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Do cognitive interventions alter the rate of age-related cognitive change?☆

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ABSTRACT

There has recently been a great deal of interest in cognitive interventions, particularly when applied in older adults with the goal of slowing or reversing age-related cognitive decline. Although seldom directly investigated, one of the fundamental questions concerning interventions is whether the intervention alters the rate of cognitive change, or affects the level of certain cognitive measures with no effect on the trajectory of change. This question was investigated with a very simple intervention consisting of the performance of three versions (treatment) or one version (control) of the relevant cognitive tests at an initial occasion. Participants were retested at intervals ranging from less than 1 to 12 years, which allowed rates of change to be examined in the control and treatment groups. Although the intervention can be considered modest, participants in the treatment group had about .25 standard deviations less negative cognitive change over an interval of approximately three years than those in the control group, which is comparable to effect sizes reported with more intensive interventions. However, there were no interactions of the intervention with length of the interval between occasions, and thus there was no evidence that the intervention affected the course of age-related cognitive decline.

1. Introduction

Many different types of interventions, ranging from training on specific tasks to engagement in stimulating activities, have been found to lead to higher levels of performance in cognitive tasks (e.g., see reviews in Gross et al., 2012; Hindin & Zelinski, 2012; Jak et al., 2013; Karr et al., 2014; Kelly et al., 2014; Kueider et al., 2012; Lampit et al., 2014; Martin et al., 2011; Noack et al., 2009; Papp et al., 2009; Reijnders et al. 2012). Although reviewers differ in their estimates of the magnitude of the intervention effects, there is a consensus that cognitive interventions can be effective in increasing the level of performance in the trained tasks.

A number of intervention studies have also investigated effects of the intervention on new measures of cognitive functioning. As noted in several of the reviews cited above, the pattern of findings with transfer tests has been mixed, with some reports of significant benefits of the intervention on new tests, and other reports of little or no benefits.

Although results with untrained tasks are informative about the generalizability of intervention outcomes, the most relevant evidence for evaluating whether interventions affected age-related change concerns the trajectory of change after an intervention. Possible outcomes after an intervention has produced increases in the level of cognitive performance are illustrated in Fig. 1. Note that the critical information for distinguishing among the alternatives is not the level of performance immediately after the intervention, or the level of performance at any particular interval after the intervention, but instead the relation between performance and time since the intervention. Only if the rate of change after the intervention differs from that before the intervention, or in the absence of the intervention, could one conclude that the intervention altered age-related cognitive decline.

Because of the considerable time and expense needed to monitor cognitive performance at different intervals after an intervention, only a limited number of studies have conducted follow-up assessments with intervals greater than a few years, which may be the minimum interval necessary to detect age-related cognitive decline. Moreover, the primary interest in these studies has been the persistence or maintenance of the intervention effect, corresponding to the difference between treatment and control conditions at a particular interval after the intervention, and not whether there is an effect on age-related decline, as reflected in the slope of the function relating cognitive change to time since the intervention.

One study with data relevant to effects on rates of cognitive change is the ACTIVE project, in which the interventions consisted of 10 60–75 min sessions of memory, reasoning, or speed training. A unique feature of this project was multiple follow-up assessments up to 10 years after the intervention. Results across all measurement occasions were recently summarized in Fig. 2 in Rebok et al. (2014). Although no statistical comparisons of the slopes were reported, the rate of decline between 3 and 10 years after the intervention appeared to be nearly the same in the three training groups and in the control group for all three outcome measures, i.e., memory, reasoning, and speed. There was therefore no indication in the graphical results that

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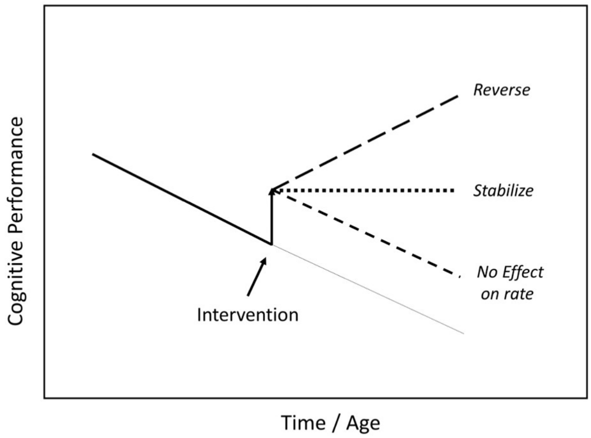

Fig. 1. Schematic illustration of possible outcomes on rate of cognitive change before and after an intervention found to increase level of cognitive performance.

the rate of change varied according to the presence, or nature, of the intervention.

A possible complication in interpreting the rate-of-change results of the ACTIVE study is that all of the participants received multiple assessments, and some received additional training, between the first and last assessment. This is a potential problem because the additional assessments and training could have altered the cognitive change trajectory. In fact, a recent study found that adults within this age range exhibited significant negative change when there was no intervening assessment between the first and last measurements, but the change was not significantly different from zero when an additional assessment occurred during the interval (Salthouse, 2014a). Repeated assessments can be a particular concern in the interpretation of intervention studies if the effects are primarily attributable to greater assessment-related performance gains in the treatment group than in the control group, with little or no influence of the intervention on fundamental processes of cognitive functioning.

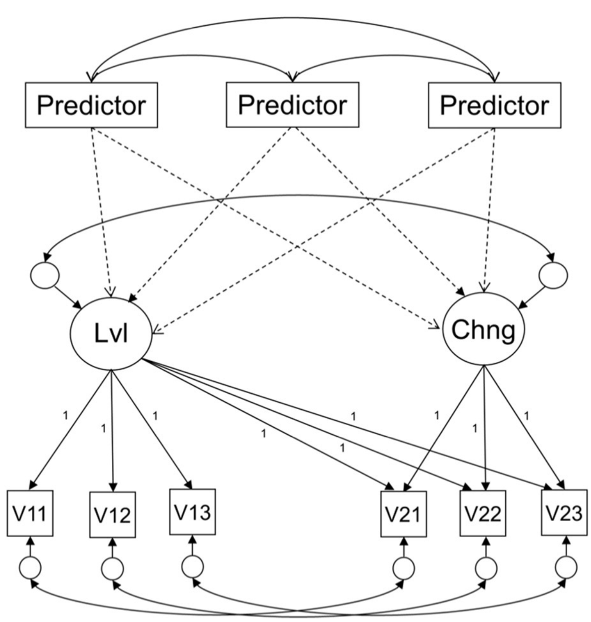

Fig. 2. Illustration of the latent change model used to assess cognitive change from the first to the second longitudinal occasion. The boxes correspond to the scores on the three tests assumed to represent each ability at the first (i.e., V1x) and second (i.e., V2x) occasions, and the circles correspond to the latent level (Lvl) and latent change (Chng) variables. Unlabeled circles represent residual variances.

Because there is no possibility of an influence of intervening assessments when everyone is only tested twice, one solution to the reactive measurement problem, in which the change trajectory may be distorted if participants are repeatedly assessed, is to rely on data from different individuals at each interval. Comparisons of this type were reported in a recent study in which participants returned for the second longitudinal occasion at variable intervals after the initial occasion (Salthouse, 2011). As one would expect, the change was progressively more negative as the interval between occasions increased.

Another article (Salthouse, 2013a) based on the same Virginia Cognitive Aging Project (VCAP) data set compared the longitudinal changes of participants who performed one version of the relevant tests at the initial occasion with the changes of participants who performed three versions of the tests. This additional experience can be considered an intervention, albeit modest compared to that in studies with more intensive training or engagement. Nevertheless, this simple practice intervention was effective in altering subsequent performance because participants with three versions of the tests at the initial occasion had less negative change over an interval of three years than participants with only one version at the initial occasion.

The purpose of the current study was to use updated longitudinal data from the VCAP data set to compare the cognitive change trajectories in a treatment (three versions of the tests) group and in a control (one version of the tests) group. The primary analyses compared the treatment and control groups with respect to the relation between cognitive change and the interval between the first (T1) and second (T2) occasions. Persistence of the intervention effects was also examined in a subsample of participants with an average interval of over 5 years. Transfer effects were investigated by comparing performance of the treatment and control groups on new measures of cognition assessed for the first time at the second occasion. In addition, intervention effects on broader aspects of functioning were examined with subjective measures of memory, thinking, and mood (anxiety, depressive symptoms), and life satisfaction. Finally, because some of the participants returned for a third (T3) occasion, effects of the intervention across the T2-T3 interval were also examined to investigate the durability of the intervention effects.

Initial effectiveness of the intervention was evaluated by the change in performance across alternate versions of the tasks administered on the second and third sessions of the first occasion. Relatively small gains were evident in tests of vocabulary and reasoning (Salthouse, 2013b), and because there was little evidence that the intervention was effective for these measures, only measures of memory, speed, and spatial visualization were included in the subsequent analyses.

Two types of analyses were conducted to examine the robustness of the results. One type was based on composite scores, with age and the interval between occasions both treated as categorical variables in analyses of variance. The other type of analysis involved estimates of latent change as the outcome variables, with age and interval treated as continuous predictor variables in regression analyses.

2. Method

2.1. Sample

Characteristics of the participants included in the analyses are reported in Table 1. Only individuals between 18 and 80 years of age with MMSE (Folstein et al., 1975) scores greater than 26 at the second occasion were included in the analyses to emphasize healthy aging.

On each occasion the participants reported to the laboratory for three sessions within a period of about 2 weeks. About one-half of the participants performed different types of cognitive tests on the second and third sessions, and the remaining participants performed alternate versions of the same tests on all three sessions (in a measurement burst design). Assignment of participants to one or three versions at the initial occasion was determined by the research goals at the time

Table 1
Sample characteristics.

Variable	One T1 version	Three T1 versions	d
N	1036	1068	
Age (in years)	51.6 (15.3)	53.3 (15.5)	.11*
Proportion female	.68	.67	NA
Self-rated health	2.1 (0.8)	2.2 (0.9)	.20*
Years of education	15.7 (2.6)	15.8 (2.6)	.03
T2 MMSE	29.1 (1.0)	29.0 (1.0)	−.10
Est. IQ	110.8 (14.4)	111.1 (13.6)	.02
Scaled scores			
Vocabulary	12.6 (3.0)	12.5 (3.0)	−.03
Digit symbol	11.4 (2.9)	11.3 (2.8)	−.03
Logical memory	12.0 (2.8)	11.8 (2.9)	−.07
Word Recall	12.5 (3.2)	11.9 (3.3)	−.16*
T1–T2 (years)	3.2 (1.9)	2.8 (1.3)	−.26*

Note. T1 = Time 1; T2 = Time 2. Values in parentheses are standard deviations. Health was a self-rating on a scale from 1 (excellent) to 5 (poor). MMSE refers to the Mini-Mental State Exam (Folstein, Folstein, & McHugh, 1975). Est. IQ is an estimate of IQ based on age-adjusted scores on three tests found to be highly related to Wechsler IV full scale IQ (Salthouse, 2014b). Scaled scores are adjusted for age and have means of 10 and standard deviations of 3 in the nationally representative normative samples (Wechsler, 1997a, 1997b). The d column contains Cohen's d estimates of effect size.

* Indicates whether the independent-groups t-test was significant at $p < .01$.

of recruitment, and was not based on level of performance in any of the tests or self-selection on the part of the participants. The other tests administered on the second and third sessions were designed to assess fluid intelligence (Salthouse, Pink & Tucker-Drob, 2008), source memory (Siedlecki, Salthouse & Berish, 2005), prospective memory (Salthouse, Berish & Siedlecki, 2004), executive functioning (Salthouse, 2010; Salthouse et al., 2003), cognitive control (Salthouse, Siedlecki & Krueger, 2006), and language production (Rabaglia & Salthouse, 2011).

Age-adjusted scaled scores and estimated IQs indicate that the participants were functioning about .5 to 1.0 standard deviations above the average level in nationally representative normative samples. Compared to participants with one version on the initial occasion, participants with three versions were slightly older, reported poorer health, and had lower scaled scores for word recall, but a shorter average interval between the two longitudinal occasions.

The research was conducted with the approval of the local Institutional Review Board, and signed consent was obtained prior to data collection.

2.2. Measures

Memory was assessed with tests of word recall, involving immediate free recall on each of four trials of the same list of 12 unrelated words, paired associates, involving recall of the response term upon presentation of the stimulus term across two lists of six word pairs, and logical memory, consisting of the recall of idea units from two stories, with two presentations of the second story. Perceptual speed was assessed with tests of digit symbol, consisting of the substitution of symbols for digits according to a code table with a time limit of 120 s, and pattern comparison and letter comparison, consisting of the rapid comparison of pairs of line patterns or sets of letters on two trials of 30 s each. Spatial visualization was assessed with tests of spatial relations, involving the selection of which two-dimensional pattern corresponded to a three-dimensional object with a time limit of 10 min, paper folding, involving the selection of the pattern of holes that would result given the displayed folds and punched hole location with a time limit of 10 min, and form boards, involving the selection of shapes that would fit into a complex form with a time limit of 8 min. In none of the tests was feedback provided about the accuracy of the responses. Reliabilities and validities (in the form of loadings on their respective ability factors) of the tests are reported in previous publications (Salthouse, 2009; Salthouse et al., 2008).

Working memory was assessed for the first time at the T2 occasion with running memory tasks involving the presentation of a sequence of between 4 and 12 items with the participant asked to report the last 4 items in the original order of presentation (Salthouse, et al., 2008). The items were letters in one version of the task, and were positions of dots in a matrix in a second version of the task. Performance was assessed in terms of the proportion of correct responses. The measures with letter and position stimuli were correlated .64 with one another, and correlations of a latent working memory variable with latent variables representing memory, speed, and spatial visualization (space) abilities were .38, .32, and .59, respectively.

The participants also completed a set of questionnaires at home on each occasion, but only responses at the T2 occasion were considered in the current analyses. The questionnaires assessed depressive symptoms (Radloff, 1977), trait anxiety (Spielberger et al., 1983), and life satisfaction (Diener et al., 1985). Additional questions elicited ratings of one's level of memory and thinking. These self reports were postulated to reflect subjective perceptions of cognitive and mental health.

2.3. Analyses

The memory, speed, and reasoning test scores were converted to z-score units relative to the mean and standard deviation on the first session of the first occasion. Some analyses were based on composite scores created by averaging z-scores for the three tests representing each cognitive ability. Other analyses were based on latent change models (McArdle & Nesselroade, 1994a; McArdle & Nesselroade, 1994b) in which the z-scores for the tests served as indicators of the relevant abilities. A path diagram of the latent change model used in the current analyses is portrayed in Fig. 2. Notice that the latent level variable (Lvl) was defined by scores on the three tests at both occasions, and that the latent change variable (Chng) was defined by residual scores created by partialling first occasion influences from the second occasion test scores. Advantages of latent change models compared to other methods of assessing change are that they accommodate missing data with the full-information maximum likelihood algorithm, they simultaneously estimate level and change in performance, they minimize measurement error, and they allow an evaluation of the fit of the model to the variance and covariance data. The models were analyzed with the AMOS (Arbuckle, 2007) structural equation program, and two fit indices were reported to assess different aspects of model fit. One was the comparative fit index (CFI), which compares the fit of a target model to the fit of a model in which the variables are assumed to be uncorrelated, and the other was the root mean square error of approximation (RMSEA), which is the square root of the mean of the differences between corresponding elements of the observed and predicted covariance matrix. CFI values above about .95, and RMSEA values less than about .08, are considered to represent good fit (e.g., Kline, 2005).

3. Results

Fig. 3 portrays memory composite score differences (i.e., T2-T1) by quintiles of the T1-T2 interval. As expected, change was more negative as the interval between the first and second occasions increased. Of particular importance, however, is that the change at each interval was more positive for participants with three versions of the tests at the first occasion compared to participants with only one version of the tests.

The initial analyses were based on the latent change models portrayed in Fig. 2. None of the quadratic relations of interval on latent change was significant, and thus only linear relations were included in the subsequent analyses. Predictors in the latent change analyses were

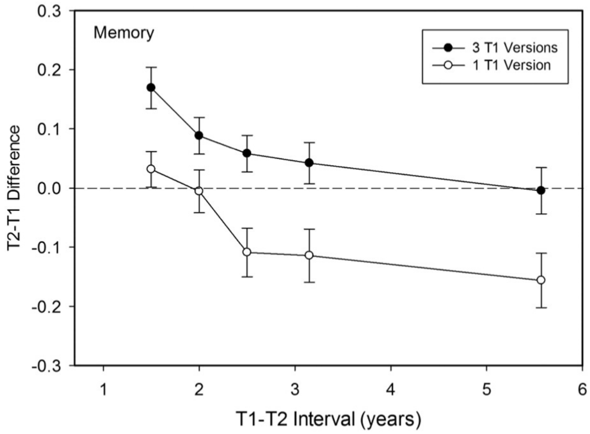

Fig. 3. Composite score difference from the first to the second occasion for memory as a function of the interval between occasions in individuals performing one or three versions of the tests on the first occasion. Each data point was based on between 130 and 290 participants.

number of T1 versions (one or three), length of the T1-T2 interval in years, age of the participant, and all possible interactions.

The latent change models with each cognitive domain had excellent fits to the data (i.e., CFI > .97 and RMSEA < .06), and in each analysis the main effects of number of T1 versions, interval, and age were all significantly ($p < .01$) different from zero. Unstandardized coefficients for the number of T1 versions for memory, speed, and space were .065, .060, and .063, respectively, those for the T1-T2 interval were −.041, −.053, and −.034, respectively, and those for age were −.007, −.005, and −.004, respectively. These results indicate that longitudinal change was more positive among participants who performed three versions of the tests at the first occasion compared to participants who performed only one version, was more negative with increases in the interval between occasions, and was more negative with increases in the age of the participants. None of the interactions of age with interval or with number of T1 versions was significant, and therefore the pattern of results can be inferred to generalize across the range from 18 to 80 years of age.

Importantly, there were no significant interactions of number of T1 versions and interval, which implies that the change trajectories were nearly parallel in the treatment (three versions) and control (one version) groups. There were also no significant interactions of the number of T1 versions and T1-T2 interval in analyses of variance on the composite score differences in which interval was treated as a categorical rather than continuous variable.

The data at different intervals involved different people, and therefore the analyses were repeated with self-rated health and word recall scaled score as covariates to adjust for possible group differences in these measures. The results in these additional analyses were very similar to those without the covariates. In order to determine whether the results might have been distorted by the wide age range of the participants, the analyses were also repeated in the subsample of participants between 60 and 80 years of age at the first occasion. The same pattern of main effects of number of T1 versions and T1–T2 interval, but no interaction, was evident in these analyses.

Results of additional comparisons of the treatment (three versions at T1) and control (one version at T1) groups are presented in Table 2. The average composite score differences were significant for all three cognitive abilities, with effect sizes ranging from .26 to .32. Moderate effect size estimates were also evident for memory and speed in participants in the highest interval quintile, in which the average T1–T2 interval was 5.6 years. However, there were no group differences, and small effect sizes, for the working memory measures performed for the first time at the second occasion, and for the self report measures of mood, life satisfaction, memory, and thinking.

Table 2
Means (and standard deviations) of cognitive and other measures in participants with one or three versions of the relevant tests on the first occasion.

Measure	One T1 version	Three T1 versions	d
T2–T1 change across all intervals (composite score differences)			
Memory (N = 815/1040)	−.05 (0.5)	.07 (0.5)	.26*
Speed (N = 1009/1063)	−.10 (0.4)	.04 (0.4)	.32*
Space(N = 901/967)	.03 (0.4)	.14 (0.4)	.27*
T2–T1 change with average interval of 5.6 years (composite score differences)			
Memory (N = 137/142)	−.16 (0.5)	−.00 (0.4)	.30
Speed (N = 272/145)	−.22 (0.4)	−.07 (0.4)	.32*
Space (N = 190/130)	−.02 (0.5)	.05 (0.5)	.14
T3–T2 change (composite score differences)			
Memory (N = 626/491)	−.01 (0.5)	.01 (0.5)	.04
Speed (N = 638/498)	−.04 (0.5)	−.00 (0.4)	.08
Space (N = 584/450)	.08 (0.4)	.05 (0.4)	−.06
T2 running memory (N = 280/631)			
Letter stimuli	0.53 (0.2)	0.54 (0.2)	.07
Position stimuli	0.52 (0.2)	0.52 (0.2)	.03
Questionnaires (N = 985/1034)			
T2 Memory re. others	4.4 (1.1)	4.4 (1.2)	.03
T2 Memory re. best ever	3.6 (1.1)	3.6 (1.1)	.02
T2 Memory re. problems	4.6 (1.2)	4.7 (1.2)	.06
T2 Think re. earlier	4.6 (1.5)	4.6 (1.5)	.04
T2 CES_D	10.8 (8.1)	10.8 (8.7)	−.00
T2 trait anxiety	34.8 (9.7)	35.0 (10.2)	.03
T2 life satisfaction	23.6 (7.0)	23.1 (7.2)	−.07

Note: Ratings of thinking and memory were on a 7-point scale ranging from 1 for "very poor" or "much worse" or "major problems" to 7 for "very good," "much better," or "no problems." The d column contains Cohen's d estimates of effect size for the group difference.
* Indicates whether the independent-groups t-test was significant at $p < .01$.

Change from the second (T2) to the third (T3) occasion was examined for participants who completed three or more longitudinal occasions. Neither the main effects of number of T1 versions, nor interactions of the number of T1 versions with the T2–T3 interval, were significant in either the regression analyses on latent changes, or in analyses of variance on composite score differences (cf. Table 2).

4. Discussion

Three major results of this study are particularly noteworthy. First, there were significant effects of an intervention consisting of different amounts of experience with the relevant tests on an initial occasion, and evidence of persistence of these effects for at least 5 years in two of the three ability domains. Second, there was no evidence of transfer of the intervention effects to related cognitive tasks, or to other measures of functioning. And third, despite the significant intervention effects, there was no indication that the rates of time-related change differed for participants with one or three test versions on the initial occasion.

The intervention in this study consisted of additional experience with two alternate versions of the original tests without any feedback about the accuracy of the responses. This is a minimal intervention compared to studies involving detailed strategy training or extensive adaptive testing on a variety of cognitively challenging tasks. Despite the modest nature of the intervention, however, the values in Table 2 indicate that the intervention effects in measures of memory, speed, and spatial visualization ranged from .26 to .32 standard deviation units. Furthermore, there was evidence of persistence of the effects because the effect sizes for the difference between the treatment and control groups for memory and speed were .30 and .32 standard deviation units more than 5 years after the intervention. Both the magnitude and persistence of the intervention effects in this study are comparable to those reported in studies with more intensive interventions.

For example, the ACTIVE study involved interventions of 10 to 15 h, and Willis et al. (2006) reported effect sizes after 5 years of .23 for memory and .26 for reasoning. Recent meta-analyses of cognitive intervention effects in older adults have also yielded effect size estimates in the range of .2 to .3 for measures of executive functioning (e.g., Karr, et al., 2014), and general cognitive functioning (Kelly et al., 2014). Although additional experience on similar tests at the initial occasion can be considered a modest intervention, the results indicate that this manipulation was as effective as 10 or more hours of deliberate training in leading to higher cognitive performance several years after the intervention. In light of these results, an important goal for future intervention research should be identification of the minimum manipulations necessary to produce meaningful effect sizes after a period of three or more years. Not only would this information likely improve the efficiency of future interventions, but it may also be valuable in identifying the critical aspects of effective interventions.

Although the working memory measures had moderate correlations with the target cognitive abilities, there was no evidence of generalization of the intervention effect to these new tests. There were also no differences between the treatment and control groups on the self report measures of mood, life satisfaction, and memory and thinking, which can be assumed to represent subjective perceptions of the participants. These results therefore provide no evidence of transfer of the intervention effects to different measures of functioning.

In addition to the main effect of the intervention, apparent in the more positive longitudinal change for individuals with three versions at the initial occasion compared to those with one version, there was a main effect of the length of the interval between occasions on the measures of cognitive change, in the form of more negative change with longer intervals between occasions. The key question in the current study was whether there was an interaction of these two main effects, such that the relation between interval and change varied according to the presence or absence of the treatment.

The results from different cognitive domains and from different types of analyses were consistent in indicating that the answer to this question was no. In all three cognitive measures, and in both latent change analyses and analyses of variance on composite scores, there was no evidence of a shallower rate of change when three versions of the tests were performed at the initial occasion compared to when only one version was performed. Moreover, the failure to detect significant differences is unlikely to be attributable to low power because the samples of over 1000 participants in each group was associated with a power of .99 to detect small ($d = .2$) effect sizes.

Because none of the interactions with age was significant, there was no evidence that the intervention effects, or the interval effects, varied as a function of age. These results extend earlier findings on subsets of the current sample in which there were no age differences in the effects of the number of T1 versions (Salthouse, 2013a), and no age differences in the effects of T1-T2 interval on change (Salthouse, 2011). The gains associated with additional test experience, and the rate at which change becomes more negative over time, therefore appear to be unrelated to age in healthy adults under 80 years of age.

Several limitations of the study should be noted. First, the study was not a randomized clinical trial, but instead was a quasi-experimental study capitalizing on the differential assignment of participants to conditions in which they performed either one or three versions of the cognitive tests on the initial occasion. However, it is important to note that even though assignment to the groups was not random, formation of the groups was not based on level of performance, or preferences of the participants, and instead was determined by research goals at the time of the study. Another limitation is that the intervention in the current study was short-term, consisting of additional experience with two alternative versions of the tests on the first occasion, and the results may not generalize to other interventions, particularly those consisting of enduring lifestyle changes. That is, it is possible that continuous engagement will alter trajectories of change if for no other reason than that the on-going activity repeatedly boosts the level of performance. It is also important to note that in some cases an increase in the level of the measures could have as much practical importance as an alteration of the rate of change if the affected measures are critical for relevant aspects of functioning.

In summary, the effects of the intervention in this study were restricted to the practiced measures with no transfer to other measures, and the additional experience with the tests merely shifted the overall level of the function relating change to interval without altering the rate of change. There is therefore no evidence that the intervention affected the mechanism that contributes to the more negative change associated with increases in the interval from the first occasion. At least with this particular intervention, which in terms of magnitude and persistence over an interval of 5 years had effect sizes comparable to more intensive interventions, there was no influence on age-related cognitive decline. Because modifying the course of cognitive aging is an important goal of many interventions, future intervention research should be designed to determine whether the intervention alters the slope of the function relating performance to time, or simply increases the level of the function without affecting the rate of change.

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