Brain Changes

A few models have been proposed to interpret the effects of cognitive training on the brains of older adults. Some of these models focus on naturally occurring compensation in older adults, in contrast to formal cognitive training approaches. One set of models (Clement & Belleville, 2012) has proposed that compensation in the early AD phase occurs by increasing activation within the specialized structurally impaired network. Other models propose that brain lesions can reveal latent regions that would have otherwise remained silent when performing the task. For instance, the HAROLD model (Cabeza, 2002) proposes that compensation occurs in aging through the recruitment of latent regions located contralaterally to those that are typically recruited by the task. According to the CRUNCH model (Reuter-Lorenz & Cappell, 2008), compensation is supported by both increased activation of specialized brain regions and by strategic recruitment of alternative regions. These two models align well with the findings that memory training in older adults often results in new activation of alternative (latent) brain regions, but they fail to account for the fact that attention training often reduces activation and that alternative types of training result in different types of brain changes.

In their theoretical framework for the study of adult cognitive plasticity, Lovden, Backman, Lindenberger, Schaefer, and Schmiedek (2010) argue that changes in plasticity occur when there is a mismatch between the environmental demand and the capacity of the system; their view of plasticity is more in line with a magnification perspective of training. Furthermore, they propose that processes representing plasticity result in *structural* brain changes that have functional consequences. They distinguish plasticity from the transient changes in pre-existing processes which would reflect the flexibility of the system in the face of changing demands; transient changes reflecting flexibility are more in line with a compensatory training approach. Finally, they argue that neuroplasticity can occur both following alteration of processing efficiency or modification in the knowledge base or strategy. Thus, reactive or plasticity processes might occur following a range of training modalities, but adaptive methods that adjust the task or training demands to the individual's capacity are those that would optimize plasticity. Notably, because this model distinguishes between flexibility and plasticity, one implication is that training studies involving examination of brain changes should report structural changes in addition to changes in functional activation.

The Scaffolding Theory of Cognitive Aging (STAC) proposes that cognitive compensatory scaffolding processes act to reduce the adverse effects of neuronal and functional changes and promote functional independence. Initially proposed in 2009 (Goh & Park, 2009), the model proposed that the aging brain retained the potential for positive neuroplasticity in response to stimulation and new learning and that engagement resulted in increased compensatory frontal and/or bilateral activation. In a revised version, the STAC-r model integrated individual differences in life course events as factors that had the potential to enrich or to deplete neural resources and compensatory capacities (Reuter-Lorenz & Park, 2014). Both the initial and the revised models propose that formal interventions and training can enhance cognitive resources and compensatory scaffolding and can have an effect on neuroplasticity.

The INTERACTIVE model proposed by Belleville et al. (2014), suggests that training-induced changes in activation depend on a complex interaction between the training modalities (i.e., format, target, training sequence) and the subject's individual factors (i.e., the presence, severity and location of a lesion, subject's cognitive reserve, level of expertise). Individual factors such as a genetic potential for brain plasticity, higher premorbid IQ or educational background might favor the use of an alternative network or structural remodeling. Pre-training proficiency might also be a relevant factor. Brain-based models of procedural learning have proposed that there is a shift in the regions of activation as a function of the level of automaticity in learning a task (Doyon & Benali, 2005). A similar phenomenon might occur when learning to apply complex new strategies. In addition, different populations may be differentially sensitive to restoration versus compensation effects. For instance, the efficacy of a restorative approach is probably dependent on the amount of structural damage in the impaired region with an optimal effect in the middle range of damage.

The model also proposes that the pattern of change in activation should align with the cognitive processes that are mobilized by the training. For instance, repeated or incremental practice on a task should result in decreased activation within the brain regions involved in a task, due to more efficient processing in specialized regions. In contrast, interventions involving metacognition or the teaching of new strategies would result in increased activation of the brain networks involved in those particular strategies. Thus, a finding that training results in activation of a network that was not active prior to training, should reflect the fact that there is a change in the process by which the task is completed. Hence, predicting the effect that a training format will have on the brain requires a precise understanding of the cognitive mechanisms that the intervention engages or modifies.

In a recent study that was published in support of their model, Belleville et al. (2014) report that the type and loci of the brain's response to training are largely dependent on the type of training provided. Attention training can also result in increased activation when compensatory strategies are taught. They compared healthy older adults' post-training changes in activation, following either repeated practice on tasks (alphanumeric equation judgments and visual detection tasks) under either focused attention (*single repeated*) or training in combining the two tasks under different conditions of attention priority (*divided variable*). In the latter condition, participants learned to control their attentional focus by exerting top-down regulation and by relying on their metacognitive abilities. *single repeated* training made participants faster and more accurate when asked to solve the alphanumeric equations under single-tasking and this was accompanied by reduced activation in the right inferior frontal gyrus, right middle frontal gyrus, left middle frontal gyrus, and in the left thalamus. This suggests increased efficacy of specialized regions with no qualitative change in the way the task was completed. This finding is coherent with the notion that repeated practice will result in decreased activation in brain regions that were active prior to training. In turn, the *divided variable* training increased activity in the right prefrontal cortex area 10 under dual-tasking conditions. As this is a region involved in orchestrating the basic executive functions needed to accomplish novel tasks and is critical for metacognition, it has been suggested to reflect the use of more active metacognitive and control capacities.

Neuroimaging as a Predictor of Training Response

Individuals differ in their response to cognitive training. One important question is identifying the factors that distinguish responders from non-responders, so that clinicians can determine who will benefit most from an intervention. Cerebral differences may contribute to individual differences in training effects. The performance gain following Space Fortress video game training that emphasized variable priority attention allocation was predicted by the pre-training volume of the dorsal striatum but not by pre-training volume of the hippocampus (Erickson et al., 2010). This result could be due to the role of the striatum in dopaminergic function; dopamine has been found to be involved in interindividual variability in cognitive aging (Li et al., 2008). Persons with greater dopamine availability might have more potential for training-related neuroplasticity, irrespective of the type of training provided.

An alternative explanation is that neurobiological predictors depend on the regions that are implicated by the training. For instance, Engvig et al. (2012b) reported that larger left hippocampal volume in persons with subjective cognitive decline was related to larger behavioral gain following a multimodal memory training program. Of note, they also found depression predicted post-training memory change independently from hippocampal volume and that the two combined factors explained almost 38% of the variance in training efficacy. Thus, the predictive value of the different brain regions might depend on their level of relevance to the training program. Training of episodic memory might be best predicted by hippocampal regions whereas training of attentional control might be predicted by the striatum, a region involved in executive control.

One hypothesis regarding transfer is that it will be found to the extent that there is overlap between the regions engaged in the training and those involved in the transfer task. This was supported by Dahlin et al. (2008) who trained younger and older adults with an updating training task. They assessed effect on a letter updating test and transfer on the n-back test, which implicates updating as well, and on the stroop tests which do not involve updating but require frontal lobe-mediated executive processes. In younger adults, all three tasks were found to activate a frontoparietal network prior to training but only the n-back and letter task showed a common left striatum activation. Thus no training effect was expected on the stroop task if transfer depended specifically on improvement of the striatum. Training was found to improve letter memory and there was transfer to the n-back, but not to the stroop task. Importantly, training increased activation in the same left striatal region that was activated by the letter and n-back task and this was found for the letter and n-back task but not for the Stroop task.

In a second experiment involving older adults in contrast to the prior study with young adults, they found a reduced training effect on the letter task and no transfer on the n-back task. They also found that older adults failed to activate their striatum prior to training and that the training-related increase in striatal activation was limited to the letter task. The authors conclude that the limitation in transfer following updating training in older adults might be due to their impaired striatal function.

Thus, there are indications that brain imaging can be used to predict both individual differences in training outcomes and also the extent of transfer expected from different training formats. Neuroimaging studies have suggested two brain regions—the striatum and the hippocampus—that seem to be implicated in the efficacy of cognitive training. One question is whether these are generic regions which would predict training and transfer whatever the type of training provided. For instance, Engvig suggested that adults with greater hippocampal volume might have a larger degree of brain plasticity and more potential for restoration or that those individuals have more reserve. However, these regions don't seem to correspond to generic regions as they are systematically related to training efficacy. Rather, their contribution appears to depend on the type of training provided, the hippocampus predicting efficacy of memory training, and striatum predicting executive training efficacy.

In summary, brain imaging provides key information regarding the impact of the environment on the brains of older adults with or without cognitive impairments. Studies investigating training-induced brain changes indicate that brain imaging is sensitive to training, that it can be used as a surrogate marker to detect clinically reliable effects, and that the regions that are modified by training are highly coherent with the nature of the intervention, involving brain areas that are reflective of the type of strategies that are learned. The studies indicate a cognitive neuroscience perspective that is not totally biologically determined. Undoubtedly, current models of age-related brain organization should be aware of studies of training-induced brain changes as these can provide a complex set of results to enrich models of cognitive and neural compensation and plasticity in older adults.

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