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Cognitive training and plasticity: Theoretical perspective and methodological consequences

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Abstract

Purpose—To provide an overview of cognitive plasticity concepts and findings from a lifespan developmental perspective.

Methods—After an evaluation of the general concept of cognitive plasticity, the most important approaches to study behavioral and brain plasticity are reviewed. This includes intervention studies, experimental approaches, cognitive trainings, the study of facilitating factors for strategy learning and strategy use, practice, and person-environment interactions. Transfer and durability of training-induced plasticity is discussed.

Results—The review indicates that methodological and conceptual advances are needed to improve the match between levels of behavioral and brain plasticity targeted in current developmental research and study designs.

Conclusions—The results suggest that the emphasis of plasticity studies on treatment effectiveness needs to be complemented by a strong commitment to the grounding of the intervention in a conceptual framework.

1. The concept of cognitive plasticity

Cognitive plasticity has typically been defined in terms of the individual's latent cognitive potential under specific contextual conditions. Specifically, plasticity has been defined in terms of the capacity to acquire cognitive skills (Jones et al., 2006; Mercado, 2008). Cognitive skills are cognitive functions that an organism can improve through practice or observational learning and that involve judgment or processing beyond perceptual motor skills. The definition of cognitive plasticity usually involves a contrast between the individual's current average level of performance under normative conditions and one's latent potential.

Several aspects of the definition of cognitive plasticity should be noted. First, cognitive plasticity deals with *intraindividual* potential, the range of plasticity within an individual (Baltes and Lindenberger, 1988). While interindividual differences in intraindividual plasticity are often studied, plasticity focuses on intraindividual change or potential. Second, the *context* within which cognitive plasticity is studied needs to be specified. Cognitive

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plasticity has often been examined within an experimental or intervention context, and this will be the focus in this article. The individual's average level of cognitive functioning in normative, everyday experience is then contrasted with the range of plasticity exhibited under experimental or training conditions. Specification of the contextual conditions under which plasticity is studied is critical since the range of plasticity manifested will vary on the basis of such factors as the duration, intensity, or instructional procedures used in the intervention. Third, cognitive plasticity has generally been studied within a short *time frame*. Most training studies range from one session to, at most, several months in length; there may be many practice trials, but these occur within a short time period. Hence, the range of plasticity exhibited may also be constrained by the temporal length or intensity of the intervention. It should be noted that early in the study of cognitive plasticity within the field of cognitive aging, plasticity was assessed almost exclusively with behavioral measures. However, recently, there is increasing interest both in the conceptual relationship between cognitive plasticity and neural plasticity and in experimental studies that examine cortical changes occurring concurrently with the behavioral training or intervention efforts (Jaeggi et al., 2008; Nyberg, 2005; Westerberg and Klingberg, 2007).

1.1. Cognitive plasticity and life-span developmental theory

The concept of plasticity is closely linked to life span theory's conception of development as a process of lifelong adaptation (Baltes et al., 2006; Thomae, 1979). Life span theory maintains that development is modifiable or plastic at all phases of development; however, there are constraints and limits on developmental plasticity, and these constraints and limits vary by period of development. A major goal of life span developmental research has been to examine the range and limits of plasticity at various phases of the life span. With respect to cognition, adaptation involves the interplay between assimilating the environment to existing forms of thought and accommodating one's thought to the environment. Development is conceptualized as multidimensional, multidirectional, and multifunctional (Baltes, 1987). Cognition would then be expected to involve multiple dimensions or levels rather than a single global approach to general intelligence (i.e., *g*). The multidirectionality of development implies that there will be both growth (gains) and decrement (losses) at any developmental stage, although with advanced aging the losses may outweigh the gains. Various abilities or cognitive processes would then be expected to vary in their developmental trajectories with some exhibiting positive or negative linear trends and others exhibiting nonlinear trends.

The importance of a strong theoretical or conceptual framework to guide all major aspects of a behavioral intervention program is a crucial principle stressed throughout this article and in the work and writings of other researchers in the field (Baltes, 1987; Borkovec, 1994; Camp, 1999; Lerner, 1986; Schulz and Martare, 1999). An adequate conceptual framework often begins with a basic theory of some aspect of lifespan development and then is extended and enriched by decades of descriptive and intervention research. The conceptual framework needs to be viewed as dynamic, a work in progress, rather than a theory established by a former giant in the field (or at an earlier stage in the researcher's own professional career) and set in stone. Ideally a developmental theory or framework *describes* the lifespan developmental trajectory of a phenomenon, articulates possible *explanatory mechanisms* for development and change in the phenomenon, and based on these components of description and explanation offers insight regarding the plasticity or *modifiability* of the phenomenon, either across the lifespan or at specific developmental periods (Baltes and Willis, 1977; Bandura, 1989; Lerner, 1986; Schaie, 2000).

2. Key questions: Cognitive plasticity and behavioral training

In this article, we discuss five broad issues or questions that we consider to be central to any theory or conceptual framework for the study of cognitive plasticity. The first question deals with the levels (brain, behavior) at which plasticity has been or needs to be examined in relation to cognitive training and the relationship or interplay between plasticity at various levels. In this article, we focus on the behavioral level of cognitive plasticity, and within the behavioral level, we focus on behavioral cognitive interventions. The second question focuses on the processes or mechanisms for achieving plasticity. The third question focuses on the temporal durability of cognitive plasticity. Fourth, we consider the issue of transfer of training effects to abilities and processes other than those which were the target of training. Finally, we discuss the various contexts in which cognitive plasticity needs to be studied.

3. Behavioral plasticity: Cognitive interventions

Cognitive training research has focused on cognitive processes (e.g., processing speed and inhibition; Ball et al., 2002; Jones et al., 2006), primary mental abilities (e.g., inductive reasoning, spatial orientation, and episodic memory; Schaie and Willis, 1986), higher-order cognitive constructs (e.g., fluid intelligence and executive functioning; Jaeggi et al., 2008), and global cognition involving multiple cognitive domains. In addition, the impact of noncognitive interventions (e.g., exercise and nutrition; Colcombe and Kramer, 2003) on cognition has been examined and is of increasing interest.

Most behavioral cognitive interventions have focused on processes and abilities previously shown in longitudinal research to exhibit relatively early age-related decline (e.g., mid sixties) or to be associated with cognitive impairment. Thus, intervention have focused on fluid and process-based abilities (reasoning, episodic memory, speed, working memory, and executive functioning). There has been a parallel between the abilities targeted for training and the brain areas and structures of interest. The greatest normative atrophy in cortical volume has generally been reported for the prefrontal regions and somewhat smaller atrophy for the temporal and parietal areas. Executive control, fluid abilities, and some memory processes that have been the target of intervention are supported by prefrontal and temporal regions of the brain.

Earlier in this article, we noted that cognitive plasticity has most commonly been conceptualized as an individual's latent cognitive potential or the individual's cognitive capacity under certain specified conditions. Hence, observable indicators or behavioral indices of cognitive plasticity are needed. For a number of cognitive researchers (Harlow, 1959; Thorndike, 1901), key behavioral indicators of intellectual capacity include the capacity to learn a cognitive skill, the rate at which the skill is learned, and the highest performance (asymptote) reached (Zimprich et al., 2008).

3.1. Experimental approach to study of plasticity

The concept of behavioral intervention does not have a singular meaning. Schulz and Martire (1999) state that "an intervention study involves actions that alter, or are intended to alter, relationships between observable phenomena." (p. 2). The goal of intervention is that some agent under human control can be manipulated to bring about desired change; thus, the design of choice in most cases is a randomized trial. The action of interest typically has a definable onset and in many cases a clear termination. In a chapter on interventions in life-span development and aging, Baltes and Danish (1980) consider a gerontological intervention as programmatic attempts aimed at modification of the course of psychological aging. In a prior edition of the *Handbook of the Psychology of Aging*, a psychological

intervention was defined as planned processes of behavioral change that employ a deliberate application of psychological principles and theory (Smyer et al., 1990).

3.1.1. Features of cognitive intervention studies—In this article, behavioral interventions will be considered to have in general the following characteristics. The intervention is a planned effort with the goal of manipulating or altering behavior. The key independent variable is behavioral in nature. In many instances, the dependent variable(s) are also behaviors (outcomes). The target of the intervention is an individual, typically an older adult. Given that it is a planned effort, the intervention typically has a defined onset and often a defined duration and termination. The design should involve a comparison group and individuals are randomly assigned to groups. Ideally, the intervention is grounded in one or more theoretical or conceptual framework(s) and is based on prior descriptive research. The hypothesized causal links between the intervention and the outcome should be stated and, the mechanisms or processes which mediate the intervention should be explicated. Many of the above characteristics are representative of the broader domain of experimental research of which behavioral intervention research is a class. In contrast to many experiments, intervention studies are often of a longer duration involving multiple training sessions, and the temporal durability of outcome(s) is expected to be longer. Moreover, intervention studies often involve multiple levels of outcomes and a broader assessment battery.

There has been the assumption that the primary goal of behavioral intervention research should be to assess the efficacy of a given intervention – to examine whether there is positive gain in functioning as a result of training. While determining the efficacy of a given intervention is an important objective, programmatic intervention research should be aimed at the broader goal of answering a series of theoretically important empirical questions (Baltes and Willis, 1977; Hazlett-Stevens and Borkovec, 1999; Schulz and Martire, 1999). When couched within a particular theory or conceptual framework, programmatic intervention research seeks to address questions, such as: What is the nature of the problem or deficit? What specific mechanisms, processes, or components of the intervention are responsible for the desired change? What individual difference variables are associated with responsivity to change? How can the change be maintained?

Magnitude of performance improvement on the target ability of training for the intervention group in comparison to control groups has been the primary outcome of interest and thus an indicator of the range of cognitive plasticity that could be evoked under the intervention condition. Although cognitive plasticity is concerned with change at the intraindividual level, most training studies have reported performance improvement or plasticity at the level of the group mean; hence, information on the proportion of individuals exhibiting reliable intraindividual change is obscured, as is the absolute range of plasticity and asymptotic levels attained. Given that plasticity is an intraindividual concept, comparison of the individual's performance after training with performance at earlier developmental periods prior to training would be optimal. However, longitudinal data on intraindividual change are rarely available. Comparison of asymptotic levels across age-groups is problematic given that the groups may differ on factors other than age that affect plasticity. A testing-the-limits condition has been used in some training studies to examine the asymptotic level of training improvement under increasingly demanding conditions. For example, in a series of memory training studies using the method of loci, asymptotic level was assessed by increasing the speed of word recall (Kliegl et al., 1989) or by engaging

4. Cognitive training: Processes and mechanisms

A primary goal of intervention studies is to produce a desired outcome – a change in behavior. An equally important objective, but one that is often not addressed adequately, is understanding how and *why* a certain outcome is achieved. A strong theoretical or conceptual framework for the intervention is critical in examining the processes or mechanisms underlying a change in behavior. The conceptual framework specifies in detail the processes or mechanisms through which a given outcome is to occur (see conceptual framework discussed in Jobe et al., 2000, Willis et al., 2005). In a recent chapter on intervention research with the elderly, Schulz and Martire (1999) identified one of the most common shortcomings of existing intervention studies to be the failure to articulate a theoretical model that specified the mechanisms for achieving intervention outcomes. An associated deficit in intervention studies has been the lack of appropriate measurement of hypothesized mechanisms.

4.1. Strategies and skills

In cognitive training research, instruction on some form of cognitive strategy is hypothesized to be one of the primary mechanisms or processes by which change in cognitive behavior occurs (Charness, 1985; Kliegl et al., 1989; Salthouse, 1991). A strategy can be defined as one of several alternative methods for performing a particular cognitive task (Salthouse, 1991). Verbal memory training studies have focused on strategies including the method of loci (Kliegl et al., 1989, 1990; Rebok and Balcerak, 1989; Yesavage, 1990), organization, visualization or imagery (Hill et al., 1989; Yesavage, 1990; Zarit et al., 1981), and formation of associations (Dunlosky and Hertzog, 1998, in press). Camp's recent intervention work with demented elderly has utilized a technique or strategy known as spaced retrieval (Camp, 1999). Charness and colleagues have taught adults strategies for squaring two-digit numbers mentally (Charness and Campbell, 1988). Training on spatial orientation ability has focused on strategies facilitating mental rotation of objects, including identifying two salient features of the object and naming of abstract objects (Schaie and Willis, 1986). Our training research on inductive reasoning has involved strategies for identifying a serial pattern, including saying the pattern aloud, underlining repetitions in the pattern and marking skips in a pattern (Willis and Schaie, 1986).

Study of the mechanisms underlying an outcome involves not only a conceptual framework that specifies the particular processes or mechanisms of interest but also developing procedures for independent assessment of the mechanisms (e.g., strategies; Dunlosky and Hertzog, in press; Saczynski et al., 2002; Saczynski et al., 2004). Theory-guided intervention research requires assessing both whether use of the processes or strategies becomes more proficient or frequent as the intervention progresses, and whether increased usage of the strategies is associated with enhanced performance on training outcome (Saczynski et al., 2002). For example, if utilization of the method of loci is the strategy hypothesized to enhance list learning, then a) increased usage and/or improvement in the ease with which the loci strategy is implemented must be demonstrated and b) increased frequency or improvement in strategy use should be shown to be associated with recall of a greater number of words on the list.

A number of different questions regarding strategy usage may be important to address, depending on the nature of the strategy and outcome variables. Probably the most common strategy variable is frequency of usage of the strategy. Other aspects of strategy usage include the proficiency or speed with which the strategy is employed. Speed or proficiency of usage is important if the task is timed or speeded or if processing of significant information is involved.

4.1.1. Criteria for the study of strategies—Salthouse (1991) has specified a number of criteria for the study of strategies in cognitive aging. These criteria may be stated in the following manner when applied to intervention research. First strategies are assumed to be specific to the outcome that is the target of training. Second, all participants involved in the intervention are assumed to be capable of learning and executing the strategy. Third, the evidence provided to demonstrate use of strategies must be distinct from the measure of the outcome variable. Fourth, it is assumed that differences in performance on the outcome will be associated with strategy use. In training research, it is important first to show an increase in appropriate strategy usage from baseline to post-training for the treatment group when compared with control groups. In addition, the increased strategy usage must be shown to account for significant variance in enhanced performance on the related outcome measure.

These assumptions regarding the strategies or mechanisms underlying the effectiveness of the intervention have important implications for intervention study design and methodology. The assumption that a strategy or mechanism is specific to a particular cognitive outcome has implications for specification of the hypothesized pattern of training transfer and for the measures selected to assess training outcomes. The issue of training transfer will be discussed in a later Section of this article. It is important to note here, however, that the assumption that a particular strategy is specific to a given task implies an ability-specific model of training transfer. Training a particular strategy should result in improvement only on the cognitive ability or process with which the strategy is assumed to be associated.

There is increasing emphasis to include outcome measures in cognitive training research that involve “real world” problems that are often cognitively complex or that involve physical as well as cognitive processes (Willis et al., 2005). For example, medication compliance may be proposed as an outcome for a memory training program focusing on cognitive strategies and mnemonics. Park and colleagues (Park and Jones, 1997), however, have shown that medication compliance is a cognitively complex task that involves a variety of distinct memory processes, including working memory, verbal memory, and prospective memory. Moreover, for some individuals memory compliance involves sensory and manual processes required to read the label or open the medicine bottle.

The research literature indicates that distinct memory strategies are associated with each type of memory process. The memory training program may be effective only for those aspects of medication compliance that involve the memory processes associated with the strategies trained. Thus, when specific strategies or mechanisms are the focus of training and hypothesized to account for intervention outcomes, it is critical that the outcome measures map carefully on the strategies and cognitive processes trained. Weaker training effects are to be expected for complex outcome measures involving cognitive processes that are not directly trained in the intervention.

The second and third criteria that all participants being compared are capable of learning and using the strategy and that level of performance on the outcome is associated with strategies also have implications for training programs. A strong interpretation of the second and third assumptions is the “strategy-as-cause” position assuming that all participants are capable of learning and using the strategy regardless of their ability level (Salthouse, 1991). Performance on the outcome variable is moderated by strategy usage. Some researchers, however, have suggested that certain strategies place heavy demands on memory or other cognitive resources and hence may be beyond the capabilities of some participants (Charness, 1981, 1985; Finkel and Yesavage, 1989). In a related vein, investigators have suggested that strategy utilization may be associated with factors such as motivation, efficacy beliefs, and social constraints (Cavanaugh et al., 1985; Dunlosky and Hertzog, 1998; Dunlosky et al., 2005). Yesavage and colleagues have found personality

characteristics such as openness to experience related to learning of strategies associated with face-name recall (Gratzinger et al., 1990). An individual differences approach to training would in this case be called for with screening of participants for the required level of ability or other person characteristics deemed necessary to learn and use the strategy.

4.1.2. Factors facilitating learning of a strategy and strategy usage—Cognitive aging research has found that many older adults do not spontaneously use appropriate strategies (Kausler, 1994). This finding may suggest that older adults find certain strategies difficult to learn and to use and thus need additional assistance in mastering a particular strategy. Alternatively, older adults may question the utility of the strategy or doubt their ability (i.e., efficacy) to use the strategy successfully. Finally, older adults may have difficulty determining the problems or contexts in which a particular strategy would be useful.

Some training studies have employed pretraining components to facilitate learning of strategies shown to be particularly difficult for older adults. The method of loci and forming associations through imagery are two strategies that have been shown to be highly effective in learning unrelated words, yet are difficult for older adults to master (Gratzinger et al., 1990; Hill et al, 1989). Two forms of pretraining have been used to facilitate the learning of these strategies; each form of pretraining focuses on a different hypothesis regarding the difficulty in learning the strategy. The first form of pretraining focuses on enhancing imagery skills. There is some support for a decline in imagery processes with age; moreover, some older adults question the utility of forming images, particularly fanciful images, or find it stressful (Verhaegen and Marcoen, 1994, 1996). Practice in imagery has been administered prior to memory training in work by Yesavage and colleagues (Hill et al, 1989; Yesavage, 1990). Similarly, pretraining in relaxation techniques has been employed prior to training (Hayslip, 1989; Yesavage, 1990). Relaxation techniques are employed to reduce the stress of using the imagery procedure or of learning a difficult strategy such as method of loci. In a related vein, Bandura (1989) has suggested that affect is important in developing and maintaining self efficacy. Induced positive mood has been shown to enhance perceived self-efficacy, whereas despondent mood diminishes perceived self efficacy (Hertzog et al., 1998; Kavanagh and Bower, 1985; West et al., 1989).

If the treatment outcome variable is cognitive complex or involves multiple components, the participant may be required to determine for which outcome measures the strategy trained is appropriate and useful (Dunlosky and Hertzog, 2001). For example, if the list of words is unrelated, then the method of loci may be a more productive strategy. In contrast, with a list of related words, formation of meaningful categories may be more effective. The intervention procedure in this case may need to train not only on the specific strategies but also give guidance in determining in what instances a given strategy is likely to be most useful. The intervention would then involve not only training on a specific strategy but enhancing executive or metacognitive processes (see also Salomon and Perkins, 1989), which are hypothesized to affect the selection and monitoring of strategies over a wider range of cognitive tasks. The intervention would require training of metacognitive strategies or skills, on which there is much less empirical research, and also provide practice not only on problems for which the strategy is relevant but also problems for which the strategy is not relevant (McKeough et al., 1995).

These higher-order skills and metacognition has been discussed as a part of self-regulated learning and memory monitoring (Dunlosky and Hertzog, 2001). Bandura (1989) has suggested that development of self-regulatory capabilities requires instilling a resilient sense of efficacy as well as imparting skill in using a given strategy. If the elderly are not fully

convinced of their personal efficacy they rapidly abandon the strategy they have been taught when they fail to get quick results or it requires bothersome effort.

The mnemonic training research of Rebok and Balcerak (1989) on the method of loci found use of the strategy improved the memory performance of older adults but did not raise their beliefs in their memory efficacy. The lack of an association between the strategy and self efficacy may explain why only thirty-nine percent of participants used method of loci during generalization tests of memory for digits. In contrast younger adults whose self efficacy increased as a result of mnemonic training spontaneously used the loci aid in generalization memory tasks.

Bandura argues that training in cognitive strategies can produce more generalized and lasting effects if self efficacy beliefs are increased and participants see an association between strategy use and increased control of their memory. Bandura (1989) sees direct mastery experiences as a particularly effective way of building efficacy beliefs. Participants perform memory tasks with and without mnemonic aids and compare the results. Evidence of better memory performance with mnemonic aids provides participants with persuasive demonstrations that they can exercise some control over their memory by enlisting cognitive strategies. Such efficacy validating trials not only serve as efficacy builders, but also put on trial the value of the techniques being taught.

4.1.3. Measurement of strategy usage—As noted by Schulz (Schulz and Martire, 1999) prior behavior intervention research has often lacked not only specification of the process or mechanisms underlying the intervention, but also distinct measurement of the targeted strategies. There have been several common procedures for determining strategy usage, each having limitations (Dunlosky and Hertzog, 1998, 2001). The most common and simplest procedure for determining strategy usage has been to ask participants to report on the strategy used after they have completed the task (Cohen and Faulkner, 1986). The validity of these reports is unknown since there is often no means of verifying the accuracy of the self reports. In a recent study, Dunlosky and Hertzog (2001) found that retrospective reports were not completely consistent with concurrent reports, suggesting that the validity of retrospective reports is somewhat diminished by forgetting, particularly in older adults. Other procedures for assessing strategy usage include thinking aloud and then analyzing recordings for indications of strategy use. Also analyzing time allocated to each portion of a sequential task (Salthouse and Prill, 1987) can provide evidence of strategy use. The distribution of these times forms a profile of processing durations which can be considered a reflection of the strategy used.

In our training research on inductive reasoning ability, the strategies trained provide an objective record of strategy use. Participants are taught to mark the patterns in reasoning problems with specific types of markings to indicate pattern repetitions, pattern skips and pattern replications (Willis and Schaie, 1986). Reliable instances of pattern usage at pre- and posttest were coded. Significant pre-posttest increases in pattern usage were shown for the reasoning training group compared to participants trained on spatial orientation. Moreover, increases in strategy usage accounted for significant variance in factor scores of reasoning ability performance (Saczynski et al., 2000).

4.2. Practice

Life span theorists (Baltes, 1987) have identified three levels of performance that provide a profile of an individual's plasticity. *Baseline performance* indicates the individual's initial status (level) of performance on a cognitive task without intervention or support. *Baseline plasticity* refers to the extended range of possible performance (performance improvement) when additional resources are provided. For example, this form of plasticity has been

examined shortly after participants are taught memory strategies, such as the method of loci. This level of plasticity involves brief instruction in a strategy or the provision of a cognitive resource but little or no practice in use of the strategy. *Developmental reserve capacity* or *developmental plasticity* refers to the further range of performance improvement that occurs as a result of the opportunity or context within which cognitive resources can be fully activated (e.g., through extensive practice that optimizes strategy or cue utilization). Recent training research has compared the range of performance improvement under baseline plasticity versus developmental plasticity conditions. A greater range of plasticity was found under the developmental reserve plasticity condition (extended practice with the strategy or mnemonic) than the baseline plasticity condition in memory training research using the method of loci (Brehmer et al., 2007; Jones et al., 2006). It was suggested that the greater range of plasticity shown in the developmental plasticity condition is due to information binding (Craik, 2006) involved in use of the method of loci strategy, that is, the formation of associations between novel words to be remembered and different loci in a certain sequence. Functional imaging during the various phases of the training study indicated that greater activation in the medial temporal lobe was found for participants who exhibited greater plasticity during the developmental reserve capacity phase; activation of the medial temporal lobe was hypothesized to be related to formation of associations and with information binding.

4.2.1. Dose-response—The question is whether the range of plasticity varies with the length or intensity of the treatment. Most training studies have been relatively brief, and thus the dose – response issue has received limited attention. Several studies have shown an increased magnitude of effect (range of plasticity) with booster sessions that supplemented the initial intervention (Ball et al., 2002; Jaeggi et al., 2008; Willis et al., 2006). Some recent studies also suggest that there may be age differences in dose – response relations (Brehmer et al., 2007).

5. Transfer of training

Transfer is a central concept in learning theory and in training research that has been studied and debated over much of the past century (Detterman and Sternberg, 1993). Discussion regarding the construct is usually traced back as far as the writings of Thorndike and Woodworth (1901). While issues related to transfer have been occasionally addressed in cognitive training studies with the elderly (Fisk et al., 1997; Willis and Baltes, 1981; Willis, 1987, 1990) discussion of the history and assumptions regarding transfer have received relatively limited attention in cognitive aging. However, transfer is becoming a critical issue as large scale behavioral clinical trials targeting psychological and social constructs become more frequent in gerontology. These trials often examine whether intervention into the cognitive and social constructs studied by gerontologists have implications for maintaining (i.e., transferring to) competence in activities associated with the health and independence of the elderly (Coon et al., 1999; Jobe et al., 2000).

This Section begins with a brief review of the broader transfer literature (Cormier and Hagman, 1987; Detterman and Sternberg, 1993; McKeough et al., 1995; Voss, 1990), followed by a more in-depth discussion of the literature on mechanisms to foster transfer and the specification of a continuum of transfer. It is important to note that although transfer has been extensively studied and debated for over a decade, there is still often limited consensus on critical aspects of the construct (Detterman and Sternberg, 1993).

5.1. Defining transfer and a brief history

The first task is to define transfer as a construct. Transfer is said to occur when learning in one context enhances performance in a somewhat different context (Salomon and Perkins,

1989), or transfer occurs when prior learned knowledge and skill affect the way in which new knowledge and skills are learned and performed (Cormier and Hagman, 1987). Detterman (1993) has defined transfer as the degree to which a behavior will be repeated in a new situation. Transfer refers to a recognition that various terms and entities of one set can be mapped onto those of another set (Ceci and Ruiz, 1993). In job training, transfer has been defined as the application in the workplace of the knowledge, skills and attitudes learned in training. While definitions of transfer differ, there is a common often unstated but critical assumption: *A prerequisite for transfer is that some form of initial learning has occurred – there must be at least a minimal mastery of information or skills for the opportunity for transfer to exist* (Salomon and Perkins, 1989)

A narrow and a broad view of transfer have existed. The narrow view of transfer is closely tied to that of learning (Voss, 1990). At the time of Thorndike's and Woodworth's early research on transfer (1901), the dominant theory of human learning was associationism. Thorndike concluded that when transfer occurs it occurs because of common elements in the two situations. Given this orientation, Thorndike concluded that only near transfer is likely to occur.

The broad view of transfer is based on the position that throughout the history of the study of intelligence, a hallmark of intelligence and of an intelligent person has been the ability to think abstractly and to derive general principles from concrete exemplars. The core of intelligence, “g,” from Cattell's notion of fluid intelligence (Cattell, 1963) to Sternberg's triarchic theory (Sternberg, 1985) has been described in terms of thinking abstractly, and making inductions. Humans learn to abstract relevant knowledge and skills from prior experiences to their advantage in new or novel situations. They *transfer* the essence of knowledge, skills, and principles acquired in prior contexts to how they think and behave in sometimes dramatically new situations.

These two different views regarding transfer are reflected in two classic theories of education (Ceci and Ruiz, 1993; Detterman, 1993) that continue to have followers into the present day. Early in the twentieth century the doctrine of formal disciplines was a dominant educational approach. This approach held that training in one discipline enabled one to think more effectively and hopefully abstractly in many other disciplines. For example, specific training in Latin or chess were regarded as exercise that fostered the development of logical reasoning in general. The research of Thorndike arguing for only near transfer was in response to the wide spread acceptance of the formal disciplines approach in the early twentieth century.

The second educational approach has focused on domain-specific learning – explicitly teaching information, principles and strategies within each domain. The individual can learn to transfer knowledge and principles to multiple situations *within* a given substantive domain. Training in a specific domain such as Latin is not likely to result in enhanced reasoning and understanding in another domain such as physics (Detterman, 1993).

5.2. Three aspects or dimensions of transfer

Major issues studied and debated throughout the twentieth century regarding transfer can be summarized in terms of three aspects or dimensions: 1) The *how* or *mechanisms* of transfer; 2) *What* is transferred; and 3) The *amount* or *breadth* of transfer.

1. The how or mechanisms of transfer—A major question regarding transfer, even near transfer, has focused on the mechanisms by which transfer occurs. Salomon and Perkins (1989) have proposed that transfer can occur by different routes or mechanisms, or

combinations of mechanisms. They hypothesize two major internal mechanisms by which transfer can occur: *Transfer due to Automaticity* and *Transfer due to Mindful Abstraction*.

Transfer due to Automaticity involves the processes of: a) extensive practice in varied contexts, b) stimulus control, and c) automaticity. A skill or other cognitive element is learned and practiced in a variety of contexts until it becomes automated. If practiced in a variety of somewhat related and expanding contexts, execution of the skill or cognitive element can become increasingly flexible. Automatization occurs as a result of extensive practice (Shiffrin and Schneider, 1977). The processing and behavior becomes fast, effortless, and relatively unlimited by processing capacity. The behaviors and cognitions are stimulus controlled. One's cognitive system automatically applies the learned behavior whenever it identifies situational cues it takes to be prototypical of a particular category of situations. A plus of this form of transfer is that it usually increases the efficiency of the behavior; the behavior is performed fast, effortlessly, and with reduced processing demands. The limitation of this mechanism for transfer is that automaticity inhibits analytic reflection. Conscious control and analytic awareness is reduced by automaticity. In an extensive, ongoing, well designed program of research, Fisk, Rogers and colleagues are conducting training studies with older adults that address many issues related to automaticity as a mechanism for transfer (Fisk et al., 1991; Fisk et al., 1990; Fisk et al., 1997).

Transfer due to mindful abstraction is the second mechanism of training transfer proposed by Salomon and Perkins (1989). The processes involved in this mechanism of transfer are: a) mindful, deliberate, deep processing of information (Langer, 1989), and b) the abstraction or decontextualization of cognitions. Abstractions generally take the form of a rule, principle, schema, or prototype. Abstraction is the principle by which transfer occurs; abstraction provides a bridge from one context to another. Formation of the abstraction is a mindful, deliberate process that typically occurs during the learning process (although see backward reaching process below).

Salomon and Perkins (1989) suggest two alternative ways in which mindful abstraction may lead to transfer. The first type is called "forward reaching." In this case, the participant mindfully abstracts basic elements during the initial learning situation in anticipation of making a later application. The information is learned or encoded as a general principle in the initial learning and new applications of the general principle occur almost spontaneously in later situations (transfer). In the second type called "backward reaching" the abstraction actually occurs in the transfer situation rather than in the initial learning situation. One is faced with a new situation and deliberately searches for relevant information from prior situations that might be applicable in the new/transfer context. The principle is learned originally for a context-specific purpose, but the individual at a later occasion is able to reformulate the information or principle to a higher level of abstraction.

Transfer due to mindful abstraction probably better characterizes the training process conducted in training on fluid abilities (Schaie and Willis, 1986) and perhaps in application of some memory strategies (Dunlosky and Hertzog, 2001; Hill et al., 1989; Rasmussen et al., 1999). The elder is trained on general rules or strategies (e.g., looking for certain types of patterns in inductive reasoning problems, applying method of loci to list of words), and is given practice in applying (transferring) these rules or strategies to new instances of the problem. As discussed in the Section on cognitive strategies, the participant must not only learn to apply the rule or strategy to the next instance of the problem, but also must determine whether or not a given strategy applies or which strategy applies when faced with problems varying in the specific cognitive strategy needed to solve a problem.

2. What is transferred—As noted above, the concepts of learning and transfer are closely intertwined. *What* is hypothesized to be transferred will depend on the researcher's or interventionist's theories of learning and of intelligence or cognition. In an associative approach to learning, transfer is viewed as being narrow or near to the initial learning and context. *What* is transferred is defined in S-R terms, in terms of identical or similar elements between the learning and the transfer situation. In contrast, theories of intelligence and learning approaches that focus on concepts such as learning-to-learn, procedural knowledge, and expertise are concerned with the ability of the individual to form abstractions, develop hierarchies of knowledge, and identify general principles. This approach should lead to broader transfer across contexts. *What* is transferred is more likely to be described in terms of a subroutine, learning strategy, overarching principle, or generalized skill.

Moreover, Salomon and Perkins (1989) have argued that *what* is transferred interacts with the *mechanisms* of transfer. What is transferred through the mechanism of automaticity and practice is hypothesized to involve behavior that is unintentional, implicit, based on modeling and driven by reinforcement. These activities are involved in processes such as socialization, acculturation and experience-based cognitive development.

In contrast, transfer via mindful abstraction is more likely to occur during explicit instruction that is aimed at teaching or provoking the learner to identify a generalization. Transfer results from the *mindful* generation of an abstraction developed during the learning process (Langer, 1989). Teaching strategies and mnemonics to mildly retarded children was effective only when skills of mindful attention and metacognition were taught along with the strategies and mnemonics (Brown and Kane, 1988; Campione et al., 1995).

3. Amount or breadth of transfer—Amount of transfer refers to how much improvement results in the transfer context from attaining some level of performance in the learning context. Salomon and Perkins hypothesized that the extensive practice involved in transfer due to automaticity affects mainly the *amount* of transfer – practice leads to the automatic activation of whole “bundles” of interrelated responses. Because of bundling, amount of transfer is likely to involve the entire set of skill components or the entire knowledge set, rather than selected components of a skill or fragments of the knowledge set. For example, in transferring driving skill from one car to another, the entire repertoire of driving skills is transferred, even though certain skill components (e.g. Reaching for the clutch on a car with automatic transmission) might not be needed or appropriate.

What about amount of transfer from a mindful abstraction approach to transfer? The goal of this type of transfer is to form an abstraction or generalization that can be applied in new situations. However, the amount of transfer may depend in part on the fit or match between the level of abstraction at which a principle is learned and the level of abstraction required in a particular transfer situation. If abstraction occurs at too high a level in the initial learning, then it may interfere with applying the principle to a transfer situation. The principle is not encoded at the level of concreteness that would most easily facilitate transfer to a particular context. Salomon and Perkins suggest that automaticity as the mechanism of transfer may lead to a high incidence of transfer, but that the breadth of transfer will be more specific or narrow. That is, once a skill is automated, there should be a high likelihood that the skill will be performed in a transfer situation if the stimulus cues are present, and that it will be performed nearly flawlessly. Salomon and Perkins have made some hypotheses regarding near versus far transfer when transfer involves mechanisms of automaticity versus mindful abstraction. In transfer associated with automaticity, the individual does not consciously analyze a new situation in terms of similarities or differences compared with the initial learning situation. Similarities of prototypical cues across contexts are detected automatically. Thus, transfer to new situations occurs primarily if these situations activate

these response clusters because of automatically detected similarity of prototypical cues (Schneider & Fisk, 1984). Transfer to situations more remote from the learning context are less likely because identification of similarities would require intentional (conscious) examination of the similarities. As discussed under the Section on amount of transfer, partial components of a skill or fragments of knowledge that might be relevant in a new situation are not likely to be transferred since the complete skill or knowledge set is bundled and activated as a totality.

What of near versus far transfer is associated with mindful abstraction? While far or distant transfer appears less likely via the mechanism of automaticity, transfer to more distant contexts is hypothesized to be more likely to occur via the mechanism of mindful abstraction. The higher the level of generality at which a principle is abstracted, the broader or more distal the range of situations is to which it might be possible to apply the principle.

5.3. Levels of training outcomes and transfer

At least three major levels of outcomes are generally recognized in behavioral intervention research: Proximal, primary, and distal outcomes. The proximal outcome in cognitive training research is the key cognitive process, skill, or ability that is the target of training. The proximal outcome represents the nearest level of training transfer

The second level of intervention outcomes is often known as primary outcomes. Primary outcomes should be a product of the proximal outcome and/or share significant common variance with the proximal outcome. At least two very significant criteria must be met in order for there to be the possibility of significant training transfer at the primary outcome level: a) There must be evidence of considerable shared variance between the proximal and primary outcomes, and b) a significant training effect should be demonstrated at the level of the proximal outcome. That is, in order for a training effect at the level of the primary outcome to be ascribed to the treatment, a training effect must first be demonstrated for the proximal outcome which was the target of the intervention (Salomon and Perkins, 1989).

The third level of intervention outcomes are distal or secondary outcomes. In terms of training transfer, these would be referred to as far transfer. These are the least studied of the three levels of intervention outcomes. It is generally argued that if distal intervention outcomes occur, they are the result of “spill over” from treatment-related change in primary and proximal outcomes. For example, enhanced performance on cognitively demanding tasks of daily living might lead to distal outcomes such as improved medication adherence or maintenance of the current level of medication adherence as the individual ages. Theoretical rationales for how distal intervention outcomes would occur are not well developed and needs considerable further study.

6. Durability of training effects

A second criterion in training studies has focused on the maintenance of training effects. It is argued that temporal durability of effects is required in order for training outcomes to be meaningful and of lasting benefit. Although the number of training studies examining long-term maintenance has been limited (Jones et al., 2006), temporal durability of training effects on primary mental abilities have been reported for 5 years within a clinical trial (Willis et al., 2006) and up to 14 years after training in smaller studies (Boron et al., 2007; Willis and Nesselroade, 1990).

7. Behavioral plasticity in context

7.1. Environmental supports

It has been argued that competence does not reside solely in the individual but represents the congruence between the abilities of the individual and the demands and resources in the context (Lawton, 1982). A loss of competence resulting from incongruence between the individual and environment may reflect decreases in the abilities of the individual, changes in the environmental demands or resources, or a combination of these. In this final Section we will consider a few possible ways in which the immediate social and physical environments influence the problem solving process.

7.1.1. Social environment—The work of Kahn and Antonucci (1980) suggests that across the life course, individuals' experience multiple convoys of social networks. The individuals within the social support network change across the life course. Given the gender differences in average life expectancy, the social support network of older women often shifts from spouses to adult children and close neighbors or friends. Although the particular individuals within the support network may change, findings from research suggest that perceived level of support does not decline in old age.

The problem solving process may be influenced by the older adults social context in a number of ways. First, one's social contacts may be an important source of declarative knowledge in the problem solving process. A fundamental aspect of perceived social support is instrumental support, including individuals from whom can obtain information or advice. Second, individuals in the primary support network may significantly influence one's personalized knowledge and beliefs that are considered critical in development and modification of illness representations.

Antonucci and Jackson (1987) have suggested that efficacy beliefs may be an important mechanism by which one's social support system influences the development and maintenance of competence. These authors propose that it is through continuous interactions with a successive array of significant or supportive others that the elderly develop and maintain beliefs that they have the ability to meet the demands of the situation and to successfully mount the challenges of daily life. Significant others in one's social network may serve as a cognitive prosthesis in problem solving situations, such as medication adherence. Men in a coronary primary prevention trial were found to be more adherent to a medical regimen when they had highly supportive wives. Husbands' compliance was related to wives serving as reminders to take their medication (Doherty et al., 1983). On the other hand, more medication errors were made by elderly living alone.

7.1.2. Physical environment—Features of the physical environment can serve as external aids for memory and problem solving activities. Natural events may serve as aids. For example, memory for prospective events can be significantly enhanced by the use of ongoing activities as external supports for remembering to perform an action. A prospective memory which is time-based (take medications three times a day) may be converted to an event-based memory by linking the taking of medications to meal time (take medications after meals). Alternatively external memory aids may be introduced into the environment. Low tech items in the environment, such as timers, pill reminders, and calendars, have been found to significantly enhance the memory component in a problem solving task.

7.2. Collaborative cognition

Definitions of cognitive plasticity have typically focused on intraindividual change. However, recent research on collaborative cognition has examined the range of

enhancement of cognitive performance— associated dyadic cognitive activity or problem solving. It is possible that collaborative cognition could be considered a form of baseline plasticity within Baltes's levels-of-plasticity approach. Collaboration with others provides resources for enhancing one's range of performance in a manner similar to use of cognitive strategies. It appears that the effects of cognitive collaboration may be positive and facilitative of elders' everyday cognitive performance on a variety of tasks (i.e., prose recall, wisdom-related advice giving, comprehension of printed materials, and route planning/ everyday life management; Berg et al., 2003; Strough and Margrett, 2002). At the same time, positive effects appear to be facilitated by having familiar social partners (Margrett and Marsiske, 2004), explicit collaborative instructions, and tasks that do not rely on immediate memory recall. In addition, further research conceptualizing individual plasticity as embedded within the spousal or intergenerational dyads may be helping to explain individual differences in plasticity (Martin and Wright, 2008).

8. Summary and future directions

The background for this article lies in the significant increase in behavioral intervention research with the elderly that has occurred over the last three decades. Behavioral interventions with the elderly have evolved from experimental research conducted by a single investigator in his/her laboratory to large-scale multi-site studies (Schulz et al., 1999). Behavioral intervention research with the elderly is increasingly represented in the clinical trial arena (Coon et al., 1999; Jobe et al., 2000). Journal articles and book chapters reporting the substantive findings from these studies are beginning to appear in the literature. An aim of this article was to review and discuss selected methodological issues with respect to behavioral intervention research with the elderly. The cognitive training research literature provides many of the exemplars cited throughout the article.

A plea is made throughout the article that strong conceptual and theoretical frameworks should continue to guide the future evolution of behavioral intervention research. In the first generation of behavioral intervention research, the single investigator typically had considerable knowledge of the existing descriptive and explanatory models of the psychology of aging and grounded the intervention protocol and measurement system within these models. Thus, not only was the issue of intervention outcomes addressed, but the training research made significant contributions to the broader psychological aging literature. A reciprocal relationship existed; gerontological behavioral interventions were deeply rooted in developmental and experimental theories of aging and intervention findings contributed to further theory development.

While the recent and ongoing large-scale, multi-site behavioral intervention studies will make significant contributions to issues regarding the generalizability and representativeness of the earlier training literature, there is also the concern that the reciprocal contributing relationship between gerontological descriptive and experimental research and behavioral interventions may diminish. It is essential that the strong, almost singular emphasis on outcomes and treatment effectiveness that is characteristic of outcome intervention research and in clinical trials be complemented and even tempered by an equally strong commitment to the grounding of the intervention in a conceptual framework – with theory-based assumptions and hypotheses required and made explicit. Moreover, the role of the conceptual framework must be reviewed at each stage in the development and implementation of the intervention. Furthermore, it is important that the methodological procedures and assumptions upon which outcome interventions and clinical trials are based, which are often rooted in pharmacological intervention research, be reexamined and their applicability reevaluated as they are extended to behavioral interventions with the elderly. Behavioral intervention research must not lose its roots and heritage in the psychology of

aging, both substantively and methodologically. Each branch of research must continue to maintain a dialogue and contribute to their mutual development.

In summary, the field of behavior intervention research with the elderly is relatively young, but has experienced a period of near exponential growth in the last two to three decades, from single investigator studies involving less than one hundred participants to large scale studies involving several thousand older adults. Given the movement toward larger-scale behavioral intervention studies in aging, it appears that rapid growth of this literature will continue. Perhaps behavioral intervention research in aging is now in its adolescence or young adulthood. It is hoped that as it experiences the growth spurts, mood swings, and unlimited horizons characteristic of adolescence that it will continue to seek guidance from and affiliation with its parent disciplines in the psychology of cognition and aging, particularly with regard to theory and methods.

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