Is cognitive training an effective tool for improving cognitive function and real-life behaviour in healthy children and adolescents? A systematic review

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COMPLIANCE WITH ETHICAL STANDARDS

Conflicts of interest. The authors declare that they have no conflict of interest.

Ethical approval. This article does not contain any studies with human participants or animals performed by any authors.

AUTHOR'S CONTRIBUTIONS

María Ángeles Jurado and Sandra Luis-Ruiz contributed to the conception and design of the article. Sandra Luis-Ruiz and Xavier Caldú performed the literature search, data extraction and synthesis. Sandra Luis-Ruiz wrote the draft of the manuscript and Cristina Sanchez-Castañeda took part in editing and table and figure preparation. All authors critically reviewed and commented on previous versions of the manuscript. All authors read and approved the final manuscript.

ABSTRACT

Computerised cognitive training (CCT) has been applied to improve cognitive function in pathological conditions and in healthy populations. Studies suggest that CCT produces near-transfer effects to cognitive functions, with less evidence for far-transfer. Newer applications of CTT in adults seem to produce certain far-transfer effects by influencing eating behaviour and weight loss. However, this is more unexplored in children and adolescents. We conducted a systematic review of 16 studies with randomised controlled design to assess the impact of CCT on cognitive functioning and real-life outcomes, including eating behaviour, in children and adolescents with typical development (PROSPERO registration number: CRD42019123889). Results show near-transfer effects to working memory, with inconsistent results regarding far-transfer effects to other cognitive functions and real-life measures. Long-term effects show the same trend. Far-transfer effects occurred after cue-related inhibitory control and attentional training, although effects seem not to last. CCT may be a potential weight-loss treatment option but more research is needed to determine the specific characteristics to enhance treatment outcomes.

Keywords: cognitive training, executive functions, weight status, childhood, systematic review

1. INTRODUCTION

Cognitive training can be considered as a type of cognition-based intervention, which is aimed at enhancing cognitive functioning directly or indirectly, as opposed to interventions that focus principally on behavioural, emotional or physical functions (Bahar-Fuchs, Clare and Woods, 2013). Cognitive training (also “retraining”, “remediation” or “brain training”) typically comprises guided practice on a set of standardised tasks designed to reflect specific cognitive functions such as attention, working memory (WM) or problem-solving, and they can be administered in paper-and-pencil or computerized form or may contain analogues of activities of daily living (Bahar-Fuchs et al., 2013). In the last years, computerised cognitive training (CCT) is becoming very popular since it possesses several advantages over traditional methods such as more engaging interfaces, efficient and adaptable delivery and the need for less personnel resources (Jak, Seelye and Jurick, 2013).

Typically, CCT has been applied to several pathological conditions characterised by cognitive impairment, such as brain injury (Phillips et al., 2016), neurodevelopmental disorders, attention deficit hyperactivity disorder (Cortese, Ferrin, Brandeis, Buitelaar, Daley, Dittmann et al., 2015), and learning disabilities (Peijnenborgh, Hurks, Aldenkamp, Vles and Hendriksen, 2016). However, there is also growing interest in the impact of CCT in healthy samples (Cardoso, Dias, Senger, Colling, Seabra and Fonseca, 2018; Lampit, Hallock and Valenzuela, 2014). In fact, CCT has been promoted by commercial companies since it is considered to be effective for a very wide range of conditions and outcomes, from several neurological and mental diagnoses to sports performance, general cognitive ability, everyday memory and even driving ability (Simons et al., 2016).

An important issue in the field when assessing the efficacy of interventions is the distinction between near and far-transfer effects, which depends on the similarity or dissimilarity between the training task and the outcome measure. Near-transfer occurs when the training and the outcome tasks are identical or highly similar, whereas far-transfer refers to an improvement in different tasks or cognitive skills (Simons et al., 2016). In this sense, Simons et al. (2016) have found that cognitive training efficacy varies depending on the type of tasks used as a measure. Results from published peer-reviewed intervention studies indicate improved performance on trained tasks, with fewer effects on closely related tasks (near-transfer) and even less with distantly related tasks (far-transfer) (Simons et al., 2016). In line with this, other authors have also described that far-transfer to real-world measures (in which functional outcomes or everyday functioning are included) has been limited throughout studies (Harvey, McGurk, Mahnckec and Wykes, 2018).

Newer applications of CCT have been proposed as treatment in overweight and obese populations because of certain far-transfer effects, such as its influence on eating behaviour in healthy adults (Kakoschke, Kemps and Tiggemann, 2015; Oomen, Grol, Spronk, Booth and Fox, 2018) and its potential as treatment in overweight and obese populations (Eichen, Matheson, Appleton-Knapp and Boutelle, 2017; Jones, Hardman, Lawrence and Field, 2018). According to the stimuli used, CTT can be divided in: a) generalised interventions, that are aimed at increasing the overall cognitive capacity by training to arbitrary cues (such as generalised inhibitory control [IC] or WM training) and, b) cue-specific interventions, addressed to reinforcing associations in which specific cues (those relevant to the outcome behaviour, e.g., food stimuli for eating behaviours) are paired with cognitive responses (such as attention bias modification, cue-specific IC training or approach/avoidance training) (Jones et al., 2018). Among these interventions, it has been suggested that generalised IC training has limited potential to influence food intake or choice, whereas a few studies have demonstrated initial promising findings for WM training (Jones et al., 2018). Moreover, most cue-related interventions have demonstrated some degree of success in modifying food intake or choice (Jones et al., 2018). Specifically, cue-related IC training has been shown to prompt reductions in emotional eating and even in objective measures of body mass index (BMI) (Jones et al., 2018). Nevertheless, even within cue-related IC interventions, it is important to consider the type of training task, as previous studies have demonstrated that the Go-No Go Task produces stronger effects than others do, such as the Stop Signal Task or the Antisaccade Task (Jones et al., 2016). Thus, the results of the intervention may be influenced by the type of training task used.

The cognitive approach to eating behaviour is based on previous studies suggesting that cognitive functions are important determinants of people's responses to food stimuli and eating choices (Higgs, 2016) and also a key factor for a successful dietetic and exercise planning (Cortese, Comencini, Vincenci, Speranza and Angriman, 2013). Several models of self-control in adults suggest that the capacity to resist an immediate reward in favour of longer-term goals depends on a balance between two neural systems: a) an executive decision system involved in impulse control, associated with lateral and medial regions of the prefrontal cortex, and b) a reward system that computes the value of an outcome, associated with areas such as the orbitofrontal cortex/ventromedial prefrontal cortex and the striatum (Higgs, 2016). Therefore, an imbalance between these two neural systems may explain deregulated eating choices, as the executive decision system may fail to inhibit the response to rewarding stimuli. In fact, in adults with obesity, previous studies have shown that they seem to have more difficulties at inhibiting responses than normal-weight individuals (Hall, 2012; Higgs, 2016; Hofmann, Friese and Roefs, 2009) and also at delaying a smaller monetary reward in favour of a larger one (Jarmolowicz, Cherry, Reed, Bruce, Crespi, Lusk et al., 2014). This might be explained by a general enhanced reward response but also by reduced IC (Bickel, Wilson, Franck, Mueller, Jarmolowicz, Koffarnus et al., 2014). Likewise, deficient IC along with altered reward sensitivity may induce impulsive and deregulated eating behaviours (such as binge eating, external eating or emotional eating), which, in turn, would obstruct the accomplishment of dietetic regimen (Cortese et al., 2013).

Besides IC and reward sensitivity, WM has also been involved in eating behaviour. Dohle, Diele and Hofmann (2018) suggested that WM contributes to persisting with long-term goals such as healthy eating by maintaining goal relevant information, redirecting attention away from tempting stimuli or by suppressing information that is not in line with long-term goals. Thus, in an appetizing situation, the long-term goal is held on and the tempting desire can be downregulated (Dohle et al., 2018). Finally, other cognitive functions such as planning and organizational skills have been proposed as relevant factors for a successful adhesion to dietetic regimen and regular physical exercise (Cortese et al., 2013).

In children and adolescents, although less is known, there are also several studies supporting self-control models. Neuroimaging studies showed that the neurocircuitry of appetitive behaviours includes not only reward-processing regions, like the striatum and the ventral tegmental area, but also regions implicated in evaluating the overall salience of food, like the orbitofrontal and ventromedial prefrontal cortices (Keller and Bruce, 2018). Likewise, there is also evidence about the role of the prefrontal cortex in decision-making and self-control, which is critical for facilitating healthy eating behaviours in children and adolescents (Keller and Bruce, 2018). However, the prefrontal cortex has a protracted course of development, while the brain networks that facilitate motivation and reward develop at an early age (Keller and Bruce, 2018). For this reason, some authors have hypothesised that younger individuals may be at increased vulnerability for health risk behaviours such as unhealthy food intake than adults (Steinberg, 2014).

On the other hand, cognitive and behavioural studies have shown that higher levels of impulsivity are associated to sensitivity to reward and both aspects are related to overeating (Van den Berg et al., 2011). Other authors have found that reward sensitivity is associated positively with fast-food consumption (De

Cock et al., 2016; De Decker et al., 2016; De Decker et al., 2017), unhealthy snacking (Stok et al., 2015) and even a higher BMI (Rollins, Loken, Savage and Birch, 2014). In participants with obesity, there is some evidence of a negative relationship between body-weight status and several aspects of cognitive function, including executive function (EF), attention, and even motor skills (Liang, Matheson, Kaye and Boutelle, 2014). Among all the executive domains assessed, IC is the most consistently reported to be impaired, although there is certain support for reward sensitivity, attention/set-shifting and WM impairments (Reinert, Po'e and Barkin, 2013). IC has also been related to treatment success, as more impulsive children lost less weight after a behavioural treatment (Nederkoorn, Jansen, Mulkens and Jansen, 2007). Moreover, executive impairment has also been associated with obesity-related behaviours like increased food intake, disinhibited eating and less physical activity, being a relevant factor in weight-loss interventions (Liang et al., 2014).

Regarding cognitive interventions to moderate eating behaviour in children and adolescents, the issue remains rather unexplored. A previous review that includes studies until 2016 suggested that weight loss treatment outcomes can be optimised by enhancing executive skills through different types of interventions (Hayes, Eichen, Barch and Wilfley, 2018). Nevertheless, studies in Hayes et al.'s review are quite heterogeneous (i.e., multicomponent behavioural interventions, physical activity programs or episodic future thinking) and, actually, only two studies had specifically applied cognitive training, so robust conclusions cannot be drawn to date. For this reason, and along with the above-mentioned studies supporting that cognitive training may influence eating behaviour and with the evidence also corroborating the relationship between cognitive functions and several eating and obesity-related behaviours, we conduct the present review. Our aim is to update and critically revise the data on the use of computerised cognitive training as a tool to improve cognitive function in typically developing children and adolescents, with and without overweight/obesity. The rationale is that children and adolescents may show more risk of unhealthy behaviours (e.g., unhealthy food intake) than adults (Steinberg, 2014). EF and associated EF processes such as self-control continue to develop throughout the second decade of live, associated to the maturity of the prefrontal cortex (Francis and Riggs, 2018). Thus, during this developmental period, reward processes ("bottom up") are particularly salient, whereas self-control processes ("top down") -required to regulate impulses- are not fully mature (Geier, 2013). Altogether, these particularities may produce an increase of deregulated behaviours (Francis and Riggs, 2018). Therefore, studies including young individuals regardless of their weight status are of our interest.

In addition, we focus on computerised interventions, since they can be advantageous not only because younger populations are very familiar with the use of electronic devices (Darling and Sato, 2017) and fond of using them, but also, because of the benefits computerised intervention has over traditional methods (i.e. visually engaging interfaces, efficient and adaptable delivery and the possibility to adapt training content and difficulty to individual performance) (Jak et al., 2013). Moreover, CCT does not involve the high demand for resources in person such as qualified personnel, office space, and commute to the training site, which can be tedious to beneficiaries (Jak et al., 2013). Finally, we selected studies with a randomised controlled design because of the quality of this type of design, referred to as the gold standard in the clinical research paradigm (Sullivan, 2011).

The specific objectives of our review are:

a) To summarise and assess the impact of CCT on cognitive functioning in children and adolescents with typical development.

b) To summarise and assess the impact of CCT on non-cognitive domains and real-life outcomes, including eating behaviour, and its applicability in the field of overweight and obesity.

c) To examine the long-term effects of CCT on these outcomes and its capacity to reinforce weight loss maintenance.

2. METHOD

This systematic review was carried out by two independent reviewers conducted in accordance with the PRISMA guidelines for reporting systematic reviews (Moher et al., 2009) and registered on the 11th of July, 2019 in the International Prospective Register of Systematic Reviews (PROSPERO; registration number CRD 42019123889).

2.1. Inclusion and exclusion criteria

Inclusion criteria for study selection were: (i) randomised controlled design with a minimum of one active and/or passive control group; (ii) English or Spanish language; (iii) minimum of 15 participants; (iv) typically developing children and/or adolescents (v) sample mean age from 6 to 18; (vi) interventions with computerised cognitive training; (vii) reporting at least one outcome of cognitive performance, assessed with cognitive tests and/or standardised neuropsychological battery. Additionally, long-term outcomes, real-life outcomes such as subjective measures (i.e., questionnaires), eating behaviour and/or weight measures (i.e., food intake and BMI) and other non-cognitive outcomes (i.e., mood and activities of daily living) were also extracted if available.

Exclusion criteria were: (i) >5% of the sample with any diagnosis of neurological, neurodevelopmental, neurocognitive or psychiatric disorders and/or sensory impairments, or presence of any diagnosis of severe medical diseases which may produce cognitive deficits related to the condition or its treatment, and (ii) interventions that are not aimed at improving cognitive functioning directly (i.e., cognitive-behavioural therapy, parent-skills training, transcranial stimulation, physical activity).

2.2. Search strategy

An electronic search was conducted in December 2018, using the Web of Science, PubMed, Cochrane Central Register of Controlled Trials, PsycInfo, PsycArticles and CINAHL databases. Keyword search used a combination of the following terms: (executive function OR working memory OR inhibition OR attention OR flexibility OR delay OR reward OR cognitive OR neurocognitive OR neuropsychological) AND (training OR remediation OR rehabilitation OR stimulation OR intervention OR computer). Non-target interventions such as cognitive behavioural therapy, parent training, transcranial stimulation or physical activity were excluded from the search (adding NOR operator). Several limits were set regarding the date of publication (2008-2018), the age group (6-12 and 13-18 years) and the methodology applied (clinical trials). In case it was not possible to apply age group limits because of database format, several search terms were added (child* OR school* OR adolescen* OR young OR youth OR teen). Reference lists were also reviewed to identify articles of interest.

2.3. Selection strategy

From 1157 initial records, duplicates were removed. Remaining records (n=694) were screened by reading titles and abstracts, which involved the exclusion of those not complying with inclusion criteria (n=646). If in doubt, full texts were assessed using the same criteria (n=48). Overall, 16 papers were considered suitable for final inclusion (Figure 1).

2.4. Data extraction and quality assessment

The data extraction form was presented in PROSPERO (CRD 42019123889; https://www.crd.york.ac.uk/PROSPERO/display_record.php?RecordID=123889). Sought data included: authors, year of publication, country, language, sample characteristics (health status, age, gender), study design (type of training and control groups, number of participants in each group), training features (targeted cognitive function(s), length and frequency of sessions, training period, programs and delivery), assessment time points and assessment tools, main cognitive outcomes and other relevant results. Other relevant results, included if available, were long-term outcomes, subjective measures (i.e., mood questionnaires), eating behaviour and/or weight measures (i.e., food intake and BMI) and other non-cognitive outcomes (i.e., activities of daily living). Reported effect sizes were also coded when available and, additionally, we calculated d_{ppc2} (Morris, 2008) for all significant results when data allowed it. Effect sizes were interpreted according to Cohen's and Rosenthal's criteria (Maher, Markey and Ebert-May, 2013).

To assess the quality of included studies, The Collaboration's 'Risk of bias' tool was used (Higgins, Altman and Sterne, 2011), assessing risk of bias at the study level. For missing and incomplete data, eight original authors were contacted and three of them answered providing the required information. Extracted data were compared between the two researchers and disagreements were solved by consultation to data in original papers and through discussion.

3. RESULTS

A summary of the details of the 16 articles is shown in Table 1. Results are discussed below.

3.1. Studies characteristics

Studies were conducted in the United Kingdom (n=5), Belgium (n=2), Switzerland (n=2), Australia (n=2), the Netherlands (n=1), Germany (n=1), the United States (n=1), Israel (n=1) and Iran (n=1).

Most of the trials used a single control group that could be passive (Johnstone et al., 2012; Nevo and Breznitz, 2014; Pugin et al., 2015; Roberts et al., 2016; Tayeri et al., 2016; Verbeken et al., 2013) or active (Astle et al., 2015; Boutelle et al., 2014; Karbach et al., 2015; Verbeken et al., 2018). The remaining studies used both types of control group (Dunning et al., 2013; Hitchcoch et al., 2017; Murray et al., 2018; Studer-Luethi et al., 2016) or more than one active control group (De Voogd et al., 2016). Finally, a study used two active control groups (Porter et al., 2018) but the second one will be considered as a training group for the review purposes, as described further below (section 3.3.2.2).

3.2. Participants

A total of 1735 participants (820 males/915 females) were enrolled in the 16 studies reviewed, ranging from 27 to 452 per study. Sample mean age ranged from 6.24 to 14.41 years. Participants were children aged 6 to 9 in five studies (Dunning et al., 2013; Karbach et al., 2015; Nevo and Breznitz, 2014; Roberts et al., 2016; Studer-Luethi et al., 2016) whereas in one only study the age range was from 5 to 6 years (Murray et al., 2018). In other four studies (De Voogd et al., 2016; Hitchcoch and Westwell, 2017; Pugin et al., 2015; Tayeri et al., 2016) all participants were adolescents (aged 10 to 18). The six remaining studies used mixed samples of children and adolescents (Astle et al., 2015; Boutelle et al., 2014; Johnstone et al., 2012; Porter et al., 2018; Verbeken et al., 2013; Verbeken et al., 2018). Among them, only one study included children aged 4 to 11 years (Porter et al. 2018).

Most studies involved schoolchild samples with no available data regarding weight status (Astle et al., 2015; De Voogd et al., 2016; Dunning et al., 2013; Hitchcoch and Westwell, 2017; Karbach et al., 2015; Murray et al., 2018; Nevo and Breznitz, 2014; Porter et al., 2018; Roberts et al., 2016; Studer-Luethi et al., 2016; Tayeri et al., 2016). Two studies included general samples recruited by advertising with no weight status data (Johnstone et al., 2012; Pugin et al., 2015). The three remaining studies involved children and adolescents with overweight/obesity (Boutelle et al., 2014; Verbeken et al., 2013; Verbeken et al., 2018).

3.3. Training features

3.3.1. Delivery and duration

Most interventions were solely school-based (Dunning et al., 2013; Hitchcoch and Westwell, 2017; Murray et al., 2018; Nevo and Breznitz, 2014; Porter et al., 2018; Roberts et al., 2016; Studer-Luethi et al., 2016; Tayeri et al., 2016) while a few were home-based (Astle et al., 2015; De Voogd et al., 2016; Johnstone et al., 2012; Pugin et al., 2015), lab-based (Boutelle et al., 2014; Karbach et al., 2015) and clinic-based (Verbeken et al., 2013; Verbeken et al., 2018).

The session duration ranged from 7 to 60 minutes, with a duration between 15 and 45 minutes in most studies (Astle et al., 2015; Dunning et al., 2013; Hitchcoch and Westwell, 2017; Johnstone et al., 2012; Karbach et al., 2015; Nevo and Breznitz, 2014; Pugin et al., 2015; Studer-Luethi et al., 2016; Tayeri et al., 2016; Verbeken et al., 2013; Verbeken et al., 2018), while a few lasted less than 15 minutes (Boutelle et al., 2014; De Voogd et al., 2016; Murray et al., 2018; Porter et al., 2018). In another study the session length was quite variable (Roberts et al., 2016).

The amount of training sessions ranged from one to 25, while the whole training period lasted from 1 day to 8 weeks. In most studies, participants completed 14 to 25 sessions over 4-8 weeks (Astle et al., 2015; Dunning et al., 2013; Hitchcoch and Westwell, 2017; Johnstone et al., 2012; Karbach et al., 2015; Nevo and Breznitz, 2014; Roberts et al., 2016; Studer-Luethi et al., 2016; Verbeken et al., 2013), which means training every day or almost every day. In two studies, participants underwent six to 12 sessions over 5-6 weeks (Tayeri et al., 2016; Verbeken et al., 2018). In one study, participants performed eight sessions over 3 weeks (De Voogd et al., 2016), whereas in another study of the same length, the number of training sessions was variable, from seven to 20 sessions (Pugin et al., 2015). Finally, in two studies the training was performed in a single session (Boutelle et al., 2014; Porter et al., 2018) and in another one, in three sessions (Murray et al., 2018).

3.3.2. Training tasks (generalised vs. cue-specific)

3.3.2.1. Generalised interventions

A large majority of studies applied generalised interventions (13 of 16), being the WM training the most frequent in eight studies (Astle et al., 2015; Dunning et al., 2013; Hitchcoch and Westwell, 2017; Karbach et al., 2015; Pugin et al., 2015; Roberts et al., 2016 ; Studer-Luethi et al., 2016; Tayeri et al., 2016). Half of these studies used the *Cogmed* program (Astle et al., 2015; Dunning et al., 2013;

Hitchcoch and Westwell, 2017; Roberts et al., 2016) which typically involved completing series of interactive, verbal and visual-spatial tasks that require the temporary storage and reordering of information. Some examples were recalling a sequence of numbers that light up in a certain order or remembering the order in which boxes were lit and repeat the sequence by selecting the appropriate boxes (for further details, see www.cogmed.com). Two more studies (Karbach et al., 2015; Pugin et al., 2015) used WM tasks from the *Braintwister WM training battery* (Buschkuehl, Jaeggi, Kobel, and Perrig, 2007; Buschkuehl et al., 2008). Karbach et al. (2015) carried out the farm and safari task, in which participants had to reproduce an animal sequence seen before in the correct order by subsequently clicking on the appropriate pictures. Pugin et al. (2015) applied a visual n-back training task, in which participants had to remember the position of a square and indicate by button pressing when the square appeared on the same position as n positions before. Finally, two studies used n-back tasks (Studer-Luethi et al., 2016; Tayeri et al., 2016). Studer-Luethi et al. (2016) carried out two ad-hoc visual n-back tasks (similar to Jaeggi et al.'s, 2010) with squares and animals as stimuli. Tayeri et al. (2016) chose an ad-hoc dual n-back task (developed by Jaeggi et al., 2003) with visual and auditory stimuli simultaneously.

Three more studies also applied WM training, but combined with general IC training (Johnstone et al., 2012; Verbeken et al., 2013) and with reading abilities (Nevo and Breznitz, 2014). Johnstone et al.'s (2012) consisted in two ad-hoc tasks: the first being a WM task (*Feed the Monkey*), in which participants had to search hidden visual stimuli and retain their screen position to match with other equal stimuli showed after. The second was a Go No-Go task, in which participants had to respond to pictures from one pre-potent 'Go' category whilst refraining from responding to any other pictures. Verbeken et al. (2013) chose two tasks; the first being a WM task of the *Braingame Brian* (based on Prins et al., 2011), in which participants had to retain sequences of rectangles that light up and reproduce them in the right order. The second was an ad-hoc Go No-Go task (developed by Dovis et al., 2008), in which participants had to respond to one key button or another depending on which side of the screen the stimuli were presented; then, a stop signal was introduced after the stimuli and participants had to inhibit their ongoing responses. Nevo and Breznitz (2014) used the *Working Memory Program* (WMP, Breznitz and Shany, 2011) and the *Reading Acceleration Program* (RAP, Breznitz and Bloch, 2010). The WMP had four parts: the digit recall (repeating digits in their original order), the block-matrix task (recalling the order of the cell's colour changes in a matrix), the reverse digit span task (recalling a sequence of digits in reverse order) and the reverse block matrix task (recalling the order of the changes in the cell's colour in reverse order).

The RAP encompassed several tasks of decoding, fluency, and comprehension at the levels of words, sentences, and paragraphs.

Only one study (Murray et al., 2018) carried out an auditory attention training based on *Wells' Attention Training Technique* (Wells, 1990). It consisted of a range of sounds (e.g., traffic, running water) presented simultaneously, some of which were continuous and others were intermittent and appeared at different spatial locations. Participants were guided to focus their attention to different sounds and locations sequentially.

Lastly, for the purposes of the present work, we considered that Porter et al.'s (2018) also conducted a generalised intervention (generalised IC training) as they applied two ad-hoc Go No-Go tasks (based on Lawrence et al., 2015), the first being designed with food stimuli and considered cue-specific (described above in Section 3.3.2.2), and the second being designed with technology and sports stimuli (originally conceptualized as an active control task). As their aim was to modify food choices, we did not consider this task as cue-specific. The task required participants to respond to Go signals (happy emoticons) paired with sports stimuli and inhibit the response to No-Go signals (sad emoticons) paired with technological stimuli.

3.3.2.2. Cue-specific interventions

A minority of studies applied cue-specific interventions (4 of 16 studies). Two studies made cue-related visual attention training (Boutelle et al., 2014; De Voogd et al., 2016) whereas only one did cue-related IC training (Porter et al., 2018). The last study targeted more than one cognitive function, combining cue-related IC training with cue-related visual attention training and approach/avoidance training (Verbeken et al., 2018).

Boutelle et al. (2014) and De Voogd et al. (2016) both used different paradigms of an ad-hoc dot-probe training task. Boutelle et al. (2014) developed the *Attention Modification Program* (AMP-Food, based on Najmi and Amir, 2010), which consisted of a dot-probe task with pairs of food words (i.e., cake) matched with neutral words (i.e., pencil). The position of the neutral word on the screen indicated the position of the subsequent probe, which acted as a contingency reinforcement such that the probe always appeared in the position of the neutral word (training attention away from food cues and toward neutral cues). De Voogd et al. (2016) modified the *Dot-Probe training* of MacLeod et al. (2002) using emotional stimuli with pairs of angry-neutral faces or neutral-neutral faces (to obscure the contingency). The probe location was always the location of the neutral face in angry-neutral trials and random in neutral-neutral trials. De Voogd et al. (2016) also included another training group doing an ad-hoc visual search attention task (based on Dandeneau et al., 2007), in which participants had to find and select the single happy face in a grid of negative emotional faces.

Porter et al. (2018) used two ad-hoc Go No-Go tasks (based on Lawrence et al., 2015). The first was designed with food stimuli (described here) and the second with arbitrary stimuli (already described in Section 3.3.2.1). The cue-specific IC training task required participants to respond to Go signals (happy emoticons) paired with healthy food stimuli and inhibit the response to No-Go signals (sad emoticons) paired with unhealthy food stimuli.

Verbeken et al. (2018) combined three ad-hoc tasks, the first being a Go No-Go task (based on Houben, Havermans, Nederkoorn, and Jansen, 2013) with Go signals paired to healthy food pictures and No-Go signals to unhealthy food pictures. The second task was a dot-probe task (adapted from MacLeod et al., 1986) with pairs of healthy-unhealthy pictures and the probe presented in the healthy picture. The third task consisted of an approach/avoidance task (adapted from Wiers, Rinck, Kordts, Houben, and Strack, 2010). Participants had to press the up arrow on the keyboard when the unhealthy food picture was tilted to the right, zooming the image out (mimicking an avoidance), or press the down arrow key when the healthy food picture was tilted to the left and making the picture zoom in (mimicking an approach).

3.4. Risk of bias

A summary of the risk of bias is shown in Figures 2 and 3. Based on the Cochrane's risk of bias tool (Higgins et al., 2011), eight studies demonstrated high risk of bias in at least one domain (Hitchcoch and Westwell, 2017; Johnstone et al. 2012; Murray et al., 2018; Porter et al., 2018; Pugin et al., 2015; Roberts et al., 2016; Tayeri et al., 2016; Verbeken et al., 2013), six studies showed an unclear risk of bias in several domains (Astle et al., 2015; Boutelle et al., 2014; De Voogd et al., 2016; Dunning et al., 2013; Nevo and Breznitz, 2014; Studer-Luethi et al., 2016) and only two studies had low risk of bias in all domains (Karbach et al., 2015; Verbeken et al., 2018).

3.5. Training effects

Training effects were classified as follows: 1) near-transfer to cognitive outcomes (the training task and the outcome task are highly similar, e.g. two different tasks of WM); 2) far-transfer to cognitive outcomes (the outcome task assesses other cognitive functions than the trained one, e.g. IC task after WM training); and 3) far-transfer to real-life measures (the outcome task and the training task are highly dissimilar and the measure involve functional aspects, e.g. behavioural difficulties).

3.5.1. Near-transfer to cognitive outcomes

3.5.1.1. Generalised interventions

Cognitive training showed near-transfer effects to minimum one cognitive function in 6 of the 10 studies with generalised interventions at post-training. Among the seven studies training only WM, significant improvements in WM were found in four studies, with benefits in visual WM (Karbach et al., 2013), verbal WM (Tayeri et al., 2016) and both visual and verbal WM (Astle et al., 2015; Dunning et al., 2013). Effect sizes ranged from medium to large (Dunning et al., 2013; Karbach et al., 2015). Another study found a trend towards significance in visual WM (Studer-Luethi et al., 2016). Finally, two studies reported no differences in verbal WM (Pugin et al., 2015) and both visual and verbal WM (Hitchcoch and Westwell, 2017). In addition, short-term memory improved in two studies (Dunning et al., 2013; Tayeri et al., 2016), with effect sizes ranging from medium to large (Dunning et al., 2013).

Among the three studies training WM combined with other cognitive functions, significant improvements in WM were found in two studies, with benefits in visual WM (medium effect size) after WM with IC training (Verbeken et al., 2013), and both visual and verbal WM benefits (large effect size) after WM with reading skills training (Nevo and Breznitz, 2014). A third study found no differences in visual WM after WM with IC training, although there was a trend towards significance in verbal WM (Johnstone et al., 2012). Moreover, short-term memory improved in one study with medium effect size (Verbeken et al. 2013). In contrast, two studies showed no benefits in inhibition after a combined training of WM and IC (Johnstone et al., 2012; Verbeken et al., 2013). The third study with a combined training (WM and reading skills) showed significant improvements in certain reading skills (word fluency and accuracy) with medium effect sizes, but no differences in others (reading comprehension, pseudo-word fluency and accuracy) (Nevo and Breznitz, 2014).

Regarding long-lasting effects of generalised interventions, it is worth noting that only 8 of 13 studies included follow-up assessments. Among the seven studies with WM training and near-transfer follow-up assessments, five studies reported long-lasting benefits in WM, with follow-up periods ranging from 1 to 12 months (Dunning et al., 2013; Karbach et al., 2015; Pugin et al., 2015; Roberts et al., 2016; Tayeri et al., 2016). Effects sizes were large in all studies with available data (Dunning et al., 2013; Karbach et al., 2015; Pugin et al., 2015). However, three other studies did not find these benefits at 3, 12 and 24 months (Hitchcoch and Westwell, 2017; Studer-Luethi et al., 2016; Roberts et al., 2016). Long-term effects in short-term memory remained at 6 and 12 months of follow-up, but not at 24 months in one study (Roberts et al., 2016) whereas in another study there was no effect (Dunning et al., 2013).

3.5.1.2. Cue-specific interventions

Cognitive training showed near-transfer effects to minimum one cognitive function in 1 of the 3 studies with cue-specific interventions at post-training. Between the two studies training cue-related visual attention, a study found a significant decrease in attentional bias to emotional stimuli when assessed with a visual searching task (De Voogd et al, 2016). The other study reported a trend to an increase in attentional bias to food stimuli in the control group while remaining stable in the training group (Boutelle et al., 2014). A third study which carried out cue-related IC training combined with cue-related attention and approach bias training found no differences in any of these cognitive functions (Verbeken, 2018).

3.5.2. Far-transfer to cognitive outcomes

3.5.2.1. Generalised interventions

Cognitive training showed far-transfer effects to minimum one cognitive function in 8 of the 10 studies with generalised interventions at post-training. Among the six studies training solely WM, far-transfer effects were found in attention (small effect size) (Dunning et al. 2013), crystallized intelligence (medium effect size) (Studer-Luethi et al., 2016), fluid intelligence (Tayeri et al., 2016) and reading skills (effect sizes from small to large) (Dunning et al., 2013; Karbach et al., 2015). However, there were some inconsistent results, as a similar amount of studies did not found benefits in these outcomes. Specifically, differences were not found in attention (Hitchcoch and Westwell, 2017), intelligence (Dunning et al., 2013, Pugin et al., 2015) or reading skills (Hitchcoch and Westwell, 2017). Lastly, cognitive functions that did not improve after WM training were IC (Dunning et al., 2013; Karbach et al., 2015; Pugin et al., 2015; Studer-Luethi et al., 2016), switching ability (Karbach et al., 2015) and mathematical skills (Dunning et al., 2013; Hitchcoch and Westwell, 2017; Karbach et al. 2015).

Among the two studies training WM combined with other cognitive functions, a study found improved reaction time after WM along with IC training, but no benefits in attention (Johnstone et al., 2012). A second study of combined WM and reading skills training found benefits in visual and verbal WM in the group only training reading skills (Nevo and Breznitz, 2014).

There was only one study training auditory attention. This study found far-transfer effects in inhibition and delay of gratification (medium and large effect sizes, respectively) (Murray et al., 2018).

Finally, there was only one study that applied generalised IC training and showed no differences in decision-making with food stimuli (Porter et al., 2018).

Regarding long-lasting effects of generalised interventions, most of the studies found no maintenance effects at several follow-up periods. Among the seven studies with WM training and follow-up assessments, only two studies showed significant effects in reading skills (sentence counting) at 12 months (large effect size) (Dunning et al., 2013) and some effects in fluid intelligence and memory at 1 month (Tayeri et al., 2016). Overall, data showed lack of benefits in IC (Dunning et al., 2013; Karbach et al., 2015; Pugin et al., 2015; Studer-Luethi et al., 2016), attention (Dunning et al., 2013; Hitchcoch and Westwell, 2017), switching (Karbach et al., 2015) and reading or mathematics skills (Dunning et al., 2013; Hitchcoch and Westwell, 2017; Karbach et al., 2015; Roberts et al., 2016; Studer-Luethi et al., 2016). Regarding intelligence, most of the studies also reported non-significant results (Dunning et al., 2013; Pugin et al., 2015; Roberts et al., 2016; Studer-Luethi et al., 2016).

3.5.2.2. Cue-specific interventions

Cognitive training showed far-transfer effects to minimum one cognitive function in the only study applying cue-specific interventions and far-transfer tasks at post-training. Benefits after cue-related IC training were demonstrated in decision-making related to healthy food choices (with medium effect size) (Porter et al., 2018).

3.5.3. Far-transfer to real life outcomes

Outcomes differed in their nature depending on the purpose of the study. A few studies explored functional aspects through several rating scales such as attentional, behavioural, socio-emotional difficulties or academic achievement, whereas others evaluated eating behaviour or aspects related to weight.

3.5.3.1. Generalised interventions

Cognitive training showed far-transfer effects to minimum one of the above-mentioned outcomes in 1 of the 3 studies with generalised interventions and assessing functional aspects at post-training.

The only study with solely WM training reported no differences in social, emotional, behavioural difficulties or academic achievement (Hitchcoch and Westwell, 2017). Similarly, the two studies with combined WM and IC training and assessing functional aspects showed no differences in behavioural difficulties (Johnstone et al., 2012), behavioural inhibition difficulties and BMI (Verbeken et al., 2013). However, there were some benefits in child carers' ratings of behavioural EFs such as WM and metacognition, with medium effect sizes (Verbeken et al., 2013).

Regarding long-lasting effects of generalised interventions, none of the studies exploring attentional, behavioural or socio-emotional outcomes found significant differences at 3, 6, 12 and 24 months after finishing the training in any social, emotional, attentional or behavioural measures (Johnstone et al., 2012; Hitchcoch and Westwell, 2017; Roberts et al. 2016). There were no long-lasting effects in quality of life either (Roberts et al., 2016). Finally, only one study reported significant effects in weight loss maintenance at 2-months follow-up, although it was not significant at 3-months (Verbeken et al., 2013).

3.5.3.2. Cue-specific interventions

Cognitive training showed far-transfer effects to minimum one functional outcome in the three studies with cue-specific interventions. Between the two studies training cue-related visual attention, one study found that training influenced the tendency to eat in the absence of hunger with a medium effect size (Boutelle et al., 2014), although there were no differences in salivation, craving or food preferences. The other study found no differences in attentional, behavioural or socio-emotional difficulties (De Voogd et al., 2016).

The study that carried out cue-related IC training combined with cue-related attention and approach bias training found reduced behavioural inhibitory problems as reported by educators (large effect size) (Verbeken et al., 2018) but no differences in BMI.

Regarding long-lasting effects of cue-specific interventions, two studies included follow-up assessments (De Voogd et al., 2016; Verbeken et al., 2018). No differences were found in attentional, behavioural or socio-emotional difficulties at 3, 6 and 12-months follow-up (De Voogd et al., 2016) nor in BMI two months after training (Verbeken et al., 2018).

4. DISCUSSION

4.1. Summary of findings

The first objective of this review was to present the impact of computerised cognitive training on cognitive functioning in children and adolescents with typical development. Roughly, among generalised interventions, results have shown that WM training produces near-transfer effects to WM. Near-transfer effects are not so consistent in other cognitive functions such as IC after generalised IC training or reading skills after combined WM and reading skills training. Among cue-specific studies, it seems that cue-related visual attention training produces near-transfer effects to attentional bias, although there was only one study to strongly support this conclusion.

Regarding far-transfer effects to other cognitive domains among generalised interventions, results are inconsistent as a similar number of studies have found significant and not significant effects after WM training in attention, intelligence and reading skills. In addition, data provide no evidence for far-transfer effects in IC, switching ability and mathematical skills. Likewise, lack of far-transfer effects has been shown in decision-making with food stimuli after generalised IC training. Finally, it seems that auditory attention training produces far-transfer effects in inhibition and delay of gratification. Among cue-specific interventions, far-transfer effects to decision-making have been found after cue-related IC training.

Overall, these findings are in line with previous works in children with attention deficit hyperactivity disorder and learning disabilities (Cortese et al., 2015; Peijnenborgh et al., 2016). In fact, transfer effects have been a focus of debate for years (Melby-Lervåg and Hulme, 2013; Redick, Shipstead, Harrison, Hicks, Fried, Hambrick et al., 2013; Shipstead, Redick and Engle, 2012) and recent reviews and meta-analyses exploring this issue have shown that, whereas WM training produces large effects in identical or similar tasks (near-transfer effects), this effect is not so clear in other cognitive domains (far-transfer effects) (Aksaylia, Sala and Gobet, 2019; Melby-Lervåg, Redick and Hulme, 2016; Simons et al., 2016). Additionally, whereas WM training programs in the reviewed studies were typically performed in 15-25 sessions over 4-6 weeks, cue-related attention and IC training periods were not as long, so any absence of consistent evidence in these domains could be potentially explained by such short training periods. Hence, there is a need for novel studies focused on, first, defining the minimum effective session duration and training periods and, second, establishing guidelines for the implementation of cognitive training.

The second objective was to summarise and assess the impact of CCT on non-cognitive domains and real-life outcomes, including eating behaviour, and its usability in the field of overweight and obesity. On the one hand, reviewed studies aimed at exploring the impact of generalised cognitive training on these outcomes reported mostly non-significant results. Nevertheless, only a few studies assessed these aspects, so no conclusions can be drawn. In this regard, it continues to be necessary to place emphasis on functional outcomes and to overcome traditional studies of WM training, which focus primarily on assessing neuropsychological outcomes (Chacko, Feirsen, Bedard, Marks, Uderman and Chimiklis, 2013). On the other hand, cue-specific training studies typically aimed at exploring eating behaviour or aspects related to weight showed some benefits of cognitive training in influencing eating choices but found no effects on BMI at post-training. Related to this, previous studies have shown that cue-specific cognitive training, specially cue-related IC training, generally influenced food intake or food choice in the laboratory (Jones et al., 2018; Yang, Shields, Wu, Liu, Chen and Guo, 2019) and that may contribute to weight-loss. Nevertheless, more research is needed to test the cognitive training effect on weight loss before giving specific recommendations (Yang et al., 2019). In this regard, it could be possible that cue-specific interventions may not be enough to influence so strongly such complex processes as weight loss and weight loss maintenance, as other EFs such as WM and cognitive flexibility contribute to moderating eating behaviour (Dohle et al., 2018). It has been hypothesised that if cognitive training could enhance WM, it could exert some influence on other EF domains, which, at the same time are linked to eating behaviour (Jones et al., 2018) and dietetic and exercise planning (Cortese et al., 2013). WM is considered a core EF (Diamond, 2013; Diamond and Lee, 2011) together with IC and cognitive flexibility, and these three core EFs support more complex self-regulatory skills such as planning, decision-making, and problem solving. Thus, reinforcing WM may contribute to the development of healthier diet and exercise habits by integrating knowledge and behavioural skills (Hayes et al., 2018; Jones et al., 2018). In fact, there is no reason to restrict cognitive training to just one cognitive function, as maybe combined training approaches (both generalised and cue-specific interventions) would enhance treatment outcomes. Thus, effective interventions targeting other relevant cognitive functions are needed in order to increase transferability to real contexts.

Furthermore, an important consideration is which type of stimuli would work better, since it is possible that food-related or non-food related training would make a difference, as previous research has shown (Yang et al., 2019), and even the similarity/dissimilarity between the training task and the measure task has been shown to influence results (Simons et al., 2016). In this regard and taking into account the above-mentioned considerations about far-transfer effects (Melby-Lervåg et al., 2016; Simons et al., 2016), it would be very interesting to introduce stimuli as similar as possible to those that children face in their daily life, in order to increase the effects of transference to real contexts.

Regarding our third objective, assessing long-term effects of cognitive training and the possibility to reinforce weight loss maintenance, it must be highlighted that only half of the selected studies assessed them. Similar to post-training outcomes, main benefits were found in WM after WM training (near-transfer effects). Unfortunately, far-transfer effects on IC, attention, switching or intelligence seemed not to last in time in most cases. Furthermore, far-transfer effects to real-life outcomes at follow-up were not encouraging either, as only one study reported significant effects in weight loss maintenance at 2-months follow-up, but not at 3-months, after generalised IC training. Likewise, no long-term effects were found in attentional, social, emotional or behavioural difficulties or quality of life after generalised or cue-specific interventions. Overall, these results are consistent with previous literature assessing the effects of EF training in other populations, in which the lack of long-lasting effects is considered a major issue (Diamond and Lee, 2011; Melby-Lervåg and Hulme, 2013). Thus, it may be a more general limitation of these types of interventions. However, most of the studies in eating behaviour and weight loss are focused on short-term outcomes (Yang et al., 2019), so longer duration studies are needed to better understand how cognitive training could be helpful to treat overweight and obesity.

4.2. Limitations

There are some limitations in our study that must be taken into account. First, regarding sample characteristics, we included typically developing individuals that could be overweight/obese or not. It is possible that cognitive training influences cognitive functioning in a different way depending on weight status and its potential cognitive impairment. These factors could have introduced baseline differences that may modulate training gains. In addition, as only three studies included overweight/obese samples we could not conduct subgroup analyses to determine cognitive training's usability in the field of overweight and obesity, despite it was our initial aim. Second, eligible outcomes across studies differed depending on their specific objectives, even though all studies targeted cognitive improvement. Third, and related with the previous considerations, the heterogeneity across samples and assessed outcomes made the application of meta-analytic techniques difficult, so that our results are fully based on a narrative review. Nevertheless, additional effect sizes were calculated to better summarize the effect of interventions. Fourth, only two studies showed a low risk of bias in all domains (Karbach et al., 2015;

Verbeken et al., 2018). In fact, risk of bias assessment has shown some methodological weaknesses in one of the six evaluated bias domains in half of the included studies. Despite it represents a low proportion of risk across all domains and studies and it is expected not to invalidate the results, it must be underlined that most of the studies did not report all the data to properly assess risk of bias in several domains. Therefore, conclusions drawn in this review are partially based on well-conducted studies but lack of information regarding several bias domains do not allow providing more robust evidence. In this regard, we recommend that future papers should include all information to properly assess the quality of studies and promote the transparency of data.

5. CONCLUSION

We can conclude that WM training has been shown as the principal approach among generalised interventions targeting cognitive function in children and adolescents. Main near-transfer effects have been obtained in WM after WM training, with medium to large effects sizes, while far-transfer to other cognitive functions is not strongly supported. These data imply, on the one hand, that WM training could be a potential option as a part of weight loss programs since it may reinforce self-control processes involved and contribute to learning healthy habits. However, new studies exploring the impact of WM training directly on eating behaviour and weight measures are necessary. On the other hand, cue-specific interventions seem to influence eating choices, but more studies applying IC or attentional bias training are needed to extend these findings. Additionally, there is no reason to restrict cognitive training to only one cognitive domain if there are several EFs involved in eating behaviour. Furthermore, new approaches targeting both generalised and cue-specific training should arise to examine their effects and determine how to apply them in an effective way in obesity.

Another conclusion that can be drawn from this review, with practical implications, is that if long-term effects of cognitive training are still dubious and not well supported, maybe computerised cognitive training has to be introduced as a part of more complex treatment programs. It could work as a form of reinforcement from time to time, depending on specific neurocognitive outcomes for each individual at different times of the therapy process. Therefore, more research is needed to establish how to integrate computerised cognitive training in a specific and individualized way in order to help people lose weight. Cognitive training literature has been criticised for assuming a ‘one treatment-fits-all approach’ (Franken and van de Wetering, 2015; Jones et al., 2018) and, in this sense, pre-screening individuals for specific biases and cognitive deficits may increase the therapeutic potential of these models by identifying individual factors that confer vulnerability to overeating (Folkvord et al., 2016). Research should lead efforts towards understanding how cognitive training could be useful to enhance correct eating behaviour at the individual level, and not only at the group level (Jones et al., 2018).

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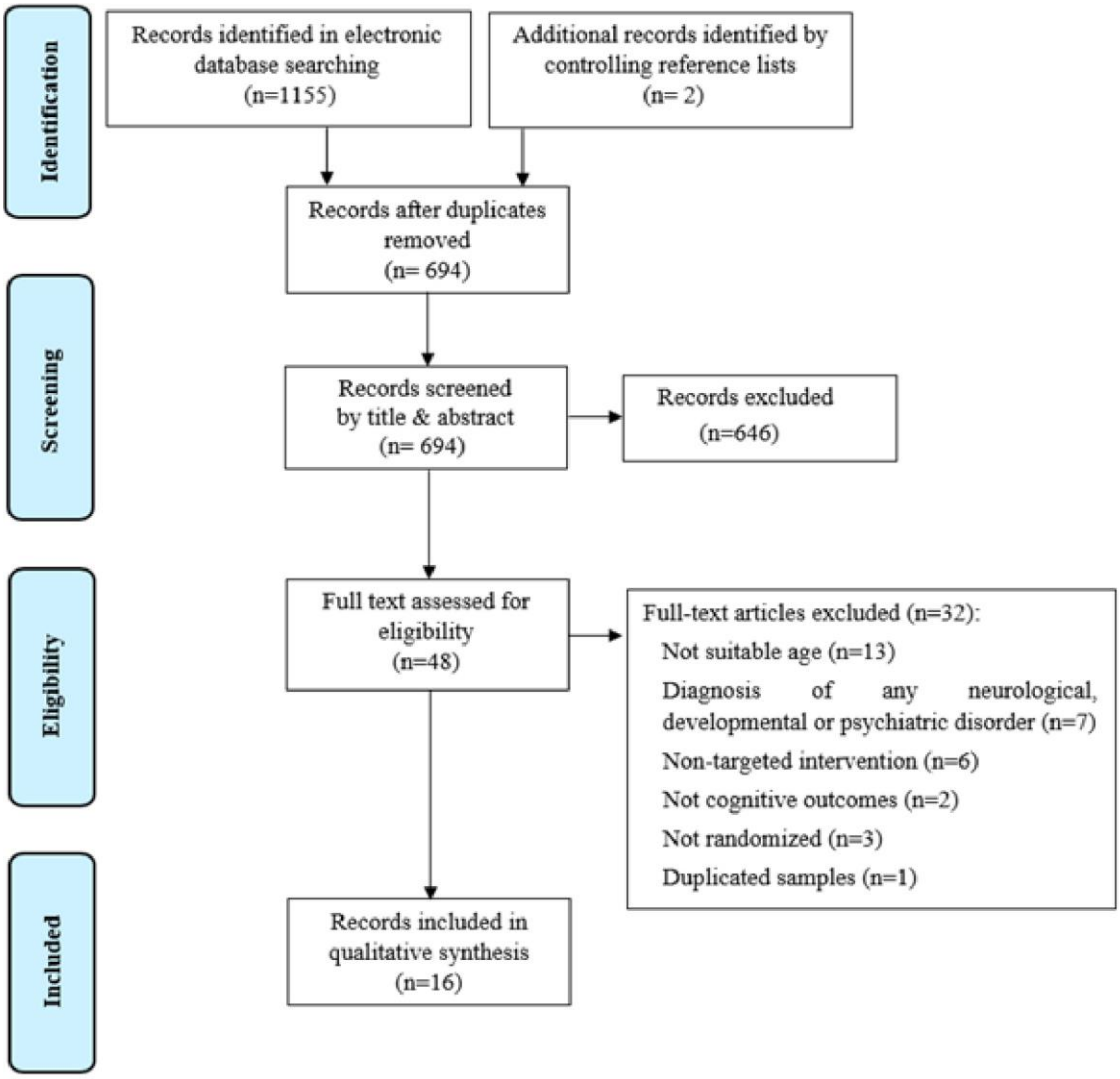
830 **FIGURE CAPTIONS**



831 **Fig. 1** PRISMA Flow diagram for study inclusion

Fig. 2 Summary of risk of bias within studies, based on Cochrane Risk of Bias Tool (Higgins et al., 2011)

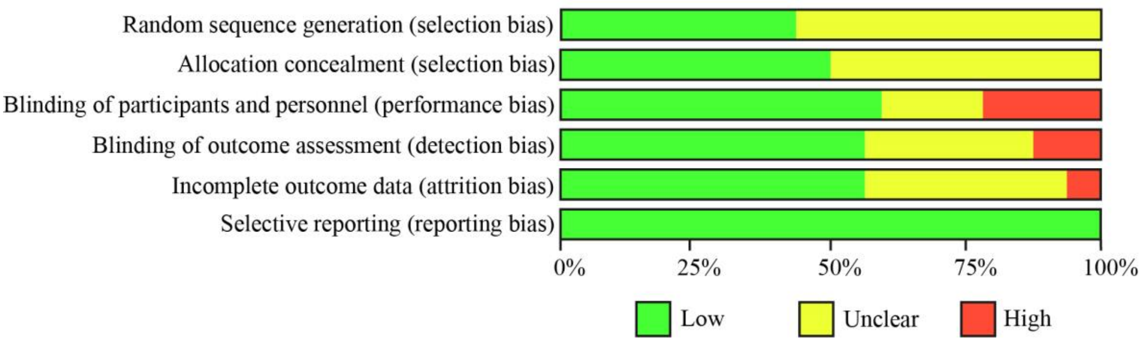


Fig. 3 Risk of bias across studies, based on Cochrane Risk of Bias Tool (Higgins et al., 2011)

TABLES

Table 1. Details of cognitive training studies included in the review

Table 1

Details of cognitive training studies included in the review

Author (year), language, country	**Training: targeted function, delivery, program**	**Design: training group (TG) (n) and control group (CG) (n)**	**Sample: weight status, age (mean ± SD), gender**	**Assessment time points**	**Cognitive outcomes (assessment tool), author's effect size, *calculated effect size*[a]**	**Other results (assessment tool), author's effect size, *calculated effect size*[a]**
Astle et al. (2015), English, UK	Verbal/ visual WM, home-based, Cogmed	TG (n=13): 20-25 sessions (30-45') over 4-6 weeks, tasks require the temporary storage and reordering of information, adaptive difficulty. Active CG (n=14): equivalent to TG, same difficulty over sessions.	NA, aged 8-11 (TG: 9.9 ± 0.8y; CG: 9.9 ± 0.9y), 10 males/17 females	Pre-post	↑ Visual and verbal WM (AWMA)	Neural connectivity data (not included)
Boutelle et al. (2014), English, US	Cue-related visual attention, lab-based, ad-hoc	TG (n=14): 1 session, 288 trials (7') of combinations of a probe type and screen position. Following word pairs (food - neutral), dot probe presented on neutral word position. Active CG (n=15): equivalent to TG, probe presented on neutral or food position, equal frequency.	Overweight and obese, aged 8-12 (10.83 ± 1.28y), 16 males/13 females	Pre-post	~ attention bias to food cues (DPT)	↕ Eating (EAH %), *d_{ppc2}=.60* ↕ Eating (EAH kcal), *d_{ppc2}=.64* ↔Craving, liking (Likert's) ↔Salivation (SHP)
De Voogd et al. (2016), English, Netherlands	Cue-related visual attention, home-based, ad-hoc	TG_1 (n=126): 8 sessions (15') over 3 weeks, visual search of a single happy face in a grid of negative emotional faces. TG_2 (n=128): 8 sessions (8') over 3 weeks, 160 trials of combinations of a probe type and screen position. Following angry-neutral or neutral-neutral faces, dot probe presented on angry face position or randomly (neutral-neutral trials). Active CG[1] (n=38): equivalent to TG_1, neutral stimuli (flowers). Active CG[2] (n=48): equivalent to TG_2, probe presented on neutral or food position with equal frequency.	NA, aged 11-18 (14.41 ± 1.20y), 144 males/ 196 females	Pre-post, follow-up (3, 6,12 m, only questionnaires)	↓[1,2] Attentional bias (EVST) ↔ Attentional bias (DPT)	↔Subjective attentional control (ACS) ↔Anxiety/depression (SCARED, CDI) ↔Self-esteem (RSES) ↔Perseverative thinking (PTQ) ↔Test anxiety (PMT-K) ↔Socio-emotional, behavioural problems (SDQ)

Table 1 (*continued*)

Dunning et al. (2013), English, UK	Verbal/ visual WM, school-based, Cogmed	TG (n=34): 20-25 sessions (30-45') over 6 weeks, tasks require the temporary storage and reordering of information, adaptive difficulty. Active CG (n=30): equivalent to training group, same difficulty over sessions. Passive CG (n=30): no intervention.	NA, Aged 7-9 (8.42 ± 0.66y) 47 males/47 females	Pre-post, follow-up (12 m)	*Post-training*: ↑ Visuospatial STM (AWMA), d=.87, d_{ppc2}=*1.08* ↑ Visuospatial STM (AWMA), d=.57, d_{ppc2}=*.64* ↑ Verbal WM (AWMA), d=.99, d_{ppc2}=*1.57* ↑ Verbal WM (AWMA), d=1.63, d_{ppc2}=*2.26* ↑ Visuospatial WM (AWMA), d=.67, d_{ppc2}=*1.04* ↑ Visuospatial WM (AWMA), d=.77, d_{ppc2}=*1.07* ↑ Following instructions (ad-hoc WM task), d=.71, d_{ppc2}=*.79* ↑ Written expression (KTEA), d=.69, d_{ppc2}=*.51* ↑ Sentence counting (WORD), d=1.10, d_{ppc2}=*.51* ↑ Basic reading (WORD), d=.62, d_{ppc2}=*.27* ↑ Omissions (CPT), d=.32, d_{ppc2}=*.36* ↑ Verbal WM (AWMA), d=.59, d_{ppc2}=*.70* ↑ Sentence counting (WORD), d=.61, d_{ppc2}=*.31* ↑ Basic reading (WORD), d=.85, d_{ppc2}=*.34* ↑ Omissions (CPT), d=.24, d_{ppc2}=*.28* ↔ Verbal IQ, performance IQ (WASI), maths (WOND), commissions (CPT) *Follow-up:* ↗ Verbal WM, d=1.16, d_{ppc2}=*1.28* ↗ Sentence counting, d=1.18, d_{ppc2}=*1.28*	Not assessed
Hitchcoch and Westwell (2017), English, Australia	Verbal/ visual WM, school-based, Cogmed	TG (n=54): 25 sessions (45') over 5 weeks, tasks require the temporary storage and reordering of information, adaptive difficulty. Active CG (n=45): equivalent to training group, same difficulty over sessions. Passive CG (n=49): habitual activities.	NA, aged 10-13 (12.25 ± 0,56y), 68 males/80 females	Pre-post, follow-up (3 m)	↔ WMI (WISC) ↔ Attention (TEA-CH) ↔ Task- related attention[b]	↔ Social, emotional, behavioral difficulties (CBCL) ↔ Academic achieve-ment(PAT)

Table 1 (*continued*)

Johnstone et al. (2012), English, Australia	Visual WM and general IC, home-based, ad-hoc	<u>TG_1</u> (n=23): 25 sessions (15-20') over 5 weeks, 'Feed the Monkey' game. Bananas had to be found in those boxes presented before. Go-No Go game in which participants responded to one of eight pictures. <u>TG_2</u> (n=20): equivalent to previous training group, adding an EEG device to monitor attention level and extra reward. <u>Passive CG</u> (n=25): waitlist.	NA[c], aged 7-13 (TG_1: 9.1 ± 2.1y; TG_2: 9.9 ± 2.0y; CG: 9.8 ± 2.1y), 42 males/ 26 females	Pre-post, follow-up (6 weeks, only behavioural measures)	↑$_{1,2}$ Reaction time to neutral stimuli (Flanker task) ↔ Interference, facilitation effects, correct responses (Flanker task) ↔ Inhibition (Go-No Go task) ↔ Attention (Oddball task) ↔ Visual WM (Counting span) ϒ$_{1,2}$ Verbal WM (Digit span)	↔Behavior (CPRS-R, BRS) EEG data not included
Karbach et al. (2015), English, Germany	Visual WM, lab-based, Brain-twister	<u>TG</u> (n= 14): 14 sessions (40') over 8 weeks, "farm task" and "safari task", participants had to reproduce an animal sequence seen before in the correct order by subsequently clicking on the appropriate pictures, adaptive difficulty. <u>Active CG</u> (n= 14): equivalent to training group, low-level difficulty over sessions.	NA, aged 7-9 (8.4 ± 0.07y), 14 males/14 females	Pre-post, follow- up (3 m)	*Post-training:* ↑ Visual WM (WM-ST), <u>η_p^2=.21</u>, d_{ppc2}*=2.43* ↑ Reading ability (KRT), <u>η_p^2=.18</u>, d_{ppc2}*=2.51* ↔Mathematical ability (GMT) ↔Switching, inhibition (TSP) *Follow-up:* ↑ Visual WM, <u>η_p^2=.18</u>, d_{ppc2}*=3.39* ↔Switching, inhibition, reading ability, mathematical ability	Not assessed
Murray et al. (2018), English, UK	Verbal/ auditory attention, school-based, Wells' Attention Training Technique	<u>TG</u> (n= 30): 3 sessions (11') over 1 week. Sounds presented simultaneously at different spatial locations and a narrator instructs children on where to focus their attention. <u>Active CG</u> (n= 33): 3 sessions (11') over 1 week, progressive muscle relaxation following verbal instructions. <u>Passive CG</u> (n=38): habitual school activities.	NA, aged 5-6 (6.24 ± 0.33), 40 males/ 61 females	Pre-post	↑↑Delay of gratification (Marshmallow Task), <u>η_p^2=.14,</u> TG vs Active CG: d_{ppc2}*=.48* TG vs Passive CG: d_{ppc2}*= .58* ↑Verbal inhibition (Day/Night task) <u>η_p^2 =.09</u>, d_{ppc2}*=.55*	Not assessed

Table 1 (*continued*)

Nevo and Breznitz (2014), English, Israel	Verbal/ visual WM and verbal decoding, fluency and comprehension, school-based, WMP and RAP	TG_1 (n=27): 12 sessions of RAP + 12 sessions of RAP over 8 weeks. TG_2 (n=27): 12 sessions of RAP + 12 sessions of WMP (adaptive difficulty) over 8 weeks. TG_3 (n=23): 12 sessions of WMP (adaptive difficulty) + 12 sessions of RAP over 8 weeks. Passive CG (n=20): no training. WMP: digit recall task, block-matrix task, the reverse digit span task and the reverse block matrix task. RAP: tasks of decoding, fluency, and comprehension at the levels of words, sentences, and paragraphs. All: each session lasted 24’ approximately	NA, aged 8-9 (8.6y), 50 males/ 47 females	Pre, after 12 sessions, and post	*Post-training:* ↑$_2$ Word fluency (AF-NWRT), d_{ppc2}=*.57* ↑$_1$ Word accuracy (AF-NWRT), d_{ppc2}=*.67* ↑$_{1\text{-}3}$ Phonological STM (AWMA), TG_1 vs Passive CG: d_{ppc2}=*1.40* TG_2 vs Passive CG: d_{ppc2}=*1.01* TG_3 vs Passive CG: d_{ppc2}=*.97* ↑$_{1\text{-}3}$ Visuospatial complex memory (AWMA), TG_1 vs Passive CG: d_{ppc2}=*1.08* TG_2 vs Passive CG: d_{ppc2}=*.97* TG_3 vs Passive CG: d_{ppc2}=*1.06* ↑$_{1,2}$ Phonological complex memory (AWMA), TG_1 vs Passive CG: d_{ppc2}=*.88* TG_2 vs Passive CG: d_{ppc2}=*1.13* ↑$_1$ Episodic buffer (AWMA), d_{ppc2}=*1.02* ↔ Visuospatial STM (AWMA) ↔ Reading comprehension (ERT) ↔ Pseudo-word fluency, pseudo-word accuracy (AF- NWRT)	Not assessed
Porter et al. (2018) Study 2, English, UK	Cue-related inhibitory control/ generalised inhibitory control[d], school-based, ad-hoc	TG (n=29): 1 session, go= healthy food (75%), no go=unhealthy food (25%). Active CG[1] (n=25): 1 session, go=healthy food (50%) no go=unhealthy food (50%). Active CG[2] (n=27): 1 session, go=sport stimuli (75%), no go=technology stimuli (25%). All: 5 blocks per 32 trials (1500ms; intertrial-interval of 1000 ms; 7’ per session).	NA, aged 4-11 (7.54 ± 2.22y), 45 males/ 36 females	Pre-post	↑^{1,2}Decision making (healthy food, hypothetical shopping task[e]), η_p^2=.118, TG vs ACG[1]: d_{ppc2}=*.65* TG vs ACG[2]: d_{ppc2}=*.44*	Not included

Table 1 (*continued*)

Pugin et al. (2015), English, Switzerland	Visual WM, home-based, BrainTwister	TG (n=14): 7-20 sessions (30') over 3 weeks, visual n-back task, participants had to remember the position of a square as n before, increasing difficulty adapted to individual. Passive CG (n=15): following habitual activities.	NA, aged 10-16 (TG: 12.97 ± 0.40y; CG: 13.23 ± 0.37y), 29 males	Pre-post, follow-up (2-5 m)	*Post-training:* ↔Verbal WM (ANB, LNST), number-span task, fluid intelligence (matrix reasoning, TONI), inhibition (SCWT), interference (FT) *Follow-up:* ↑ Verbal WM, $d_{ppc2}= 1.51$ ↔Number-span task, fluid intelligence, inhibition, interference	Not assessed
Roberts et al. (2016), English UK	Verbal/ visuospatial WM, school-based, Cogmed	TG (n=226): 20-25 sessions (35-60') over 5-7 weeks, tasks require the temporary storage and reordering of information, adaptive difficulty. Passive CG (n=226): following habitual activities.	NA, aged 6-7 (TG: 6.9 ± 0.4y; CG: 6.7 ± 0.4y), 212 males/ 240 females	Pre, follow-up (6, 12 and 24 m)	*Follow-up (6m):* ↑ Visuospatial STM, verbal WM (AWMA) ↔IQ (WASI2) *Follow-up (12m):* ↑ Visuospatial STM ↔Verbal WM ↔Academic achievement (WRAT4) *Follow-up (24m):* ↔Visuospatial STM, verbal WM ↔Academic achievement	*Follow-up (all):* ↔Attention problems (Conners' 3 ADHD index) ↔Socioemotional difficulties (SDQ) ↔Quality of life (PEDSQL)* ↔Learning competency (ARS) ↔Approach to learning (SRS)
Studer-Luethi et al. (2016), English, Switzerland	Visual WM, school-based, ad-hoc	TG (n=34): 17-20 sessions (15') over 4 weeks, 2 tasks; visual n-back (coloured square stimuli) and span task (animal stimuli). Active CG (n=31): 17-20 sessions (15') over 4 weeks, games targeting reading comprehension, and syntax, among others. Passive CG (n=30): following habitual activities.	NA, aged 7-8 (8.25 ± 0.5y), 62 males/ 33 females	Pre-post, follow-up (3m)	*Post-training:* ↑↑Crystallized intelligence (vocabulary, CFT), $\underline{\eta_p^2=.10}$ ≈ WM (backward colour span task) ↔Inhibition (Stroop task), fluid intelligence (RPM), scholastic abilities (KRT, DEMAT 2+) *Follow-up:* ↔Crystallized and fluid intelligence, WM, inhibition, scholastic abilities	Not assessed

Table 1 (*continued*)

Tayeri et al. (2016), English, Iran	Visual/ verbal WM, school-based, ad-hoc	TG (n=36): 12 sessions (45’) over 6 weeks, dual n-back task with visual and auditory stimuli, increasing difficulty. Passive CG (n=30): following habitual activities.	NA, aged 13-14 (13.48 ± 0.50y), 66 females	Pre-post, follow-up (1m)	*Post-training:* ↑ Fluid intelligence (RAPM), general memory, STM, working memory (WMS) *Follow-up:* ↑ Fluid intelligence, general memory, working memory ↔STM	Not assessed
Verbeken et al. (2013), English, Belgium	Visual WM and general IC, clinic-based, Braingame Brian and ad-hoc	TG (n=22): 25 sessions (40’) over 6 weeks, 2 tasks; WM task, participants had to retain sequences of rectangles and reproduce them, adaptive difficulty. Go-No Go task with stop signal. Passive CG (n=22): treatment as usual (CBT techniques).	Overweight and obese, aged 9-14 (9.79 ± 1,04y), 24 males/20 females	Pre-post, follow-up (2-3m, only BMI)	↑ STM visual memory (CBTT-forward) η^2=.13, d_{ppc2}=.75 ↑ Visual WM (CBTT-backwards) η^2=.14, d_{ppc2}=.53 ↔Inhibition (ST)	*Post-training:* ↑ WM, meta-cognition (BRIEF) η^2=.10; .12, d_{ppc2}=.22; .71 ↔Inhibition (BRIEF) ↔BMI *Follow-up (2m):* ↑ BMI, η^2=.16, d_{ppc2}=.20 *Follow-up (3m):* ↔BMI
Verbeken et al. (2018), English, Belgium	Cue-related inhibitory control, cue-related attention and approach bias, clinic-based, ad-hoc	TG (n=21): 6 sessions (30’) over 5 weeks, combining 2 of 3 training tasks with food stimuli. Active responses[f] always matched to healthy food stimuli. Active CG (n=15): equivalent to training group, active responses* randomly matched to either healthy or unhealthy food stimuli.	Overweight and obese, aged 9-15 (12.06 ± 1.47y), 17 males/ 19 females	Pre-post, follow-up (2m, only BMI)	↔Inhibition (Go-No Go task) ↔Attention bias (VP) ↔Approach bias (ATT)	*Post-training*: ↓Inhibitory problems (caregiver’s BRIEF), η_p^2 =.26, d_{ppc2}= 1.91 ↔BMI *Follow-up:* ↔BMI

Note. ACS = The Attentional Control Scale; ADHD = Attention/Deficit Hyperactivity Disorder; AF-NWRT = Alef and Taf (A-Z) Normative Word Reading Test; ANB = Auditory N-Back; ARS = Academic Rating Scale; ATT = Approach/avoidance task; AWMA = Automated Working Memory Assessment; BMI = Body Mass Index; BRIEF = Behavioral Rating Inventory of Executive Function; BRS = Purpose-designed Behaviour Rating Scale; CBCL = Child Behavior Checklist; CBT = Cognitive-Behavioural Therapy; CBTT = The Corsi Block-Tapping Task; CDI = Children's Depression Inventory; CFT = The Culture Fair Intelligence Test; CPRS-R = Conners’ Parent Rating Scale revised; CPT = Continuous Performance Test; DEMAT 2+ = German Mathematics Test for Secondary Classes; DPT = Dot Probe Task; EAH = Eating in the Absence of Hunger free access paradigm; EEG = Electroencephalogram; ERT = Elul Reading Test; EVST = The Emotional Visual Search Task; FT = Flanker Task; GMT = German Mathematics Test; KRT = Knuspels Reading Test; KTEA = Kaufman Test of Educational Attainment; LNST= Letter-Number Sequencing Task; NA = Not available; PAT = The Progressive Achievement Test; PEDSQL = Pediatric

Quality of Life Inventory; PMT-K = Performance Motivation Test for Children; PTQ = The Perseverative Thinking Questionnaire; RAP = Reading Acceleration Program; RAPM = Raven's Progressive Advanced Matrices; RPM = Raven's Progressive Matrices; RSES = Rosenberg Self-Esteem Scale; SCARED = Screen for Child Anxiety Related Emotional Disorders; SCWT = Stroop Colour-Word Test for Children; SDQ = Strengths and Difficulties Questionnaire; SHP = Strongin-Hinsie Peck method; SRS = Social Rating Scale; ST = The Stop Task; STM = Short-term memory; TEA-CH = Test of Every Day Attention for Children; TONI = Test of Nonverbal Intelligence; TSP = Task-switching paradigm; VP = Visual-probe attention task; WASI = Wechsler Abbreviated Scales of Intelligence; WM = Working Memory; WMI = Working Memory Index of Wechsler Intelligence Scale for Children; WMS = Wechsler Memory Scale. WM-ST = Working Memory-Span Task; WMP = Working Memory Program; WOND = Wechsler Objective Number Dimensions; WORD = Wechsler Objective Reading Dimensions; WRAT4 = Wide Range Achievement Test, 4th edition.

[a] Effect sizes from authors' report, not available in some studies and *calculated effect sizes*, not viable in some studies.
[b] Participants had to select among 6 choices of what they were thinking, while doing reading comprehension and mathematics tasks.
[c] The sample included ADHD children, but only healthy children data were taken into account.
[d] For the purposes of the review, we consider that the Active CG[2] underwent a generalised IC training.
[e] Ad-hoc task in which participants had to choose between healthy food cards or unhealthy food cards.
[f] Active responses: the participants had to press the keyboard in response to certain stimulus (Go-No Go and visual-probe attention tasks); in approach/avoidance task, it refers to an approach response.

Meaning: ↑ significant increase (TG> active CG); $\uparrow^{x,y}$ significant increase (TG> active CG^{x,y}); ↑ significant increase (TG> passive CG); $\uparrow_{x,y}$ significant increase (TG$_{x,y}$ > passive CG); ↑ significant increase (active CG > TG); ↑ significant increase (active CG > passive CG); $\downarrow^{x,y}$ significant decrease (TG <active CG^{x,y}); ~ trend for significance (TG> active CG); ~ trend for significance (TG> passive TG); $\sim_{x,y}$ trend for significance (TG$_{x,y}$> passive TG); ↔ no differences between groups; ↗ training group significant predictor