SUBMITTED RESEARCH

Longitudinal impact and effects of booster sessions in a cognitive training program for healthy elderly

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ABSTRACT

This paper reports the results from a three-years follow-up study to assess the long-term efficacy of a cognitive training for healthy older adults and investigates the effects of booster sessions on the cognitive performance of the participants using an innovative analytical approach from information theory. Design: semi-randomized quasi-experimental controlled design. Participants: 50 healthy older adults, ($M = 73.3$, $SD = 7.77$) were assigned into an experimental ($N = 25$; Mean age = 73.9; $SD = 8.62$) and a passive control group ($N = 25$; mean age = 72.9; $SD = 6.97$). Instruments: six subtests of WAIS and two episodic memory tasks. Procedures: the participants were assessed in four occasions: after the end of the original intervention, pre-booster sessions (three years after the original intervention), immediately after the booster sessions and three months after the booster sessions. Results: the repeated measures ANOVA showed that two gains reported in the original intervention were identified in the follow-up: Coding ($F(1, 44) = 11.79$, $MSE = 0.77$, $p = .001$, $\eta^2 G^2 = .084$) and Picture Completion ($F(1, 47) = 10.01$, $MSE = 0.73$, $p = .003$, $\eta^2 G^2 = .060$). After the booster sessions, all variables presented a significant interaction between group and time favorable to the experimental group (moderate to high effect sizes). To compare the level of cohesion of the cognitive variables between the groups, an entropy-based metric was used. The experimental group presented a lower level of cohesion in three of the four measurement occasions, suggesting a differential impact of the intervention with immediate and short-term effects, but without long-term effects.

KEYWORDS

Cognitive training, Long-term efficacy, Entropy

Introduction

The area of cognitive training has accumulated considerable evidence towards the positive impact of training protocols on cognitive performance assessed immediately after the intervention (immediate effects; Martin, Clare, Altgassen, Cameron, & Zehnder, 2011; Nguyen et al., 2019a; Rebok et al., 2014, p. @reijnders2013cognitive). Most of the positive effects reported in the literature are in abilities that are part of the *the same* cognitive domain trained during the intervention (trained skills) and for abilities that are not part of the cognitive domain trained, but that pertain to a closely related domain (near transfer effect).

The field has been challenged by a lack of evidence for long-lasting effects of cognitive gains after intervention. The most challenging goal has to do with keeping the cognitive gains for a long period of time (long-term efficacy) (Law, Barnett, Yau, & Gray, 2014; Nguyen et al., 2019a). There has been a growing interest in investigating the long-term efficacy of cognitive training programs, especially due to the restricted number of long-term follow-up studies compared to the more common immediate effect studies (pre-test, intervention, short-term follow-up test).

In a recent meta-analysis and systematic review (see: Nguyen et al., 2019a) with a sample of 2,088 articles, only 64 studies met the standard eligibility criteria in accordance with the Cochrane Handbook for Systematic Reviews (Higgins & Green, 2011) and the American Psychological Association's Meta-Analysis Reporting Standards (see: Cooper, 2011). From the 64 studies included, only 16 examined the long-term efficacy of cognitive training programs, with the follow-up length ranging from 3 weeks to 18 months ($Mean_{months} = 6.83, SD = 5.09$).

Given the relevance of long-term follow up studies to explore the durability effect of cognitive training programs, the current paper aims to assess the participants originally trained by Golino, Mendoza, and Golino (2017), three years after the first intervention. Additionally, eight booster sessions were included for the experimental group after the follow-up assessment, to check if the inclusion of additional training sessions is effective in improving the cognitive performance.

Literature Review

The durability effect is valuable evidence for the high quality and strength of a cognitive intervention program. Some of the most important and robust studies in the cognitive training field indicate that elderly people are able to retain the cognitive gains (training effects) from several months (Borella, Carretti, Riboldi, & De Beni, 2010; Brehmer, Westerberg, & Bäckman, 2012; Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008; Günther, Schäfer, Holzner, & Kemmler, 2003; Kramer, Hahn, & Gopher, 1999; Yang & Krampe, 2009) up to several years (Ball et al., 2002; Neely & Backman, 1993; Rebok et al., 2014; Willis & Nesselroade, 1990; Willis et al., 2006).

The Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study shows strong long-term efficacy in improved performance of trained skills and the daily functioning of participants from a cognitive training program. According to the reported results (Rebok et al., 2014), the cognitive training gains for reasoning and processing speed were maintained for 10 years after the original intervention, and at least 5 years for memory, with booster sessions with intervals of 1 and 3 years. The

results of previous research suggest that the durability of cognitive gains for healthy elderly people involves a multiplicity of cognitive domains, such as memory, reasoning, processing speed and attention (Rebok et al., 2014; Willis & Nesselrode, 1990; Yang & Krampe, 2009). There is also support for the durability effect for executive functions and daily functioning (Dahlin et al., 2008; Wilkinson & Yang, 2016).

The ACTIVE project was the first multicentric longitudinal study to provide strong evidence supporting the durability effect in elderly people, but many questions remain open. Could the same durability effects be observed in elderly people who infrequently participate in cognitively engaging activities? Can the durability effect be achieved if booster training sessions are conducted after long periods of time? How does the cognitive performance of participants before the booster sessions compare to their cognitive performance after the intervention? To increase durability effects, how many training sessions need to be implemented and what abilities should be focused on? (Kelly et al., 2014; Salthouse, 2006).

When investigating the long-term efficacy of a cognitive training program, the inclusion of booster sessions, as well as the format and frequency of training sessions must be controlled. Booster sessions are typically conceived as a short version of a cognitive training program; their impact on the cognitive system can potentially lead to a re-activation of the cognitive skills previously trained. In their systematic and meta-analytical review, Kelly et al. (2014) and Nguyen et al. (2019a) showed that multidomain adaptive interventions that include booster sessions after the end of the training period can lead to an extension of the immediate gains and to a slower decline of the trained abilities. The authors argue that the additional tasks used in the booster sessions help maintain the cognitive strategies that were learned during the original training phase, strengthening the neuroplasticity mechanism in the aging process (Kelly et al., 2014; Nguyen et al., 2019a).

Nevertheless, not all studies in the area of cognitive training include booster sessions during their follow-up assessments which may negatively impact the long-term efficacy of cognitive intervention programs (for a detailed review, see: Borella et al., 2010; Brehmer et al., 2012; Dahlin et al., 2008). At the same time, there is also strong support for the long-lasting impact of the cognitive training programs even among studies that did not include booster sessions. Neely and Backman (1993), for example, reported positive outcomes for a memory training in a follow up assessment three years after the intervention. A study conducted by Ball et al. (2002) found that the impact of the cognitive training on the trained skills lasted for 2 years. Nguyen et al. (2019a) also showed evidence of small, but significant training effects for both near and far-transfer effects. The durability of the cognitive gains due to a cognitive intervention program is an important aspect to be investigated in the area of aging, especially given that the observed decline in cognitive functioning during the aging process negatively impacts people's autonomy and quality of life (Borella et al., 2010; Brum, Borella, Carretti, Guidotti, & Yassuda, 2018).

Research Design

As stated in the introduction, the current paper aims to assess the participants originally trained by Golino et al. (2017) three years after the first intervention. The goals are twofold. First, a traditional follow-up study after three years of the original

intervention will compare the experimental and the control group to verify if the original gains of the former group reported by Golino et al. (2017) are maintained after a long interval of time. The second goal is to assess the short-term impact of eight booster sessions in the cognitive performance of the experimental group using a shorter version of the cognitive training program for elderly people developed by Golino et al. (2017). This study follows a semi-randomized quasi-experimental controlled design, with two groups: an experimental (training) group and a passive control group. Considering previous studies assessing the durability effect of cognitive training on elderly people (e.g., Wilkinson and Yang (2016)) we hypothesize that the experimental group will keep surpassing the passive control group in terms of cognitive performance in all measurement occasions (pre-booster sessions, immediately after the booster sessions and the three-month follow-up).

Sample and Measures

From the original sample of 80 healthy non-institutionalized elderly individuals that participated in the study of Golino et al. (2017), 50 subjects were recruited for our follow up study. There were 36 women and 14 men, ages 63 to 92 years old ($M = 73.3$; $SD = 7.77$; Median = 73). The recruitment procedure (from December 2017 to January 2018) used the same exclusion criteria adopted by Golino et al. (2017): 1) diagnosis of senile dementia via a clinical interview; 2) sensory deficits (visual and/or auditory) that prevented the understanding and execution of the training tasks; 3) presence of psychiatric disorder; and 4) addiction (alcohol and other drugs). The participants were asked to read and sign the Informed Consent Form, approved by the university's IRB. None of the 50 participants met the exclusion criteria. After the primary assessment they were allocated into the same experimental ($N = 25$; Mean age = 73.9 years; $SD = 8.62$) and control groups ($N = 25$; mean age = 72.9 years; $SD = 6.97$) as the original study (Golino et al., 2017). The experimental group has an average of 5.64 years of education ($SD = 4.75$), while the passive control group has an average of 5.88 years of education ($SD = 4.36$).

Table 1 shows relevant information regarding the main descriptive characteristics of the participants. No statistically significant differences were found between the groups for any of the variables shown.

[INSERT TABLE 1 HERE]

To check the exclusion criteria and characterize the sample, five instruments were used. The first is a structured interview of the participants' medical history, designed particularly for this research. The interview covered each participant's current clinical state, the existence of emotional and cognitive symptoms, diagnosis of psychiatric disorders and of senile dementia. The second was the *Criteria of Economic Classification* (CCEB - 2016), a reliable classification system that estimates people's purchasing power. The third instrument used was the Geriatric Depression Scale (Sheikh & Yesavage, 1986), which aims to assess and quantify depressive symptoms in the elderly population. For this research, a reduced version of the scale was used, comprised by 15 items (Almeida & Almeida, 1999). Participants with scores higher than 7 were excluded from the sample. The forth instrument used was the Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975), a brief questionnaire used to assess cognitive decline and the severity of dementia. It contains simple questions to assess different cognitive domains: time and space orientation, short-term memory,

arithmetic, language comprehension and basic motor skills. The exclusion criteria suggested by **Valle (2009)** (INCLUIR REFERENCIA) was used in the current paper, excluding participants with scores lower than 24. Finally, the Instrumental Activities of Daily Living Scale (IADL) developed by Lawton and Brody (**1969**) was used to assess daily functioning. The version of the IADL scale used (Lopes dos Santos & Virtuoso Júnior, **2008**) contain tasks in seven domains: the use of phone, making purchases, preparing meals, household activities, walking outdoors, autonomy to control medication and finances management.

To assess the training effects, three instruments were used. The *grocery list recall task* (Yassuda, Lasca, & Neri, **2005**) contains a list of 35 grocery items, used to assess immediate recall. Scores were calculated by the amount of words remembered by the participant and ranged from 0 to 35. The *story recall task* (Yassuda et al., **2005**) assesses the amount of ideas retrieved after reading a text. The score varies from 0 to 4 (with each point corresponding to an idea). After reading a text, the participant is requested to recall the story, with as much information and details as possible. The third instrument is the *Wechsler Adult Intelligence Scale* (WAIS-III; Wechsler, **1997**), including only six subtests (listed below) that are conceptually linked to the trained cognitive functions and that were used in the primary study (Golino et al., **2017**): (1) *Picture completion* - assesses the ability to distinguish essential details from non-essential, categorization, and perceptual organization; the total score ranges from 0 to 25 points; (2) *Digit symbol-coding* - assesses the skill to learn unfamiliar tasks, speed and accuracy, focused attention and visual-motor coordination, with the total score ranging from 0 to 133 points; (3) *Digit span* - assesses short-term auditory memory and working memory, with a total score ranging from 0 to 30 points; (4) *Symbols search* - assesses focused attention, processing speed, planning and information codification for subsequent processing; (5) *Arithmetic* - assesses mental calculation, complex numerical problem solving, working memory, fluid intelligence, short-term acquisition and recovery, and sequential processing, with a total score ranging from 0 to 22 points; (6) *Matrix Reasoning* - assesses logical and abstract reasoning, non-verbal, holistic and simultaneous processing, spatial visualization and visual organization, with scores ranging from 0 to 26 points.

Procedures

After proceeding with the participants screening, the exclusion criteria were checked and the participants ($N = 50$) were assigned to the experimental ($N = 25$) or the passive control group ($N = 25$), in accordance with the original study (Golino et al., **2017**). For each measurement occasion (pre-booster sessions, immediately after the booster sessions and a three-month follow-up), the cognitive assessment consisted of one or two appointments per participant, in accordance with the availability of the participants, with a 20 minutes interval between the first and second trial block of tasks (in the case of assessments made in only one day). The tasks were split into two blocks: (1) Episodic Memory-list, Episodic Memory-story, Figure completion and Coding; (2) Arithmetic, Matrix Reasoning, Digit Span and Symbols search. When a second appointment was required, each session used only one of the two block of tasks. The order of the block of tasks were randomized within groups.

The experimental group participated in an eight-sessions booster training (paper and pencil format, multimodal cognitive training). The booster sessions focused on training strategies to improve attention, processing speed, episodic memory and work memory.

Each of the eight individual training sessions lasted for 60 minutes, once a week. The booster training protocol used in the current study was adopted from the original protocol developed by Golino et al. (2017), maintaining the multi-domain modality and the focus on training cognitive strategies to improve cognitive abilities that are more prone to decline with age. The control group completed the individual cognitive assessments at the same time of the experimental group, in each measurement occasion (pre-booster sessions, immediately after the booster sessions and a three-month follow-up).

Data Analysis

To investigate the differences between groups (experimental and control), a repeated measures ANOVA was used, with group membership as the between subject effect and time as the within subject effect. The Shapiro-Wilk test was used to verify if the variables are normally distributed. Variables that did not present a normal distribution were transformed (i.e. normalized) using the `bestNormalize` package (Peterson & Cavanaugh, 2019). The effect size was calculated using the generalized eta squared (see: Olejnik & Algina, 2003). All analysis were implemented in R (R Core Team, 2017).

Additionally, an innovative approach based on entropy was used to measure the impact of the cognitive intervention. Entropy is a measure of uncertainty or disorder of a random variable (Shannon, 1948; Watanabe, 1960; Wiener, 1961). It can also be used to assess the degree of uncertainty (or disorder) of a set of variables, with lower values indicating lower uncertainty in the organization of the variables (Golino et al., n.d.). Entropy measures were originally applied in physics (Watanabe, 1960), but its application has increased over the years in different areas, such as communication and neuroscience (Paninski, 2003), and psychology (Golino et al., n.d.).

For a discrete random variable X , entropy is calculated using the distribution of $p(X)$ and is maximized when all events of X are equiprobable (i.e., $p(x) = \frac{1}{N}$, where N is the number of elements of X ; Shannon, 1948). The most common method to estimate the entropy of a random variable is the maximum likelihood estimator (MLE) (Antos & Kontoyiannis, 2001). Let X be a discrete random variable that takes on values in a set $X = (x_1, x_2, \dots, x_n)$, with a probability mass function $p(x) = P(X = x)$, the MLE estimator of entropy is:

$$H(X) = - \sum_{i=1}^n p(x) \log p(x). \quad (1)$$

Entropy was popularized after the publication of the mathematical theory of communication by Shannon (1948). Years earlier, however, Watanabe (1939) developed a modified index of entropy termed *total correlation* to measure not only the uncertainty of random variables, but also the strength of their correlation beyond their average interaction (Watanabe, 1960). The total correlation of a set of variables $\mathcal{X} = (x_1, x_2, \dots, x_n)$ is calculated as follows (Watanabe, 1960):

$$C_{tot_x} = \left(\sum_{i=1}^n H(x_i) \right) - H(x_1, x_2, \dots, x_n) \geq 0. \quad (2)$$

Considering two sets of variables, v and ω , the difference between their joint entropy and the sum of their individual entropies is a measure of the correlation between them (Watanabe, 1960). As pointed by Golino et al. (n.d.), total correlation captures the decrease of ignorance of ω provided by the observation of v , being a non-linear measure of uncertainty and association.

An example illustrates well what total correlation captures, and why using it to investigate the impact of cognitive interventions can provide useful information that traditional linear and parametric statistical techniques can't. Suppose we have four random normal variables (A, B, C and D). In a baseline condition these variables present the same mean ($M = 15$) and standard deviation ($\sigma = 5$), and their correlation is:

$$\mathbf{Cor} = \begin{bmatrix} 1 & 0.4 & 0.5 & 0.6 \\ 0.4 & 1 & 0.4 & 0.5 \\ 0.5 & 0.4 & 1 & 0.3 \\ 0.6 & 0.5 & 0.3 & 1 \end{bmatrix} \quad (3)$$

Now, this baseline condition can be compared to four different conditions, varying the means and the correlation between A, B, C and D. In the first condition (*high correlation*), the means and variances of the variables are the same as the baseline condition, but variable A presents a higher correlation with the remaining variables (B, C and D): 0.6, 0.7 and 0.8, respectively. The second condition (*low correlation*) is the same as the first, but the correlation between A and B, C and D is now set to 0.1, 0.2, 0.3, respectively. In the third condition (*high mean*), the four variables present the same correlation and variances as the baseline condition, but now variable A has a mean of 25. Finally, the fourth condition (*low mean*) is similar to the third, but the mean of A is now set to 5.

To illustrate what happens with the total correlation in each condition (including the baseline), a brief simulation was implemented. For each condition, 1,000 datasets with four variables (A, B, C and D) and 1,000 observations were generated. The data generation mechanism used is described next. For each simulated dataset, four independent random normal variables with mean μ and standard deviation σ were generated with $N = 1000$, generating a data matrix D . The simulated dataset has variables that are independent from each other, therefore the correlation among the variables is zero. To obtain a transformation of the variables with the same mean (μ) and standard deviation σ , but with a desired correlation matrix $\mathbf{Cor}$, a simple transformation can be implemented:

$$D_{New} = D \times \mathbf{Cor}_{Cholesky} + \sigma + \mu \quad (4)$$

Where D is the original data (with four independent normal random variables and 1,000 observations), $\mathbf{Cor}_{Cholesky}$ is the Cholesky decomposition of the desired correlation matrix, μ and σ are the mean and standard deviation of the original data, and D_{New} is the new data with 1,000 observations and four normal random variables with correlation matrix $\mathbf{Cor}$.

Figure 1 presents the mean and the distribution of the total correlation calculated in each simulated dataset, per condition (left side) as well as the 95% confidence interval of the total correlation means (right side). As expected, total correlation changes with the change in the correlation between variables and with the change in their means. The total correlation of the variables increases if the correlation increases, but the mean and standard deviation is kept the same. On the other side, total correlation decreases if the correlation is lower and the mean and standard deviation remains unchanged. When the correlation is the same, but the means increases or decreases, total correlation decreases.

Figure 1. Total correlation per condition tested

An analysis of variance would indicate a significant difference between the baseline conditions and the high and low mean conditions, only. But would suggest that conditions one and two (high and low correlation) are not statistically different from the baseline. This statement is obvious, since analysis of variance is used to verify the difference between means, not being suited to verify differences between correlations. However, it is important to point this obvious characteristic of the analysis of variance, since this is a standard technique used to quantify the impact of cognitive intervention protocols.

Compared to a traditional analysis of variance, total correlation offers at least two

important advantages. Firstly, it is a non-parametric and non-linear metric, not requiring the data to be normally distributed and enabling the measurement of non-linear relations. Secondly, it varies not only with the variation of the mean, but also with the variation of the correlation between variables. This is an important characteristic that can give additional relevant information to studies investigating the impact of cognitive interventions.

In cognitive training studies, it is expected that some skills or abilities will improve due to the intervention. However, not all skills or abilities trained will improve. If we quantify only the average variation per skill or ability (or construct measured pre and post-intervention), we might be losing information regarding the level of cohesion of the variables. A higher cohesion means that the distribution of the variables (or scores) per person is more uniform. For example, if people are improving all their skills or abilities, then they will present higher scores for every measured variable. Conversely, if people are losing their skills or abilities, then they will present lower scores in all measured variables. In both cases, the cohesion of the variables is high. However, some skills or abilities may be improving, while other are unchanged. In this case, the level of cohesion among the variables measured will be lower, because the distribution of the scores per individual won't be very uniform.

Therefore, in cognitive training studies, we can expect that the cohesion among variables measured pre and post-intervention should decrease for the experimental group (compared to the control group), if only a subset of skills or abilities are being impacted by the training protocol. Total correlation, as mentioned earlier, is a non-linear metric that can capture the level of cohesion among variables.

Total correlation was estimated using the **EGAnet** package (Golino & Christensen, 2019). To calculate the 95% confidence interval of total correlation, a bootstrap approach (Chihara & Hesterberg, 2011) was used in which the observed data is resampled without replacement 1,000 times with 20 observations each. The codes used in the current paper, the data and the RMarkdown file used to combine text, data and code is available in an Open Science Framework repository: https://osf.io/b35eq/?view_only=812f21139c30411095d8f0e3fea14dd7. The current research received approval from the local IRB.

Results

The repeated measures ANOVA using the participants' scores in the follow-up study (three years after the original intervention, but before the booster sessions), showed that out of the three gains reported by Golino et al. (2017), two were maintained in the period of three years: there was a significant interaction for time and group membership for Coding ($F(1,44) = 11.79$, $MSE = 0.77$, $p = .001$, $\hat{\eta}_G^2 = .084$) and Picture Completion ($F(1,47) = 10.01$, $MSE = 0.73$, $p = .003$, $\hat{\eta}_G^2 = .060$), with moderate effect sizes. Notably, a significant interaction was also found for Symbol Search ($F(1,38) = 7.12$, $MSE = 0.77$, $p = .011$, $\hat{\eta}_G^2 = .055$), Arithmetic ($F(1,47) = 5.21$, $MSE = 0.61$, $p = .027$, $\hat{\eta}_G^2 = .030$), Memory History ($F(1,37) = 4.64$, $MSE = 0.58$, $p = .038$, $\hat{\eta}_G^2 = .044$) and Memory List ($F(1,37) = 7.29$, $MSE = 0.70$, $p = .010$, $\hat{\eta}_G^2 = .084$), which was not found in the original study. No considerable interaction effect was found for Digit Span ($F(1,47) = 2.57$, $MSE = 0.80$, $p = .116$, $\hat{\eta}_G^2 = .022$) and Matrix Reasoning ($F(1,47) = 2.74$, $MSE = 0.75$, $p = .105$, $\hat{\eta}_G^2 = .019$).

Table 1. ANOVA - Follow-up three years after the original study.

Variables	Effect	F	df_1^{GG}	df_2^{GG}	MSE	p	$\hat{\eta}_G^2$
Digit Span	Group	3.25	1	47	1.17	.078	.039
	Time	5.23	1	47	0.80	.027	.043
	Group x Time	2.57	1	47	0.80	.116	.022
Coding	Group	0.79	1	44	1.48	.380	.012
	Time	0.72	1	44	0.77	.401	.006
	Group x Time	11.79	1	44	0.77	.001	.084
Picture Completion	Group	0.06	1	47	1.71	.802	.001
	Time	18.18	1	47	0.73	.001	.104
	Group x Time	10.01	1	47	0.73	.003	.060
Symbol Search	Group	0.25	1	38	1.70	.619	.005
	Time	6.73	1	38	0.77	.013	.052
	Group x Time	7.12	1	38	0.77	.011	.055
Arithmetic	Group	1.96	1	47	1.55	.168	.029
	Time	5.76	1	47	0.61	.020	.033
	Group x Time	5.21	1	47	0.61	.027	.030
Matrix Reasoning	Group	0.28	1	47	1.54	.596	.004
	Time	9.87	1	47	0.75	.003	.064
	Group x Time	2.74	1	47	0.75	.105	.019
Memory - List	Group	1.87	1	37	0.82	.179	.026
	Time	33.70	1	37	0.70	.001	.297
	Group x Time	7.29	1	37	0.70	.010	.084
Memory - History	Group	1.19	1	37	1.01	.283	.020
	Time	5.96	1	37	0.58	.020	.056
	Group x Time	4.64	1	37	0.58	.038	.044

However, it is important to point that the time/group effect found does not favor the experimental group (Figure 2). While both groups presented a decline in their average performance, the experimental group had the sharpest decline. Surprisingly, the control group surpassed the experimental group in most of the cognitive variables measured.

The scenario changes after the booster sessions. While the control group continued in its trajectory of decline, the experimental group showed improved performance in all variables measured (Figure 2). The results point to a positive short-term effect of the booster sessions, since all variables presented a significant interaction between group and time. Arithmetic ($F(1, 47) = 20.93$, $MSE = 0.16$, $p < .001$, $\hat{\eta}_G^2 = .060$), matrix reasoning ($F(1, 47) = 21.77$, $MSE = 0.21$, $p < .001$, $\hat{\eta}_G^2 = .067$), picture completion ($F(1, 47) = 20.11$, $MSE = 0.28$, $p < .001$, $\hat{\eta}_G^2 = .069$), digit span ($F(1, 47) = 18.92$, $MSE = 0.16$, $p < .001$, $\hat{\eta}_G^2 = .076$), coding ($F(1, 47) = 19.28$, $MSE = 0.26$, $p < .001$, $\hat{\eta}_G^2 = .097$) and memory list ($F(1, 47) = 44.33$, $MSE = 0.15$, $p < .001$, $\hat{\eta}_G^2 = .129$) presented moderate effect sizes. Variables that presented large effect sizes were symbol search ($F(1, 47) = 23.40$, $MSE = 0.48$, $p < .001$, $\hat{\eta}_G^2 = .167$) and memory history ($F(1, 47) = 34.56$, $MSE = 0.16$, $p < .001$, $\hat{\eta}_G^2 = .148$).

The results of the follow-up assessment three months after the booster session indicate

Table 2. ANOVA - Immediate short-term effects of the booster session (pre vs. post-booster sessions).

Variables	Effect	F	df_1^{GG}	df_2^{GG}	MSE	p	$\hat{\eta}_G^2$
Digit Span	Group	8.17	1	47	0.63	.006	.121
	Time	27.03	1	47	0.16	.001	.105
	Group x Time	18.92	1	47	0.16	.001	.076
Coding	Group	5.44	1	47	0.74	.024	.079
	Time	3.61	1	47	0.26	.064	.020
	Group x Time	19.28	1	47	0.26	.001	.097
Picture Completion	Group	0.35	1	47	1.31	.556	.006
	Time	4.91	1	47	0.28	.032	.018
	Group x Time	20.11	1	47	0.28	.001	.069
Symbol Search	Group	0.04	1	47	0.71	.850	.000
	Time	2.48	1	47	0.48	.122	.021
	Group x Time	23.40	1	47	0.48	.001	.167
Arithmetic	Group	3.38	1	47	0.93	.073	.058
	Time	12.65	1	47	0.16	.001	.037
	Group x Time	20.93	1	47	0.16	.001	.060
Matrix Reasoning	Group	1.62	1	47	1.14	.209	.028
	Time	5.03	1	47	0.21	.030	.016
	Group x Time	21.77	1	47	0.21	.001	.067
Memory - List	Group	0.11	1	47	0.81	.741	.002
	Time	0.44	1	47	0.15	.510	.001
	Group x Time	44.33	1	47	0.15	.001	.129
Memory - History	Group	0.01	1	47	0.53	.914	.000
	Time	0.29	1	47	0.16	.590	.001
	Group x Time	34.56	1	47	0.16	.001	.148

Table 3. ANOVA - Three month follow-up of the booster session (pre-booster sessions vs. three-month follow-up).

Variables	Effect	F	df_1^{GG}	df_2^{GG}	MSE	p	$\hat{\eta}_G^2$
Digit Span	Group	10.96	1	47	0.70	.002	.148
	Time	29.66	1	47	0.24	.001	.138
	Group x Time	21.27	1	47	0.24	.001	.103
Coding	Group	2.33	1	47	0.60	.134	.032
	Time	6.18	1	47	0.29	.017	.041
	Group x Time	33.01	1	47	0.29	.001	.186
Picture Completion	Group	0.32	1	47	0.98	.574	.005
	Time	9.94	1	47	0.43	.003	.060
	Group x Time	30.47	1	47	0.43	.001	.164
Symbol Search	Group	0.10	1	47	0.57	.755	.001
	Time	2.81	1	47	0.57	.100	.029
	Group x Time	24.59	1	47	0.57	.001	.207
Arithmetic	Group	5.48	1	47	0.80	.023	.091
	Time	23.67	1	47	0.14	.001	.069
	Group x Time	33.07	1	47	0.14	.001	.093
Matrix Reasoning	Group	1.87	1	47	1.16	.177	.033
	Time	6.89	1	47	0.21	.012	.022
	Group x Time	24.18	1	47	0.21	.001	.073
Memory - List	Group	0.91	1	47	0.57	.344	.013
	Time	1.94	1	47	0.27	.170	.013
	Group x Time	47.68	1	47	0.27	.001	.247
Memory - History	Group	5.09	1	47	0.38	.029	.064
	Time	3.37	1	47	0.22	.073	.026
	Group x Time	66.14	1	47	0.22	.001	.342

that the differences found between the experimental and the control group were not just maintained (since all variables presented a significant interaction between group and time) but actually increased. The effect sizes ranged from moderate to high. Matrix reasoning ($F(1, 47) = 24.18$, $MSE = 0.21$, $p < .001$, $\hat{\eta}_G^2 = .073$), arithmetic ($F(1, 47) = 33.07$, $MSE = 0.14$, $p < .001$, $\hat{\eta}_G^2 = .093$), digit span ($F(1, 47) = 21.27$, $MSE = 0.24$, $p < .001$, $\hat{\eta}_G^2 = .103$) presented moderate effect sizes, while picture completion ($F(1, 47) = 30.47$, $MSE = 0.43$, $p < .001$, $\hat{\eta}_G^2 = .164$), coding ($F(1, 47) = 33.01$, $MSE = 0.29$, $p < .001$, $\hat{\eta}_G^2 = .186$), symbol search ($F(1, 47) = 24.59$, $MSE = 0.57$, $p < .001$, $\hat{\eta}_G^2 = .207$), memory list ($F(1, 47) = 47.68$, $MSE = 0.27$, $p < .001$, $\hat{\eta}_G^2 = .247$) and memory history ($F(1, 47) = 66.14$, $MSE = 0.22$, $p < .001$, $\hat{\eta}_G^2 = .342$) presented large effect sizes.

Figure 2 shows the mean and 95% confidence interval of the scores on each cognitive variable, per group and measurement occasion.

Total correlation per group

Figure 3 shows the mean and 95% confidence interval of total correlation per group and measurement occasion (including the post-test of the original study). The experimental

Figure 2. Resampled means and confidence intervals for each variable, in each measurement point

Figure 3. Total correlation per group

group presented a lower total correlation in comparison to the control group in the post-test of the original study, in the post-test of the booster sessions and in the three month follow up. This indicates a lower level of cohesion among the cognitive measures for the experimental group.

Computing the difference between the highest and the lowest score for each participant in each measurement occasion can shed some light into why the experimental group presents a lower level of cohesion than the control group. Figure 4 shows that experimental group presents a higher mean difference between the highest and the lowest score for each participant in comparison to the the control group in the post-test of the original study and in the two post-tests of the booster sessions (post-booster sessions and three month follow-up). This is due to a greater level of dispersion of the scores for the experimental group, which leads to a decreased level of cohesion compared to the control group.

Figure 4. Average difference (resampled means and confidence interval) between the maximum and the minimum score across variables per group in each measurement point

At the same time, computing the difference between the maximum and the minimum average correlation between variables for each group, in each measurement point, can also help us understand the results of total correlation. Figure 5 shows that the experimental group has a lower mean difference of average correlation in the post-test of the original study and in the two post-tests of the booster sessions. This indicates that the cognitive variables in the experimental group are less strongly related and that

the difference between the variable with the highest and the lowest average correlation is much smaller compared to the control group.

The mean and 95% confidence intervals depicted in Figure 4 and Figure 5 were computed using a bootstrap approach (Chihara & Hesterberg, 2011), in which the observed data is resampled without replacement 1,000 times with 20 observations each.

Figure 5. Average difference (resampled means and confidence interval) between the maximum and the minimum average correlation per group in each measurement point

Discussion

Immediate positive effects of cognitive training programs for elders are well known in the cognitive aging literature (immediate effects; Martin et al., 2011; Nguyen et al., 2019a; Rebok et al., 2014, p. @reijnders2013cognitive). On the other hand, long-term effects are much less frequently investigated, even though a central goal of cognitive interventions in aging is to positively impact the cognitive capacity of individuals for a long period of time.

Given the need to study the long-term effects of cognitive training programs, the current paper assessed a subsample of 50 participants three years after the original intervention study they were a part of conducted by Golino et al. (2017). While

the original study reported significant differences between the experimental and the control group (time/group interaction effects) for three variables, our study found significant differences for two of them (coding and picture completion), plus four other variables (symbol search, arithmetic, memory history and memory list), with effect sizes varying from small to moderate. However, the time/group effect found favored the control group, that surpassed the experimental group in most of the cognitive variables measured in the three-year follow-up. The experimental group presented the strongest decline in terms of cognitive performance. This result shows that the original intervention did not present a long-term durability, contrasting with classical studies showing durability of cognitive gains (training effects) ranging from months (Borella et al., 2010; Brehmer et al., 2012; Dahlin et al., 2008; Günther et al., 2003; Kramer et al., 1999; Yang & Krampe, 2009) to several years (Ball et al., 2002; Neely & Backman, 1993; Rebok et al., 2014; Willis & Nesselroade, 1990; Willis et al., 2006).

However, the pattern reverses after the booster sessions, the experimental group showed improved performance in all cognitive measures assessed immediately after the booster sessions (immediate gains) compared with the passive control group. The short-term efficacy of the booster sessions indicates a near transfer effect for visual semantic memory, focused attention, episodic memory, processing speed and working memory, as well as a far transfer effect for reasoning.

Most of the literature reports a loss of the cognitive gains after the end of the cognitive intervention programs (Hertzog, Kramer, Wilson, & Lindenberger, 2008; Kounti et al., 2011; Nguyen et al., 2019b). Hertzog et al. (2008) argue that once the set of stimuli (cognitive training) that were supporting the cognitive responses is taken away, the performance levels return to the baseline performance, or close to it. The results of the present study are in accordance with this expected pattern, with no long-lasting impact demonstrated in the absence of booster sessions. Similar results have been reported by the literature (Ball et al., 2002; Martin et al., 2011; Rebok et al., 2014; Willis et al., 2006), supporting the argument that the durability effects are stronger with (or even conditional on) the inclusion of booster sessions.

The long-term efficacy of cognitive trainings is one of the most critical issues that has challenged the field of cognitive training for elderly people. One could argue that the lack of support for the long-lasting impact of the cognitive gains achieved after the intervention weakens the cognitive enrichment hypothesis (Salthouse, 2006). However, it's also possible that the lack of support for long-term effects of cognitive interventions could be attributable to some methodological limitations that have been pointed in the literature, such as the difficulty to control for multiple cofounders that can account for the age-related cognitive decline (Karch & Verhaeghen, 2014; Melby-Lervåg, Redick, & Hulme, 2016).

The current paper also utilized a non-linear measure termed *total correlation* to assess the level of cohesion of the cognitive variables per group. In the context of cognitive interventions, it is expected that the gains in performance will negatively impact the cohesion of the cognitive variables, since the cognitive training can have an impact on two different fronts. A successful cognitive intervention will generate an increase in performance on cognitive measures, leading to higher mean scores for the experimental group in comparison with the control group. At the same time, the correlation between variables may be lower for the experimental group, since the gains in performance are not equal for every cognitive measure used. As a consequence, the experimental group may present lower total correlations, or lower cohesion.

It is well established in the literature that different cognitive variables age differently (Salthouse, 2010). Some variables decline over time with different onsets of performance decrease, while others may stabilize or even improve over time, as in the case of vocabulary (Salthouse, 2010). Therefore, it is expected that the level of cohesion of the cognitive variables (or their total correlation) can decline with time, since the performance in some variables decline, while others remain stable or improve with time.

In our study, the three-year interval (aging effect) revealed that the control group presented a decrease in the level of cohesion, possibly due to the expected differential aging effects on the cognitive variables used here. The trajectory of the means for the control group showed that some of the variables declined over time as others improved, which could possibly explain the loss of cohesion among the variables.

The experimental group, on the other hand, had a slight increase in cohesion during the three-year interval, possibly because the gains in performance due to the original intervention faded, so the performance in the cognitive variables returned to its original levels (i.e., declined during this interval). It's possible to observe that all variables showed a similar pattern of change in performance (means) during this three-year interval, leading to a higher cohesion in the cognitive structure for the experimental group.

The pattern of the cohesion levels was investigated using two strategies. Combined, the mean difference between the highest and the lowest score for each participant, and the difference between the highest and the lowest average correlation points to a direction suggested by the brief simulation shown on Figure 1. In sum, cohesion decreases both if there is variability in the means of the variables (decreasing or increasing) and if the linear correlation between variables decreases. That's exactly what happened with the experimental group. In three different measurement occasions, i.e. the post-test of the original study and in the two post-tests of the booster sessions (post-booster sessions and three month follow-up), the experimental group presented higher means than the control group, but also lower correlation between variables. The higher means and lower correlations, captured well by the non-linear index of total correlation, are complementary supporting evidence for the idea that the booster sessions impacted the cognitive structure of the experimental group.

At the same time, the level of cohesion increased for the control group in the two post-booster sessions measurements. At first sight this may seem a strange pattern, since the control group continued in its downward trajectory (in terms of the means of the variables used in this study). But the simulation presented briefly in this paper explains this pattern. The level of cohesion among variables (i.e. total correlation), increases if one or more variables presents a higher correlation with the other variables, leading to an increase in the difference between the highest and the lowest average correlation. The difference in the average correlation shown in Figure 5 that this is exactly what happens with the control group.

Conclusion

For many decades, the cognitive training field has investigated for how long the positive effects of an intervention lasts. The evidence points to a genral trend of loss in the long-term: once the cognitive training is taken away, the cognitive performance returns

to its baseline level. Without relevant long-lasting effects, the cognitive enrichment hypothesis has been questioned. The current paper shows that booster sessions can be a promising strategy to maintain the level of cognitive performance gained during the training. In the current paper we show that not only the booster sessions improved people’s cognitive performance, on average, but it reversed the trajectory of cognitive decline (due to a regression to the baseline cognitive performance). Our result endorses the growing agreement in the field that the long-term efficacy of a training is reachable when associated with booster sessions. Despite the importance of adding booster sessions in cognitive training protocols, the number of studies with long-term follow-up assessments that also includes booster training is scarce probably due to methodological and material limitations. We believe that this scenario can be changed by developing automated, self-administered cognitive trainings that can be deployed in personal mobile devices. Moving from in-person training protocols to mobile-based interventions have the potential to revolutionize the field, enabling the administration of longer lasting, more intensive cognitive interventions, with multiple booster sessions over the years.

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