Cognitive Training Enhances Working Memory Capacity in Healthy Adults. A Pilot Study

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Abstract

Working Memory (WM) was previously conceptualized as a heritable trait resistant to extraneous influences. Recently, emerging evidence suggests that WM capacity can be improved by repeatedly using it as part of a cognitive training. In this pilot study, a new online cognitive training program is proposed. Twenty-five young healthy adults completed the training on their home computers. Before and after the training participants’ WM and attention capacity were measured. Results demonstrated that a short cognitive training produce significant improvements in participants’ WM (d=0.91) and attention capacity (d=0.66). It appears that healthy adult participants benefit from such a cognitive training.

1. Introduction

Working memory (WM) represents a fundamental cognitive ability that plays a crucial role in daily activities (i.e., focusing on a task, problem solving, interacting with others), in work and academic performance. WM was defined as the ability to temporarily retain, process, and manipulate information during simple or complex activities (Baddeley, 2003). It was argued that WM consists of a storage component (the items from long-term memory activated above a certain threshold), and an attention component (the limited capacity of processing associated with the central executive function; Engle, Tuholski, Laughlin, & Conway, 1999; Miclea, 1999).

WM is associated with fluid intelligence (Engle, Tuholski, et al., 1999), it predicts academic performance (Gathercole, Picknering, Knight, & Stegmann, 2004; Roberts et al., 2011), and low levels of WM are associated...
with attention disorders (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005), and behavioral problems (Aronen, Vuontela, Steenari, Salmi, Carlson, 2005).

Classically, WM has been conceptualized as a permanent trait, closely correlated to general intelligence (Engle, Kane, & Tuholski, 1999; Kyllonen, & Christal, 1990). Not only this capacity to temporarily store and process information was considered limited (Miller, 1956) but recent evidence showed that limitation of working memory is somewhere between one and four information chunks (Cowan, 2005; Kolk, Chwilla, van Herten, & Oor, 2003; McElree, 2001). Moreover, WM was seen as a highly heritable trait (Kremen et al., 2007), being resistant to extraneous experiences (Campbell, Dollaghan, Needleman, & Janosky, 1997).

Despite these arguments, there is emerging evidence that WM is actually malleable, and can be improved by either practice or medication. For example, Klingberg’s research team developed a WM training program (i.e., ‘RoboMemo’) and tested its effectiveness in a series of studies. The program successfully increased WM capacity in children with poor memory (Holmes, Gathercole, & Dunning, 2009), in children with attention deficits and hyperactivity disorder (Holmes et al., 2010; Klingberg, Forssberg, & Westerberg, 2002; Klingberg et al., 2005; Mezzacappa, & Buckner, 2010), and in adult patients after stroke (Westerberg et al., 2007). Holmes, Gathercole, and Dunning (2009) demonstrated that children with WM deficits improved their performance after completing this intensive five-week training program. More importantly, these gains generalized to WM components that were not specifically trained, also leading to improvements in mathematical skills.

Other WM training programs also yielded positive results. Jaeggi, Buschkuehl, Jonides, and Perrig (2008) used a “dual n-back” task which engage multiple executive processes as it involves the simultaneous tracking of auditory-verbal and visuo-spatial sequences. Varying the amount of training from eight to 19 days, the authors noticed improvements not only within the training tasks, but also in the general fluid intelligence displayed at the end of the training by their adult sample. Using another program upon both young and old adults, Schmiedek, Lovden, and Lindenberger (2010) found a positive transfer from the training tasks to untrained WM measures, to fluid intelligence and reasoning. This study is impressive not only by the large number of sessions (i.e., 100), but also by the fact that the transfer was assessed by the latent constructs of nine heterogeneous reasoning tasks.

Most of the above-mentioned studies used a relatively long time interval for their training (i.e., between 4 and 27 weeks, and between 20 and 100 sessions) and had a laboratory approach (i.e., participants visited the lab/school for each training session). Most importantly, training schedules regarding the intensity and the amount of necessary practice have not been studied systematically, with few exceptions (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Vogt et al., 2008). Therefore, in the present investigation we tested the effectiveness of a shorter WM training delivered via the Internet. Inspired by the potential of cognitive training to enhance the WM capacity we investigated whether it is doable to implement a three-week (15 sessions) online cognitive training program, whether young healthy adults would benefit from such a short intervention, and whether preliminary effect sizes would encourage us to further use this system.

To test these hypotheses, we designed a new WM training program that enables participants to exercise their cognitive abilities by completing five different modules. To optimize the training effects we made the program adaptive. Twenty-five young healthy adults completed the training program on their home computers. To evaluate the program impact, a battery of cognitive tasks was administered before and after the training.

2. Method

2.1. Participants

A convenience sampling procedure was used in this study. Fifty young healthy adult participants, undergraduate students were recruited (28 were females, age range 20-26 years, M = 21.82, SD = 1.28). After participants agree to complete the study, they were randomly assigned into either the training or the control condition.
2.2. Procedure

After reading the informed consent, participants in the training group signed a subsequent contract, stating once again their intention to complete the trial. Before the training began, we assessed the WM and attention capacity of all participants. Throughout the next three weeks, the experimental group engaged in a cognitive training program by practicing five different memory games each week. The games were presented in the same order, with a different game for each working day of the week. The software was set up to automatically end the session after 30 minutes from login. A wait list control group was used to assess the impact of the training with a between-subject design. Shortly after finishing the program, participants completed the post-assessment. Subsequently, participants were debriefed and received an individualized feedback via email.

2.3. Measures

To assess participant’s WM capacity we used the Working Memory Test (WMT, Miclea & Domuta, 2003). The WMT is conceptually similar to the well-known Letter Number Sequencing Scale (Wechsler, 1997) and consists of combinations of numbers and letters verbally presented to the participant. After hearing each sequence, the participant is asked to recall the numbers first, in ascending order, and then the letters, in alphabetical order. The WMT displayed sound psychometric proprieties (Miclea & Domuta, 2003).

To measure participant’s attention capacity we used the classical Toulouse-Pieron Test (1998). On one page presenting similar but not identical objects, participants have to identify the 4 targets presented at the top of the page. The test is time-limited, and participant’s correct answers, omissions and incorrect answers are computed.

2.4. The cognitive training program

The training program consists of five online modules. We designed five modules in order to make the training interesting and non-repetitive. Throughout the intervention, each module is presented only three times (i.e., once per week), being available for 30 minutes. A detailed description of each module is presented in Table 1. Task difficulty was matched to participants’ current performance on a trial-by-trial basis. This process of increasing the difficulty level continued throughout each session.

Table 1. The cognitive training program A

| Module name          | Module description                                                                 |
|----------------------|-------------------------------------------------------------------------------------|
| 1. The light organ   | Lamps arranged in a 5 x 3 grid are presented on the screen. Participants watched several lights go on, and then reproduce the same sequence. |
| 2. Words             | Word items are successively displayed on the screen. Then, another set of word items are successively displayed and participants have to decide which words were presented before. |
| 3. Classifying objects | Word items from two categories (i.e., “Animals” or “Plants”) are successively displayed in order to be classified. Participants have to remember the number of items classified in each category. |
| 4. Sorting numbers   | A string of digits are presented on the screen. Subsequently, participants have to reproduce the digit string in either increasing, decreasing or backward order. |
| 5. Colors            | Numbers painted in different colors are successively displayed. Participants have to remember the color of numbers. |

3. Results

The experimental and the control group participants were comparable in terms of demographics, attention and WM capacity at the beginning of the study (all t NS). To examine whether this cognitive training increases participants’ cognitive abilities both a between- and a within-subject design were used. To compare the pre- and post-training WM and attention scores a within-subject t test was computed. For the experimental group the mean
WM score increased from 16.20 (before the training) to 22.32 (after the training), $t(48) = -8.34, p < .001, 95\% \text{ CI} [-7.63, -4.60]$. The calculated effect size (Cohen’s $d = 0.91$) suggests the existence of a strong effect. Significant improvement in participants attention performance as a result of the training were also found $t(48) = -4.14, p < .001, d = 0.66, 95\% \text{ CI} [-2.45, -0.82]$. To further compare the two experimental conditions, a between subject-design was used for the posttest scores. Significant differences for WM $t(48) = 4.42, p < .001, d = 1.19, 95\% \text{ CI} [3.77, 10.06]$ but not for attention (t NS) were found. When estimating the impact of training programs on WM capacity, previous studies reported comparable effect sizes: $d = 1.42$ (Chein & Morrison, 2010), $d = 0.93$ (Klingberg et al. 2005), $d = [0.62–1.55]$ (Holmes et al., 2009), and $d = [0.83–1.58]$ (Westerberg et al., 2007).

Overall, our results are in line with the one presented by Klingberg, Forssberg, and Westerberg (2002) who concluded that a deficit in WM is not necessary for improvement to occur. This suggests that even healthy participants can benefit from a computerized training program.

4. Discussion

The results of this pilot study show that a relatively short cognitive training produce significant improvements in young healthy adults’ WM ($d = 0.91$, within-subject comparison) and attention capacity ($d = 0.66$, within-subject comparison). However, when comparing the two experimental conditions, participants in the training group demonstrated superior results only for WM ($d = 1.19$). We demonstrated once again that WM is malleable, and that important benefits can be achieved by repeatedly using this capacity, even for participants with no previous deficits. Because a limited number of measures were used in this study, we can only speculate about the educational significance of our results. However, previous research demonstrated that WM constrains the intellectual operations required in mathematics and science (Gathercole et al., 2004), and WM training leads to improvements in reading skills among college students (Chein & Morrison, 2010). Other studies also demonstrated that the cognitive training effects generalize to other tasks such as problem solving and reasoning (Klingberg et al., 2002), and improves IQ scores (Klingberg et al., 2005). This association between central executive functions and reasoning/IQ is based on the common skills or processes involved, such as the capacity to operate simultaneously with a certain number of objects. That is why improvements in WM capacity lead to improvements in reasoning, IQ, and academic performance.

Being available on the Internet, this kind of cognitive training provides the means to reach many individuals, including those who might not be inclined to consult a psychologist for assessment or treatment. Therefore, such training programs could be used both as a preventive intervention, as well as a convenient way to promote cognitive skill development in normal healthy adults. However, participants’ age appear to be important, as it was demonstrated that cognitive training programs are more effective in young rather than old adults (Schmiedek et al., 2010). Finally, the efficiency of different WM programs was clearly demonstrated with individuals that have WM deficits (Klinberg et al. 2005, Mezzacappa, & Buckner, 2010; Vogt et al., 2009).

The conclusions we can draw from this pilot study are limited by the fact that we did not include any measures of transfer (i.e., a fluid intelligence test). Future studies that investigate the effectiveness of cognitive training should evaluate transfer if they want to investigate the extent to which an improved WM capacity affects other cognitive abilities. Because we used only a control group without training, we cannot fully reject the idea that motivational aspects were responsible for certain improvements in the outcome measures. Our passive control group did not offer the best control for the effects of expectancy, adherence to a training schedule, or computer use. Nevertheless, the standardized performance measures of WM and attention indicate positive changes following the training, and these changes are comparable with those reported in similar studies. Finally, without a follow-up session, it was impossible to determine whether the improvements observed in this study are time limited or whether they have long-term effects. Consequently, future studies should include a long-term follow-up to determine not only the existence of initial improvement, but also its sustainability.
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