Journal of Cognitive Enhancement
https://doi.org/10.1007/s41465-017-0056-x

ORIGINAL ARTICLE

Computerized Progressive Attention Training (CPAT) vs. Active Control in Adults with ADHD

Tamar Kolodny[1] · **Yael Ashkenazi**[2] · **Moran Farhi**[3] · **Lilach Shalev**[3,4]

Received: 15 April 2017 / Accepted: 10 November 2017

Abstract

Higher education students with ADHD cope with various academic obstacles such as difficulty to sustain attention while studying and deficient ability to focus attention effectively on academic tasks. Shalev et al. (*Child Neuropsychology*, *13*(4), 382–388, 2007) have developed a computerized progressive attentional training (CPAT) program for children with ADHD, which is composed of four sets of structured tasks designed to uniquely activate various attentional functions: sustained-, selective-spatial, orienting-, and executive-attention. The goal of the present study was to evaluate the effect of the CPAT vs. an active control training program on improving attention functioning among high functioning adults with ADHD. Thirty participants, randomly assigned either to the CPAT or to the active control (computer games; CG) groups, completed 16 1-h training sessions across 8 weeks. Attention functioning was assessed using both objective and subjective tools three times: before the intervention (pre-test), after the intervention (post-test), and at follow-up (2–3 months later). Participants in the CPAT group exhibited significantly greater improvements in selective-spatial attention and in executive attention tasks (that were different than the attention training tasks) compared to participants in the CG group, and these gains were maintained at follow-up. These results provide strong evidence for near transfer effects of the CPAT. In addition, modest improvement in sustained attention was recorded in both training groups. However, analyses of the self-reported ADHD symptoms across the three points of assessment showed no change in either group. Future studies with larger samples should replicate and elaborate the present findings in order to assess whether the near transfer effects of the CPAT program could be translated to everyday functioning in high functioning adults with ADHD.

Keywords Adult ADHD · Attention training · Cognitive training

Introduction

Attention-deficit/hyperactivity disorder (ADHD) was thought to be exclusively a childhood disorder. However, it is now recognized that ADHD frequently persists into adulthood, troubling approximately 2.5% of the adult population (American Psychiatric Association 2013) and generating significant impairments in academic, occupational, social, and emotional functioning (Barkley et al. 2006; Biederman et al. 2006). In particular, higher education poses great challenge for students with ADHD, coping with various academic difficulties such as inability to sustain attention while studying and deficient ability to focus attention on academic tasks (Prevatt et al. 2006; Reaser et al. 2007). At present, ADHD is primarily treated with medications which can ameliorate many of the core symptoms. However, some persons do not respond to

---

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s41465-017-0056-x) contains supplementary material, which is available to authorized users.

✉ Lilach Shalev
lilachsm@tauex.tau.ac.il

[1] Department of Cognitive Science, The Hebrew University of Jerusalem, Jerusalem, Israel

[2] Department of Psychology, The Hebrew University of Jerusalem, Jerusalem, Israel

[3] Constantiner School of Education, Tel-Aviv University, Tel-Aviv, Israel

[4] Sagol School of Neuroscience, Tel-Aviv University, Tel-Aviv, Israel

medications at all or have adverse responses and hence are lacking medical treatment (20–50%; Wilens et al. 2002). Furthermore, most individuals treated with medications continue to evidence at least some residual symptoms and functional impairments (Advokat 2010; Antshel 2015; Rapport et al. 2013). Therefore, recommendations for treatment of ADHD call for further intervention concomitant with medications (Safren 2006), in order to provide patients with skills for coping with attentional impairments. The high prevalence of ADHD and the broad negative impact on everyday lives of individuals has led researchers to examine a wide range of treatment alternatives, including psychotherapies, biofeedback, and cognitive training, to name a few.

An emerging important relevant intervention for ADHD is cognitive training. Klingberg and his colleagues (Klingberg et al. 2002, 2005) demonstrated that 5 weeks of computerized working memory training (CWMT; Cogmed) in children with ADHD not only enhanced working memory performance but also ameliorated ADHD symptoms according to parents' ratings, both post-intervention and at a 3-months follow-up. In the above studies, participants in the experimental group who completed approximately 25 training sessions in which the level of task difficulty was gradually and personally adjusted were compared with participants in a control group, who completed similar number of training sessions that were shorter and comprised of fixed low level working memory tasks irrespective of the participants' performance.

During the last several years, two studies have examined the effect of CWMT on higher education students with ADHD. In the first one, Gropper and her colleagues (Gropper et al. 2014) investigated the effect of CWMT in college students with ADHD or learning disabilities. Compared to participants in a waitlist control group, participants in the CWMT group improved on WM tasks and they reported decreased levels of ADHD symptoms that were maintained in the follow-up assessment. However, since no active control group was included in this study, it is impossible to conclude that the positive outcomes were specific to the CWMT. Indeed, in another study of CWMT, Mawjee et al. (2015) studied whether CWMT improves WM in everyday activities and translates to other cognitive functions in adults with ADHD while controlling for motivation, engagement, and expectancy. The authors compared standard and shortened versions of adaptive CWMT. Results showed that both standard and shortened adaptive CWMT produced similar improvements in criterion measures (i.e., standardized tests of working memory that closely resembled training activities from CWMT) compared to a waitlist control group. However, no near- and far-transfer effects were recorded. Thus, the authors concluded that standard (i.e., full length) CWMT did not substantially improve WM in everyday life in college students with ADHD and questioned the WM training effects that were reported in previous studies.

In a recent study, Stern and her colleagues (Stern et al. 2014) investigated the effects of a different computerized cognitive training, aimed at training attention, memory, and executive functions—AttendFocus (of the "AttenGo" online cognitive training system—www.attengo.com) in adults with ADHD. They contrasted between a protocol with high cognitive control demand and a protocol with relatively low cognitive control demand. Significant positive changes in symptom ratings, ecological subjective measures of executive functions, and occupational performance were found in both groups, while no significant changes were found in neurocognitive measures and subjective self-reports of quality of life. Notably, no specific benefits of the high cognitive control demand protocol over the low demand protocol were documented. The authors suggested that the absence of protocol by time of testing interaction effects may have resulted from weak statistical power, non-unique cognitive training, and/or placebo effects.

Similar shortcomings could also be attributed to the abovementioned CWMT studies. The positive effects that were reported in those studies investigating the utility of working memory training in ADHD could have been the results of differences in motivation and engagement of participants in the experimental groups and in the active control groups. It should be emphasized that the absence of proper active control group is perhaps the most substantial pitfall in training/intervention studies. Training studies that do not include an active control group or that include an active control group that entails lower motivation and engagement compared to the experimental training group do not permit the inference of any specific conclusion regarding the effectiveness of the latter. Another major pitfall is the lack of blind evaluation. As long as the testers are aware of the group classification of participants, the validity of the recorded effects is questionable. Further limitations of the previous studies include too homogeneous groups and lack of measures of functional impairment (Chacko et al. 2013; Rapport et al. 2013).

Thus, as briefly described above, and as concluded by several recent reviews and meta-analyses (Cortese et al. 2015; Melby-Lervåg and Hulme 2013; Rapport et al. 2013), not enough evidence were accumulated to support the efficacy of cognitive training in ADHD. In particular, the existing studies do not support the claim that the outcomes of cognitive training in general and of working memory training in particular, are transferable to other cognitive domains and/or to everyday functioning. Furthermore, it has been asserted that neurocognitive treatment in ADHD should be based on basic neuroscience and that researchers ought to further elaborate "next-generation" neurocognitive training programs that specifically target core neurocognitive deficits that are well documented in ADHD (e.g., deficits in sustained attention and executive control) and to improve the implementation of these interventions in order to strengthen their scope and to fulfill their therapeutic potential (Chacko et al. 2014; Cortese et al. 2015; Sonuga-Barke et al. 2014). In addition, it was suggested that multi-component interventions may have greater potential due to the heterogeneous nature of ADHD.

The above crucial requirements are well addressed in the computerized progressive attention training program that was developed over a decade ago by Shalev et al. (2007) for children with ADHD. The CPAT is derived from Tsal, Shalev, and Mevorach's multifaceted model of attention (Tsal et al. 2005) that was conceptualized in light of Posner and Petersen's (Petersen and Posner 2012; Posner and Petersen 1990) influential theory of attention networks. Tsal and his colleagues' model refers to four distinct functions within the attention regime: (a) sustained attention, the ability to allocate attentional resources to a non-attractive task over time while maintaining a relatively constant level of performance; (b) selective-spatial attention, the ability to focus attention on a relevant target while ignoring adjacent distracters; (c) orienting attention, the ability to direct attention over the visual or auditory field according to sensory input, and to disengage and reorient efficiently; and (d) executive attention, the ability to control attention, and to resolve conflicts of information and/or responses. In other words, executive attention enables us to suppress irrelevant information and to process effectively the relevant information. While the above attention functions constantly interact, they act as separate (at least to a certain extent) cognitive modules. Thus, different cases of ADHD may result from a deficit in any of the attention functions (or any combination of deficits; Tsal et al. 2005). This model was supported in several studies that demonstrated large heterogeneity in the attention profiles of children, adolescents, and adults with ADHD (Lukov et al. 2014; Segal et al. 2015; Shalev et al. 2016b; Tsal et al. 2005).

The CPAT is thus a theory driven program which focuses on training these four components of attention, using four sets of structured tasks. The set of tasks that aims at improving sustained attention uses a continuous performance task (CPT) in which a long series of stimuli is presented and participants are required to respond as fast and as accurate as they can to a pre-specified target that appears on minority of trials and to refrain from any response on all other cases. The set of tasks that addresses selective-spatial attention uses conjunctive visual search tasks in which participants are requested to decide as fast and accurate as possible whether or not a display contains a target item. The set of tasks that trains orienting attention uses a task in which a string of stimuli is presented in the periphery and one of the items is signaled by a couple of arrow heads and participants are instructed to identify this item as fast and accurate as they can. The set of tasks that practices executive attention uses hierarchical figures (large shapes comprised of small elements; for instance, a large cube made of small smiley faces), and requires conflict resolution. A full description of the training tasks could be found in Section 1 in the Supplementary materials, and an illustration of each task is presented in Fig. 1 and in more detail in the Supplementary Figures S1–S3.

In the CPAT program, performance is encouraged by tight schedules of feedback and participants automatically advance in ordered levels of difficulty contingent upon performance. In a study with children with ADHD, 8 weeks of training with the CPAT program resulted in far transfer effects: significant improvements in academic performance and reduction of parents' reports of inattention (Shalev et al. 2007). No similar improvements were observed for children in the active control group whose sessions consisted of standard computer games. In another study, children with fetal alcohol spectrum disorder that completed the same CPAT protocol improved significantly in non-trained academic skills (Kerns et al. 2010). A recent study used the CPAT to train patients after stroke and documented analogous near and far transfer effects—increase in sustained attention and enhancement of other cognitive functions (e.g., language, memory, number skills, and praxis; Sampanis et al. 2015). The fact that the CPAT produced far transfer outcomes both in the case of individuals who suffer from developmental attention deficits and in the case of people who suffer from acquired attention deficits strengthens the hypothesis that the underlying mechanism of the generalization effects is improved attention and/or cognitive control functioning which facilitates various aspects of everyday functioning.

Our goal in the present study was to investigate whether the CPAT is an effective intervention for higher education students with ADHD. Note that unlike children with attention deficits, university and college students with ADHD are a specific sub-sample of the ADHD population, who are well experienced and successful in coping with their difficulties, specifically in an academic context. These individuals managed, in many cases aided by various prolonged interventions, to effectively compensate for their difficulties, and to get accepted to their academic programs. Hence, in the present study we use the term "high functioning adults with ADHD" to describe this population. Nonetheless, these students still cope with unique challenges throughout their studies (Prevatt et al. 2006; Reaser et al. 2007), and could benefit from cognitive training if it will improve their attention functioning and/or ameliorate the magnitude of ADHD symptoms which in turn will hopefully improve their academic performance. Although it is especially challenging to demonstrate improvement in a population that is high functioning to begin with, the benefit for students with ADHD could be substantial, making them an important target-population for an intervention study.

In light of the recent reviews of cognitive training in ADHD and their critical view about the essential need for appropriate active control group in studies that aim at evaluating the utility of cognitive intervention, the active control

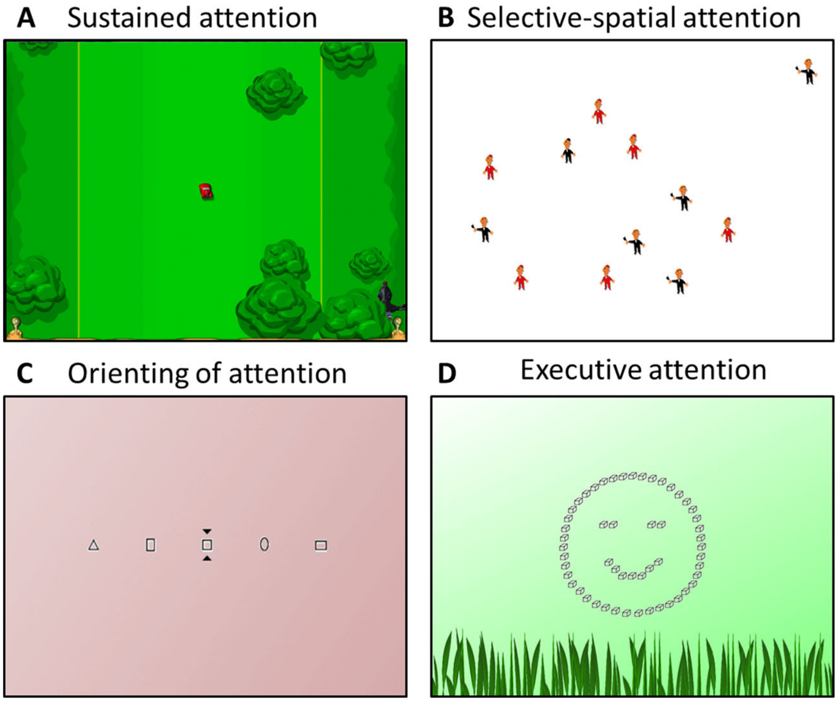

Fig. 1 Illustration of the CPAT (computerized progressive attentional training). A comprehensive description of tasks is included in the Supplementary. The figures depict examples of tasks. **a** Sustained attention, report the red car as soon as it appears on the screen. **b** Selective-spatial attention, determine whether a man figure dressed in black and wearing a hat is presented in the display or not. **c** Combined orienting and selective attention, identify the item pointed by the arrowheads—is it a square or a circle? **d** Executive attention, determine if the local elements constructing the global shape are smileys

training in the present study was designed to match as closely as possible to the CPAT group in all surrounding non-specific effects of training. Participants in this group were trained on four standard computer games (CG) that emphasized visual search abilities, visual motor planning, and object tracking; and hence were expected to improve selective-spatial attention (Green and Bavelier 2003, 2007). Crucially, all games in the CG sessions included a major component of feedback and adaptive advancement in difficulty levels. Moreover, the procedure of training was similar for CG and CPAT participants: all participants had the same number and length of sessions; they all had individual appointments in the lab, and had a one-by-one interaction with a fixed trainer. The above similarities between the two training protocols should not mask the qualitative differences between them: unlike standard computer games that are developed in order to produce amusement and to engage the player, and often combine various cognitive demands, the CPAT is, as described above, a theoretically driven program based on the four functions of attention model (Tsal et al. 2005) and was developed particularly for children with ADHD considering the cognitive characteristics of this population. Another major characteristic of the CPAT is the use of a tight schedule of highly informative positive feedbacks, which also translate to accumulation of points. Here, due to the fact that each of the four categories of training tasks specifically addresses a given function of attention, the feedbacks and points serve not only as motivation and entertainment boosters, as in all standard computer games, but also as informative tool in the cognitive level—it informs the trainee that s/he performed the task effectively (i.e., managed to focus attention in a limited area and ignore adjacent distractors, succeeded in inhibiting impulsive responses, managed to effectively cope with conflict etc., Shalev et al. 2016a).

The study included 30 adults with ADHD, trained over a period of 2 months. Before and after training, as well as 3 months after completion of the intervention, participants' performance was assessed on three attention tasks (that were different from the training tasks) reflecting functioning in sustained, selective-spatial, and executive attention (conflict resolution). In addition, participants evaluated the severity of inattention and hyperactivity/impulsivity symptoms in their daily life by using a self-report ADHD questionnaire.

Importantly, when assessing the effectiveness of cognitive training, it is critical to evaluate not only how evidence support the hypothesis that training yields improvement, but also the valid hypothesis that training does not improve performance or outcomes. While classical frequentist statistics based on null hypothesis significance testing (NHST) only provide the former, evidence in favor of the null can be quantified using Bayesian statistics. The Bayes factor (BF) is calculated as the ratio between the probability of observed data given the null hypothesis and its probability given the alternative. Thus, if an effect is truly absent, it will be reflected in a large Bayes factor; whereas, if an effect is not found due to low statistical power, this will result in a Bayes factor close to 1, indicating that the data does not provide sufficient evidence for either hypothesis (see Jarosz and Wiley 2014; Rouder et al. 2012; and other resources for comprehensive description of the Bayesian approach). In the current study, we complement our standard analyses with Bayesian analyses, to aid interpretation of null results.

Materials and Methods

Participants

The target population of participants for the current study was adults with ADHD who perform poorly in neuropsychological attention tasks. Students in the Hebrew University of Jerusalem, previously diagnosed with ADHD by a qualified psychiatrist or neurologist, were recruited for the study. Participants provided copies of their diagnosis reports to assure complete and valid evaluations were conducted. All the participants had intact color vision, no uncorrected visual problems, and no diagnosis of mood or anxiety disorders, conduct disorder, or any other neurological disorder. All potential participants went through the pre-test assessment battery including five visual attention computerized tests and the MATAL self-report questionnaire for symptoms of inattention and hyperactivity/impulsivity in childhood and adulthood (Ben-simon et al. 2009). Participants who scored 1 SD or more from a control group mean in at least one of the attention tasks and scored 2 SDs or more from norm mean in at least one of the four MATAL subscales (see more details below), were invited to participate in the training program. This procedure resulted in a group of 35 participants. Participants were pseudo-randomly assigned to the attentional training group (CPAT) or the computer games group (CG), matched based on age and sex. Five participants failed to complete the follow-up session and were excluded from analysis, yielding a final sample of 30 participants, 15 in each group (CPAT, six males; mean age = 25.0; SD = 2.1; CG, seven males; mean age = 25.2; SD = 3.3; $\chi^2_{gender} = .14$; n.s.; $t_{age}(28) = .23$; n.s.). All participants filled a written informed consent form describing the study and its aims, and were aware of the existence of two training groups in the study. They were told that both training protocols are based on previous studies with other populations (i.e., not adults with ADHD). After the follow-up testing session, participants in the computer games group were informed about the study design and were offered to go through the attentional training if they desired. All participants were paid at the follow-up session 200 NIS (approximately $50) for participation, to encourage attainment.

Training Procedure

The training program was carried out over a period of 8 weeks consisting of two 1-hour sessions per week. Training sessions were held in the lab; each participant was seated in a quiet room and was supervised by a research assistant during the entire session. Participants who were regularly treated for ADHD with psychostimulants (two in each group, using methylphenidate) were on their medication during training (but off medication on the assessment sessions).

Attentional Training Program (CPAT)

The training software for the attentional training group was the CPAT, used in Shalev et al. (Shalev et al. 2007). The software consists of four categories of computerized exercises, each aimed at one of the four functions of attention: sustained, selective-spatial, orienting, and executive attention. Each category consists of several levels of difficulty, and the advancement of participants between levels is individually adjusted, according to improvement of RTs relative to one's own baseline, for each category separately. The procedure of individual gradual advancement is designed to maintain constant challenge, minimize frustration, and aims at maximizing benefit of training. The training software includes tight feedbacks to encourage improvement: online auditory feedback for errors and online positive visual feedback for fast reaction times (relative to one's own baseline). In the sustained attention training tasks, online visual feedbacks were absent to refrain from rewards that decrease the need for sustained attention. Additional feedback included display of accumulated points on the end of each given training task and in the summary of each training session. During each training session, participants completed 2–3 blocks of each exercise category. A full description of the training tasks could be found in Section 1 in the Supplementary materials, and an illustration of each task is presented in Fig. 1 and in more detail in the Supplementary Figures S1–S3.

Computer Games Training Program

The computer games training program included four popular captivating computer games, with a challenging visuo-motor component and an inherent emphasis on reaction time, in free web-based versions[1]: Tetris (http://www.net-games.co.il/online-games/Tetris.html), requiring high spatial ability and previously shown to improve spatial performance (Okagaki and Frensch 1994); GlueFo (http://www.bored.com/games/play/183/GlueFO.html), requiring rapid discrimination and movement while attending multiple moving stimuli; String Avoider (http://www.bored.com/games/play/81/String-Avoider.html), practicing the hand-eye coordination and motor skills; and Filler (http://www.shockwave.com/gamelanding/filler.jsp), requiring distributed attention and online planning in a quickly changing environment. All computer games entailed individually based gradual increase of difficulty level and included inherent scoring and feedback mechanisms. Notably, however, difficulty levels were not

---

[1] Some of the games used in the training program are no longer available in the links provided. However, versions of these games are easily found in other websites and platforms, through any web search engine, using the names: Tetris, GlueFo, String Avoider, and Filler.

maintained between sessions. Participants played all games during each training session.

Assessment Tasks

In each testing session (pre-test, post-test, and follow-up), participants completed three[2] visual attention computerized tasks which were used to assess different aspects of attention functioning (based on Tsal et al. 2005). Participants using psychostimulants abstained from medication at least 24 h prior to each assessment session.

Conjunctive continuous performance task (CCPT) was used to assess sustained attention. Participants were presented with a long series of stimuli and were requested to respond to a single prespecified target, defined by a conjunction of color and shape, while withholding responses to all other stimuli. This task is described in detail elsewhere (Shalev et al. 2011). Importantly, this task taps the same construct as the training task in the CPAT that targets sustained attention, and relies on a similar type of continuous performance paradigm. However, it consists of different stimuli, different background, and different distractors than the training task in the CPAT.

Conjunctive visual search task (CVST) was administered to assess selective-spatial attention. Participants were instructed to search for a target stimulus, defined by a conjunction of color and shape, appearing among distractors. The set size (i.e., number of distractors) varied between 4, 8, 16, and 32, creating different levels of attentional load. Half the trials contained a target stimulus and half did not, only target-present trials with 8, 16, or 32 items were analyzed. The detailed apparatus of this task can be found elsewhere (Shalev et al. 2016b). Here too, the paradigm is similar to the training task in the CPAT that practices selective-spatial attention, but the stimuli, the number of items and the spatial display were completely different from the training task.

Spatial stroop-like task (SSLT) was used to assess conflict resolution which is a major aspect of executive attention. Participants had to respond to the location of an arrow stimulus appearing on the screen, while ignoring the direction the arrow is pointing at. Fifty percent of the trials were congruent (e.g., an arrow pointing upward appears in the upper half of the screen) and 50% of the trials were incongruent (e.g., an arrow pointing downward appears in the upper half of the screen). The congruency effect reflects the extent to which conflicting irrelevant information is being effectively suppressed, which is a component of executive attention. This task, including an additional matched condition of direction judgment while ignoring the location dimension, is described in detail elsewhere (Shalev et al. 2016b). Note that this paradigm utilizes bi-dimensional stimuli where a dimension needs to be ignored, whereas the training task in the CPAT that targeted executive attention employed hierarchical figures. These different paradigms both tap into conflict resolution.

Testing at every time point was conducted by an experimenter who was blind to the group assignment of each participant. The order of administration was counter-balanced across participants and across sessions. None of the participants were on stimulant medication during testing.

In all tasks, mean reaction time was calculated in each condition for correct responses only, after excluding extremely short (< 150 ms) or long (> 3000 ms) responses and responses deviating more than two SDs (for the CVST and SSLT) or three SDs (for the CCPT) from the participants' mean in the respective condition.

For the CCPT, the dependent measures were omission and commission errors, and the coefficient of variation (ICV), computed as the ratio of SD and mean of RT (Dankner et al. 2017; Saville et al. 2011; Wagenmakers and Brown 2007).

For the other tasks, dependent measures were inverse efficiency scores (IES), computed as mean RT divided by accuracy rates in different conditions: set sizes in the CVST (8, 16, or 32) and congruent and incongruent trials in the SSLT. Inverse efficiency scores are used to incorporate both aspects of performance within a single measure, and are appropriate in the current study where accuracy rates are high (Bruyer and Brysbaert 2011; Townsend and Ashby 1983).

In the pre-test session only, two more attention tasks were included—a go/no-go task to assess response inhibition (see Segal et al. 2015 for a full description of the task), and a spatial cued-identification task to assess orienting of attention (see Shalev et al. 2011 for details of this task). These were included in the pre-test session to give a broad description of one's attention functioning profile, and were used together with the other assessment tasks as inclusion criteria for the study. For selection purposes, summarizing measures were extracted for each attention task, based on differences in RT and accuracy between different conditions, as described in Lukov et al. (2014) and in Segal et al. (2015). These summarizing measures were converted to *Z*-scores based on the mean and SD of a control group, consisting of 100 healthy adult participants (unpublished data). A *Z*-score of −1 or lower in at least one of the attention tasks (total of 5) was a threshold requirement for participation in the training program.

Behavioral ADHD Symptoms Assessment

In each testing session (pre-test, post-test, and follow-up), participants completed the MATAL ADHD questionnaire, referring to symptoms of inattention and hyperactivity/impulsivity in childhood and adulthood (Ben-simon 2007; Ben-simon

---

[2] We did not administer the fourth task that assesses orienting attention since a valid administration of the orienting task requires tracking eye movements, as saccades to the peripheral targets may undermine the validity of results. Unfortunately, an eye tracker system was not available in the setup for this experiment; thus, orienting of attention was not included in the outcomes assessments.

et al. 2009). A detailed description of the questionnaire is included in Section 2 in the Supplementary Materials. All subscales were used to determine participation in the study (see Participants), but only scales of adulthood were used to assess differences before and after training. Unfortunately, some subjects failed to complete the questionnaire on their follow-up session (four in the CPAT group and three in the CG group). Thus, analyses that include the follow-up session are based on a partial sample of 23 participants in total, whereas analyses regarding the pre-test and the post-test only are based on the whole sample.

Data Analysis and Design

To evaluate the effect of training on attentional functioning, the dependent measures in each of the assessment tasks were analyzed by a mixed repeated-measures ANOVA that included session (pre-test, post-test, or follow-up) and condition (different levels for each attention task) as repeated within-subject factors, and group (CPAT or CG) as a between-subjects factor.[3]

To assess the transfer of training effects to everyday functioning, ANOVAs were performed for the MATAL questionnaire inattention and hyperactivity/impulsivity scores, with session and group as within- and between-subject factors, accordingly.

The fundamental effect of interest in the ANOVAs was interaction of session and group, indicating changes in performance occurring in the CPAT group, above and beyond the CG group. Planned interaction contrasts were conducted to examine the interaction in pairwise analyses of session: three-way ANOVAs were carried out as before, but with only two levels of the session factor (pre-test and post-test, or pre-test and follow-up). Effect sizes were estimated by partial η^2 for ANOVAs, and by Cohen's *d* for *t* tests. When calculated for paired *t* tests, Cohen's *d* was adjusted to correct for dependence among means (Morris and DeShon 2002).

These analyses were performed using both traditional NHST statistics and Bayesian statistics. Traditional statistics were carried out with SPSS version 24.0. Bayesian analyses were conducted using JASP statistical software version 0.8 (JASP Team 2017) with default prior scales. For brevity, where results are unequivocal we report only traditional F and *p* values, and the full Bayesian analysis is included in Section 5 in the Supplementary Materials. We present base factors (BF) in cases where the null hypothesis (i.e., no specific training effect: no group × session interaction) could not be rejected by traditional frequentist statistics, and the BF provides quantification of support for the null hypothesis.

Finally, in order to allow individual differences exploration and to correlate between improvements in the assessment tasks and the progress in the training tasks, gain scores were computed for each participant in each assessment task. Gain scores were computed as differences in performance between the post-test/follow-up and pre-test. For the CCPT, the gain score was the subtraction of ICV between sessions. For the CVST and SSLT, gain scores were computed using IES scores of the most difficult task condition, i.e. largest search set size and incongruent trials, respectively. Training progress scores were computed as differences in level and/or score between first and last training session, for each of the training components (four categories of training tasks in the CPAT and four games in the CG).

Results

Assessment of Training Performance

All participants demonstrated improvement in the tasks or games they were practicing, and all moved forward in the levels of difficulty in all components of training. Importantly, this was evident in both the CPAT and the CG groups, indicating that although the computer games were not designed especially for training, they provide an adequate active control training program.

Several measures were used to assess these effects, and were submitted to two-tailed paired *t* tests. For the CPAT group, the overall score per session (aggregated across categories of exercise) increased significantly throughout training (1st session score = 352 points, last session score = 818 points; $t(14) = 11.89$, $p < .001$, Cohen's $d = 3.5$), with an increase for each and every individual participant in the group. All subjects reached at least the fourth level of difficulty in all exercises, and the median was 7/8th level. In the CG group, participants progressed in difficulty levels in all games, from a median level of 4 to 7 in the Gluefo ($t(14) = 17.7$, $p < .001$, Cohen's $d = 3.4$), 6 to 13 in the Filler ($t(14) = 11.1$, $p < .001$, Cohen's $d = 2.4$), 12 to 20 in String Avoider ($t(14) = 12.3$, $p < .001$, Cohen's $d = 1.9$), and 3 to 6 in Tetris ($t(14) = 6.3$, $p < .001$, Cohen's $d = 1.4$). Here again, improvement was achieved by each individual participant and in each computer game practiced.

Effect of Training on Attentional Performance

Effects of training on attention functioning were estimated by examining changes in the performance of the assessment tasks at the three time points of testing: before training, immediately

---

[3] The main analysis for CVST and SSLT was conducted with the inverse efficiency scores described above, and the main analysis for the CCPT was conducted with the ICV. However, these analyses were repeated using raw RTs as dependent measures, and also using logarithmically transformed RTs to reduce skewness and kurtosis of the data and better comply with the assumptions of analysis of variance. These additional analyses yielded similar pattern of results as did the main analyses, and are not further reported.

after training, and in a follow-up session. Improvement in performance was observed in both training groups in all three assessment tasks. Importantly, improvement was greater for the CPAT group than for the CG group for both CVST and SSLT, and the latter was maintained in the follow-up session held 2–3 months after completion of the training program. We, hereinafter, describe results in each of the assessment tasks in detail.

Sustained Attention

Sustained attention was estimated by the CCPT. Error rates for adults in this task are generally very low; thus, training has not been expected to yield significant changes in terms of errors/accuracy rates. Descriptive statistics for omissions (misses) and commissions (false alarms) are reported in Table 1. The main outcome measure in the CCPT was ICV (see Methods), and a 3-way ANOVA (see Fig. 2 for descriptive statistics) revealed a main effect of session (F(2,56) = 15.6, $p < .001$, $\eta_p^2 = .36$), indicating that participants in both training groups have improved with training. The interaction effect of session × group failed to reach significance (F(2,56) = 1.7, $p = .19$, $\eta_p^2 = .06$). Planned interaction contrasts were conducted nonetheless, and replicated the absence of a significant interaction effect in the pairwise comparisons as well (pre-test vs. post-test and pre-test vs. follow-up). The Bayesian analysis pointed out that the data are 1.6 times more likely under a model including main effects only than under a model including the main effects and their interaction. This is considered positive, though weak, evidence against the hypothesis of different training effects in the CPAT and CG groups.

Selective-Spatial Attention

Selective-spatial attention was estimated by CVST, analyzed with a 3-way ANOVA with inverse efficiency scores (IES) as a dependent measure. Session (pre-post, post-test, or follow-up) and search set sizes (8, 16, or 32 items) were within-subject factors, and group (CPAT or CG) was the between-subject factor (see Fig. 2 and Supplementary Figure S4 for descriptive statistics). As expected in this task, there was a main effect of set size, indicating that performance deteriorated with increased set size (F(2,56) = 90.0, $p < .001$, $\eta_p^2 = .76$). A main effect of session indicated that both groups improved with training (F(2,56) = 14.8, $p < .001$, $\eta_p^2 = .35$), and an

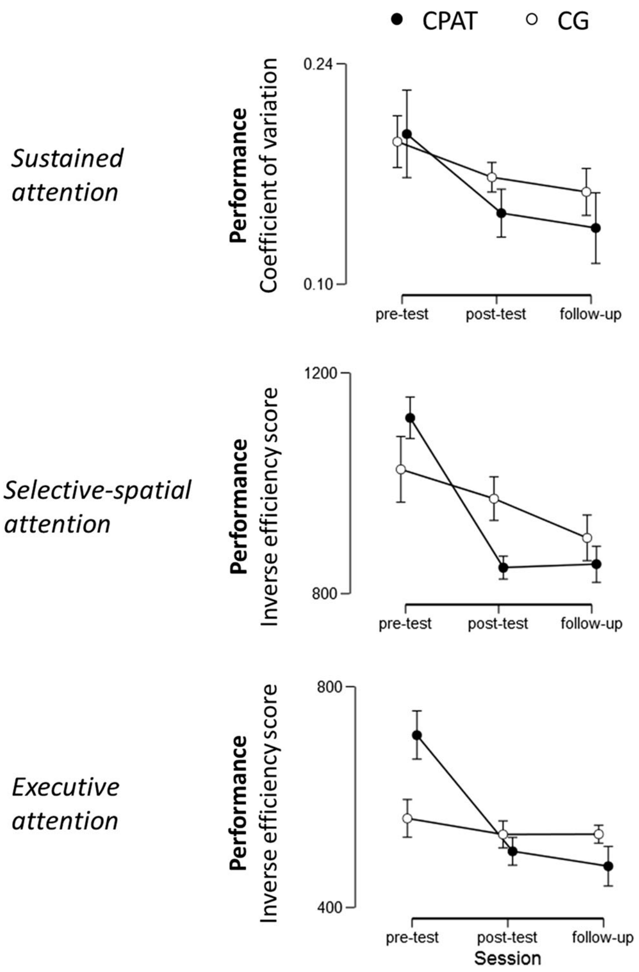

Fig. 2 Performance in the assessment tasks by training group and testing session. For selective-spatial attention and executive attention, the figures present performance in the most difficult condition, that is set size of 32 items for the CVST (conjunctive visual search task) and incongruent trials for the SSLT (spatial Stroop-like task). The other conditions are depicted in the Supplementary Figure S4. Error bars denote standard errors. Differences in slopes represent the interaction effect of testing session and group, indicating enhanced changes in performance occurring in the CPAT group, above and beyond the changes in the CG group

Table 1 Error rates in the CCPT by training group and testing session

		CPAT			CG		
		Pre-test	Post-test	Follow-up	Pre-test	Post-test	Follow-up
Omissions	M (%)	4.08	2.01	1.74	1.99	1.63	3.16
	SD (%)	(5.01)	(4.64)	(5.33)	(3.19)	(2.34)	(6.75)
Commissions	M (%)	2.22	0.54	0.57	1.26	1.03	1.08
	SD (%)	(3.63)	(0.74)	(0.76)	(1.52)	(1.00)	(0.90)

**CCPT* conjunctive continuous performance test, *CPAT* computerized progressive attentional training, *CG* computer games interaction of session and set size (F(4,112) = 2.8, $p < .05$, $\eta_p^2 = .09$) indicated greater performance change in large sets. Importantly, there was an interaction of session and group, indicating that participants in the CPAT group presented greater improvements than participants in the CG group (F(2,56) = 4.3, $p < .05$, $\eta_p^2 = .14$). Interaction contrasts for the session × group effect revealed that they interacted significantly for the pre-test and post-test (F(1,28) = 5.4, $p < .05$, $\eta_p^2 = .16$), and marginally significantly when comparing pre-test to follow-up (F(1,28) = 3.7, $p = .065$, $\eta_p^2 = .12$).

Executive Attention

Executive attention functioning was measured with the SSLT, with IES for congruent and incongruent trials as the dependent measure (see Fig. 2 for descriptive statistics). As expected in this task, there was a main effect of congruency (F(1,28) = 21.6, $p < .001$, $\eta_p^2 = .44$), where performance on incongruent trials was lower than in congruent ones. There was a main effect of session (F(2,56) = 14.6, $p < .001$, $\eta_p^2 = .34$) indicating that both groups improved with training/time, and an interaction of session and group showing that greater improvement was achieved by participants in the CPAT group (F(2,56) = 6.6, $p < .005$, $\eta_p^2 = .19$). Interestingly, there was also a significant three-way interaction of group, session, and congruency (F(2,56) = 4.1, $p < .05$, $\eta_p^2 = .13$). Interaction contrasts revealed that the three-way interaction remained significant only when comparing pre-test to follow-up (F(1,28) = 5.7, $p < .05$, $\eta_p^2 = .17$). This indicates that the improvement of CPAT participants from pre-test to follow-up was larger for the more difficult incongruent trials, resulting in a decreased interference effect which could point out better conflict resolution. Interaction contrasts for the session × group effect revealed that they interacted significantly both for the pre-test versus post-test (F(1,28) = 7.7, $p < .01$, $\eta_p^2 = .22$), and also when comparing pre-test to follow-up (F(1,28) = 8.0, $p < .01$, $\eta_p^2 = .22$). Taken together, these results indicate that the CPAT induced a unique effect of improvement in executive attention, maintained up to the follow-up session. Since there were differences in pre-test performance between the CPAT and CG groups in this task, we performed additional ANOVAs, using percent change from pre-test as the dependent measure (see Section 4 in the Supplementary Materials for more details). This analysis corroborated the results of the main analysis, indicating a significant group effect both for post-test gain (F(1,28) = 7.5; $p < .05$, $\eta_p^2 = .21$) and for follow-up gain (F(1,28) = 10.6; $p < .005$, $\eta_p^2 = .28$).

Individual Subjects' Data

To complement the group results presented above, we examined training gain for individual participants. For this purpose, we calculated gain scores as the difference in measures of the assessment tasks between pre-test and post-test, and between pre-test and follow-up. As shown in Fig. 3, there are substantial individual differences. However, more CPAT participants had positive gain scores than CG participants, and gains were larger. Furthermore, gains were preserved from the post-test to the follow-up session for majority of participants, indicating long-term benefits of the training program.

At last, we examined whether training gains in the different assessment tasks correlated with training progress in different training components, defined by level and score (in each training group separately). No significant and reliable correlates were found.

Transfer of Training Effects to Everyday Functioning

Transfer effects were examined by analyzing scores of the MATAL ADHD symptoms rating scale. Two-way ANOVAs were conducted with group (CPAT or CG) as a between-subject factor and session (pre-test, post-test, or follow-up) as a within-subject factor, once with inattention scores as the dependent variable and once with impulsivity/hyperactivity scores. No significant effects were found using traditional statistics, for neither symptom scores (Table 2), i.e., the rate of reported ADHD symptoms did not change following the training, in neither group. Bayesian analyses confirmed that the data is most likely under the null hypothesis of no transfer effects: $BF_{01} > 1$ for all models, and specifically $BF_{01} = 6.4$ for the full model with group × session interaction when examining inattention scores, and $BF_{01} = 45.5$ for impulsivity/hyperactivity scores. The same pattern of results was obtained for pairwise comparisons of pre-test versus post-test and pre-test versus follow-up, and also when considering each group separately.

Discussion

Adult ADHD is quite common and it entails various difficulties in everyday life. The most frequent and effective treatment in ADHD is psychostimulant medications; however, in many cases even when significant positive treatment response is documented, cognitive and academic difficulties remain at least to a certain extent. Thus, many students in higher education with ADHD constantly seek for efficient ways that can ameliorate their attention difficulties in the academic environment. The goal of the present study was to evaluate the effect of attention training for this population of high functioning adults with ADHD, when controlling for general training effects of motivation, engagement, and contact with trainers. To do so, we designed an active control training program, with sessions as similar as possible to the attention training program conducted with the CPAT. The computer games that were selected for the control training program required visual

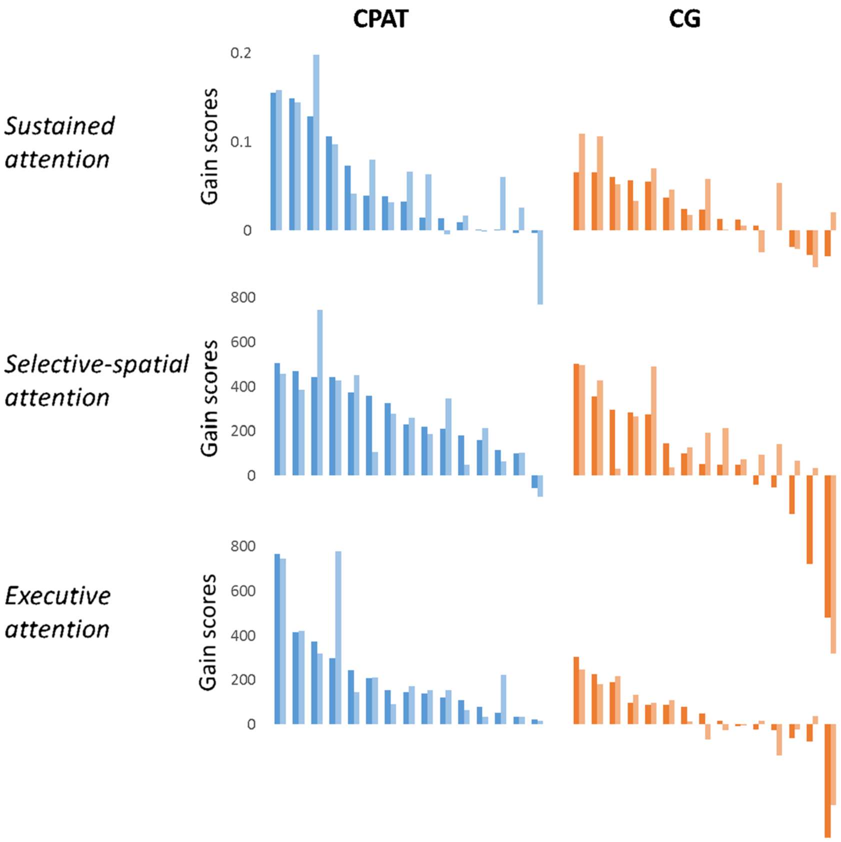

Fig. 3 Gain scores of individual participants. Gain scores were calculated as differences in performance of assessment attention tasks between pre-test and post-test/follow-up (see Methods). Each pair of adjacent bars represents one participant; blue bars represent participants in the attention training group (CPAT); orange bars represent participants in the computer games group (CG). Dark-colored bars (left in each adjacent pair) indicate post-test gain scores; light-colored bars (right in each adjacent pair) indicate follow-up gain scores. Participants in the CPAT group demonstrated greater training gains than participants in the CG group, persisting in the follow-up session

search abilities, visual-motor skills as well as visual-spatial planning. They were adaptive, provided various feedbacks, and emphasized fast responses. Finally, the CG sessions were conducted in the lab and were led by trainers exactly as the CPAT sessions. Thus, in both the CPAT and the CG sessions, we created conditions that encouraged engagement and commitment of the trainees. Indeed, when examining progress in the training tasks throughout the program, robust advancements in difficulty levels and in scoring were recorded throughout the training sessions in both training groups. This demonstrates that the CG program was successful as an active control, as necessary in order to evaluate any unique effects of the CPAT neurocognitive training.

In the present study, training consisted of 16 1-h personal training sessions per participant, administered across 8 weeks. Our results demonstrate improvements in untrained attention tasks performance. Importantly, we documented group by testing session interaction effects in selective-spatial attention and in executive attention, which were maintained for a significant period after training completion. These interaction effects demonstrate unique gains that can be attributed to the specific contents of the CPAT program above and beyond the general improvements expected by engaging in a long-term training program. In the case of selective-spatial attention, participants improved their ability to focus attention on a restricted area while better suppressing adjacent irrelevant information. Interestingly, in the case of executive attention, a triple interaction was also obtained (group by testing session by congruency). That is, the unique CPAT gain tended to be especially pronounced in incongruent trials, where participants had to suppress the processing of irrelevant conflicting information of the target stimulus. This suggests that the CPAT

Table 2 MATAL self-reported ADHD symptoms questionnaire scores by training group and testing session

		CPAT			CG		
		Pre-test	Post-test	Follow-up	Pre-test	Post-test	Follow-up
Inattention	M	2.05	1.97	1.82	1.83	1.67	1.78
	SD	(0.29)	(0.47)	(0.60)	(0.40)	(0.42)	(0.37)
Hyperactivity/impulsivity	M	1.5	1.54	1.44	1.56	1.56	1.53
	SD	(0.59)	(0.56)	(0.64)	(0.50)	(0.39)	(0.34)

**CPAT* computerized progressive attentional training, *CG* computer games program may have caused participants to be more efficient in conflict resolution, which is an important component of cognitive control that has been shown to be impaired in previous studies with individuals with ADHD (Hervey et al. 2004; Segal et al. 2015). As for sustained attention, participants in both groups showed significant improvement following training, which was maintained in the follow-up assessment. This points out that both training protocols are beneficial for sustained attention, perhaps due to the fact that alertness and speed were emphasized in both and because both training programs require participants to stay focused for long periods of time. We conclude that the CPAT produced unique near transfer effects, as reflected in improvements in the attention assessment tasks, which were different than the training tasks. Importantly, these unique near transfer effects were maintained at least 3 months after the completion of the CPAT program, indicating long-term effects of training.

Given the above positive sustainable outcomes of the CPAT, we expected to find similar effects on subjective evaluation of attention functioning. Nonetheless, no significant effects were found. The null effects were reaffirmed by Bayesian statistics, providing substantial evidence for lack of an effect on inattention symptoms and very strong evidence for the absence of training effect on hyperactivity/impulsivity symptoms (interpretation based on guidelines by Jeffreys 1961). Obvious possibilities are that the CPAT does not decrease everyday symptoms of inattention, hyperactivity and impulsivity among high functioning adults with ADHD, as measured by self-report of ADHD symptoms, or that our sample size was too small to detect such effects. Alternatively, it could be that the questionnaire we used is not sensitive enough to subtle changes, and that other subjective measures of everyday functioning could have detected finer differences. Yet another possibility is that for some participants, taking part in this study increased the awareness to the attention difficulties they are coping with, thus interfering with the estimation of symptoms severity. This possibility raises the question of what should be appropriate subjective outcome measures in studies of cognitive training for adults with ADHD. It has been suggested that instead of report of ADHD symptoms, a better measure would be report of the need for compensatory strategies to cope with symptoms (Knouse and Safren 2010). In addition, other objective measures of daily life functioning such as academic performance are important in order to assess the broad impact of any given treatment. In light of the significant improvements that were obtained in academic performance in the previous CPAT studies with children with attention difficulties, it would be very informative to include measures of academic performance in future studies with adults as well.

Participants in the present study were students in higher education. It was hypothesized that it would be more difficult to demonstrate benefits of cognitive training in adults who are already high functioning and using compensatory mechanisms to overcome their attention deficits. Hence, if the CPAT is beneficial to this specific sub-group, it could be even more robust and impactful for general adult ADHD population. However, this ought to be directly investigated in larger and more heterogeneous samples of participants.

Markedly, participants in the current study did not fully utilize the CPAT options. Only about half the levels of difficulty were reached in each task, even by the “fastest trainees.” Interestingly, in a previous CPAT study that was conducted with children (Shalev et al. 2007) participants reached higher levels of difficulty. This could be attributable to a somewhat slower (but perhaps more sustainable) learning process in adults with ADHD compared to children with ADHD. It may imply that adults require longer training programs to reach optimal results.

Several researchers have previously highlighted the importance of developing neurocognitive interventions that are based on well-studied theories and that are strictly designed to probe relevant cognitive mechanisms. In addition, it is necessary to strengthen the link between the cognitive functions that are being trained and their roles in everyday functioning (Chacko et al. 2014; Jaeggi et al. 2011; Shalev et al. 2016a). The current study, albeit limited by the small number of participants, provides promising preliminary evidence for the suitability and efficacy of the CPAT as a cognitive training program. Taken together with the results of four previous studies that investigated the CPAT with various populations who suffer from attention difficulties (Kerns et al. 2010; Muller Spaniol et al. 2017; Sampanis et al. 2015; Shalev et al. 2007), we suggest that the CPAT provides a good fit to the above requirements and encourage future large scale studies using the CPAT and any other similar neurocognitive training.

Another important issue that should be addressed in future investigations relates to the role of feedback in cognitive training (Shalev et al. 2016a). Online precise feedbacks are essential to probe optimal learning and to produce effective training. Moreover, such feedbacks not only can encourage learning but also can stimulate self-efficacy, self-confidence, and motivation. Thus, when designing new neurocognitive interventions particular considerations should be devoted to the schedule and content of feedbacks.

Finally, given the high heterogeneity of ADHD it is reasonable to expect that different cognitive training protocols will suit different individuals with ADHD. Thus, in order to fulfill the potential of cognitive training in ADHD, it will have to be further developed to afford larger flexibility and enable effective personalization. Naturally, to accomplish this imperative challenge, many more cognitive training studies in ADHD are required, preferably with large samples. Additionally, it is recommended that future cognitive training studies will include a direct assessment of motivation using a standard questionnaire in order to confirm that differences in outcome measures cannot be explained by differences in motivation.

To conclude, unique near transfer effects were measured in the CPAT group which support the claim that the CPAT is useful in enhancing attention functioning not only in children that face attention difficulties but also in high functioning adults with ADHD. Yet, several important questions regarding the CPAT are still unanswered. Further investigations with larger sample sizes, using differential CPAT protocols (e.g., different numbers of sessions, different selection of training tasks, different types of feedbacks) and with broader populations are crucial to isolate the contribution of each training component and to assess the potential of transfer of training effects to real life functioning.

Funding Information This study was funded by a grant from the Chief Scientist of the Ministry of Science to LS.

References

Advokat, C. (2010). What are the cognitive effects of stimulant medications? Emphasis on adults with attention-deficit/hyperactivity disorder (ADHD). *Neuroscience and Biobehavioral Reviews, 34*(8), 1256–1266. https://doi.org/10.1016/j.neubiorev.2010.03.006.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders (DSM-5®)*. American Psychiatric Pub.

Antshel, K. M. (2015). Psychosocial interventions in attention-deficit/hyperactivity disorder: update. *Child and Adolescent Psychiatric Clinics of North America, 24*(1), 79–97. https://doi.org/10.1016/j.chc.2014.08.002.

Barkley, R. A., Fischer, M., Smallish, L., & Fletcher, K. (2006). Young adult outcome of hyperactive children: adaptive functioning in major life activities. *Journal of the American Academy of Child & Adolescent Psychiatry, 45*(2), 192–202. https://doi.org/10.1097/01.chi.0000189134.97436.e2.

Ben-simon, A. (2007). Development of a battery for the assessment of learning disabilities in higher education: A summarizing report. Jerusalem.

Ben-simon, A., Beyth-Marom, R., Inbar-Weiss, N., & Cohen, Y. (2009). Regulating the diagnosis of learning disability and the provision of test accommodations in institutions of higher education. In 34th International Association for Educational Assessment (IAEA) annual conference. Cambridge.

Biederman, J., Monuteaux, C., Mick, E., Spencer, T., Wilens, E., Silva, M., … Faraone, V. (2006). Young adult outcome of attention deficit hyperactivity disorder: a controlled 10-year follow-up study. *Psychological Medicine*, *36*(2), 167. https://doi.org/10.1017/S0033291705006410.

Bruyer, R., & Brysbaert, M. (2011). Combining speed and accuracy in cognitive. *Psychologica Belgica, 51*, 5–13. https://doi.org/10.5334/pb-51-1-5.

Chacko, A., Feirsen, N., Bedard, A.-C., Marks, D., Uderman, J. Z., & Chimiklis, A. (2013). Cogmed working memory training for youth with ADHD: a closer examination of efficacy utilizing evidence-based criteria. *Journal of Clinical Child & Adolescent Psychology, 42*(6), 769–783. https://doi.org/10.1086/498510.Parasitic.

Chacko, A., Kofler, M., & Jarrett, M. (2014). Improving outcomes for youth with ADHD: A conceptual framework for combined neurocognitive and skill-based treatment approaches. *Clinical Child and Family Psychology Review, 17*(4), 368–384. https://doi.org/10.1007/s10567-014-0171-5.

Cortese, S., Ferrin, M., Brandeis, D., Buitelaar, J., Daley, D., Dittmann, R. W., … Sonuga-Barke, E. J. S. (2015). Cognitive training for attention-deficit/hyperactivity disorder: meta-analysis of clinical and neuropsychological outcomes from randomized controlled trials. *Journal of the American Academy of Child and Adolescent Psychiatry, 54*(3), 164–174. https://doi.org/10.1016/j.jaac.2014.12.010.

Dankner, Y., Shalev, L., Carrasco, M., & Yuval-Greenberg, S. (2017). Prestimulus inhibition of saccades in adults with and without attention-deficit/hyperactivity disorder as an index of temporal expectations. *Psychological Science, 28*(7), 835–850. https://doi.org/10.1177/0956797617694863.

Green, C., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature, 423*(6939), 534–537. https://doi.org/10.1038/nature01647.

Green, C., & Bavelier, D. (2007). Action-video-game experience alters the spatial resolution of vision. *Psychological Science, 18*(1), 88–94. https://doi.org/10.1111/j.1467-9280.2007.01853.x

Gropper, R. J., Gotlieb, H., Kronitz, R., & Tannock, R. (2014). Working memory training in college students with ADHD or LD. *Journal of Attention Disorders, 18*(4), 331–345. https://doi.org/10.1177/1087054713516490.

Hervey, A. S., Epstein, J. N., & Curry, J. F. (2004). Neuropsychology of adults with attention-deficit/hyperactivity disorder: a meta-analytic review. *Neuropsychology, 18*(3), 485–503. https://doi.org/10.1037/0894-4105.18.3.485.

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Shah, P. (2011). Short- and long-term benefits of cognitive training. *Proceedings of the National Academy of Sciences of the United States of America, 108*(25), 10081–10086. https://doi.org/10.1073/pnas.1103228108.

Jarosz, A. F., & Wiley, J. (2014). What are the odds? A practical guide to computing and reporting Bayes factors. *The Journal of Problem Solving, 7*, 2–9. https://doi.org/10.7771/1932-6246.1167.

JASP Team (2017). JASP (Version 0.8.4) [Computer software] <https://jasp-stats.org/>.

Jeffreys, H. (1961). *Theory of probability* (3rd ed.). Oxford: Oxford University Press, Clarendon Press.

Kerns, K. A., Macsween, J., Vander Wekken, S., & Gruppuso, V. (2010). Investigating the efficacy of an attention training programme in children with foetal alcohol spectrum disorder. *Developmental Neurorehabilitation, 13*(6), 413–422. https://doi.org/10.3109/17518423.2010.511421.

Klingberg, T., Forssberg, H., & Westerberg, H. (2002). Training of working memory in children with ADHD. *Journal of Clinical Experimental Neuropsychology, 24*(6), 781–791.

Klingberg, T., Fernell, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlstrom, K., … Westerberg, H. (2005). Computerized training of working memory in children with ADHD–a randomized, controlled trial. *Journal of American Academy of Child and Adolescent Psychiatry*, *44*(2), 177–186. https://doi.org/10.1097/00004583-200502000-00010.

Knouse, L. E., & Safren, S. A. (2010). Current status of cognitive behavioral therapy for adult attention-deficit hyperactivity disorder. *Psychiatric Clinics of North America, 33*(3), 497–509. https://doi.org/10.1016/j.psc.2010.04.001.Current.

Lukov, L., Friedmann, N., Shalev, L., Khentov-Kraus, L., Shalev, N., Lorber, R., & Guggenheim, R. (2014). Dissociations between developmental dyslexias and attention deficits. *Frontiers in Psychology, 5*, 1501. https://doi.org/10.3389/fpsyg.2014.01501.

Mawjee, K., Woltering, S., & Tannock, R. (2015). Working memory training in post-secondary students with ADHD: a randomized controlled study. *PLoS One, 10*(9), 1–21. https://doi.org/10.1371/journal.pone.0137173.

Melby-Lervåg, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental Psychology, 49*(2), 270–291. https://doi.org/10.1037/a0028228.

Morris, S. B., & DeShon, R. P. (2002). Combining effect size estimates in meta-analysis with repeated measures and independent-groups designs. *Psychological Methods, 7*(1), 105–125. https://doi.org/10.1037/1082-989X.7.1.105.

Muller Spaniol, M., Shalev, L., Kossyvaki, L., & Mevorach, C. (2017). Attention training in autism as a potential approach to improving academic performance. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-017-3371-2.

Okagaki, L., & Frensch, P. A. (1994). Effects of video game playing on measures of spatial performance: gender effects in late adolescence. *Journal of Applied Developmental Psychology, 15*(1), 33–58. https://doi.org/10.1016/0193-3973(94)90005-1.

Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience, 35*, 73–89. https://doi.org/10.1146/annurev-neuro-062111-150525.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13*, 25–42. https://doi.org/10.1146/annurev.ne.13.030190.000325.

Prevatt, F., Petscher, Y., Proctor, B., Hurst, A., & Adams, K. (2006). The revised learning and study strategies inventory: An evaluation of competing models. *Educational and Psychological Measurement, 66*(3), 448–458. https://doi.org/10.1177/0013164405282454.

Rapport, M. D., Orban, S. A., Kofler, M. J., & Friedman, L. M. (2013). Do programs designed to train working memory, other executive functions, and attention benefit children with ADHD? A meta-analytic review of cognitive, academic, and behavioral outcomes. *Clinical Psychology Review, 33*(8), 1237–1252. https://doi.org/10.1016/j.cpr.2013.08.005.

Reaser, A., Prevatt, F., Petscher, Y., & Proctor, B. (2007). The learning and study strategies of college students with ADHD. *Psychology in the Schools, 44*(6), 627–638. https://doi.org/10.1002/pits.20252.

Rouder, J. N., Morey, R. D., Speckman, P. L., & Province, J. M. (2012). Default Bayes factors for ANOVA designs. *Journal of Mathematical Psychology, 56*(5), 356–374. https://doi.org/10.1016/j.jmp.2012.08.001.

Safren, S. A. (2006). Cognitive-behavioral approaches to ADHD treatment in adulthood. *Journal of Clinical Psychiatry, 67*, 46–50.

Sampanis, D., Mevorach, C., Shalev, L., Mohammed, S., & Humphreys, G. (2015). Reducing cognitive deficits after stroke through computerized progressive attentional training (CPAT): a pilot study. *Pyhsical Medicine and Rehabilitation-International, 2*(7), 1058.

Saville, C. W. N., Pawling, R., Trullinger, M., Daley, D., Intriligator, J., & Klein, C. (2011). On the stability of instability: optimising the reliability of intra-subject variability of reaction times. *Personality and Individual Differences, 51*(2), 148–153. https://doi.org/10.1016/j.paid.2011.03.034.

Segal, D., Mashal, N., & Shalev, L. (2015). Semantic conflicts are resolved differently by adults with and without ADHD. *Research in Developmental Disabilities, 47*, 416–429. https://doi.org/10.1016/j.ridd.2015.09.024.

Shalev, L., Tsal, Y., & Mevorach, C. (2007). Computerized progressive attentional training (CPAT) program: effective direct intervention for children with ADHD. *Child Neuropsychology, 13*(4), 382–388. https://doi.org/10.1080/09297040600770787.

Shalev, L., Ben-Simon, A., Mevorach, C., Cohen, Y., & Tsal, Y. (2011). Conjunctive continuous performance task (CCPT)—a pure measure of sustained attention. *Neuropsychologia, 49*(9), 2584–2591. https://doi.org/10.1016/j.neuropsychologia.2011.05.006.

Shalev, L., Kataev, N., & Mevorach, C. (2016a). Training of cognitive control in developmental disorders: pitfalls and promises. In R. Schiff & R. Joshi (Eds.), *Interventions in learning disabilities*. Literacy Studies (Perspectives from Cognitive Neurosciences, Linguistics, Psychology and Education), vol 13. Springer, Cham. https://doi.org/10.1007/978-3-319-31235-4_15

Shalev, L., Kolodny, T., Shalev, N., & Mevorach, C. (2016b). Attention functioning among adolescents with multiple learning, attentional, behavioral, and emotional difficulties. *Journal of learning disabilities, 49*(6), 582–596. https://doi.org/10.1177/0022219415579125.

Sonuga-Barke, E., Brandeis, D., Holtmann, M., & Cortese, S. (2014). Computer-based cognitive training for ADHD. *Child and Adolescent Psychiatric Clinics, 23*(4), 807–824. https://doi.org/10.1016/j.chc.2014.05.009.

Stern, A., Malik, E., Pollak, Y., Bonne, O., & Maeir, A. (2014). The efficacy of computerized cognitive training in adults with ADHD: A Randomized Controlled Trial. *Journal of Attention Disorders*. https://doi.org/10.1177/1087054714529815.

Townsend, J. T., & Ashby, F. G. (1983). Stochastic modeling of elementary psychological processes. Cambridge: Cambridge University Press.

Tsal, Y., Shalev, L., & Mevorach, C. (2005). The diversity of attention deficits in ADHD: The prevalence of four cognitive factors in ADHD versus controls. *Journal of Learning Disabilities, 38*(2), 142–157. https://doi.org/10.1177/00222194050380020401.

Wagenmakers, E., & Brown, S. (2007). On the linear relation between the mean and the standard deviation of a response time distribution. *Psychological Review, 114*(3), 830–841. https://doi.org/10.1037/0033-295X.114.3.830.

Wilens, T. E., Spencer, T. J., & Biederman, J. (2002). A review of the pharmacotherapy of adults with attention-deficit/hyperactivity disorder. *Journal of Attention Disorders, 5*(4), 189–202. https://doi.org/10.1177/108705470100500401.