

Cognitive Plasticity: Findings from Cognitive Training Studies

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Abstract : Human development has been shown to be modifiable at all phases in the lifespan, although the range of modifiability may vary by chronological age and life experiences. Cognitive Plasticity is concerned with the individual's capacity to acquire cognitive skills and may be assessed in both brain structure and behavior. Cognitive Plasticity in cognitive aging research has most frequently been examined through short-term cognitive training studies, examining the range of modifiability of cognition through intervention procedures. Findings from cognitive training research both within the Seattle Longitudinal Study and the ACTIVE clinical trial of cognitive intervention are reported. These cognitive training studies have reported that the majority of community-dwelling older adults can improve their cognitive ability through brief training programs; there are wide individual differences in responsiveness to training. Training is effective both for older adults who have declined in their ability and those with no cognitive decline. Cognitive training effects have been maintained over several years. There are limitations and constraints on cognitive plasticity. Chronic health conditions may moderate the efficacy of cognitive interventions, and only modest training effects have been found for older adults with cognitive impairment such as dementia. Future research on cognitive training and plasticity should examine the efficacy of interventions for maintaining everyday activities. Multiple cognitive abilities are involved in everyday tasks, and thus cognitive cross training across abilities may be required. With aging, the individual needs to set priorities on the abilities and activities of most importance to the individual and choose challenging activities that one enjoys and will engage in regularly.

Key words : ACTIVE clinical trial, challenging activities, cognitive abilities, cognitive impairment, cognitive plasticity, cognitive training, everyday activities, individual differences, range of modifiability, Seattle Longitudinal Study

Cognitive Plasticity

The concept of plasticity is closely linked to life span theory's conception of development as a process of lifelong adaptation (Baltes, Lindenberger, & Staudinger, 2006). 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.

Cognitive plasticity has often been defined in terms of the individual's latent cognitive potential under certain contextual conditions. Plasticity has been defined in terms of the capacity to acquire cognitive skills (Jones et al., 2006; Mercado, 2008). Cognitive skills are here defined as the abilities 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 & Lindenberger, 1988). Second, the *context* within which cognitive plasticity is studied needs to be specified. In most studies, cognitive plasticity has been examined within an experimental or intervention context. 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. Hence, the range of plasticity exhibited may also be constrained by the temporal length or intensity of the intervention. It should be noted that in the study of cognitive plasticity within the field of cognitive aging, plasticity was originally 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, Buschkuhl, Jonides, & Perrig, 2008; Nyberg, 2005; Westerberg & Klingberg, 2007).

Adult Cognition and Cognitive Training

The discussion of findings from research on cognitive training needs to be placed in the context of prior longitudinal research on normal age-related change in cognitive behavior. Our approach to the study of intellectual aging has been to focus on the changes that occur with age in a number of *psychometric mental abilities*. The psychometric approach assumes that adult intelligence can be described in terms of a number of mental abilities; the adult's level of functioning on each ability is inferred from his/her performance on a number of tests known to represent that ability (Thurstone, 1962). The mental abilities perspective maintains that adult intelligence needs to be studied as a *multidimensional* phenomena, involving a number of different mental abilities; this approach is in contrast to a unidimensional, global perspective that focuses on a single composite test score that describes overall level of intellectual functioning (*g*), such as is obtained on the Wechsler Adult Intelligence Scale (Wechsler, 1981).

Differential patterns of ability change.

In the adjacent article by Schaie, it was shown that various abilities exhibit different patterns of change from young adulthood to old age. For example, abilities such as inductive reasoning and spatial orientation show a modest increase in young adulthood, are stable in midlife and then show age-related decline beginning in the mid sixties. In contrast, abilities such as verbal ability do not show normative decline until the mid seventies.

Two items are noteworthy in terms of differential ability change. First, the age of peak performance varies by ability, occurring in young adulthood for inductive

reasoning, but not until late middle age for verbal ability. Second, the age at which reliable decline is first noted varies by ability, occurring in the mid 60's for inductive reasoning, but not until the mid 70's for verbal ability.

Individual differences in rate and pattern of ability decline.

Normative data on the pattern and rate of change in cognitive abilities has been presented in the adjacent article by Schaie. There are wide individual differences in the age of onset of reliable ability decline, and in the rate of decline. Older adults in the Seattle Longitudinal Study were classified as whether they had remained stable or declined for the preceding seven-year interval (60 to 67 years, 67 to 74 years, 74 to 81 years (Schaie, 2005). Although reliable age-related decline occurs, on average, in the mid 60's on inductive reasoning, considerable variability becomes evident when the pattern of change is examined at the individual level. For example, only 20% of adults exhibited reliable age-related decline from 60 to 67 years of age; 36% experienced decline between 67 and 74 years, and over 60% showed decline between 74 and 81 years. Thus, age-related decline is a highly individualized phenomenon, even when considering abilities that exhibit relatively early normative onset of decline.

Cohort differences in level of ability performance.

The study of individual variability in ability functioning is further complicated by the large cohort differences in level of performance, discussed in the adjacent article by Schaie. When the ability performance of successive birth cohorts is examined at the same chronological age, there are significant differences in level. The cohort trends vary across different abilities. There is a strong linear positive cohort trend for inductive reasoning, with each successive cohort performing at a higher level; there are also positive linear trends for the earlier cohorts for space and verbal ability, with a plateauing of cohort differences for the more recent cohorts. In contrast, there is a curvilinear trend for number ability, and a negative trend, at least for the earlier cohorts, for word fluency.

Implications of adult cognition for cognitive training research.

At least three implications from the findings of longitudinal research need to be considered in the design of cognitive training. First, there are differences among abilities in the age of onset of reliably detected

decline. If one of the objectives of intervention is to examine the remediation of cognitive decline, then the timing of the intervention needs to take into account average age of onset of decline for a given ability (Willis, 1990a,b). Since most adults do not experience reliably detectable decline in psychometric mental abilities until old age, interventions begun in middle age would need to target that smaller subset of individuals suffering unusually early decline. Even in old age, there is almost a ten-year span over which different abilities begin to show, on average, reliable decline. Intervention efforts could initially be targeted for abstract reasoning and speed-related abilities, since these abilities exhibit normative patterns of decline beginning in the mid 60's. On the other hand, interventions focused on acculturated skills, such as verbal abilities, should be targeted at older ages, since reliable decline on these abilities, on average, is not detected until the mid 70's.

Second, intervention efforts must consider the wide individual differences in age of onset of decline (Schaie & Willis, 1986). As noted above, many older adults have not experienced reliable decline even by age 70 in those abilities, such as inductive reasoning, that exhibit normative patterns of decline in the mid 60's. Unless the developmental history of an individual is known, it is not possible to determine whether training improvement reflects the remediation of prior decline or enhancement of performance for an individual who has not experienced decline (Willis, 1987, 1990b). If training researchers studied only subjects 80 years of age or older, then they could reasonably assume that most of their subjects had experienced some age-related decline. However, subjects seeking out training are generally the young-old, that age period in which there are the widest

individual differences in patterns of decline.

Third, one must take into account cohort differences in level of performance. This is particularly important when training efforts are focused on mental abilities showing positive cohort trends. In comparing the training outcomes, for example, of young old (60-74 year olds) versus old-old adults (75+ years), both age groups may profit from training but the old-old group may be functioning at a lower level due to initial cohort differences in performance level.

Seattle Training Study: Design and Methods

Design of the Seattle Training Study.

We now turn to the presentation of findings from the Seattle Training Study. All subjects were older adults drawn from the Seattle Longitudinal Study (SLS). Subjects in the Seattle Training Study had been participants in the SLS for at least 14-years prior to the training study. The training study was begun in 1984 (Schaie & Willis, 1986; Willis, 1990a; Willis & Schaie, 1986a, 1993). There were two replicates of the training study in 1991 and 1998. Figure 1 presents the design of the Seattle Training Study.

Subjects' performance was examined on two primary mental abilities, Inductive Reasoning and Spatial Orientation, over the fourteen years prior to training. Subjects were classified as having reliably declined over the fourteen year interval on one or both of the abilities, or as not having declined. Subjects were assigned to training on Inductive Reasoning or on Spatial Orientation on the basis of their decline status. Subjects who had declined on only one of the abilities was assigned to training on the ability on which they had declined. Subjects who had declined on both abilities or

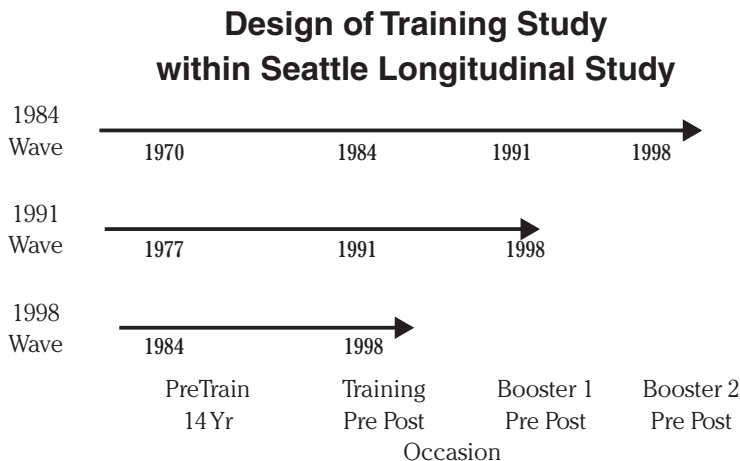


Figure 1. Design of Seattle Training Study: 3 Replicates (Waves) of Training

who had remained stable on both abilities were randomly assigned to training on one of the abilities. Approximately one-half of the subjects had not declined on either ability; approximately 15% had declined on one of the abilities but not on the other; only 20% of the subjects had declined on both abilities. All subjects were posttested following the training program.

There was a follow-up of participants seven years after the initial training. Subjects were pretested to assess their current level of performance and to examine the question of the temporal durability of training effects. Subjects then took part in booster training on the same ability on which they were originally trained. The booster training was very similar in format to the original training program. Subjects were posttested following the booster training. For the first wave of training (1984), participants were followed for 14-years after training.

Abilities trained.

Inductive Reasoning and Spatial Orientation abilities were the focus of the two training programs (Schaie, 1985; Thurstone, 1962). Of the five mental abilities examined within the Seattle Longitudinal Study, these two abilities were selected for training since many elderly were expected to be disadvantaged in their performance for two reasons. First, these abilities exhibit a relatively early age for onset of decline, in the mid 60's. Second, these abilities show positive cohort trends; thus, even elderly who had not experienced decline may function at a lower level on these abilities, compared with more recent cohorts, as a function of cohort differences.

Inductive Reasoning involves abstract thinking, often assessed under speeded conditions. Tests of Inductive Reasoning require the subject to identify the pattern or relational rule in a series of numbers or letters and to utilize the rule to determine the next letter or number in the series. Spatial Orientation also involves abstract thinking, but with regard to nonverbal material. The subject must be able to mentally rotate a two-dimensional figure in two-dimensional space. Tests of Spatial Orientation require the subject to identify which of six figures could be rotated in two-dimensional space to the same position as a stimulus figure.

Description of the two training programs.

The focus of the training was on facilitating the subject's use of effective cognitive strategies identified in previous research on the respective abilities (Schaie & Willis, 1986; Willis, 1990c).

For the *Reasoning training program*, the pattern description rule(s) used in problem solution were identified. Four major types of pattern description rules (identity, next, skips, and backward next) were identified, similar to those discussed previously in the literature (Holzman, Glaser, & Pellegrino, 1976; Kotovsky & Simon, 1973). Practice problems and exercises were developed, based on these pattern description rules. Practice problems often involved content other than letters so that the applicability of these rules to other content areas could be explored. For example patterns of musical notes and travel schedules were devised based on these rules, and subjects were to identify the next note or destination in the series. Subjects were taught through modeling, feedback, and practice procedures to identify these pattern description rules.

For the *Space training program*, a content analysis of the PMA Spatial Orientation test was conducted to identify the angle of rotation for each answer choice. Practice problems were developed to represent the angle rotations identified in the task analysis (45°, 90°, 135°, 180°). Cognitive strategies to facilitate mental rotation that were focused on in training included: a) Development of concrete terms for various angles; b) practice with manual rotation of figures prior to mental rotation; c) practice with rotation of drawings of concrete, familiar objects prior to introduction of abstract figures; d) subject-generated names for abstract figures; and e) having the subject focus on two or more features of the figure during rotation. These cognitive strategies had been identified in prior descriptive research on mental rotation ability (Cooper & Shepard, 1973; Kail, Pellegrino, & Carter, 1980).

Key Questions in Cognitive Training Research

Five issues related to training effects are discussed below. 1) What is the magnitude of training improvement? 2) What individual difference characteristics are related to participants' responsiveness to training procedures? 3) Are the training effects durable over time? 4) How general or broad are the training effects? and, 5) What are current directions in training research focusing on everyday outcomes?

Seattle Training Study: Major Findings

Training Effects for Stable and Decline Subjects

Figure 2 presents the mean inductive reasoning scores for stable and decline subjects trained on reasoning at three occasions: a) Fourteen years prior to training; b) at the pretest, immediately before training; and c) at the 1

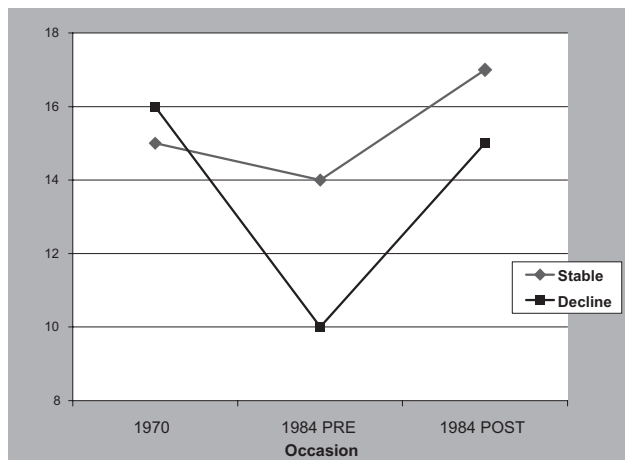


Figure 2. Inductive Reasoning: Stable and Decline Training Participants at 14-years prior to training, pretest, and posttest.

posttest, following training (Willis, 1990a). The pattern of training results was similar for spatial ability. Fourteen years prior to training, stable and decline subjects were performing at the same level on each target ability. At the pretest, decline subjects were performing at a significantly lower level. Training resulted in significant performance gain for both stable and decline subjects. However, the nature of the training effects is *qualitatively different* for the two groups. For decliners, training was effective in returning their performance close to their score level fourteen years prior to training. On the other hand, after training the stable group was performing, on average, above their score level fourteen years prior to training. For stable subjects then, the effect of training was to raise their performance level above that previously demonstrated, while for decliners there was partial remediation of age-related decline.

The above figures provide information on training effects in terms of mean scores. Plasticity, however, is construed as an intraindividual phenomenon, and therefore assessment of training effects at the individual level is of particular interest (Schaie & Willis, 1986; Willis, 1990b). Two questions can be examined. First, what proportion of stable and decline subjects demonstrated significant training gain from pretest to posttest? Second, what proportion of decline subjects exhibited remediation to their score level fourteen years prior to training? With regard to the first question, approximately 50% of subjects in each training group showed significant improvement from pretest to posttest. There was a trend for a greater proportion of decline subjects to show improvement in both training conditions. The second question deals with the proportion of decline

subjects showing complete remediation of prior age-related decline. To assess remediation of decline, we examined the proportion of decline subjects whose performance at posttest was equal to or greater than their score fourteen years previously, in 1970. Approximately 40% of decline subjects exhibited complete remediation. There was no significant difference in the proportion of subjects for whom remediation occurred for reasoning versus space training. Thus, the data suggest that decline on both space and reasoning ability is responsive to training efforts.

Individual difference in responsiveness to training

Not all individuals profit to the same degree from training intervention. What individual difference variables account for substantial variability in training effect? Three variables are of particular note in our research: Gender, cohort and chronic disease.

Gender differences. Gender differences in psychometric ability performance have been consistently noted at early stages in the lifespan (Linn & Petersen, 1985; McGee, 1979). For example, mean score differences in favor of males have been reported in spatial orientation ability, beginning in middle childhood, although there is considerable overlap in the distribution of scores for males and females. Likewise, gender differences in favor of women have been observed for the psychometric ability of inductive reasoning (Schaie, 2005). There is the question of plasticity with regard to gender differences in old age. That is, would cognitive training in old age be effective in reducing the magnitude of the gender difference?

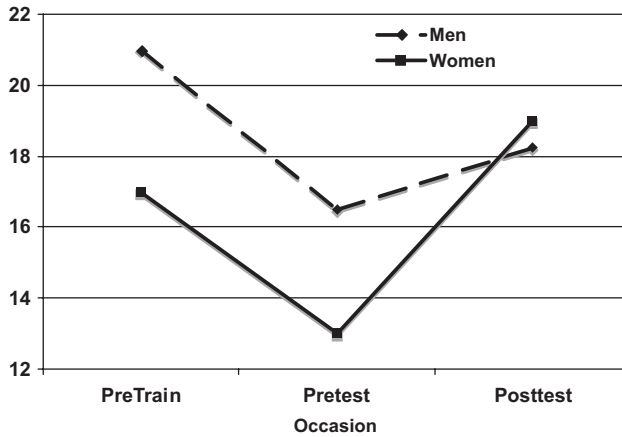


Figure 3. Gender Differences in Training Gain on Spatial Orientation Ability: 14-Years prior to training, at pretest, at posttest.

Figure 3 presents findings with regard to gender differences in old age on spatial orientation ability; data are presented for those subjects experiencing reliable decline on spatial orientation (Willis & Schaie, 1986a). Significant mean score differences in favor of men are shown fourteen years prior to the training intervention. Over the fourteen years prior to training, significant age-related decline occurs for men and women. Of interest is the finding that the magnitude of the gender difference remains relatively constant across this period of decline. Women exhibit greater training gain (posttest) than do men. As a result of gender differences in training improvement, women at posttest are performing, on average, at a level comparable to that of the men. The gender difference in mean level of performance has been largely eliminated as a function of training

Cohort differences. Positive cohort trends have been reported for inductive reasoning and to a lesser extent for spatial orientation in cohort sequential research (Schaie, 2005; Schaie & Hertzog, 1983). Assuming cohort differences in level of performance, there is the question of whether training effects would differ by age/cohort. Figure 4 shows mean scores on inductive reasoning at four occasions (1970, 1977, 1984 pretest, 1984 posttest) for three age/cohorts; the 1903 birth cohort shown at ages 67, 74, and 81; the 1910 birth cohort shown at ages 60, 67, and 74 years; and the 1917 birth cohort shown at ages 53, 60, 67 years (Willis, 1990a). Significant age-related decline on inductive reasoning has occurred for the 1903 and 1910 cohorts (left side of figure) prior to training. The performance of the 1917 cohort was relatively stable over the 1970-1984 period; they were

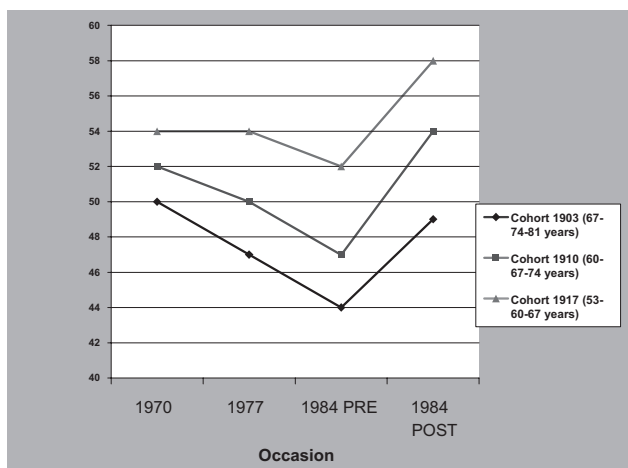


Figure 4. Cohort Differences in Training Gain on Inductive Reasoning Ability: 3 Birth Cohorts at 14-years prior to training, at pretest, at posttest.

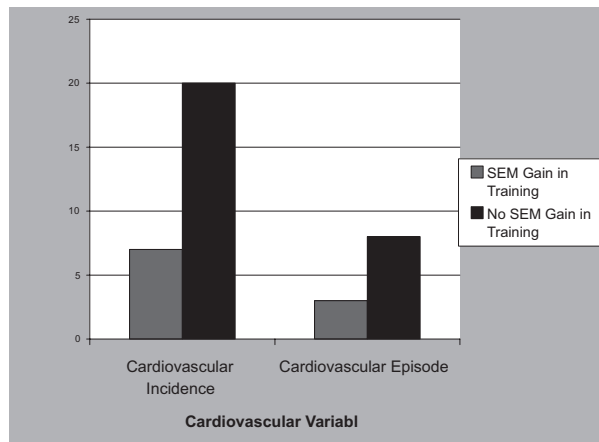


Figure 5. Number of Cardiovascular Events: Participants showing significant training gain (SEM) vs nonsignificant training gain

middle-aged during most of this interval. Note that after training the 1910 and 1917 cohorts were performing, on average, at a level above their 1970 base. In contrast, for the 1903 cohort, there was partial remediation of age-related decline.

Note also that age/cohort differences in level of performance are present at all points of measurement. While training was effective in remediating decline, on average for the two most recent age/cohorts, the magnitude of training effects was not sufficient to eliminate cohort differences (Willis, 1990a). Indeed, there is a slight fanning out of the cohorts' performances across measurement occasions.

Chronic disease. Hypertension is one of the earliest manifestations of cardiovascular disease and has been one of the most extensively investigated diseases with respect to cognitive behavior. Hypertension has been associated with lower cognitive performance in tests of attention, learning, memory, executive functioning and psychomotor speed (Waldstein & Elias, 2001). Crystallized verbal abilities appear to be less affected. In a 20-year longitudinal study, the magnitude of cognitive decline was 12.1% greater for persons who were hypertensive than for those who were never hypertensive. Thus chronic hypertension is associated not only with level of performance, but also with accelerated longitudinal decline in cognition (M. F. Elias, Robbins & Elias, 1990).

In the SLS training study we examined the effect of hypertension on participants responsiveness to training procedures. We compared the average number of times a diagnosis of hypertension or cardiovascular disease (incidence) appeared in the participants' medical

records for participants who demonstrated training gain greater than a standard error of measurement versus the number of diagnoses for participants with training gain of less magnitude than a standard error of measurement. Participants with a higher number of medical diagnoses related to hypertension or cardiovascular disease were significantly less likely to show reliable training gain (i.e., gain greater than a standard error of measurement).

In summary, we have examined three sources of *interindividual* variability in training enhancement: Gender, cohort differences and hypertension/cardiovascular disease. The training intervention was effective in reducing or eliminating gender differences in performance on measures of spatial orientation. Following training, women were on average performing at the same level as men. Training, however, was not as effective in reducing or eliminating individual differences associated with cohort or cardiovascular disease. Cohort differences in mean performance level remain, or increased slightly, as a function of training. At the same time, with respect to *intraindividual* change, training was uniformly effective. That is, men and women and all three birth cohorts exhibited significant improvement. Participants with a higher number of diagnoses of hypertension or cardiovascular disease were significantly less likely to show reliable training gain on reasoning ability.

Temporal Durability of Training Outcomes

The durability of training effects take on added significance when intervention research is considered within a lifespan perspective. The concern is not only that significant improvement in cognitive performance

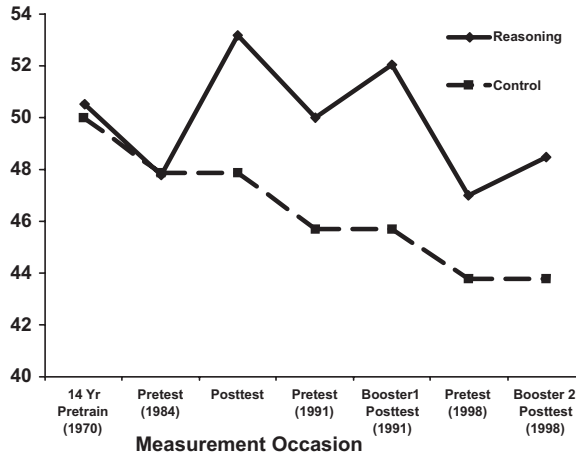


Figure 6. Long-term Durability of Training Effects: 28-year change for participants trained on Inductive Reasoning vs Comparison Group

be demonstrated immediately after training, but whether training has implications for patterns of cognitive development several years after the intervention (Willis & Nesselroade, 1990). The longitudinal design of the Seattle study permits examination of these issues. Figure 6 presents the long-term durability of cognitive training effects for reasoning ability- from fourteen years prior to the initial training to fourteen years after the initial training (including 2 boosters at 7- and 14-years after the initial training). There was some dissipation of training effects after training. However, the booster sessions at 7- and 14-years after initial training were effective in partially regaining the initial training effects. The performance of the training group remained above the performance of the comparison group at all occasions after initial training.

Several conclusions regarding the durability of training effects can be articulated (Willis & Schaie, 1993). First, the long terms effects of training were most evident for subjects who had been classified as having declined on the target ability. There is suggestive evidence, therefore, that training may be particularly effective if it is begun after subjects begin to evidence decline. Second, training effects were somewhat more potent and more durable for inductive reasoning (as compared to spatial orientation training). Both stable and decline subjects trained on inductive reasoning were performing above the level of functioning exhibited prior to training. Third, with one exception, subjects trained on a specific ability were functioning at a higher level on that ability than comparison subjects trained on another ability. That is, except for stable subjects trained on spatial ability, subjects remained at an advantage on the ability trained

in comparison with those not so trained.

Long-term outcomes related to training gain

Not all older adults benefit equally from cognitive training. It is possible that the limited training effects shown for some adults may be associated with a very early preclinical phase of cognitive decline and impairment. Findings from a limited number of prospective dementia studies indicate a lengthy preclinical phase of cognitive decline that can extend up to several decades preceding the onset of Alzheimer's disease (Elias, Beiser, Wolf, Au, White, & D'Agostino, 2000). We have examined the relationship between training effects for reasoning ability and subsequent mental status for SLS training participants (Figure 7). Specifically, we examined the predictive validity of cognitive training that occurred 14-years, 7-years, or approximately one year prior to an assessment of mental status (i.e., assessment for possible cognitive risk or dementia). Training effects occurring 14-years prior to mental status ratings indicated that those subsequently rated as probably demented did not differ in magnitude of initial training gain on reasoning ability. However, training effects 7-years prior to mental status ratings (trained in 1991) indicated those subsequently rated as probably demented experienced less training gain on reasoning ability. Training effects at 1-year prior to mental status ratings differed among the three mental status groups. At one year prior to mental status assessment, training gain for normal functioning subjects was approximately 0.40 SD units, compared to 0.25 SD units for those cognitively at risk, and 0.10 SD units for those probably demented. Training effects on spatial ability were not predictive of

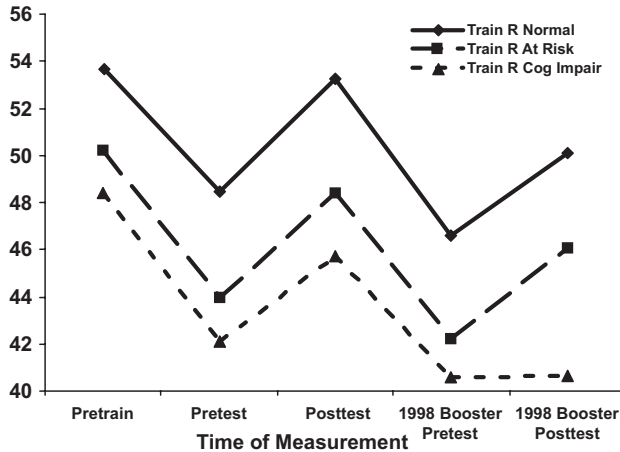


Figure 7. Inductive Reasoning Training: Long-term effects in 3 Groups and Prediction of Cognitive Risk

mental status group membership.

Summary of Findings: Seattle Training Study

The Seattle Training study examined whether training would be effective both for older adults who had experienced prior decline on the ability trained (decliner) and for older adults with no decline (stable). Training was conducted on two abilities showing early age-related decline: inductive reasoning and spatial orientation. Both groups (decliner, stable) showed significant training improvement. These findings were replicated at two waves of training in 1991 and 1998. Responsiveness to training was examined for three individual difference variables: gender, cohort, presence of hypertension/cardiovascular disease. For spatial orientation training, women showed greater training gain than men, such that there was no gender difference in ability level, on average, at posttest. Cohort differences in level of performance remained at posttest; however, all cohorts showed training gain. Participants with more diagnoses of hypertension were less likely to show reliable training improvement than those with fewer diagnoses of hypertension or cardiovascular disease. Training effects were maintained at 14- and at 7-years after training (in comparison to the group trained on the other ability). Training gains were related to subsequent diagnosis of cognitive risk or possible dementia.

Current Directions in Training Research

Limitation of prior studies.

In the 1980's and 1990's, researchers at other universities conducted training studies on other abilities showing early age-related decline, such as memory

(Rebok & Balcerak, 1989) and speed of processing (Ball, 2002), and reported significant training effects for these abilities. While these training studies reported significant effects, several limitations in these studies were noted. The studies were typically conducted by a single investigator at one university. There was the question of whether similar training effects would be found if conducted at different sites and with more diverse samples of older adults. The samples had been generally homogeneous (Caucasian, well educated). While long-term maintenance of training effects had been demonstrated in the Seattle study, most training studies did not have long-term findings. Some training studies had not randomly assigned participants to training conditions. Different studies had used different training protocols. There was the need to develop standardized protocols for training programs. Finally, none of the training programs had been conducted within the methodology for a Randomized Clinical Trial (RCT). A clinical trial requires an Intent to Treat protocol; all randomly assigned participants are included in the analyses, even those who never participate in training or drop out very early in training.

New directions in training and training outcomes.

Most prior training research, such as the Seattle study, had as its major outcome improvement on the mental ability which was the focus of training. That is, did training on reasoning result in improvement on reasoning ability? A new outcome for training studies was now being proposed. "Would training on cognitive ability(ies) maintain or enhance older adults' ability to perform the tasks needed for independent living?" The

new outcome focused, not on the cognitive ability trained, but on tasks associated with independent living. Specifically, would training on basic cognitive abilities result, not only improvement on the abilities trained, but also on tasks related to daily living?

There is currently an ongoing large multi-site cognitive training study, funded by the National Institutes of Health, aimed at addressing some of the limitations of earlier training studies and also aimed at addressing this new outcome (Ball et al., 2002; Jobe et al., 2001; Willis et al., 2006). This study is known as the ACTIVE Trial (Advanced Cognitive Training in Vital Elderly). Before briefly summarizing the findings (to date) of ACTIVE, we will very briefly discuss research on the relation between cognition and activities of daily living.

Cognition and Tasks of Daily Living

Defining and Assessing Activities of Daily Living. There are classes of everyday activities that are critical for adaptive functioning in common life situations (Schaie, 1978; Willis & Schaie, 1986b). A major concern in old age is maintenance of independent living; the focus is on domains of activities in which an older person must remain competent in order to live independently (Willis, 1996). For example inability to perform tasks, such as comprehending medicine bottle labels or utilizing information in the phone directory, may lead to curtailment of independent living for many elderly (Willis et al., 1992; Willis & Schaie, 1993). Seven domains of activities have been identified in prior research to be critical for living independently. These are known as Instrumental Activities of Daily Living (IADLs). The domains are: Managing health and medications; managing finances; managing one's household; use of telephone and communications; managing transportation; shopping; meal preparation.

There have been two major approaches to assessment of older adults' competence in the IADLs: 1) Older adults' self report of their ability to perform these activities, and 2) Objective assessment of older adults' doing exemplar IADL tasks, or solving problems related to exemplar IADL tasks (e.g., reading a medication label and determining how many pills one should take in a day) (Willis & Schaie, 1986b; Willis, 1991).

Relation of mental abilities and competence in IADLs. Are the abilities studied in cognitive training research related to IADL activities? We have suggested that a hierarchical relationship may exist between these two forms of mental competence (Schaie, 1978; Willis, Jay, Diehl, & Marsiske, 1992; Willis & Marsiske, 1991; Willis &

Schaie, 1986b). The most elemental components are ability factors, such as the primary mental abilities (e.g., memory, reasoning, speed, vocabulary) represented within a psychometric approach to traditional intelligence (Thurstone, 1962). Because activities (IADLs) in real-world contexts are of necessity complex, we assume that no single ability factor can adequately predict performance on an activity of daily living (Willis & Marsiske, 1991; Willis & Schaie, 1993). Rather some combination of ability factors is required to account for competence in an activity. For example, comprehending a medication label may involve verbal, reasoning and mathematical abilities. Activities such as IADLs are cognitively complex and involve multiple basic abilities. Our prior research indicates that a significant amount of variance in performing IADL activities can be accounted for by a combination of basic abilities, but there is considerable variance not accounted for by these abilities. Importantly, the combination of abilities accounting for variance includes both fluid (e.g., reasoning, speed) and crystallized or acculturated abilities (e.g., verbal).

Our research suggest several points regarding the relationship between basic abilities and everyday activities. First, there are significant and reliable relationships between cognitive abilities studied in the laboratory and the cognitive skills involved in many tasks of daily living encountered by the elderly. Second, everyday tasks are cognitively complex and involve combinations of several basic mental abilities. Third, the particular combination of abilities involved will vary across different types of everyday activities. Fourth, when studied longitudinally, activities of daily living decline somewhat later, on average, than basic abilities. Whereas, fluid abilities decline on average, by the mid sixties, activities of daily living do not decline, on average until the late sixties or early seventies. This difference in onset of decline may be due to daily activities being "practiced" everyday and also because crystallized as well as fluid abilities are involved.

The ACTIVE study and daily activities as a training outcome.

Aims and design of the ACTIVE study. We now return to summarize the findings to date of the ACTIVE training study (Jobe et al., 2001). The major aim of the ACTIVE study has been to examine whether training on basic cognitive abilities would result in older adults' maintaining their activities of daily living (IADLs), when compared to a control group. Older adults received

training on one of three basic abilities: memory, reasoning, speed. It was hypothesized that training on basic abilities would enhance the cognitive skills which underlie competence in activities of daily living. Thus, trained participants would show improvement on the basic ability on which they were trained and that they would show better maintenance of everyday activities, as compared to a control group.

The study was conducted in six geographical areas in the U.S., including over 2300 participants. Participants were randomly assigned to one of three interventions (memory, speed, reasoning) or a control group. Trainees received ten ninety minute training sessions. At one-year and at three years after training, a random subset of each training group received four booster sessions. All participants were reassessed at two-, three and five years after training.

Major findings on ability training. Participants in each intervention (memory, speed, reasoning) showed significant improvement, compared to the control group (Ball et al., 2002; Willis et al., 2006). This training improvement was maintained through the five-year follow-up. Training effects were shown only for the ability on which participants were trained. That is, participants trained on memory showed effects on memory, but not on speed or reasoning. Participants who received booster sessions performed at a higher level than trainees not receiving booster sessions.

Major findings on activities of daily living. No training effects on activities of daily living were found at one-, two- or three- years after training (Willis et al., 2006). At the 5-year follow-up, training participants reported having less difficulty performing activities of daily living (IADLs) than did the control group. This finding was significant for the group trained on reasoning, and there was a strong trend for the memory and speed training groups. In addition, the speed trained participants who received booster training performed faster on a test of exemplar everyday tasks (e.g., speed of looking up a phone number in a directory), compared to the control group.

Why were findings on activities of daily living delayed until the 5-year follow-up? The ACTIVE participants were healthy older adults living in the community who were performing well on IADL activities at the beginning of the study. Thus, differences in IADL performance could not be observed until the control group began to decline on IADL activities. This decline in the control group began to be evident at the 5-year follow-up. Recall that prior longitudinal research on everyday activities

had shown that everyday activities decline, on average, at a later age than decline begins for basic abilities, such as speed, memory and reasoning. It is hypothesized that the maintenance of the training effects on the basic abilities (through the 5-year follow-up) provided the cognitive support for the trained participants to report better IADL functioning, compared to the controls. A 10-year follow-up is currently in progress in order to examine the long-term training outcomes with respect to everyday activities.

Summary and Concluding Remarks

At the beginning of this chapter we stated that cognitive training research provides a useful approach for the study of plasticity in old age. In this final section, we will suggest three implications from the findings of cognitive training research for the study of plasticity.

Studying plasticity within a life-span context. The longitudinal design of the Seattle study has permitted an examination of plasticity within a developmental context (Willis, 1990a; Schaie & Willis, 1986). A life-span perspective involves consideration of *current* level of functioning in the context of *prior* and *future* developmental trajectories. Findings from our training studies indicate considerable cognitive plasticity for older persons with two very different prior developmental profiles. Both subjects experiencing prior decline and those who had remained stable demonstrated significant training improvement. However, knowledge of the individual's prior developmental history had a major impact on our interpretation of the nature of training improvement. For decliners, training improvement represented a remediation. But for stable subjects, training improvement represented more advanced levels of performance than previously demonstrated. Likewise, examining the temporal durability of training effects and the individual's subsequent developmental trajectory provided a more complete understanding of the nature of plasticity. There is suggestive evidence, for example, that the durability of training effects and the potential for profiting from further intervention efforts may be related to the individual's prior developmental history. That is, long term plasticity may actually be somewhat greater for individuals suffering prior performance decline.

The multidimensional nature of plasticity: Growth, stability, and remediation. A life-span approach suggests that even in old age, plasticity must be considered to be a multidimensional and multidirectional construct (Willis, 1990c). The stereotypic view of cognitive aging as

one of unremitting, universal decrement has contributed to the assumption that plasticity in old age always involves *remediation* of lost skills rather than the acquisition of new responses. From the perspective of cognitive training research, we must conceptualize potential or plasticity along three directions: Potential for growth, potential for stability (maintenance), and potential for remediation.

Potential for growth involves the older adult's ability to demonstrate further quantitative or qualitative increases in knowledge base or skill beyond those shown at an earlier age. The capacity of the stable subjects in our training study to achieve significant training gain is evidence for potential for cognitive growth or gain, even in late life. Potential for maintenance involves the aging individual's capacity to maintain the same level of skill or performance as they progress from young old to old-old age. Indeed, maintaining their current level of functioning appears to be the major goal of many older adults! While much discussion of plasticity has tended to focus on gains or remediation, the elderly's potential to maintain their current level of functioning with advancing age needs further consideration. Finally, potential for remediation involves the opportunity for partial remediation or attainment of a skill or performance level that has shown previous age-related decline.

Study of plasticity in the context of individual differences. The primary focus in the study of plasticity is on *intraindividual* variability. This involves examining the individual's current range of functioning in the light of his or her prior and future levels of functioning. The individual serves as their own baseline. However, plasticity or intraindividual variability needs to be examined in the context of sources of interindividual differences. For example, in our training research we have examined plasticity in relation to gender differences and in relation to age/cohort differences. Whereas the range of plasticity was sufficient to eliminate, on average, long standing gender differences in level of performance on spatial orientation tasks, age/cohort effects persisted in spite of considerable intraindividual plasticity within each cohort.

Training research suggests that there is considerable cognitive plasticity in later life. Plasticity must be examined in the context of the individual's prior developmental history and may involve gain, stability, or remediation. Plasticity is not a "sky's the limit" phenomenon. There are boundaries and limits and it is important that these boundary conditions be studied

within a developmental framework. Knowledge of the individual's prior gains and losses will therefore contribute greatly to our understanding of plasticity in later life.

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