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Cognitive Interventions and Aging

The Impact of Speed of Processing Training on Cognitive and Everyday Functions

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We combined data from six studies, all using the same speed of processing training program, to examine the mechanisms of training gain and the impact of training on cognitive and everyday abilities of older adults. Results indicated that training produces immediate improvements across all subtests of the Useful Field of View test, particularly for older adults with initial speed of processing deficits. Age and education had little to no impact on training gain. Participants maintained benefits of training for at least 2 years, which translated to improvements in everyday abilities, including efficient performance of instrumental activities of daily living and safer driving performance.

RESEARCHERS have well established that a variety of cognitive abilities, including memory, processing speed, and problem solving, decline with increasing age (for examples see Birren, Woods, & Williams, 1980; Madden, 1992; Schaie, 1996; Smith & Earles, 1996). These findings are especially important considering the established links between basic cognitive abilities and everyday functional abilities (Allaire & Marsiske, 1999; Cahn-Weiner, Malloy, Boyle, Marran, & Salloway, 2000; Owsley, Sloane, McGwin, & Ball, 2002; Willis, Jay, Diehl, & Marsiske, 1992). For example, Bäckman and Hill (1996) concluded that laboratory-based measures of cognitive abilities can reliably predict functional competence among older adults. More recently, Burdick and colleagues (2005) confirmed that cognition is a significant predictor of older adults' difficulties with basic and instrumental activities of daily living, which lead to loss of independence.

Considering both the impact of cognitive decline upon everyday abilities, and the importance of everyday abilities to sustained independence, there is increasing interest in helping older adults maintain cognitive fitness for as long as possible. Therefore a great deal of research has gone into pursuing the question of whether cognitive decline can be reversed or delayed through cognitive training. This research has established that older adults can improve cognitive abilities (Ball & Sekuler, 1986; Ball, Beard, Roenker, Miller, & Griggs, 1988; Hayslip, Maloy, & Kohl, 1995; Schaie & Willis, 1986; Willis, Bliezner, & Baltes, 1981) with training protocols targeting memory, reasoning, and speed of processing, among other cognitive domains (Ball et al., 2002; Ball et al., 1988; M. M. Baltes, Kuhl, Gutzmann, & Sowarka, 1995; P. B. Baltes & Willis, 1982; Caprio-Prevette & Fry, 1996; Hayslip et al., 1995; Kramer, Larish, & Strayer, 1995; Mohs et al., 1998; Neely & Bäckman, 1995; Oswald, Rupprecht, Gunzelmann, & Tritt, 1996; Willis et al., 1992; Willis & Schaie, 1994). These studies have also demonstrated that cognitive training is very specific to the ability trained, with very little transfer of training to untrained cognitive domains; and improvements have been limited to tasks very similar to the training itself (Kramer & Willis, 2002; Neely & Bäckman, 1995; Willis et al., 1981; Willis & Schaie, 1994).

Ultimately, the goal of cognitive training is to enhance or sustain cognitive abilities at healthy levels for longer portions of the life span in the hope that everyday functioning will benefit. The underlying premise is that functional decline, at least in part, is the result of age-related cognitive decline. Therefore, by extension, maintaining adept cognitive function should result in the maintenance of functional abilities. Cognitive training programs hypothetically have the potential to postpone, slow, or reverse age-related cognitive decline, thereby prolonging functional competence. For example, if training occurs before cognitive decline is evident, although there may be no immediate improvement due to ceiling effects, prevention or postponement of decline would be evident if the control group showed evidence of decline longitudinally whereas the trained group did not. Alternatively, training may slow the rate of decline if both the training and control groups evidenced longitudinal decline but the slope of decline was steeper for the control group. Finally, if training occurs after both training and control groups have experienced decline, the training group may demonstrate significant immediate improvement, which booster training could potentially maintain. This finding would support a reversal of cognitive decline if the slope for cognitive function became positive or flat.

Speed of Processing Theory

Birren (1974) first theorized that generalized slowing of abilities underlies the cognitive decline that often occurs with age. Abundant evidence now exists that, as a part of the normal aging process, many individuals experience a decline in the speed with which they process information (Salthouse, 1985, 1990). Subsequent research confirmed that researchers can attribute late-life cognitive decline to slower processing speed (Salthouse, 1993; Schaie, 1989, 1994). Several recent longitudinal studies have indicated that speed of processing accounts for significant proportions of cognitive decline experienced by older adults over time (Finkel et al., 2004; Lemke & Zimprich, 2005; Zimprich, 2002).

Speed of Processing and Everyday Performance

Scientists have connected cognitive processing speed abilities to competent everyday performance among older adults in several areas. For example, visual information processing speed, as indicated by Useful Field of View (UFOV®; UFOV is a Registered Trademark of Visual Awareness Inc., Birmingham, AL) test performance, reliably predicts driving competency (Ball & Owsley, 1993; Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Owsley et al., 1998). Older drivers with speed of processing difficulties, as measured by the UFOV test, are more than twice as likely as older adults with intact speed of processing to incur an at-fault crash during the subsequent 3 to 4 years (Ball et al., 2006). Researchers have also related processing speed measured in this manner to an elevated risk for falls (Sims, McGwin, Pulley, & Roseman, 2001; Staplin, Gish, & Wagner, 2003) and to reduced life space and driving space (Stalvey, Owsley, Sloane & Ball, 1999; Owsley, Stalvey, Wells, & Sloane, 1999). Experts associate speed of processing with performance of mobility tasks, such as transitioning from sitting to standing, as well as with balance and gait (Owsley & McGwin, 2004) and functional reach (Riolo, 2003). Additionally, scientists have related speed of processing, as measured by the UFOV test, to the performance of other instrumental activities of daily living, including quickly and accurately looking up phone numbers, counting out change, finding a particular item on a crowded shelf, and reading food and medication labels (Owsley et al., 2002). Furthermore, faster speed of processing is particularly important in that this ability is associated with maintained health status with advancing age (Hultsch, Hammer, & Small, 1993; Rosnick, Small, Borenstein Graves, & Mortimer, 2004). Considering the strong association between speed of processing and everyday performance, as well as health status, speed of processing training may particularly have the potential to enhance everyday functioning among older adults.

What Is Speed of Processing Training?

Speed of processing training involves trainer-guided practice of computer-based nonverbal exercises that are presented very briefly and involve target detection, identification, discrimination, and localization (Ball et al., 2002; Ball et al., 1988; Sekuler & Ball, 1986). Speed of processing training has the primary aim of improving the fluid ability of mental processing speed (not psychomotor reaction time) such that trainees can process increasingly more information and increasingly more complex information over briefer periods of time. This is consistent with limited time and simultaneity mechanisms thought responsible for the age-related decrease in fluid cognition according to speed of processing theory (Salthouse, 1996). It is important to note, however, that there is no pure measure of processing speed, and any task designed to improve this ability undoubtedly requires and affects other cognitive and sensory skills as well.

The training primarily involves practice with feedback, although the trainer teaches some task-specific strategies for enhancing performance as well. Trainers also offer suggestions, encouragement, and personalized modifications of difficulty for the trainee according to a specified protocol. At a display speed and task difficulty level tailored to their ability, trainees practice blocks of 16 trials. Trainees receive immediate feedback after each trial and see their total correct trials at the end of each block of trials. Trainers tell the trainees that their goal is to achieve performance of 10 to 12 correct trials for each training block. Once the participant reaches this level of performance on two blocks, display speed decreases. This procedure continues until the trainee reaches the speed of processing goal for the particular task, at which point task complexity increases. Reaction time is not measured and is not a factor in scoring the training protocol. Rather, display speed (controlled by a full-field, backward mask) is the primary manipulation made throughout the training.

According to the specified training protocol, each basic task has a speed of processing criterion goal. Training proceeds at individualized levels of complexity until the trainee can identify a single visual target at a display speed of 30 ms, can identify a visual target and simultaneously localize a peripheral target at a display speed of 40 ms, and can perform this task when the peripheral target is embedded in distractors at a display speed of 80 ms. Repeated practice of tasks of incrementally increasing complexity and decreasing display speed helps trainees to reach these goals. The overall goal of the training technique is to enhance cognitive processing speed by gradually increasing task difficulty while decreasing display speed until trainees achieve mastery through practice.

Speed of Processing Training Tasks and the UFOV Test

The training tasks involve at least three basic levels of complexity that are similar to the three subtests of the UFOV assessment (for details on the UFOV test, see Edwards, Vance, et al., 2005; Edwards et al., 2006). However, in training, all aspects of task difficulty are modified to produce at least 18 different tasks that are presented at 10 different display speeds for the purpose of enhancing an individual's abilities with practice. For example, whereas the UFOV subtests each involve a central task of visual target identification (car or truck), in training the central task complexity is modified to be easier (target detection) or more difficult (discrimination of two targets or performing a visual discrimination concurrent with an auditory task). Similarly, whereas UFOV Subtests 2 and 3 involve localization of a peripheral target at a set eccentricity, in training the target eccentricity, location, and both target and distractor luminance are modified to vary task complexity. In the UFOV test, display speed is varied between 16.67 and 500 ms in a double-staircase fashion (controlled by a full-field backward mask) to determine threshold of processing speed. In training, based upon an individual's existing abilities, display speed is specified at one of 10 durations between 20 and 400 ms for blocks of 16 trials for the purpose of enhancing processing speed. Generally, the training method involves gradually increasing the complexity of the center task (from detection, to identification, to discrimination of two targets, to concurrent visual and auditory tasks), and adding and increasing the complexity of a peripheral task (increasing eccentricity; adding distractors; or changing luminance of the target, distractor, or both). As the trainees progress, the trainer decreases display speed. As trainees achieve mastery of a particular task at the briefest duration, difficulty increases and training continues, aimed toward reaching another speed goal.

Speed of Processing Training Compared to Other Cognitive Training Protocols

Unlike other cognitive training protocols, such as reasoning or memory training (Ball et al., 2002; Rebok, Montaglione, & Bendlin, 1998; Willis & Schaie, 1986), speed of processing training tasks are nonverbal. Memory and reasoning training techniques, similar to Kramer and colleagues' dual-task training techniques (Kramer et al., 1995; Kramer, Larish, Weber, & Bardell, 1999), primarily target strategies for improving performance. Speed training as described here, however, targets practice of tasks and is intended primarily to improve a basic cognitive ability, speed of information processing. Kramer and colleagues' dual-task training involves performance of two different tasks simultaneously (monitoring and alphabet–arithmetic tasks). Their training technique primarily aims to improve one's ability to manage and coordinate multiple tasks by varying the priority emphasis that trainees assign to each of the tasks. Such dual tasks would be quite attentive in nature. Speed training, on the other hand, requires the simultaneous processing of peripheral information (a preattentive visual search task) while performing an attentive primary task, and there is not sufficient time during the tasks for participants to switch attention from the primary task to the periphery. Interestingly, whereas researchers have commonly reported age-related declines for attentive tasks, they have thought preattentive or parallel processing of information to be stable with age (Hasher & Zachs, 1979; Hoyer & Plude, 1980). Deficits on this measure, however, occur for a subset of older adults, and the prevalence of speed of processing deficits increases with age (Ball, Roenker & Bruni, 1990). Variable-priority, dual-task training is similar to speed training in that both involve a hybrid training procedure that includes both part-task and whole-task training (Kramer et al., 1995). In speed training, as complexity of training tasks increase, the more complex tasks include components of earlier training tasks. Schooler (2001) pointed out that even in old age, carrying out complex tasks builds the capacity to deal with complex environments. Thus, we hypothesize that speed training builds capacity of everyday speeded tasks.

The Impact of Speed of Processing Training on Everyday Abilities

As reviewed previously, cognitive aging research suggests that speed of processing is particularly important for everyday performance, functioning, and maintained health status among older adults. Thus, we contend that speed of processing training can enhance these abilities. Support for the hypothesis that speed of processing training can positively impact everyday performance for older adults experiencing cognitive slowing comes from several studies (Edwards et al., 2002; Edwards, Wadley, Vance, Roenker, & Ball, 2005; Roenker, Cissell, Ball, Wadley, & Edwards, 2003), which we will review in detail.

The purpose of this article is to combine data from six studies using a specified protocol of speed of processing training in order to examine training gains in detail and, specifically, to address the following questions: "Who benefits from speed of processing training and how much?" And, "what are the mechanisms of speed of processing training improvement?" The six studies differed somewhat with respect to methodology, such as study inclusion criteria, length of follow-up, mode of training, measures in the assessment battery, and transfer of training effect sizes (Ball et al., 2002; Edwards et al., 2002; Edwards, Wadley, et al., 2005; Roenker et al., 2003; Vance et al., in press; Wadley et al., 2006). These differences, however, provide some insight with respect to differing results across studies as well as with respect to questions such as who is most likely to benefit from speed of processing training, for how long, and in what ways. We will also discuss the possible real world applications for speed of processing training.

METHODS

Across studies, participants included 2,039 community-dwelling older adults ranging in age from 55 to 95 years ($M = 73.94$, $SD = 5.96$). Education ranged from fourth grade to doctorate level, with 10% of participants having an education level of less than high school. Each of these six studies investigated the impact of completion of the computerized speed of processing training protocol upon the cognitive and everyday abilities of older adults (Ball et al., 2002; Edwards et al., 2002; Edwards, Wadley, et al., 2005; Roenker et al., 2003; Vance et al., in press; Wadley et al., 2006). Studies were the University of Alabama at Birmingham Training Study (UAB), Accelerate, Staying Keen in Later Life (SKILL), the Driving Study, Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE), and Home-Based Training.

Additionally, we compiled and examined detailed daily speed of processing training data for a subsample of speed of processing trained participants from the SKILL ($n = 104$; 60% women, 85% Caucasian) and ACTIVE ($n = 426$; 72% women, 71% Caucasian) studies in order to address specific questions regarding the mechanisms of training improvement. The SKILL speed-trained subsample included individuals who were, on average, 75 years of age with 13 years of education, and the ACTIVE subsample included individuals who were 74 years of age with 14 years of education, on average.

Inclusion criteria varied somewhat across studies (see Table 1). Some studies (ACTIVE, SKILL, Home-Based Training) included only adults with intact mental status as indicated by a particular Mini-Mental State Examination score. Others (ACTIVE, SKILL, Driving, Home-Based Training) required individuals to have a basic level of visual function. Most of the studies (with the exceptions of the UAB and ACTIVE studies) included in training only participants with initial speed of processing difficulties as evidenced by reduced UFOV test performance. Sample sizes ranged from 97 to 2,832 participants, although the largest study, ACTIVE, included three training arms (two of which served as social contact control groups for the other training group) as well as a no-contact

Table 1. Summary of Methods and Effect Sizes (Immediately Posttraining) of Studies Examining Speed of Processing Training

Study	Inclusion Criteria	Participant Ages	Participant Education Range	Speed Training (*N*)	Control Conditions	Training Mode and Duration	Follow-Up Period	Effect Size[a] (UFOV)
UAB	Community-dwelling	61–95	Grade 6 to PhD	41	No contact (equivalent time delay)	Group trainer guided; sessions 1–5 fixed; 5 weeks	—	−0.61
Accelerate	Community-dwelling, MMSE ≥ 25, VA ≥ 20/40, CS ≥ 1.35, poor UFOV	65–92	Grade 8 to PhD	74	Social- and computer-contact; Internet training control	Group and individual trainer guided; fully customized; varied	—	−0.96
SKILL	Community-dwelling, MMSE ≥ 23, VA ≥ 20/80, CS ≥ 1.35, poor UFOV	63–87	Grade 8 to PhD	106	Social- and computer-contact; Internet training control	Group and individual trainer guided; fully customized; 5 weeks	—	−1.00
Driving	Community-dwelling, VA ≥ 20/40, poor UFOV	55–86	Not known	49	Social control/usual treatment; driver simulator training	Individual trainer guided; fully customized; 2 weeks	18 months	−1.67[b]
ACTIVE	Community-dwelling, MMSE ≥ 23, VA ≥ 20/70	65–94	Grade 4 to PhD	606	No-contact control; social contact control through memory training, reasoning training	Group trainer guided; sessions 1–5 fixed; 5 weeks	2 years	−0.72
Home-Based Training	Community-dwelling, MMSE ≥ 23, VA ≥ 20/40, poor UFOV	65–91	Grade 5 to PhD	31	No-contact control; social- and computer-contact control; regular lab-based training control	Individual home via video; all sessions fixed with some customized practice; 5 weeks	—	−0.63

Notes: UFOV® = Useful Field of View test (Visual Awareness, Inc., Birmingham, AL); UAB = University of Alabama at Birmingham; MMSE = Mini-Mental State Examination; VA = visual acuity; CS = contrast sensitivity; SKILL = Staying Keen in Later Life; ACTIVE = Advanced Cognitive Training for Independent and Vital Elderly.

[a] Except where indicated, effect size calculated as (training group mean – control mean immediately posttraining) – (training group mean – control mean at baseline)/240.38 (*SD* of UFOV baseline scores across five studies).

[b] Effect size calculated as (training group mean – control mean immediately posttraining) – (training group mean – control mean at baseline)/11.9 (*SD* of UFOV % reduction baseline score in Driving study).

control group. In all of the studies, participants completed baseline and immediate posttraining batteries. The Driving and ACTIVE studies included longitudinal follow-up assessments as well.

Across studies, organizers randomized participants to take part in either speed of processing training, a social contact control group, or a no-contact control group. Researchers designed the social contact control conditions to be equivalent to the intervention with respect to all factors (e.g., amount of social contact with trainers and other participants, time spent in training, number and length of visit, guidance by trainer, exposure to computers) except for training content. Table 1 summarizes the methodological characteristics of each study in detail. The detailed methodology of each study is available elsewhere (Ball et al., 2002; Edwards et al., 2002; Edwards, Wadley, et al., 2005; Roenker et al., 2003; Vance et al., in press; Wadley et al., 2006).

Some aspects of speed of processing training (e.g., self-administered or administered by a trainer, delivered individually or in a group, duration of training period) varied across the studies (see Table 1). However, each study used the same speed of processing training program (Visual Awareness, Inc., Birmingham, AL) and standardized method of enhancing speed of processing abilities through practice of specific computerized exercises at increasingly complex levels and decreasing presentation durations. In order to make the intervention equivalent to the other arms of training in the ACTIVE study, the first five sessions of training involved practice at specified levels of complexity, whereas during the last five sessions, trainers customized the tasks to each individual's level of ability. The UAB study used this exact same training method. The Home-Based Training study involved practice on specified tasks via videotape. The videotape method was like that used in the ACTIVE and UAB studies, in that participants practiced all training tasks in the first sessions and then later practiced at customized levels, as they were directed to repeat certain exercises or progress to new exercises based on their performance (for more detail, see Wadley et al., 2006). All other studies used fully customized training techniques with task difficulty tailored to each trainee's abilities for all training sessions.

In the first session of fully customized training, trainees complete the UFOV test to determine speed of processing abilities (quantified by display speed threshold) for central target identification alone (Subtest 1), central target identification with peripheral target localization (Subtest 2), and central target identification with peripheral target localization in the presence of distractors (Subtest 3). The trainer then uses the results of this assessment to tailor task difficulty for each individual. According to the specified protocol, participants begin training at the most basic level if they are unable to identify a single object with a display speed of at least 30 ms. In this case, participants practice single-target detection, identification, and discrimination tasks until they can perform each task correctly 75% of the time at a display speed less than 30 ms. Participants who have mastered this basic level of information processing but who cannot simultaneously identify and localize visual targets at a speed of 40 ms begin training at a moderate level of complexity. Training on tasks involving simultaneous central and peripheral targets proceeds until the participant can identify a central target and simultaneously locate a peripheral target at the furthest possible eccentricity with a display speed of 40 ms. Once participants can quickly process information at the moderate level, they begin training on tasks that involve central and peripheral targets with distractors added to the display. Trainees continue practicing these tasks throughout training until they are able to process information with the most difficult central demand (multiple target discrimination) and the peripheral target at the furthest eccentricity at a display speed of 80 ms.

RESULTS

Who Benefits From Speed of Processing Training, and How Much?

Across studies, more than 90% of participants randomized to speed of processing completed the training protocol. Using data from participants who actually completed training ($n = 920$), we calculated training effect sizes using UFOV pretraining and posttraining scores, because this test is most similar to the training practices and is used to gauge training progress. To be consistent across studies, we divided the difference between the trained and control participants' UFOV performance posttraining minus the difference between the trained and control participants' UFOV performance at baseline by the baseline UFOV standard deviation. This method differed from that published in ACTIVE (i.e., where researchers pooled error terms across testing occasions, resulting in greater effect sizes). However, we used a consistent error term here to allow for comparison across studies. Table 1 reports the training effect sizes for each study. These effect sizes reflect immediate posttraining benefit.

To answer the question of what predicts training benefit, we calculated training gain as the difference between pretraining and posttraining UFOV scores. We calculated the correlations among age, education, mental status, and training gain, which are depicted in Figure 1. There was little to no correlation between training gain and education, $r = -.15$, $p < .001$; mental status, $r = -.17$, $p < .001$; or age, $r = .144$, $p < .001$. By far the strongest correlate of training gain was baseline speed of processing performance, $r = .775$, $p < .001$, as indicated by UFOV. In part, this reflects the fact that individuals with the worst performance at baseline had the most room for improvement. Training gain also correlated with all other traditional speed of processing and psychomotor speed measures and Trails B performance, albeit very weakly. Training gain was not related to visual memory or vision measures (see Table 2).

Although the training protocol and UFOV test inevitably require a variety of sensory and cognitive abilities, we assert that the training predominantly enhances processing speed through practice of the tasks. In order to verify that the program is training primarily speed of processing abilities, we examined the relationships among training gain, UFOV subtest and total scores, and various other cognitive and visual sensory tasks across the six studies. Data from other neurocognitive measures available included measures of psychomotor speed (Digit Symbol Copy), everyday speed of processing/complex reaction time (the Road Sign Test), traditional speed of processing measures (Wechsler Adult Intelligence Scale–Revised Digit Symbol Substitution, Letter Comparison, and Pattern Comparison), visual memory (Benton Visual Retention, Rey-O Complex Figure Test), and executive function (Trails B, Stroop). We measured vision with standard visual acuity and Pelli-Contrast Sensitivity charts; vision did not correlate with speed of processing training gain (ps $> .05$). Table 2 presents significant correlations (with test–retest reliability indicated on the diagonal).

Baseline UFOV performance for all three subtests was most consistently correlated to traditional speed of processing measures. However Subtest 2 of the UFOV, as well as the total score, also correlated moderately with Benton Visual Retention performance. We also found significant but small correlations for UFOV Subtest 2 and total with executive function as indicated by Trails B and Stroop performance. All three subtests of the UFOV correlated most strongly to cognitive rather than visual sensory measures.

We factor analyzed the measures included in Table 2 in order to further examine the relationships among these measures and to explore their contribution to training gain. After using the principal components extraction method, we examined the scree plot. It suggested the existence of two factors. We performed a varimax rotation with Kaiser normalization and present the factor loadings in Table 3. Factor 1 included loadings for the speed of processing, psychomotor speed, and executive function measures. Factor 2 included the visual memory tests of Benton and Rey-O, the Road Sign Test, as well as contrast sensitivity. These results indicated that the UFOV and other traditional speed of processing and psychomotor speed measures were tapping the same cognitive abilities. Executive function measures also loaded on this factor. These executive function measures also required quick speed of processing (each were timed), and, obviously, this ability would affect performance on any other cognitive task.

We formed composites based upon the factor analysis results and conducted regression analyses in order to examine predictors of training gain. Because training gain is so closely related to baseline UFOV performance, we wanted to examine the contributions of more traditional measures of speed of processing and executive function independently. We entered these on the first step, the visual memory factor on the second step, and demographic variables (age, gender, education) on the last step. Results indicated that the speed of processing/executive function factor accounted for 2% of the variance in training gain ($p < .001$), and UFOV performance in particular accounted for an additional 28% of the variance in training gain (ps $< .001$). Visual memory and demographic measures did not account for variance in training gain (ps $> .05$).

What Are the Mechanisms of Speed of Processing Training?

In order to further address how participants were improving with training, and specifically what was improving, we examined training-level data available from two of the studies (SKILL, ACTIVE) in detail. Questions of interest included: Is improvement in speed of processing equivalent across tasks? and, Which task components improve? We calculated percentages of

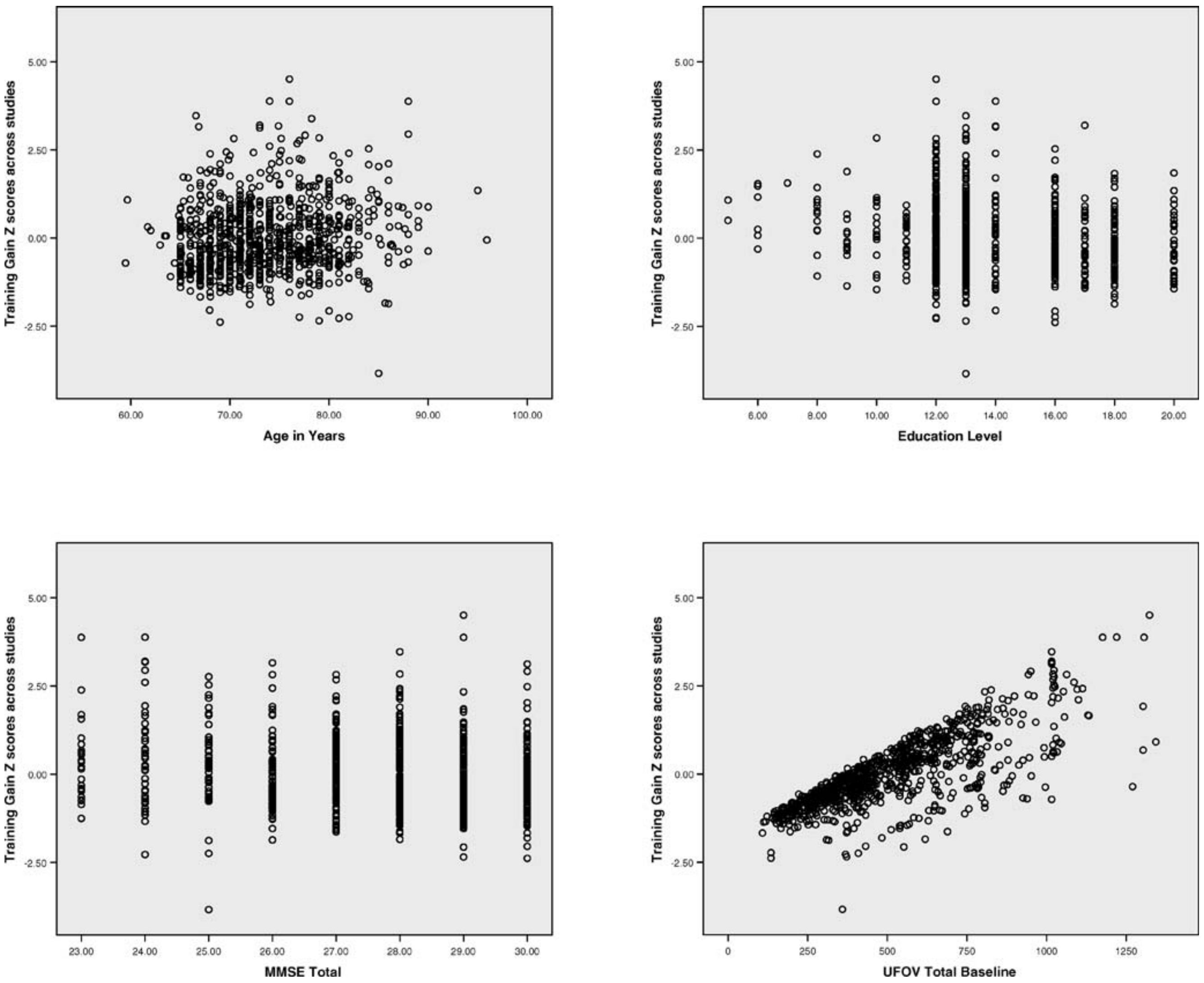

Figure 1. Relationship between training gain and age, education, mental status, and Useful Field of View (UFOV®; Visual Awareness Inc., Birmingham, AL).

total number of blocks spent on each training trial using participants from the SKILL study, in which trainers customized training per the needs of each individual. Overall, participants spent 14.7% of their training time on Task 2 and 85.0% on the more demanding Task 3. However, when we subdivided the group into impaired and nonimpaired participants according to their baseline UFOV scores (Task 2 $\geq$ 150 ms classified as impaired), we found that impaired participants spent approximately 21.3% of their time on Task 2 and 78.2% of their time on Task 3. We found that nonimpaired participants spent the majority (93.5%) of their total 5-week training time on the more complex Task 3 and only 6.4% of their time on Task 2. Sixty percent of the trained participants reached the highest speed of processing criterion goal of simultaneous central target identification, peripheral target localization in the presence of distractors at a display speed of 120 ms after 10 sessions of training.

In addition to baseline and posttest assessments, ACTIVE researchers gave UFOV assessments on Day 5 and Day 10 of training to quantify training gain. We utilized a 3 (UFOV subtests) × 4 (Time) repeated measures multivariate analysis of variance to examine the change in speed of processing performance across training. Results revealed a significant main effect of time, Wilks's $\Lambda = .275$, $F(3, 375) = 697.79$, $p < .001$, and further univariate analyses indicated significant improvement on each of the three subtests across training ($ps < .001$). We replicated these findings of significant improvement over time, Wilks' $\Lambda = .352$, $F(9, 733) = 43.60$, $p < .001$, and for all three UFOV tasks ($ps < .003$) using the training data from SKILL across Days 1 and 10 of training.

In order to address the question of whether there were differential training trajectories for persons with faster initial processing speeds, we subdivided the ACTIVE sample into a processing speed impaired group and a nonimpaired group. A 2 (Impairment group) × 3 (UFOV subtests) × 4 (Time) repeated measures multivariate analysis of variance compared the impaired and nonimpaired groups' UFOV performance across time. Results indicated a significant main effect of impairment,

Table 2. Correlations Among Training Gain, UFOV, and Cognitive Measures and Test–Retest Reliability Correlations for Controls Among UFOV and Other Measures

Measure		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 Training gain[a]		1														
	n	1,769														
2 UFOV total[a]		.522**	.767[b]**													
	n	1,769	867													
3 UFOV Subtest 1[a]		.271**	.531**	.529[b,c]**												
	n	1,769	1,924	903												
4 UFOV Subtest 2[a]		.461**	.865**	.425**	.655[b]**											
	n	1,769	1,924	1,931	872											
5 UFOV Subtest 3[a]		.436**	.850**	.254**	.508**	.716[b]**										
	n	1,769	1,924	1,924	1,924	867										
6 Pattern Comparison		−.170**	−.511**	−.285**	−.410**	−.453**	.825[b]**									
	n	300	324	324	324	324	150									
7 Letter Comparison		−.180**	−.450**	−.286**	−.383**	−.362**	.732**	.833[b]**								
	n	299	323	323	323	323	322	149								
8 Digit Symbol Substitution		−.153**	−.519**	−.253**	−.454**	−.453**	.713*	.696**	.889[b]**							
	n	1,547	1,701	1,715	1,708	1,701	324	323	151							
9 Trails B[a]		.100*	.426**	.262**	.371**	.300**	−.525**	−.460**	−.595**	.780[b]**						
	n	512	535	535	535	535	318	317	319	246						
10 Rey-O Immediate Memory		.068	−.151*	−.221**	−.263**	.051	.310**	.343**	.386**	−.327**	.787[b]**					
	n	221	227	227	227	227	97	97	97	227	109					
11 Benton Visual Retention		−.092	−.427**	−.245**	−.425**	−.262**	.473**	.529**	.562**	−.499**	.480**	.600[b]**				
	n	306	312	312	312	312	95	95	95	310	225	146				
12 Stroop[a]		.100	.397**	.178**	.365**	.311**	−.431	−.323**	−.477**	.393**	−.146	−.404**	.715[b]*			
	n	282	302	302	89	302	301	300	302	298	89	88	140			
13 Digit Symbol Copy[a]		.211**	.466**	.324**	.388**	.374**	−.581**	−.588**	−.709**	.488**	−.292**	−.445**	.422**	.881[b]**		
	n	300	324	324	324	324	323	322	324	318	97	95	89	47		
14 Road Sign Test[a]		.092**	.400**	−.009	.390**	.289**	−.434**	−.438**	−.396**	.440**	−.268**	−.388**	.231*	.402**	.993[b]	
	n	1,755	1,907	2,014	1,913	1,907	324	323	1,698	534	227	311	89	324	900	
15 Pelli-Robson Contrast Sensitivity		−.009	−.227**	−.112*	−.197**	−.146**	.236**	.245**	.200**	−.105*	.052	.056	−.130	−.138*	.073	1
	n	427	446	516	446	446	227	226	228	438	130	217	213	227	515	516

Notes: UFOV® = Useful Field of View test (Visual Awareness, Inc., Birmingham, AL).

[a] Smaller score reflects better performance.

[b] Observed test–retest correlations for control groups (no-contact and social-contact) only.

[c] Corrected for truncation.

**p* < .05 (two-tailed); ***p* < .01 (two-tailed).

Wilks's $\Lambda = .588$, $F(3, 374) = 87.46$, $p < .001$; time, Wilks's $\Lambda = .181$, $F(9, 368) = 185.62$, $p < .001$; and a significant interaction, Wilks's $\Lambda = .378$, $F(9, 368) = 67.18$, $p < .001$. Figure 2 depicts the change in mean scores discussed for the larger ACTIVE speed of processing trained group (Figure 2A), the nonimpaired trained subgroup (Figure 2B), and the impaired trained subgroup (Figure 2C). Although both the impaired and nonimpaired groups became faster after training across the tasks, participants with initial speed of processing impairments experienced the largest improvements across time for all UFOV subtests.

DISCUSSION

Using a common error term across studies, we found the weakest training effect sizes in the ACTIVE, UAB, and Home-Based Training studies. Common to the training methodology of these three studies was the use of standardized training tasks in at least half of the training sessions. However, all of the other studies we examined used training customized to the ability level of the participant, and this mode of training produced the largest training gains. Additionally, the ACTIVE and UAB studies, which had the smallest training effect sizes, included older adults with a range of speed of processing ability, thus limiting immediate training gain by ceiling effects in a subset of the participants. The training studies with the strongest effect sizes differed from the others in that they recruited for training only participants with relatively poor performance at baseline, indicating that those who were experiencing cognitive slowing were likely to receive the greatest immediate benefit from speed

Table 3. Factor Loadings for Cognitive Measures

Measure	Factor 1	Factor 2
1 Useful Field of View Test*	−.684	.177
2 Digit Symbol Substitution	−.775	−.404
3 Digit Symbol Copy	−.661	.377
4 Letter Comparison	−.739	−.337
5 Pattern Comparison	−.780	−.311
6 Stroop	−546	.210
7 Trails B	−.548	.491
8 Road Sign Test	−.314	.635
9 Rey-O Immediate Memory	.209	−.590
10 Benton Visual Retention	.479	−.599
11 Pelli-Robson Contrast Sensitivity	.639	.572

Notes: Factor 1 loadings include measures 1–7.

Factor 2 loadings include measures 8–10.

Pelli-Robson contrast sensitivity loads on both factors.

*Useful Field of View Test is a registered trademark of Visual Awareness, Inc., Birmingham, AL.

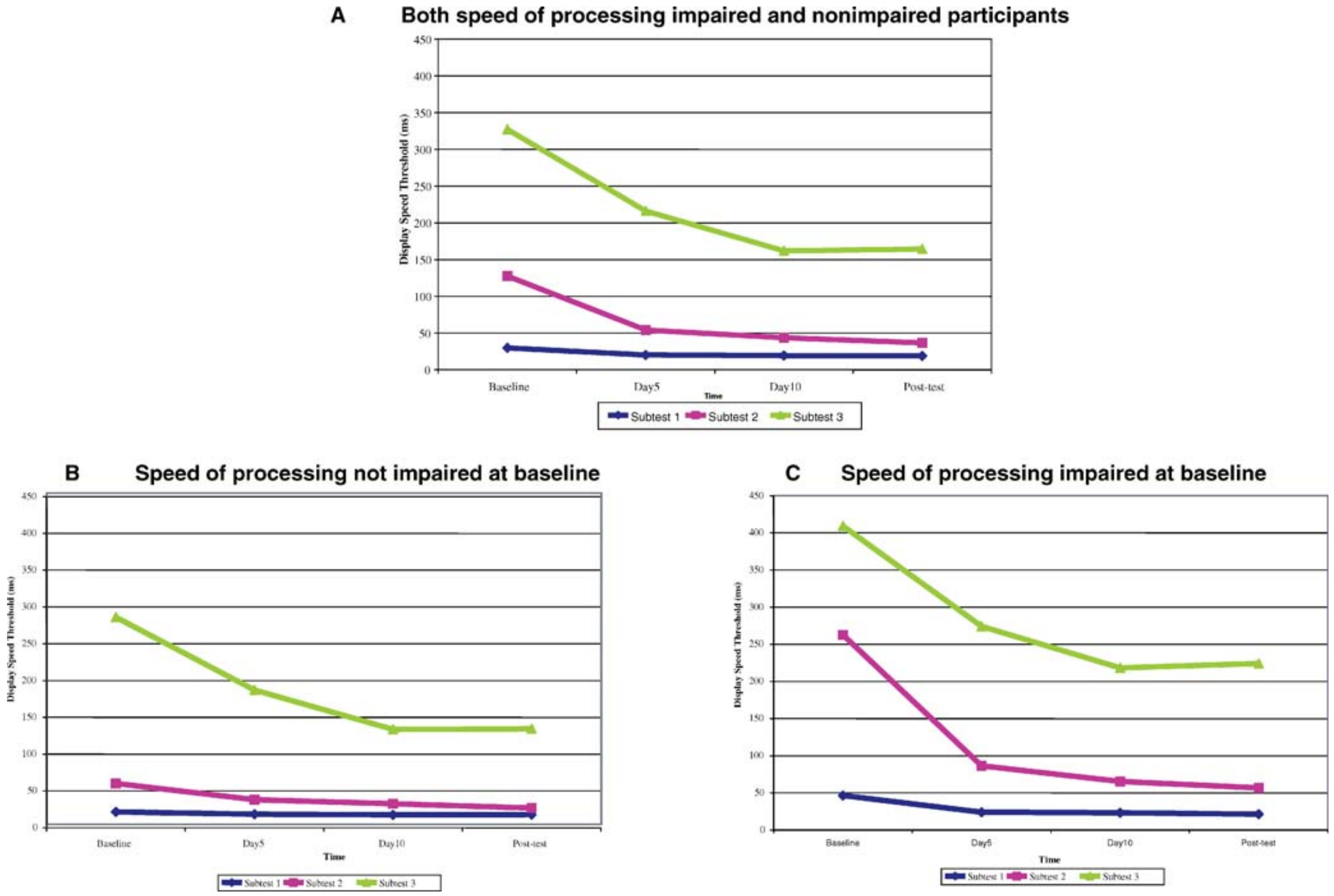

Figure 2. Useful Field of View (UFOV®; Visual Awareness Inc., Birmingham, AL) performance for subtests 1 to 3 (75% display speed threshold in ms) before, during, and after speed of processing training in ACTIVE (Advanced Cognitive Training for Independent and Vital Elderly) study sample. (**A**) Both speed of processing impaired and nonimpaired participants; (**B**) speed of processing not impaired at baseline; (**C**) speed of processing impaired at baseline.

of processing training. The Driving study observed the largest effect size. In this study, each trainee continued training until they reached a criterion level of ability, whereas the other studies administered a specified number of training sessions.

Does This Intervention Train Speed of Processing?

A common question resulting from the studies summarized in this article is, How are we certain that speed of processing is the skill being trained? Because the training technique is most similar to the UFOV test and consistently transfers to improved performance on the test, examining performance on this measure (as well as on other outcome measures to which training transfers) is the best way available to date of addressing the question of what is being trained. We designed our protocol for speed of processing training based on the UFOV concept developed and described by Ball and colleagues (Ball et al., 1988; Ball et al., 1990). There have been several versions of the UFOV over time (Edwards, Vance, et al., 2005). Originally, the test provided a measure of the extent of the visual area from which one can extract information in a single glance without eye or head movements (also referred to as the *functional field of view*). However, research indicated that the test was tapping primarily cognitive ability rather than visual function or visual fields (Owsley, Ball, & Keeton, 1995). Therefore, researchers changed the metric of the UFOV test circa 1995 (Edwards, Vance, et al., 2005) such that the test now measures threshold speed at which an individual can process visual displays of varying complexity rather than the extent of information that the individual can process. Experts have adapted this new version of the test for administration on a personal computer; the test no longer utilizes a chin rest, it includes display durations greater than 250 ms (such that eye movements can at least be initiated), and it does not vary the distance of peripheral targets from the central target (using only the farthest eccentricity). This version of the test equivalently predicts subsequent crash involvement among older drivers (Ball et al., 2006).

Results indicated that training gain is significantly related to baseline speed of processing and psychomotor speed measures; however, it is not related to visual sensory or visual memory, and it is only very weakly related to one of the executive function measures. UFOV performance loaded on a single factor with traditional speed of processing and psychomotor speed measures. Executive function measures also loaded on the same factor. These findings indicate that cognitive speed of processing measures also require executive function. UFOV performance across all subtests was consistently related to traditional speed of processing measures such as Pattern Comparison and Wechsler Adult Intelligence Scale–Revised Digit Symbol Substitution and psychomotor speed. At the same time, Subtest 2 of the UFOV in particular correlated with visual memory and executive function measures. Of course, there is no pure measure of speed of processing, and the UFOV assessment is no exception. The UFOV test and the related training protocol obviously involve a number of higher order cognitive skills, including executive function and memory. Even so, the present results indicate that speed of processing is a primary component of the training protocol. Training gain is most strongly correlated with speed of processing and psychomotor speed measures, initial UFOV performance in particular.

Looking at studies with training programs designed to boost athletic performance, a literature review by Williams and Ward (2003) indicated that attempts to improve visual function and basic perceptual abilities (such as processing speed) do not result in performance improvements. Although sports training has not shown that speed or perceptual training improves performance, it has been done with young athletes who haven't experienced cognitive decline (Williams & Ward, 2003). Similarly, our work shows that if older adults do not have speed of processing difficulties, they will not see immediate performance improvements from training. The results of these analyses indicate that speed of processing training works with older adults, particularly when they are already having difficulties with this specific ability.

Interestingly, although persons who were impaired (e.g., who had slower processing speed at baseline) typically spent more time training on Task 2 as compared to the nonimpaired group, their Task 3 performance also improved. This provides evidence that the training tasks, although varying in complexity, all involve speed of processing. In addition, those participants who were not impaired at baseline showed similar slopes of increasing speed of processing on Task 3 as the impaired group. Thus, although this training is especially beneficial to persons with initial processing speed impairment, the more challenging tasks also allow for improvements and training within a higher functioning group.

Studies of other cognitive training techniques have found similar results. For example, Schaie and Willis (1986) found that spatial orientation and inductive reasoning could be improved through training, with those who had more initial decline receiving a greater benefit. De Vreese, Belloi, Iacona, Finelli, and Neri (1998) found that older adults with objective memory loss benefited more from memory training than did older adults with subjective complaints but no measurable memory loss. In a study of multifactorial memory training, researchers found that only baseline memory measures predicted posttest scores of trainees. Mental status, education, and age were not related to benefit from training (Neely & Bäckman, 1995; Stigsdotter & Backman, 1989). It appears that those with more room for improvement benefit most, but longer longitudinal follow-up may be needed to evaluate the impact of training on less impaired individuals relative to untrained control participants, as in the ACTIVE study.

The fact that education is not correlated with, or predictive of, training gain further demonstrates that speed of processing training enhances a basic, fluid, cognitive ability. Overall it seems that the benefit from cognitive training is not dependent primarily upon demographic variables such as age or education. The finding of education as not predictive of training is consistent with some cognitive aging literature on fluid abilities, such as processing speed. Anstey and Christensen (2000) reviewed 34 studies investigating predictors of cognitive change and found that, although some results were inconsistent, education was not predictive of cognitive change in fluid abilities. Such findings support early work and theory of fluid versus crystallized cognitive abilities by Horn and Cattell (1967) and P. B. Baltes (1987). However, although (as discussed in the cognitive reserve literature) researchers usually consider education to help boost reserve and prolong cognition (Stern, 2002), it is also possible that education was not a significant predictor of training due to the low variability within our sample (90% had completed high school or higher). This may have reduced the power available to detect a significant education effect.

Researchers have found that cognitive training is effective even in persons of advanced age, indicating that human brains continue to have substantial plasticity (Kramer & Willis, 2002; 2003). Such plasticity may explain why age does not appear to have a significant negative impact on processing speed training. This is especially true given that the training using the speed of processing protocol is very flexible and can be tailored to the individual needs of the participant, thus allowing for every individual, regardless of age or ability, to advance through the program. In addition, other research has noted very little difference in learning and skill rates between young and older adults (see Kramer & Willis, 2003, for review), particularly with search skills (Ho & Scialfa, 2002). Thus, in agreement with previous research (Ho & Scialfa, 2002; Kramer & Willis, 2002, 2003), our findings indicate that age does not appear to have a strong impact on speed of processing training.

Does Improvement in Processing Speed Transfer to Everyday Abilities?

Several of the studies summarized in Table 1 (including the UAB Training, SKILL, Driving, and ACTIVE studies) also assessed the extent to which speed of processing training transfers to improved everyday abilities. We discuss the results of these studies in order to further examine whether training translates to everyday performance.

The Driving study included as the primary outcome of interest performance on an on-the-road driving test. The driving evaluation course consisted of two loops of a 7-mile urban/suburban route with a certified driving instructor in the front seat and two evaluators in the back seat. Keeping in mind situations recognized in the literature as particularly difficult for older drivers (e.g., left-hand turns across oncoming traffic; Odenheimer et al., 1994), evaluators considered certain locations in the drive to constitute places of potential danger. For each of these locations, evaluators recorded the extent to which the driver's behavior constituted a dangerous maneuver (defined as one that either required the driving instructor to take control of the car or required other vehicles to alter their courses in order to avoid a collision).

At baseline, older adults with initially poorer performance on the UFOV test made significantly more dangerous maneuvers

($M = 1.01$) than did the reference group of older adults with good UFOV test performance ($M = 0.65$). However, at immediate posttest, all three groups were equivalent in the number of dangerous maneuvers exhibited on the drive, indicating a significant reduction in the number of dangerous maneuvers for both the speed of processing trained group as well as the driving simulator trained group. Interestingly, at the 18-month assessment, both the reference group and simulator-trained group made more than one dangerous maneuver, on average, during the 14-mile drive, whereas the speed of processing trained individuals performed less than one dangerous maneuver, on average (Roenker et al., 2003).

In order to further evaluate transfer of speed of processing training to everyday abilities, researchers have used several different outcome measures. One way of evaluating everyday function involves a measure of complex reaction time known as the Road Sign Test (Ball et al., 2002; Edwards et al., 2002; Roenker et al., 2003). Scientists have used this measure in a driving simulator (Roenker et al., 2003) and have adapted it as a computerized measure of everyday speed (used in the UAB, SKILL, and ACTIVE studies). In both versions of the Road Sign Test, participants view road signs (pedestrian, bicycle, right and left turn arrows) with and without a red slash. Testers instruct participants to disregard signs with a red slash (distractors) and to respond as quickly as possible, using a computer mouse, to signs without a slash (targets). In the computerized version of the test, required reactions are moving the mouse to the left (in response to a left turn sign) or right (in response to a right turn sign) and clicking a button on the mouse (in response to a bicycle sign or pedestrian sign). Prior to the test trials, all participants practice clicking and moving the mouse until they demonstrate proficiency. In the driving simulator version of the test, participants react to turn signal signs by turning the steering wheel in the proper direction and react to bicycle or pedestrian signs by pressing the brake pedal. This measure includes two conditions in which either 3 or 6 signs are displayed on the screen at a time, and each condition includes 12 trials. Stimuli remain on the display until the participant gives a correct response. Researchers calculated the average reaction time across all trials.

Researchers found that speed of processing training transferred to enhanced Road Sign Test performance as administered in a driving simulator (Roenker et al., 2003). Individuals who underwent speed of processing training showed quicker reaction times (about 277 ms faster, on average) for Road Sign Test performance at immediate posttest relative to their baseline performance, and this improvement was maintained for at least 18 months. For a vehicle moving at 55 miles per hour, this improvement of 277 ms translates into a 22-ft shorter stopping distance (Roenker et al., 2003). Interestingly, when researchers administered the Road Sign Test via computer and required reactions with a mouse, transfer of speed of processing training was not immediately evident in the SKILL and UAB studies (Edwards et al., 2002; Edwards, Wadley, et al., 2005). However, these studies also had smaller effect sizes for the primary training outcome, UFOV.

Another measure of everyday speed is the Timed Instrumental Activities of Daily Living test (TIADL; Owsley et al., 2002). The TIADL involves laboratory measurement of five timed tasks that simulate everyday instrumental activities of daily living. Like the Road Sign Test, the TIADL is referred to in the ACTIVE study as an everyday speed measure (Ball et al., 2002). Tasks include finding a telephone number of a specific individual in the telephone directory, finding and correctly counting out 37 cents from a group of coins, finding and reading the ingredients on a food can label, finding two food items in an array of food items simulating a crowded pantry shelf, and finding and reading the directions on a medicine container. Evaluators record time in seconds required to complete each task. If the participant does not complete the task within the preset time limit, testing for that particular task discontinues. Researchers add a penalty to completion time for the tasks completed with minor errors. Researchers then transform the times for each of the tasks into Z scores, which they then equally weight to form a composite.

The SKILL and UAB studies found transfer of speed of processing training to improved performance on the TIADL test (see Table 1). Participants who underwent speed of processing training completed the TIADL tasks more efficiently (quickly) and more accurately as compared to controls. Transfer effects were greater in Studies 2 and 3, in which cognitive speed training effects were also greater.

In the ACTIVE clinical trial, performance on both the Road Sign Test and the TIADL test made up the Everyday Speed Composite. In the ACTIVE study, however, researchers did not find transfer in the primary analysis at 24 months, other than for those participants who received speed booster training prior to first annual follow-up. This could be due, in part, to the "intent-to-treat" approach to analyses in the study. However, these results are most likely due to the fact that many individuals were performing at or near ceiling on these everyday measures at enrollment, and thus longer follow-up was needed to evaluate the decline rates for both the speed-trained and control participants over time.

In the ACTIVE study, as compared to controls, speed of processing trained participants were less likely to have extensive health-related quality of life decline defined as clinically relevant drops (i.e., ≥ 0.5 *SD*) on four or more of the eight Short-Form 36 scales between baseline and the 24-month follow-up (adjusted odds ratio = 0.643). Thus, although all three training groups (speed, memory, and reasoning) improved in cognitive ability, only speed of processing training protected against extensive, clinically relevant decline in health-related quality of life at 24 months. These results are consistent with the idea that cognitive training can prevent decline in that trained participants were less likely, or at least slower, to experience decline relative to the control groups (Wolinsky et al., 2006).

With regard to whether speed of processing training prevents, postpones, or reverses cognitive decline, the answer appears to depend on the baseline ability level. Wolinsky and colleagues' (2006) results indicate that training can prevent, or at least postpone, decline in health-related quality of life among older adults who are not having speed of processing difficulties at baseline. Examining the results of studies with individuals performing poorly on the UFOV test at baseline, we found immediate improvements in both UFOV and measures of everyday performance, suggesting that in such instances speed of processing can be immediately improved (reversing decline at least temporarily). In order to truly determine whether initial speed of processing difficulties are a result of decline or whether training truly prevents, postpones, or reverses decline, further longitudinal research is needed.

How Long Do Training Effects Endure When They Occur?

Of the studies summarized in Table 1, the Driving and ACTIVE studies evaluated durability of training. In the Driving study, participants maintained significant training effects over 18 months for both the composite measure of speed of processing as well as performance on the Road Sign Test, and driving outcome measures. For ACTIVE, training effects were durable to at least 2 years. Longitudinal follow-up assessments for ACTIVE and the SKILL study will examine the extent to which training endures over a 3- to 5-year period.

What Are the Real World Applications for Such Training?

As mentioned previously, speed of processing is one of the first cognitive abilities to show decline. This decline impacts the performance of functional abilities vital for maintaining independence with advancing age. As summarized in this article, training can immediately improve speed of processing for many older adults. Research has shown such training to result in enhanced performance of everyday activities necessary for sustained independence. Thus, there are obvious practical applications for speed of processing training. A problem that remains is how to distribute such training to the older population?

Researchers conducted the final study listed in Table 1, Home-Based Training, in order to address this question. This study reflects an attempt to determine if speed of processing training can realistically be done at home using videocassette recorder technology. Preliminary results indicated that individuals in both the home-based and laboratory-based speed of processing training protocols showed significant improvement in processing speed ($p < .05$), whereas those in the social-contact control and no-contact control groups did not. Home-based training was approximately 80% as effective as computer-based training. The finding that home-based, self-administered videotape training improved processing speed significantly, and at a level only modestly below that achieved with lab-based, trainer-administered computer training, has important implications, because this program has the potential to make training benefits more widely accessible to the general public. Subsequent analyses of this self-administered training protocol will examine the impact of home-based training on other cognitive and everyday tasks and on driving performance.

Future research should explore the benefits of cognitive training for individuals with mild cognitive impairment, a population at high risk for developing dementia and functional declines that threaten independence. Currently, scientists are examining pharmacological interventions, some of which have met with limited success in dementia patients, in clinical trials among individuals with mild cognitive impairment, in hopes that earlier introduction of these agents can prevent or delay progression of cognitive decline and subsequent dementia diagnoses. Evidence warrants the simultaneous exploration of the potential of a cognitive intervention such as speed of processing training in this population as well. Indeed, several of the studies included in this review included individuals with probable mild cognitive impairment, and the studies did not find that marginal mental status impacted training gain. Thus, training in this population in particular might immediately improve cognitive abilities and may also help to maintain functional abilities, such as driving. In the future, cognitive training protocols might provide a much-needed alternative to pharmacological interventions for those individuals with mild cognitive impairment who cannot tolerate or fail to comply with medicines due to adverse effects. Furthermore, researchers can test this low-risk training protocol in combination with pharmacological interventions with individuals who respond favorably to experimental medications in order to examine incremental gains in treatment efficacy.

Summary

What the current literature does not provide is a clear understanding of what "dose" of speed of processing training participants require to experience a benefit. Experts have not yet established the durability of benefit from speed of processing training beyond 2 years, but evidence indicates that booster-training sessions improve performance over and above that of participants who receive training without booster sessions (Ball et al., 2002). Although older adults with initial speed of processing difficulties seem to benefit the most at the outset, it is still unclear whether individuals without such initial difficulties may also benefit longitudinally. It is not clear from existing data if such participants have experienced cognitive decline or whether they have throughout their lives performed more poorly on speeded tasks. Therefore, the ideal time to initiate speed of processing training is unknown. Although evidence from these analyses indicates that training enhances speed of processing ability, it is still unclear whether training may also result in an alteration of the organization of other cognitive abilities, and, if so, which abilities. Future research should address such questions.

The field needs more studies such as ACTIVE, which include large numbers of participants, long-term follow-up, and examination of the impact of training on daily functioning of participants. Longitudinal studies provide a wealth of information not available in more common pretraining to posttraining evaluations. In addition, the field needs more studies of combined approaches to cognitive improvement. If these approaches provide additive effects, combining cognitive training techniques with exercise, nutritional supplements, or drug therapy could amplify the benefits of existing cognitive training programs for older adults.

Overall, most of the cognitive training literature points to the ability of older adults to benefit from training. Researchers have evaluated and found varied methods of improving cognitive function in older adults to be effective. From one-on-one tutoring, to group training on strategies for problem solving or memory enhancement, to simply providing basic performance feedback or extended practice time, older adults seem to be able to benefit from many approaches to improve their basic cognitive abilities. Although the various techniques have divergent records of accomplishment when it comes to demonstrating transfer to additional cognitive abilities or durability of gains, they all point to the amazing plasticity that older adults retain. A decline in cognitive functioning (in the absence of disease) need not immediately be considered irreversible or even inevitable. Research shows that the speed of processing declines that commonly occur with age respond to training intervention. Speed of processing training in particular has great potential to positively impact everyday functioning among older adults.

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