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Article

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Introduction

Working memory is defined as a cognitive system that serves to store and manipulate information for a short lapse of time to complete a task (Baddeley, 2012). Research has shown a great deal of interest for this executive function over the past 10 years or so (Redick, Shipstead, Wiemers, Melby-Lervåg, & Hulme, 2015). In this short time span, interventions targeting working memory have been developed that show that it is possible to improve this function through training, namely, the repetition of specific exercises (Rapport, Orban, Kofler, & Friedman, 2013). Working memory training is believed to bring about functional and structural brain changes, in keeping with the principle of neuroplasticity (Klingberg, 2010). Indeed, problems holding and manipulating information in memory have been shown to be associated with prefrontal cortex hypoactivity (Buschkuehl, Hernandez-Garcia, Jaeggi, Bernard, & Jonides, 2014), and activation of this brain region has been shown to be stimulated by working memory training (Klingberg, 2010).

The effects of this type of intervention have caught the interest of researchers working on ADHD given that ADHD has been shown to be associated with impaired working memory (Cortese et al., 2015) and to be strongly related to inattention symptoms (Burgess et al., 2010). Studies of working memory training have been of great interest as well on account of the possible generalization of the effects of this type of intervention to other cognitive functions that share related neural networks. In this regard, improving working memory skills could contribute to improve other altered and secondary cognitive functions in individuals with ADHD, such as nonverbal reasoning and executive function, and could even reduce the frequency and intensity of inattention and hyperactivity–impulsivity symptoms (Alloway & Alloway, 2010; Schwarb, Nail, & Schumacher, 2016).

In the light of these findings, a number of programs, computer based for the most part, have been developed and marketed to train working memory in ADHD populations (Redick et al., 2015). The results of two meta-analyses have indicated that such training improved working memory (Cortese et al., 2015; Rapport et al., 2013). However, for some of the studies reviewed, the interpretation of results was limited by the absence of a control group.

Cogmed is the most widely used computer program for working memory training (Rapport et al., 2013). Its exercises target verbal and visuospatial working memory. Of the studies that have examined the program, some have observed improvements in other cognitive functions related to working memory, to nonverbal reasoning, to executive function in daily life, and to ADHD symptoms (Beck et al., 2010; Klingberg et al., 2002, 2005), while others have reported no significant effect in this regard (Chacko et al., 2013; Gray et al., 2012). In short, the results of studies of the generalization of Cogmed's effects remain mixed to this day where youths with ADHD are concerned.

In addition, it has been clearly shown that ADHD symptoms and the working memory problems associated with these persist into adulthood (Miranda, Colomer, Fernández, Presentación, & Roselló, 2015; Van Ewijk et al., 2014). However, the two literature reviews carried out exclusively on Cogmed have focused solely on youths with ADHD (Chacko et al., 2013; Dentz, Parent, Gauthier, Guay, &

Romo, 2016). To date, only two studies have examined Cogmed's effects in a population of adults with ADHD (Gropper, Gotlieb, Kronitz, & Tannock, 2014; Mawjee, Woltering, & Tannock, 2015).

In the first of these studies conducted by Gropper et al. (2014) on university students with ADHD, participants were randomly assigned to either an experimental group that received the Cogmed training or a wait-list control group. The results demonstrated that training had a direct effect on verbal and visuospatial working memory measured by tasks similar to those used in Cogmed. They also showed that problems related to executive function in daily life assessed by way of a self-report questionnaire diminished following Cogmed training and that the effect persisted 2 months later. ADHD symptoms, too, diminished after training as measured by a self-report questionnaire. However, this effect was not maintained 2 months after training completion, which underscores the importance of studying not only immediate effects but also the maintenance of effects over time.

In the second study, Mawjee et al. (2015), too, focused on university students with ADHD and used a research design similar to the one employed by Gropper et al. (2014) with an experimental group and a wait-list control group. Moreover, in both studies, Cogmed training was completed over a similar period of time (30- to 45-min sessions, 5 times a week for 5 weeks). The results of the study by Mawjee et al. (2015) showed an improvement in visuospatial working memory skills measured by tasks different from those used in the Cogmed program for the participants who completed the training. However, no improvement in verbal working memory was observed and no generalization of effects to other cognitive functions (information processing speed, nonverbal reasoning) or to ADHD symptoms was noted. In sum, the results of the studies to date have demonstrated effects on visuospatial working memory in university students with ADHD. The results concerning effects on verbal working memory, however, have been mixed, as have been those regarding the generalization of effects to other cognitive functions and ADHD symptoms. Moreover, these two studies present different methodological limitations. For one, the samples were composed solely of students with ADHD recruited from a single school, and this limits the generalization of results. For another, the two studies comprised a wait-list control group only with no placebo, and this could have introduced an expectancy bias toward the Cogmed training.

The absence of a baseline measure point several weeks prior to Cogmed training constituted another limitation, given that people with ADHD tend to show a wide variability at the cognitive and behavior levels when assessed repeatedly (Borella, de Ribaupierre, Cornoldi, & Chicherio, 2013; Myatchin, Lemiere, Danckaerts, & Lagae, 2012). Finally, some authors have recommended including an assessment at least 3 months after working memory training completion to verify its long-term effects and the generalization of effects to daily life (Hovik et al., 2015; Mawjee et al., 2015).

Objectives

Against this background, we undertook a study to evaluate the direct effects of Cogmed training on verbal and visuospatial working memory in adults with ADHD not necessarily from the university student population. We also aimed to examine maintenance of effects 6 months after training completion. Finally, in an exploratory manner, we sought to determine whether the effects of Cogmed training generalized to cognitive functioning as measured by tasks targeting nonverbal reasoning, to executive function, and to ADHD symptoms.

To this end, the performances of adults with ADHD who received Cogmed training (experimental group) were compared against those of a group of adults with ADHD who received working memory training similar to Cogmed but of a lower intensity throughout the duration of the intervention (placebo group). Evaluators and participants were blind to group assignment. The study comprised two baseline measure points and one assessment immediately following Cogmed training completion. Maintenance of effects was assessed 6 months after working memory training completion, but only for participants in the experimental group.

Our main hypothesis was that participants in the experimental group would show greater improvement in verbal and visuospatial working memory skills compared with participants in the placebo group. We also hypothesized that the Cogmed effects would be maintained 6 months after training completion. Accordingly, among participants in the experimental group, no difference would be observed between measures taken at the end of the intervention and those taken 6 months later. Finally, a difference should be noted between measures taken just prior to Cogmed training and those taken 6 months later. The generalization of effects was examined in an exploratory manner.

Method

Participants

Participants were recruited at the Clinique des Maladies Mentales et de l'Encéphale of the Centre hospitalier Sainte-Anne in Paris. All had a clinical diagnosis of ADHD established by a physician. They ranged in age from 18 to 63 years. All participants had an intelligence quotient (IQ) above 80. Participants were included in the study regardless of psychostimulant or antidepressant use. However, if participants were on medication, they had to remain on the same medication for the duration of the testing. Participants could also have an anxiety disorder or a depressive disorder associated with ADHD. They were excluded if they had a severe medical condition, an obsessive–compulsive disorder, or a psychotic disorder. In all, 80 participants who met the inclusion criteria were contacted. The characteristics of the 55 participants who agreed to take part in the study are described in Table 1.

Of these participants, seven withdrew from the study prior to Cogmed training onset and four did after onset. Completers and withdrawers did not differ on sex, age, educational attainment, socioprofessional status, or scores for any of the dependent variables. The main reason given for withdrawing was lack of time to attend sessions and trouble getting organized.

Procedure

All participants were assessed 3 times, namely, 6 weeks prior to Cogmed training onset (T1, first baseline measure point), just prior to training onset (T2, second baseline measure point), and right after training completion (T3, first posttest). Participants in the experimental group were also assessed 6 months after training completion (T4, second posttest) to examine maintenance of effects. The control group was not tested at 6-month follow-up for ethical reasons in order that these participants could receive the intervention immediately after the experimental group.

Following the second baseline measure point, participants were randomly assigned by MATLAB either to an experimental group that received the Cogmed training or to a control group that received a placebo version of the training. Participants were distributed based on sex, age, psychostimulant and/or antidepressant use, and verbal and visuospatial working memory scores at the two baseline measure points (T1 and T2).

Whereas the Cogmed sessions were expected to last 30 to 45 min for both groups, mean session duration was 41.89 min (SD = 4.69) for the experimental group and 27.25 min (SD = 2.97) for the placebo group. Training took place 5 times a week for 5 weeks. For both groups, a research assistant ensured that participants completed the training sessions on the Cogmed Internet platform. This assistant contacted participants by telephone once a week to sustain their motivation through positive verbal reinforcement and to help them get organized to be able to complete the sessions.

Performances were not discussed with participants to keep them blind to group assignment. Participants were not compensated. Finally, this study was approved (ID: 2012-A01722-41) by the Comité de protection des personnes (CPP) of France (ethical research committee) based on criteria in accordance with the principles of the Helsinki declaration (Association Médicale Mondiale, 2002).

Participant Selection

ADHD diagnosisA diagnostic interview for ADHD in adults was carried out beforehand to validate the presence of ADHD (Diagnostisch Interview Voor ADHD bij volwassene, DIVA; Kooij & Francken, 2010). This interview covered the 18 criteria of the Diagnostic and Statistical Manual of Mental Disorders (4th ed.; DSM-IV; American Psychiatric Association [APA], 1994) for ADHD in childhood adapted to adulthood. The interview was found to possess satisfactory psychometric properties, scoring 90.0 on sensitivity and 72.9 on specificity (Pettersson, Söderström, & Nilsson, 2015).

Diagnosis of disorders associated with ADHDPresence of disorders associated with ADHD was examined by a hospital practitioner on the basis of DSM-IV criteria (APA, 1994) during a clinical interview. Anxiety symptoms were investigated with the State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). This self-evaluation questionnaire is composed of two separate scales (Y-A, Y-B), one for evaluating anxiety as a state, that is, at a given moment in time, and the other for evaluating anxiety as a personality trait. The instrument's internal consistency coefficients (α = .73-.88) and test–retest reliability indices (r = .71-.85) have been reported in the satisfactory range.

Depressive symptoms were evaluated with the Beck Depression Inventory II (BDI-II; Beck, Steer, & Brown, 1996). This self-evaluation scale measures severity of depressive symptoms according to the DSM-IV criteria (APA, 1994). Test–retest reliability was found to be satisfactory (r = .80; BDI-II; Beck et al., 1996). Validation on a French population was not available. Raw scores were used for both the BDI-II and the STAI to ensure group equivalence. Results are presented in Table 1.

Estimation of IQThe Wechsler Adult Intelligence Scale III (WAIS-III) short form (Wechsler, 2000) was used to ensure all participants had an IQ above 80. This version comprises four subtests: vocabulary, similarities, block design, and matrix reasoning (Grégoire & Wierzbicki, 2009). Test–retest reliability was found to be high, r = .95.

Independent variablesData on sex, age, educational attainment, and socioprofessional status were collected at T1. Data on medication use were culled from medical records.

Instruments of measure

Verbal working memoryThe Digit Span subtest (WAIS-III; Wechsler, 2000) was used to measure verbal working memory. In this task, participants must recall a sequence of numbers presented orally. In one condition, they are asked to recall the numbers in the same order presented, and in another condition, they must recall the numbers in reverse order. Span length grows according to performance. The number of items to recall ranges from 2 to 9 in the forward condition and from 2 to 8 in the backward condition. The instrument was found to have satisfactory reliability (r = .87) and validity (r = .77) (WAIS-III; Wechsler, 2000).

Verbal working memory was measured also with the Letter–Number Sequencing subtest (WAIS-III; Wechsler, 2000). In this test, participants are presented with a sequence of numbers and letters orally. They must then recall first the numbers in increasing order and then the letters in alphabetical order. Sequence length grows according to performance (2-8 items). The instrument possesses satisfactory psychometric properties, including in terms of reliability (r = .81) and conceptual validity (r = .87) (WAIS-III; Wechsler, 2000).

Visuospatial working memoryThe Corsi block-tapping subtest from the Wechsler Memory Scale–Third edition. Version, 3e édition (WMS III; Wechsler, 2001) was used to measure visuospatial working memory. The computer version of the test developed by Prof. André Achim of Université du Québec à Montréal was chosen to ensure standard administration. In this task, a series of nine blocks is presented asymmetrically in a given space, one at a time. Participants must then recall the blocks in the same order or in reverse order (range of 2-9 blocks). The instrument has shown satisfactory test–retest reliability (r = .85; WMS III; Wechsler, 2001).

Nonverbal reasoningNonverbal reasoning was measured with the WAIS-III Matrix Reasoning subtest (Wechsler, 2000). In this task, a series of color figures are presented with one left blank. Participants must choose the figure that best completes the series from among several proposed. The task's reliability coefficient (r = .87) and conceptual validity index (r = .68) have proved satisfactory.

Working memory and executive function in daily lifeThree subscales from the Brown Attention Deficit Disorder (ADD) scales (Brown, 1996) were used: (a) Utilizing Working Memory and Accessing Recall; (b) Organizing, Prioritizing, and Activating to Work; and (c) Focusing, Sustaining, and Shifting Attention to Tasks. The scales have been shown to possess satisfactory test–retest reliability (r = .68-.80).

ADHD symptomsThe short version of Conners' Adult ADHD Rating Scale (CAARS; Conners, Erhardt, & Sparrow, 1999) is a self-report questionnaire used to evaluate ADHD symptoms in adulthood. Its 18 items are adapted from those used to evaluate children according to the DSM-IV criteria (APA, 1994). The scale comprises five subscales: (a) Inattention/Memory Problems, (b) Hyperactivity/Restlessness, (c) Impulsivity/Emotional Lability, (d) Problems With Self-Concept, and (e) 12 items covering total ADHD symptoms. The instrument has been shown to possess satisfactory test–retest reliability (r = .80; Kooij et al., 2005). Only scores on the Inattention/Memory Problems and Hyperactivity/Restlessness subscales were used in our study.

Cogmed working memory trainingThe Cogmed RM working memory training computer program (Pearson Company, Sweden) was used in this study. Participants completed the training at home. A computer, a mouse, and an Internet connection are required. The program comprises 12 exercises targeting verbal and visuospatial working memory, but only eight are set automatically and completed at each session. Task complexity varies according to performance. For the placebo group, a control version of the Cogmed program was used. The placebo version comprised the exact same exercises as did the original version of the Cogmed program. However, in the placebo version, participants had to recall two or three items at most. In the original version, the number of items to recall increases gradually as a function of the participant's performance. Thus, a participant might have to recall four, five, or six items, depending on the task being performed. Also, the research assistant offered the same support under both versions of the program.

Variables from the Cogmed training programPerformance (span size) on the second and third days of training was used as the start index, and performance on the two best training days was used as the max index. The improvement index is calculated automatically by the Cogmed program by subtracting the start index from the max index for each participant. Mean duration of sessions was examined as well.

Statistical Analyses

Statistical analyses were run on SPSS version 16. The distribution of each dependent variable at the four times of assessment was verified against the criteria proposed by Tabachnick and Fidell (2007) for normality. Only one variable had to be transformed to meet the assumption of normality, namely, the variable associated with the CAARS Inattention/Memory Problems subscale (log transformation). Weighted scores were used except for the questionnaires for which all the normative data were not available. In all the analyses performed on the variables associated with the questionnaires, age was a covariate.

Evaluation of Direct Effects of Cogmed Training

Mixed-design ANOVA (2 groups × 3 times of measure) were run to assess Cogmed's effects on working memory. The three times of measure were 6 weeks prior to training onset (T1, first baseline measure point); 6 weeks later, just prior to training onset (T2, second baseline measure point); and right after training completion (T3, first posttest). Results for the experimental group were compared against those for the placebo group. Group × Time interaction effects were sought. If an interaction effect proved significant, repeated comparisons were carried out to verify whether the effect was present between T1 and T2 and between T2 and T3. A significant interaction effect was sought between T2 and T3. Moreover, when interactions proved statistically significant, we carried out simple effect analyses to determine the differences between time points as a function of the different groups. Effect size corresponded to the difference between means at T3 (first posttest) and T2 (second baseline measure point) divided by the cumulative standard deviation at T2 (Carlson & Schmidt, 1999; Morris, 2008).

Evaluation of Effects 6 Months After Cogmed Training

For variables that showed a significant Group × Time interaction effect, maintenance of effects 6 months after program completion was assessed for participants in the experimental group through a repeated-measures ANOVA between the three following times of assessment: T2 (second baseline measure point), T3 (first posttest), and T4 (second posttest). When statistically significant results were obtained, Helmert contrasts were performed. Effect size was measured using Cohen's d based on the difference between T4 and T2 divided by the cumulative standard deviation (Cohen, 1988).

Results

Preliminary Analyses

Participants in the experimental group did not differ from those in the placebo group on any of the sociodemographic variables examined at the two baseline measure points: sex, $\chi 2 = 1.36$, df = 1, $p = .24$; education attainment, $\chi 2 = 5.22$, df = 2, $p = .07$; and socioprofessional status, $\chi 2 = 0.13$, df = 1, $p = .71$. Moreover, no differences emerged in terms of comorbidity, $\chi 2 = 1.73$, df = 5, $p = .88$, or medication use, $\chi 2 = 0.92$, df = 3, $p = .81$.

The only significant intergroup difference observed was in terms of mean duration of Cogmed sessions. Not surprisingly, given that their exercises were easier, the placebo group took less time to complete their sessions than the experimental group did to complete theirs, $F(1, 44) = 41.71$, $p < .01$.

The mean improvement index for the experimental group was satisfactory (>17), which means that participants improved over the course of training (Chacko et al., 2013). The group's mean start index was 86.24 (SD = 10.97), and its mean max index was 117.67 (SD = 17.70).

Effects on Verbal Working Memory

The Time main effect was significant, $F(2, 44) = 12.76$, $p < .001$, $\eta 2 = .23$, on verbal working memory; that is, the participants in both groups improved their performance on the Digit Span subtest. The Group main effect did not prove significant, $p = .49$. However, the Group × Time interaction effect was significant, $F(2, 44) = 4.61$, $p = .01$, $\eta 2 = .09$ (see Table 2), only between T2 (second baseline measure point) and T3 (first posttest), $F(1, 44) = 5.60$, $p < .001$, $\eta 2 = .27$. Verbal working memory scores went from 9.73 to 11.43 for the experimental group, $F(2, 44) = 16.37$, $p < .001$, and from 9.52 to 9.95 for the placebo group, $F(2, 44) = 1.78$, $p = .19$. Effect size was moderate, $d = .06$.

However, on the Letter–Number Sequencing subtest, only the Time main effect proved significant, $F(2, 44) = 7.16$, $p < .001$, $\eta 2 = .14$. Performances improved for all participants. Neither the Group main effect, $p = .95$, nor did the Group × Time interaction effect, $p = .83$, was significant. Scores for the experimental group did not differ from those for the placebo group.

Effects on Visuospatial Working Memory

Results showed the Time main effect to be significant, $F(2, 41) = 23.49$, $p < .001$, $\eta 2 = .37$, but not the Group main effect, $p = .20$. Scores increased for all participants. The Group × Time interaction effect, too, proved significant, $F(2, 41) = 9.05$, $p < .001$, $\eta 2 = .18$, but only between T2 (second baseline measure point) and T3 (first posttest), $F(1, 41) = 11.73$, $p < .001$, $\eta 2 = .23$. Visuospatial working memory scores went from 8.87 to 12.78 for the experimental group, $F(2, 44) = 38.32$, $p = .001$, and from 9.06 to 9.94 for the placebo group, $F(2, 44) = 3.48$, $p = .07$ (see Table 2). Effect size was high, $d = .83$.

Working memory and executive function in daily lifeAnalysis of the results for the Utilizing Working Memory and Accessing Recall subscale revealed no Time main effect, $p = .22$, no Group main effect, $p = .88$, and no Group × Time interaction effect, $p = .47$. Scores did not differ between groups at the different time points.

Maintenance of effectsRegarding maintenance of effects among participants in the experimental group, the Time main effect proved significant for verbal working memory, $F(2, 20) = 7.36$, $p < .001$, $\eta 2 = .27$, as measured by the Digit Span subtest (see Table 3). Results showed scores increased significantly over time. The Helmert contrasts showed a significant score increase between T2 (second baseline measure point) and T4 (second posttest), $F(1, 20) = 22.86$, $p < .001$, $\eta 2 = .54$. In other words, effects on verbal working memory persisted 6 months after training completion. Effect size was moderate, $d = .63$.

The Time main effect proved significant also for visuospatial working memory, $F(2, 20) = 17.48$, $p < .001$, $\eta 2 = .47$ (see Table 3). Results showed scores increased significantly over time. The Helmert contrasts showed scores increased between T2 (second baseline measure point) and T4 (second posttest), $F(1, 20) = 26.32$, $p < .001$, $\eta 2 = .58$. Effect size was moderate, $d = .71$. In other words, training effects on visuospatial working memory persisted for at least 6 months after program completion.

Generalization of effects

Nonverbal reasoningResults indicated that the Time main effect was significant for nonverbal reasoning as measured by the Matrix Reasoning subtest, $F(2, 43) = 11.09$, $p < .001$, $\eta 2 = .21$. Performance improved for participants in both groups. The Group main effect, $p = .52$, and the Group × Time interaction effect, $p = .24$, did not prove significant.

Executive functionResults showed that neither the Time main effect, the Group main effect, nor the Group × Time interaction effect were significant for executive function as measured by the

Organizing, Prioritizing, and Activating to Work subscale (Time, p = .52; Group, p = .12; Group × Time, p = .62) and by the Focusing, Sustaining, and Shifting Attention to Tasks subscale (Time, p = .36; Group, p = .26; Group × Time, p = .75). Scores for executive function in daily life did not differ between groups or across the different time points.

ADHD symptomsHere, too, results showed no significant Time main effect, Group main effect or Group × Time interaction effect on ADHD symptoms as measured by the Inattention/Memory Problems subscale (Time, p = .80; Group, p = .14; Group × Time, p = .12) and by the Hyperactivity/Restlessness subscale (Time, p = .75; Group, p = .60; Group × Time, p = .30). ADHD symptoms did not differ between groups or across time points.

Discussion

The main objective of this study was to examine the effects of Cogmed training on verbal and visuospatial working memory in adults with ADHD. Results indicate that verbal and visuospatial working memory capacity improved over time for participants in both the experimental group and the placebo group. This might be explained by a test–retest effect or by the possibility that the completion of working memory training exercises at whatever intensity is enough to improve this cognitive component. Still, results show that verbal and visuospatial working memory skills improved more among participants in the experimental group compared with those in the placebo group. This suggests that raising the degree of difficulty of exercises gradually as participants improve allows making greater gains where working memory skills are concerned.

From a clinical perspective, prior to training, the average working memory capacity rated a 6. This corresponds to the average rating for the general adult population (WAIS-III; WMS-III; Wechsler, 2000, 2001). These results are in line with those reported in other studies that demonstrated that Cogmed training improved working memory in people with ADHD, but not with a systematic impairment of working memory (Chacko et al., 2014; Cortese et al., 2015; Gropper et al., 2014; Mawjee et al., 2015).

Clearly, Cogmed training has a direct effect on working memory as measured on tasks similar to those completed in training. These tasks consist of recalling sequences of numbers or how figures are arranged in space, in the order presented or backward. However, when working memory was measured on a task different from the training exercises, the Cogmed program's effect was no greater in the experimental group than in the placebo group. This task consisted of memorizing a mix of letters and numbers and then recalling the numbers in increasing order and the letters in alphabetical order. In short, the program's effect on working memory is detected only when measured on tasks similar to the exercises completed during training (Redick et al., 2015). In other words, repeating a specific task helps increase span size, but this increase does not transfer to other tasks that entail different rules and potentially different memory loads.

Results show that improvements in verbal and visuospatial working memory persist at least 6 months after training completion. These results are in line with those of Gropper et al. (2014) and Mawjee et al. (2015) who demonstrated that the program's effects on working memory persisted more than 2 months after intervention completion among students with ADHD. The program's effects have also been shown to persist over 6 months in children with ADHD who completed the training (Rapport et al., 2013).

Another secondary objective of our study was to assess in an exploratory manner whether the effects of Cogmed training on adults with ADHD generalized to cognitive functions involving nonverbal reasoning, to executive function in daily life, and to ADHD symptoms. No generalization of effects was detected concerning executive function in daily life and ADHD symptoms. Other studies, too, have observed that Cogmed training did not lead to a greater improvement in executive function in daily life or in ADHD symptoms compared with a control group, among both youths and students with ADHD (Cortese et al., 2015; Mawjee et al., 2015; Rapport et al., 2013). However, Gropper et al. (2014) did report that Cogmed training diminished ADHD symptoms and improved executive function in daily life among students with ADHD, as measured on a self-report questionnaire. These differences in results can be explained by the research protocol used. Our study included a placebo group and double-blind assessments, two elements absent from the Gropper et al. study. The research design applied by Gropper et al. does not allow saying whether the results were due to a test–retest effect, a desirability bias, or Cogmed training.

The hypothesis that has driven research on the Cogmed training program is challenged by the results of our study. According to this hypothesis, improvements in working memory should generalize to other related functions based on the principle of neuroplasticity. Our study shows that, following Cogmed training, participants manage to recall 1 additional element in a verbal working memory task and 1.5 additional elements in a visuospatial working memory task. However, this increased working memory capacity does not lead to a generalization of effects to other functions or to a reduction in ADHD symptoms. There are clear gains in working memory when these are measured on tasks similar to the exercises proposed in the Cogmed training program. However, these gains have no repercussions on daily life based on self-report.

Limitations and Outlook

The first limitation that must be addressed is that the placebo version might have had an effect on working memory. Some authors have shown that recalling two or three items alone improved working memory in children with ADHD (Chacko et al., 2013). If this is true, then our placebo version could be qualified as a low-dose version of the training. The use of a wait-list control group also would have allowed controlling the potential effects of the placebo version. Second, we must bear in mind that it took participants less time to complete the placebo version. Consequently, there is no way to know whether the effects of Cogmed training on working memory are related to the increasing degree of difficulty of the tasks based on performance or to the extra amount of time spent in front of the computer. Mawjee et al. (2014) showed that Cogmed training improved working memory in students with ADHD just as much whether sessions lasted 45 min or only 15 min. However, this still suggests that the effects of the program observed in that study were indeed related to the tasks becoming progressively more difficult based on how participants performed.

Furthermore, the placebo group was not evaluated 6 months after the beginning of the study. Consequently, there is no telling for sure whether the maintenance of effects observed in the experimental group was due to the cognitive training or merely to the passage of time. Another limitation has to do with the small size of the study sample, especially at the last time point involving the assessment of effects 6 months after training completion. This reduces the scope of the results. Moreover, though our study evidenced no generalization of effects following training, 6 weeks is perhaps too short an interval for generalization to occur.

Finally, the use of self-evaluation questionnaires can be questioned as well. Participants might not realize the difficulties that they have in daily life or the changes that training produces. In future, including a hetero-evaluation would allow comparing changes reported by participants with those reported by a family member, for instance. Another possibility for measuring effects would be through the use of instruments more sensitive than questionnaires to short-term changes

(Gathercole, 2014). Also, ambulatory measures could be used to assess ADHD symptoms and executive function in daily life (Wilhelm & Schoebi, 2007).

Conclusion

Cogmed training improves verbal and visuospatial working memory in adults with ADHD as measured on tasks similar to the exercises proposed by the program. These effects persist up to 6 months after training completion. However, no generalization of effects is observed to other cognitive functions involving nonverbal reasoning, to executive function in daily life, or to ADHD symptoms.

These results challenge the claims made by Cogmed on its business website to the effect that the program is effective in treating attention problems and improving performance in daily life over the long term in adults with ADHD.

Declaration of Conflicting Interests

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