WHO BENEFITS FROM COMPUTER TRAINING OF COGNITIVE ABILITIES?

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***Abstract*— The IMPACT Study was a multi-site double-blind randomized trial evaluating the efficacy of a brain-plasticity-based cognitive training program in adults aged 65-93 with normal cognition (MMSE ≥ 26). Predefined endpoints included standardized neuropsychological assessments of memory and attention. Study results demonstrated improvements not only on the tasks trained, but also on auditory recall and working memory tasks. Although there were gains on average, it is important to know whether individual differences characteristics affect relative improvements in performance. We used linear modeling to examine performance on the endpoints as a function of main effects of age, gender, education, estimated intelligence, audiometric function, presence of tinnitus, and vision correction; and the interaction of these covariates with the training effect. We found main effects of age, with older adults gaining less, regardless of the intervention (p's < .01). None of the interactions were significant (all p's>.21), suggesting the brain plasticity program may be useful for individuals with a wide range of characteristics.**

I. Introduction

Normal age-related cognitive declines can noticeably affect performance in everyday situations[1]-[2], and perceptions of forgetfulness are associated with depression and anxiety[3]-[5]. The development of effective training interventions thus has the potential to improve the quality of life and health of older adults.

There is now a large accumulated body of evidence showing that the brain retains plasticity in old age, and that training can improve cognitive functions subject to age-related declines including episodic and working memory, attention, speed of processing, and reasoning[6]-[23].

Currently the two dominant approaches for cognitive training are based on mnemonic strategies and general recommendations for non-specific cognitive stimulation.

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While mnemonic strategies have been shown to be effective, the improvements generally do not generalize to untrained memory tasks, little is known about the durability of training gains, and it is unclear whether older adults continue to use learned strategies over time[1],[24]-[25]. Meanwhile, researchers investigating the cognitive stimulation hypothesis have been hampered by difficulties establishing the causal relationship between cognitive stimulation and cognitive performance[26].

Age and cognitive ability have been identified as characteristics that affect training benefits in studies where individual differences have been assessed. Different patterns emerge depending on whether memory or speeded performance is trained. While adults can benefit from either, the oldest old appear to gain less in memory training studies[18], [22] and comparatively more on speeded tasks[7]-[8],[15] relative to young adults and to younger elderly individuals. Cognitive ability is associated with training benefit independent of age and appears to follow the memory/speed distinction. That is, those with more cognitive resources gain more in memory training[18]-[20], and those with less resources gain more in speeded task training[7],[15],[19]. Thus, what is trained appears to be important in determining whether those with greater or less ability will benefit more.

We recently presented results from the IMPACT (Improvement in Memory with Plasticity-based Adaptive Cognitive Training) study[27]-[29]. The study was a multi-site double-blind randomized trial evaluating the efficacy of a novel approach based on principles of brain plasticity that has shown promise in initial smaller-scale studies[30]. The training program tested (Brain Fitness Program, Posit Science) targets auditory sensory functioning as a causal mechanism underlying cognitive performance. It is hypothesized that sensory system functioning improvements accomplished through intensive learning and practice could potentially result in cognitive performance gains in older adults[31].

The primary objective of the IMPACT study was to evaluate whether participants receiving the experimental treatment (ET) program improved on untrained measures of memory and attention relative to an active control (AC) cognitive training program. A secondary objective was to examine the extent of generalization across a spectrum of measures ranging from those very similar to those very distinct from the training exercises.

Study results demonstrated that intensive practice with the exercises by the ET group led to better performance on directly-trained tasks, and robust transfer of training effects to multiple untrained standardized measures of memory and attention suggested meaningful generalized gain.

While there were gains on average as a consequence of training in the IMPACT Study, we now report an analysis of whether individual differences characteristics affected relative improvements in performance, a question that has practical implications for determining who is most likely to benefit from the training.

II. METHODS

A. Design

Multi-site randomized controlled double-blind trial.

B. Participants

The sample consisted of older adults residing in Northern and Southern California and Minnesota. Inclusion criteria were age (≥ 65), Mini-Mental Status Examination (MMSE[32]) ≥26, English fluency, and ability to make time commitment. Exclusion criteria were major neurological/psychiatric illness history; history of stroke, transient ischemic attack, or traumatic brain injury; acetylcholinesterase inhibitor use; current substance abuse; significant communicative impairments; and concurrent enrollment in other studies. Recruitment used advertisements, flyers, direct mail, and presentations.

C. Procedures

The training intervention was self-administered by participants at home. No reimbursement was offered, however required computer equipment was provided until completion of training. Participants completed 40 hours of training (60 minutes/day, 5 days/week, 8 weeks).

Participants were given sequential study identification numbers and randomly assigned into an age-stratified (20% 65-69 years old; 40% 70-79; 40% 80+) treatment group. A random sequence of ET/AC assignments within each age stratum was generated before study commencement. Sites requested randomization allocation via e-mail; requests were fulfilled via concealed randomization allocation sequence administered by a single staff member.

Unblinded trainers assigned to each ET/AC participant installed the computers and contacted them at least weekly to resolve technical problems and record adverse events. Participants and clinicians administering and scoring outcome measures were blinded.

D. Experimental Treatment: Brain-Plasticity-Based Cognitive Training

The ET program consisted of 6 computerized auditory exercises specifically designed to improve speed and accuracy of information processing in the auditory system. Each exercise is continuously adaptive, adjusting difficulty to participant performance to maintain an ~85% correct rate. Correct trials are rewarded with points and animations. In aggregate, exercises contain stimulus sets that span the acoustic organization of speech, ranging from frequency-modulated sweeps to continuous sentences. Initially, all speech and non-speech stimuli are processed to stretch and emphasize rapid transitions; over the course of training these manipulations are gradually removed such that participants work with stimuli with characteristics of rapid speech. A schedule of 60 minutes/day, 5 days/week, 8 weeks is recommended in the program manual.

E. Active Control: Educational Experience Cognitive Training

The AC training was required to have high face validity; be consistent with common physician recommendations for cognitive stimulation; and match the ET for daily and total training time, interesting audiovisual content, and computer use. Thus the AC cognitive training program employed a learning-based memory training approach in which participants used computers to view DVD-based educational programs on history, art and literature. Following each hour of training, participants answered written quizzes to ensure attention and learning from training program content.

F. Measures

Basic demographics (age, education, sex, ethnicity, first language), cognitive status (MMSE, estimated IQ [Wechsler Test of Adult Reading][33]), depression (Geriatric Depression Score [GDS 15][34]), and sensory functions (audiometric function, tinnitus, hearing aid or eye glass use) were measured at pre-training visits.

The primary outcome measure (RBANS[35] Auditory Memory/Attention) was calculated from 6 RBANS sub-tests of memory and attention that use orally presented speech stimuli (list learning, story memory, digit span forward, delayed free list recall, delayed list recognition, delayed free story recall).

Standardized neuropsychological measures evaluating generalization of training effect included the Rey Auditory Verbal Learning Test (RAVLT[36]) total score (sum of trials 1-5) and word list delayed recall; the Rivermead Behavioral Memory Test (RBMT[37]) immediate and delayed recall; and the Wechsler Memory Scale (WMS-III[38]) letter-number sequencing (LNS) and digit span backwards tests. All measures were collected at pre- and post-training visits. Alternate forms of the RBANS, RAVLT, and RBMT were used to reduce re-test effects within participants and were counterbalanced.

An overall memory composite score (Overall Memory) was derived by combining RAVLT total score and word list delayed recall, RBMT immediate and delayed recall, and WMS-III LNS and digits backwards.

G. Analysis

Individual linear mixed effects models were fit to examine performance on the primary and secondary composite outcome measures (RBANS Auditory Memory/Attention; Overall Memory) as a function of main effects of age, gender, education, estimated intelligence, audiometric function, presence of tinnitus, and vision correction; and the interaction of these covariates with the training effect.

Statistical analyses were performed using SAS version 9.0 (SAS Institute Inc., Cary, NC) and SPSS version 16 (SPSS Inc., Chicago, IL), and conducted by an independent data management contractor.

III. RESULTS

The Intent-to-Treat (ITT) sample consisted of 487 participants (ET n=242; AC n=245) who completed at least one training session. Overall, participants were mean age 75.3 years, most were Caucasian (94.7%) and female

(52.4%)(Table I). About 17% of the sample used a hearing aide, and more than 9 in 10 wore glasses (94.3%). The only significant pre-training difference between the ET and AC groups was gender (ET=42.1% male; AC=53.1% male, p=0.02).

Table I. Demographic, Cognitive and Sensory Characteristics at the Pre-Training Visit

Measures	N = 487
Demographic	
Age, years mean (SD)	75.3 (6.5)
Education, years mean (SD)	15.6 (2.6)
Male, number (%)	232 (47.6%)
Caucasian, number (%)	461 (94.7%)
First Language English, number (%)	478 (98.2%)
Cognitive	
MMSE, score mean (SD)	29.1 (1.1)
Estimated IQ, score mean (SD)	113.7 (8.1)
GDS-15, score mean (SD)	1.3 (1.7)
Hours Worked	12.1 (12.8)
Sensory	
Hearing Function, 500 Hz mean (SD)	26.5 (10.5)
Tinnitus, number (%)	98 (20.1%)
Hearing Aid, number (%)	81 (16.6%)
Glasses, number (%)	459 (94.3%)

T Tests were used for continuous variables and chi square tests for categorical variables. There were no significant differences between groups with the exception of gender, which was significantly different (p=0/002).

Training effects favored the ET program for both the primary (RBANS Auditory Memory/Attention) and secondary (Overall Memory) composite measures.

Gender was the only significant between-participant predictor (Table II). Gender had a main effect on the primary (RBANS Auditory Memory/Attention; F=14.617; p<0.001), but not on the secondary composite measure. Women had higher scores on RBANS Auditory Memory/Attention both at pre- and post-training than men.

Age was a significant within-participant predictor of pre- and post-training scores for both composite outcome measures (RBANS Auditory Memory/Attention; Wald Z=2.279, p<0.05) (Overall Memory; Wald Z=2.230, p<0.05), with older participants having lower performance pre- and post-training while still receiving an overall benefit.

Table II. Linear Mixed Effects Models for Primary Outcome Measure and Overall Memory

		Model 1[1]			Model 2[2]		
Outcome Measure	Fixed/Random Factors	Parameter Test[3]	Significance	Effect Size	Parameter Test[3]	Significance	Effect Size
RBANS Auditory Memory/Attention	Visit XTraining	4.818	0.029	0.27	5.634	0.018	0.23
	Gender	14.617	<0.001	0.45	12.735	<0.001	0.33
	Visit X Training X Gender	--	--	--	1.506	NS	0.12
	Age	2.279	0.023	--	2.293	0.022	--
Overall Memory	Visit XTraining	8.363	0.003	0.37	10.002	0.002	0.30
	Age	2.230	0.026	--	2.582	0.010	--

[1]Model 1 included fixed factors (gender, hearing aid, tinnitus, glasses) and random factors (age, education, estimated IQ, GDS, hours worked, audiometric function).
[2]Model 2 examined effects of fixed and random factors that were significant in Model 1. Where gender was significant in Model 1, a three-way interaction (visit X training X gender) was included.
[3]F Statistic reported for fixed factors, Wald Z reported for random factors.

None of the other random effects or interactions included in the models were significant.

IV. Discussion

The brain-plasticity-based training program studied, resulted in improvement on two composite measures of memory and attention (RBANS Auditory Memory/Attention; p=0.029, Cohen's *d*=.27*)(*Overall Memory; p=0.003, Cohen's *d*=.37). All training was conducted in compliance with the training manual.

Older individuals in the sample benefited from training, but performed lower both pre- and post- than their younger counterparts. This finding parallels previous research on individual differences in cognitive training[18].

No interactions were found between any of the covariates included in the models with the training effects, suggesting that the training program was equally effective across the sample characteristics examined, and that older adults with a wide range of characteristics may be able to benefit from the training.

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