Cognitive Control Training for Children with Anxiety and Depression: A Systematic Review

*Elizabeth J. Edwards[1], Dajana Zec[1], Marilyn Campbell[2], Kristof Hoorelbeke[3], Ernst H. W. Koster[3], Nazanin Derakshan[4], and Jeffrey Wynne[1]

[1]School of Education, The University of Queensland, Q 4072, Australia

[2] School of Early Childhood and Inclusive Education, Queensland University of Technology, Brisbane, Australia

[3] Department of Experimental Clinical and Health Psychology, Ghent University, Belgium

[4] Department of Psychological Science, Birkbeck University College of London, United Kingdom

Author for Correspondence:
Dr Elizabeth J. Edwards
School of Education
The University of Queensland
St Lucia, QLD, 4072
AUSTRALIA
Phone: +61 481906968
Email: elizabeth.edwards@uq.edu.au

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Abstract

Cognitive control training has gained traction as an intervention for reducing anxiety and depression vulnerability in adults. There are, however, a limited number of studies investigating such training interventions for reducing symptomology of anxiety and depression in children and adolescents. Thus, we aimed to provide a robust review and qualitative synthesis of the available research in young people. Twelve articles met the inclusion criteria, and all were randomised control trials. Evidence of the efficacy of cognitive control training for relief of symptoms are reported separately for anxiety, depression, and other related psychological factors, and on the basis of type of cognitive control training paradigm. A lack of standardisation in relation to type of intervention, duration and context, outcome measures and population was observed. Results are discussed in terms of these variations and recommendations for future research are provided.

Contents

1.0 Introduction

Mental ill health is a leading cause of disability and accounts for the largest portion of years lived with disability in individuals up to 24 years-old (Erskine et al., 2015). Symptoms of anxiety (i.e., excessive disproportionate and anticipatory fear) and depression (sadness, amotivation and loss of interest in previously enjoyed activities) are the most common mental health issues found in children and adolescents, and frequently share co-morbidity (Campbell, 2006; Cummings et al., 2014). Furthermore, clinical symptoms in young people are often recognised through links to other problems (e.g., learning difficulties, recent negative life events), or when symptoms do not improve despite intervention (Headley & Campbell, 2013; Hinchliffe & Campbell, 2016). If untreated, these issues can lead to significant adverse psychosocial outcomes later in life, including worsening psychopathology, educational underachievement, substance abuse and suicidal behaviour (Boden et al., 2007; Clayborne et al., 2019; Woodward & Fergusson, 2001). Given that the median onset for anxiety is 11 years of age (Kessler et al., 2018), finding effective preventions for childhood emotional disorders requires an urgent response.

There is now considerable evidence indicating that cognitive control deficits (the ability to exert control over mental processes) play a role in emotion regulation difficulties and in the development of psychopathology (Cohen & Ochsner, 2020; Nigg, 2017; Ochsner and Gross, 2005; Schweizer et al., 2020). Notably, research shows that impairments in cognitive control can predict anxiety and depression in children and adolescents prospectively (Kertz et al., 2016; Nelson et al., 2018; Sportel et al., 2011). Cognitive theories of both anxiety (Eysenck et al., 2007) and depression (Joormann & D'Avanzato, 2010; De Raedt & Koster, 2010) hold cognitive control difficulties to account for vulnerability of anxiety and depression symptomology. For example, Eysenck et al., (2007) suggests that anxious individuals direct their attention towards potentially threatening stimuli or events in the early stages of information processing (e.g., a fear-provoking stimulus) which in turn reduces the

cognitive resources required for task performance. De Raedt and Koster (2010) suggest an interplay between cognitive and biological processes such that depressed individuals experience a mood-congruent attentional bias in the latter stages of information processing (e.g., inability to inhibit negative ruminations) which in turn sustains negative affect.

Advances towards integrating cognitive neuroscience into clinical research have focussed on investigating the reciprocity of the relationship between emotional factors and cognitive deficits, with recent conceptualisations advocating cognitive control as a transdiagnostic mechanism behind anxiety and depressive vulnerability (see Derakshan, 2020, for a review). Thus, existing cognitive paradigms have been modified to train cognitive processes with the aim of reducing emotional vulnerability for (risk of developing) anxiety and depression. There is now growing support to show that cognitive control training (CCT) is effective in reducing anxiety (e.g., Derakshan, 2020; Sari et al., 2016, Swainston & Derakshan, 2018) and depression vulnerability (see Koster et al., 2017) in adults.

1.1 Cognitive control training paradigms

Cognitive control involves processes which flexibly adapt thoughts and behaviours as required by a current goal (Cohen, 2017; Miller & Cohen, 2001). It is suggested that cognitive control involves executive functions that can be broadly operationalised into three inter-relatable, yet separate processes: mental set shifting (shifting), inhibition of prepotent responses (inhibition) and monitoring and updating of WM representations (updating; Miyake et al., 2000).

Experimental manipulations of cognitive control target the underlying cognitive deficits which are known characteristics of vulnerability for anxiety and depression (De Raedt & Koster, 2010; Eysenck et al., 2007). In adults, CCT studies have used tasks with neutral stimuli, for example, shifting tasks such as a computerised cognitive remediation task (Morimoto et al., 2014), inhibition tasks such as the flanker task (Cohen et al., 2015) and

more commonly WM tasks such as the adaptive dual *n*-back (Course-Choi et al., 2017; Grol et al., 2018; Swainston & Derakshan, 2018; see Derakshan, 2020, for a review) and the adaptive paced auditory serial addition task (aPASAT; Calkins et al., 2015; Hoorelbeke et al., 2015; Hoorelbeke & Koster, 2017; Siegle et al., 2014). Other work has employed affective WM tasks with the goal of training individuals to reduce excessive processing of emotional stimuli (Du Toit et al., 2020), for example, the adaptive affective dual *n*-back (Iacoviello et al., 2014; Schweizer et al., 2011; Lotfi et al., 2020). In addition to highly controlled experimental paradigms, other studies have used commercial WM training packages that include a variety of games to exercise numerous cognitive domains such as sustained attention, processing speed and WM more broadly, for example, Scientific Brain Training Pro (www.sbtpro.com; Bowie et al., 2013), Cogmed (CWMT; www.cogmed.com.au; Lengvenyte et al., 2020) and My Brain Solutions (www.mybrainsolutions.com; Routledge et al., 2021). Studies with adults have shown differential emotional and cognitive transfer effects (outcomes) depending on whether training used neutral or affective tasks or commercial WM packages. For instance, whereas CCT procedures relying on affective stimuli have shown to be equally effective in obtaining cognitive transfer, some studies suggest affective CCT procedures to be more effective in altering emotional outcomes in adults (e.g., Iacoviello et al., 2014; Schweizer et al., 2011).

Studies using CCT are gaining traction as an intervention capable of addressing adult anxiety and worry (see Derakshan, 2020 for review), and depression and rumination (e.g., Hoorelbeke & Koster, 2017; Siegle et al., 2007; see Koster et al., 2017 for review). In the last decade CCT research in adult populations has increased with encouraging results indicating that ~2-3 weeks of daily CCT can improve affect in remitted depressed participants (Hoorelbeke & Koster, 2017), rumination prone adults (Hoorelbeke et al., 2015), and worry prone adults (Chourse-Choi et al., 2017; Grol et al., 2018; Hotton et al., 2018). In addition,

beneficial effects have been observed in breast cancer survivors, with reductions in anxiety-related symptoms 15 months post-training (Swainston & Derakshan, 2018). Similarly, long-term beneficial effects of CCT have been observed in patients with major depressive disorder (MDD; Siegle et al., 2014) at one year follow-up, including reduced risk for recurrence of depression following remission (Hoorelbeke et al., 2021). However, much less is known regarding the effectiveness of CCT as a transdiagnostic intervention for anxiety and depression in children and adolescents which forms the focus of the present work.

1.2 Current study

The rationale for our interest in examining CCT as an intervention to protect against, and treat, childhood emotional symptoms rests with several key issues. First, poor cognitive control in early childhood has shown to be a critical risk factor for development of anxiety and depression in later childhood (Kertz et al., 2016; Nelson et al., 2018). Second, half of all lifetime mental ill health conditions emerge before adolescence (Kessler et al., 2015). Third, CCT affords much promise as an efficacious tool in reducing anxiety and depression in adults (see Dolcos et al., 2020; Koster et al., 2017). Consequently, we argue that CCT in children and adolescents may hold promise as a treatment for prevention of anxiety/depression. We conducted a systematic review to identify, evaluate, and synthesise findings from studies that contribute to evidence-based implementation of CCT, including neutral, affective and commercialized training procedures, for emotional symptoms in children and adolescents. We addressed the research question ‘Does cognitive control training influence (indicators of risk for) anxiety and depression in children and adolescents?’

2.0 Method

2.1 Literature search

Our search was conducted in accord with the guidelines for transparent reporting of systematic reviews and meta-analysis PRISMA 2015 and included additional information to

meet the requirements of the PRISMA 2020 update (Page et al., 2020; Rethlefsen et al., 2021; Shamseer et al., 2015). The data extraction and synthesis plan were preregistered with PROSPERO (https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=218541 - Identifier: CRD42020218541). In the first phase, the databases in the field of clinical psychology and psychiatry (Web of Science, Medline, APA PsycINFO, EMBASE, CINAHL and PubMed) were searched for identification of studies using CCT for potential inclusion (see Appendix). Database searches were conducted between December 10-15, 2020. Considering the diversity in applications of CCT in the context of (vulnerability for) anxiety and depression (e.g., at-risk groups or outcomes, healthy or clinical levels of anxiety, worry, depression, stress/emotional reactivity, difficulties with emotion regulation, affect, conduct, or behaviour), the search terms specified the type of CCT intervention in the title, and population of interest as key words in the abstract. Following Koster et al. (2017), we included a broad range of terms used to describe CCT: *cognitive control therapy* OR *cognitive control training* OR *cognitive control task* OR *neurocognitive training* OR *cognitive training* OR *executive control training* OR *working memory training* OR *cognitive emotional training* OR *cognitive remediation* OR *neurobehavioral therapy*, with all terms entered at the record title level. Terms *child** OR *adol** OR *you**, were entered at the level of abstract to specify the population of interest. In the second phase we screened the reference lists and Google Scholar profiles of the first authors of the manuscripts identified in the earlier phase, in addition to reference lists of theoretical papers, reviews and/or meta-analyses (i.e., snowballing). Database alerts were set up between December 10, 2020 and March 1, 2021, for additional studies matching the search criteria.

2.2 Inclusion criteria and exclusion criteria

We included published studies written in English (PhD theses were also considered) and examined effects of CCT in children and adolescents less than 18 years or considered

adults and young people that had separate analyses for children/adolescents. Samples could be young people with healthy, clinical or at-risk levels of anxiety, worry, depression, stress/emotional reactivity, or difficulties with emotion regulation, conduct, or behaviour. Studies involving participants older than 18 years of age were excluded. Studies must have included a CCT intervention that manipulated cognitive control processes directly (i.e., training procedures targeted executive processes regulating working memory functioning; e.g., updating, inhibition, shifting; Miyake et al., 2000). Studies strictly reporting effects of cognitive bias modification training were excluded. Studies were included if there was an experimental manipulation of cognitive control using CCT methodology. That is, the study had a between groups designs, such as control groups (e.g., sham training, wait-list, low-load training), and/or comparison to other therapies (e.g., cognitive behavioural therapy, mindfulness). Studies were included if an outcome/s of interest related to anxiety and/or depression. Hence, a study may have reported several outcomes such as academic, social, emotional, and behavioural changes, however, the factor of interest for the present review were measures of anxiety and depression. As such, studies reporting effects of cognitive training that did not report an outcome measure related to anxiety or depression, were excluded. Studies were included which were conducted in any/all settings.

2.3 Study selection

The first phase of the search identified 2115 records through Web of Science, Medline, APA PsycINFO, EMBASE, CINAHL and PubMed (see Figure 1). The title, abstract and full-text screening was conducted using Covidence online software (see Harrison et al., 2020 for review). Following removal of duplicates, 758 studies were screened based on title and abstract and 79 studies underwent full-text screening. Following reading of full-text copies and application of inclusion criteria, 9 manuscripts were identified for inclusion in the current systematic review. In the second phase, 12 theoretical papers/reviews/meta-analysis

were identified in the title and abstract screening phase and used for snowballing. These records were compared to the excluded/included studies resulting in one additional manuscript meeting criteria for inclusion. Moreover, a two-prong grey literature search was conducted comprising emailing the authors of the manuscripts that met final inclusion and several calls to Twitter followers of the authors of the present review and subsequent reposts (between December 23, 2020 and March 1, 2021). Fourteen CCT studies were identified that captured mood and behaviour more generally yet did not report separate pre/post measures of anxiety/depression (e.g., Pediatric Quality of Life Inventory: Total scores reported without Emotional Functioning subscale; Strength and Difficulties Questionnaire: Total scores reported without Emotional Symptoms subscale). The authors were emailed twice, within a two-week period, requesting provision of additional data (e.g., relevant subscale scores), if available. For six studies, there was no response. For five studies, authors emailed back conveying they did not have the requested subscale data for the instruments used, and for one study the author reported that raw data was inaccessible due to COVID 19, therefore not able to be included in this review (Sadeghi et al., 2020). The authors of Bigorra et al. (2016) and Roberts et al. (2016) provided subscale scores and those studies were included. Accordingly, after both phases 12 studies were included in the present systematic review (cf. Figure 1).

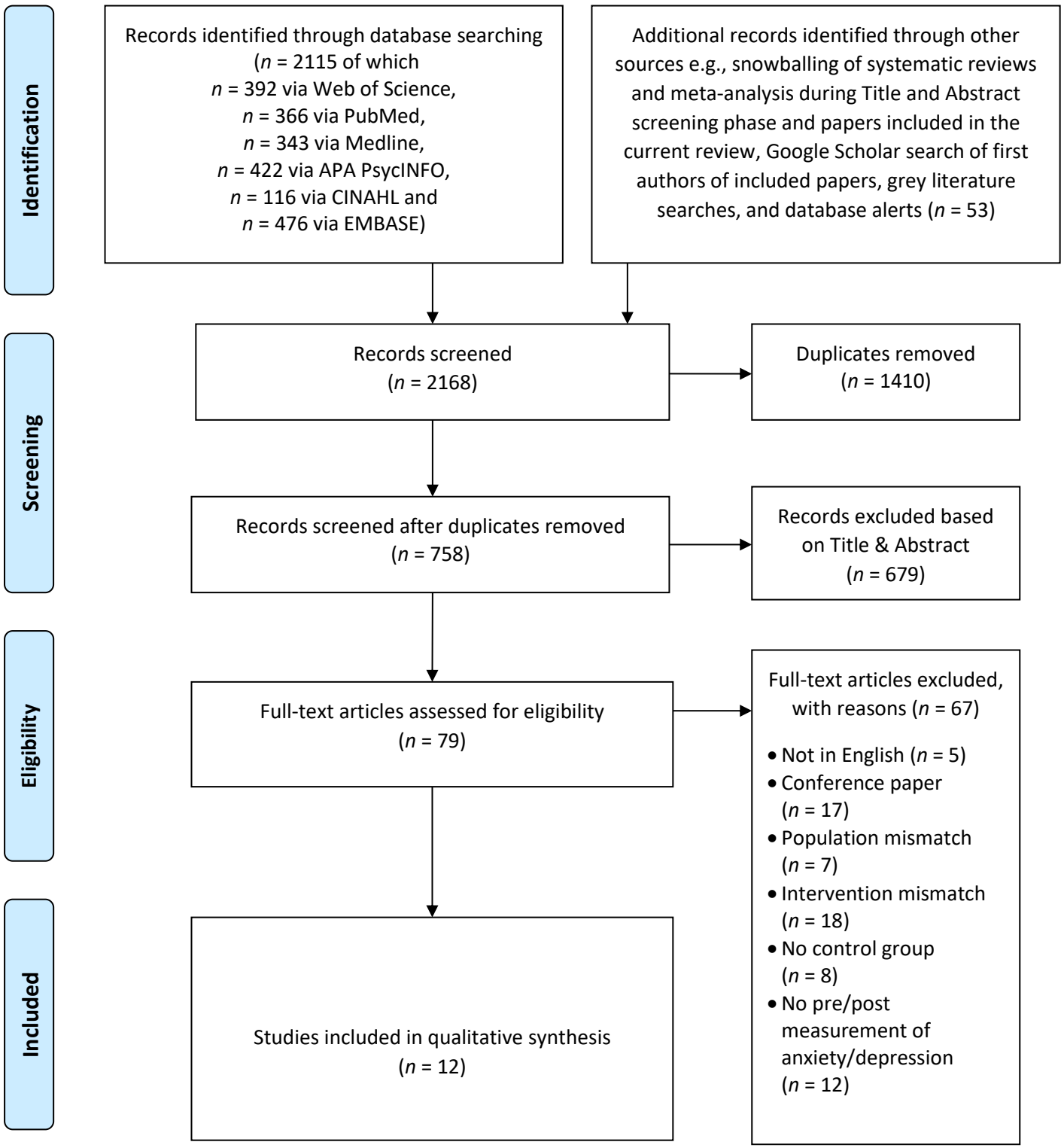
2.4 Coding procedure

All studies were screened on title and abstract by a minimum of two authors using a predefined strategy. Conflicts were resolved by other authors who did not conduct the initial screening. A similar process was used in the full-text screening phase, with coders operating independently based on a predefined ranking list of exclusion criteria. If two coders indicated to exclude an article, but disagreed on the exclusion reason, the ranking of reasons were used to make the final decision by a third coder. The measurement of κ=.84 and κ=.88 for inter-

rater agreement on inclusion/exclusion of overall and categorization of the exclusion reasons, respectively, indicated excellent agreement (Orwin & Vevea, 2009).

Figure 1

PRISMA Flow Chart



2.5 Quality and bias assessment

Methodologic quality was assessed using Downs and Black's (1998) Study Quality Appraisal Checklist. Following Hooper et al., (2008), the modified version of the checklist was used with a maximum possible score of 28. The following levels of quality were used: ≤14 = *poor*; 15-19 = *fair*; 20-25 = *good*; 26-28= *excellent* (Hooper et al., 2008). According to Downs and Black, only randomised control studies can have an excellent level of quality (see also Lowther & Newman, 2014). Two authors independently assessed the methodologic quality of each study. Where agreement could not be reached by mutual discussion, discrepancies were resolved by a third author.

3.0 Results

Due to the heterogeneous nature of the CCT interventions, duration and context, outcome measures and populations, we qualitatively synthesised the results of studies using these categories, with the aim of avoiding mixing 'apples and oranges' (Esteves et al., 2017). The synthesis subgroups (i.e., Type of CCT interventions, Duration and context, Outcome measures, Populations) were established to provide maximum value to the research and clinical area. Furthermore, in line with our PROSPERO registration (CRD42020218541) meta-analysis was not planned or conducted due to the initial searches indicating a limited number of studies fitting the inclusion criteria. Therefore, the focus of this review is a narrative synthesis providing potential directions for future research. In what follows next, we first provide a description of different training methods used (i.e., paradigm, stimuli), training dosage and context/method of delivery, outcome measures, and population under investigation, after which we discuss how this level of heterogeneity relates to emotional transfer effects observed in the literature.

3.1 Type of cognitive control training interventions

Two studies utilised CCT methods deploying tasks with neutral stimuli; the adaptive dual *n*-back (Beloe & Derakshan, 2019) to tap WM and the Go/No-Go task (Shanok et al., 2021) to train inhibitory control processes. Three studies utilised tasks with affective stimuli (de Voogd et al., 2016; Schweizer et al., 2017; Shanok et al., 2021) to investigate the efficacy of CCT on anxiety and/or depression. Lastly, eight studies employed commercial WM training packages (e.g., CWMT; Lumosity; LococTour). CWMT was used by six studies (Bigorra et al, 2016; Grunewaldt et al., 2013; Hadwin & Richards, 2016; Hitchcock & Westwell, 2017; Roberts et al., 2016; Roughan & Hadwin, 2011) with Lumosity (Corti et al., 2020) and LocoTour (Lomas, 2001) software each employed once. Studies that used commercial WM training were examined as a separate category given that these software programs are known for including a mix of tasks and games, requiring individuals to use multiple sensory modalities (e.g., auditory, visual), and process different stimuli (e.g., digits, pictures) compared to other CCT that targets a single, discrete cognitive process (Etherton et al., 2019). Furthermore, the valence of the stimuli in the commercial WM tasks is difficult to determine.

3.1.1 Cognitive control training using neutral stimuli

An adaptive *n*-back task was used by Beloe and Derakshan (2019) consisting of a 3x3 grid with white spaces. The participants' task was to identify if a location of the highlighted square and the letter (sound) matched the one presented immediately before or two, three or four trials before, with *n* signifying the number of previous trials that is being compared. The task was adapted based on the level of accuracy (either increased, decreased or stayed the same). In Beloe and Derakshan's study the comparison group was an active control condition that required participants to complete an *n*-back with a constant difficulty of *1*-back. A

modified adaptive dual *n*-back was used by Schweizer and colleagues (2017) in affective WM training, discussed below.

An adaptive Go/No-Go task was used by Shanok et al. (2021) employing a gFocus training task using neutral stimuli (i.e., faces). For each training block, participants were required to focus their attention on one of four clues (indoor, outdoor, male, female) with a Go/No-Go procedure-style by pressing a spacebar when the requested clue is present and withholding a response otherwise. Shanok et al.'s task was adaptive based on participants' answers and was positively reinforcing successful answers by providing simpler tasks for sustained attention and focus. They also included an affective version of the gFocus task, presented below, in addition to a waitlist control group for comparison.

3.1.2 Cognitive control training using affective stimuli

Affective WM training was used in three studies (de Voogd et al., 2016; Schweizer et al., 2017; Shanok et al., 2021). The affective WM training studies used different types of emotional stimuli, such as words, facial expressions, or symbols, which were mostly negative. de Voogd et al. (2016) required participants to remember the sequence of green and blue squares presented on a chessboard (4x4), while aiming to ignore emotional faces (angry, sad, fearful) presented randomly throughout the sequences. In the experimental condition the length of the sequence was adaptive depending on performance. Similarly, Schweizer et al. (2017) used a 4x4 grid using a modified n-back task where participants were exposed to negative visual stimuli (e.g., angry faces) on the screen coupled with negative verbal stimuli over the headphones (e.g., spoken word rape). The objective was to ascertain if the presented stimuli matched the stimuli presented n-trials back. Additionally, participants received positive or negative visual and auditory feedback based on their accuracy. Shanok et al. (2021) utilised emotional gFocus training based on a Go/No-Go task where emotional

expressions on the faces of the people presented in photos served as distractors. All three studies (de Voogd et al., 2016; Schweizer et al., 2017; Shanok et al., 2021) used active control conditions. Schweizer et al.'s (2017) comparison training task used geometric shapes as stimuli and distracters (neutral stimuli), whereas de Voogd et al.'s (2016) placebo condition included face stimuli; both tasks were non-adaptive (i.e., not titrated to performance). Shanok et al. (2021) included a comparison group undertaking the gFocus with neutral stimuli (active control) in addition to a passive waitlist control.

3.1.3 Commercial working memory training

Commercial WM training software uses game-like programs with specific tasks training different aspects of verbal and visuospatial memory. Most CCT studies identified within this review used CWMT (Bigorra et al., 2015; Grunewaldt et al., 2013; Hadwin & Richards, 2016; Hitchcock & Westwell, 2017; Roberts et al., 2016; Roughan & Hadwin, 2011). Within these studies, there were significant differences in the type of control group used. Bigorra at al. (2015) and Hitchcock and Westwell (2017) compared CWMT (RM) with a low load non-adaptive version of CWMT (MegaMemo, i.e., simpler task). Hadwin and Richards (2016) compared CWMT intervention with a Cognitive Behavioural Therapy, while Grunewaldt and colleagues (2013) deployed a wait-list, and Roberts et al. (2016) and Roughan and Hadwin (2011) used non-trained controls. Out of the six studies, only one used CWMT version for pre-schoolers (JM; Grunewaldt et al., 2013), while the other five used the CWMT suitable for school aged children (RM; Bigorra et al., 2015; Hadwin & Richards, 2016; Hitchcock & Westwell, 2017; Roberts et al, 2016; Roughan & Hadwin, 2011). Corti et al. (2020) used Lumosity Cognitive Training, a web-based gaming software aimed at training the cognitive domains of memory, attention, flexibility, problem-solving and speed. Lomas (2001) used LocuTour software aimed at improving attention, concentration, planning and goal-oriented behaviours for the CCT group while the control group trained on a software

targeting academic skills and achievement-oriented tasks. Although, cognitive control per se is not trained directly, commercial training packages contain games that target mental set shifting and updating processes of WM (Corti et al., 2020). All studies using CWMT contained 25 sessions over 5 weeks, while Lumosity and LocuTour were conducted over 42 sessions in 14 weeks and 40 sessions in eight weeks, respectively. In contrast to the previously mentioned CCT procedures targeting specific aspects of cognitive control (using neutral or affective stimuli), commercial CCT typically relies on a multitude of training tasks.

3.2 Duration and context

The duration and context of the CCT interventions differed between studies. No studies utilised single session intervention, however, the differences in duration were considerable, ranging from eight sessions of CCT using affective stimuli (de Voogd et al., 2016) to 40 and 42 sessions of commercial WM training used by Corti and colleagues (2020) and Lomas (2001), respectively. Furthermore, all six studies using CWMT software conducted 25 sessions over a five-week period as prescribed by the software manual (Bigorra et al., 2015; Grunewaldt et al., 2013; Hadwin & Richards, 2016; Hitchcock & Westwell, 2017; Roberts et al., 2016; Roughan & Hadwin, 2011). Interestingly, the three studies using affective WM training used the least number of sessions, with eight (de Voogd et al., 2016), 16 (Shanok et al., 2021) and 20 sessions conducted (Schweizer et al., 2017). In contrast, research conducted using targeted CCT methods with neutral stimuli, such as Shanok et al. (2021) deployed the Go/No-Go training used 16 sessions and Beloe and Derakshan (2019) employed the *n*-back task used 20 sessions.

All interventions were conducted in a home and/or school context. Given the population of interest, most researchers opted for school-based interventions (de Voogd et al., 2016; Hitchcock & Westwell, 2017; Lomas, 2001; Roberts et al., 2016; Roughan & Hadwin,

2011; Schweizer et al., 2017; Shanok et al., 2021). Three studies using CWMT software were conducted at home with parent supervision (Bigorra et al., 2015; Corti et al., 2020; Grunewaldt et al., 2013). Conversely, Beloe and Derakshan (2019) and Hadwin and Richards (2016) provided participants with a choice of completing the training at school or home.

3.3 Outcome measures

The analysis of the outcome measures showed three distinct patterns regarding instruments used to measure anxiety and depression. Five studies investigated both anxiety and depression symptomatology (Beloe & Derakshan, 2019; Bigorra et al., 2015; de Voogd et al., 2016; Hitchcock & Westwell, 2017; Shanok et al., 2021), two studies examined related concepts, such as emotional (Roberts et al., 2016) and internalizing symptoms (Corti et al., 2020) and one study examined emotion regulation (Schweizer et al., 2017). Four studies examined anxiety outcomes only (Grunewaldt et al., 2013; Hadwin & Richards, 2016; Roughan & Hadwin, 2011; Lomas, 2001). Studies used either self-reported measures or informant (parent/teacher-reported) scales, while one study used both self- and teacher-reported scales (Roughan & Hadwin, 2011).

Self-reported symptoms of anxiety were measured using the 41-item Screen for Child Anxiety Related Emotional Disorders (SCARED i.e., de Voogd et al., 2016; Shanok et al., 2021), the 49-item Revised Children's Manifest Anxiety Scale 2nd Edition (RCMAS-2; i.e., Hadwin & Richards, 2016), the 37-item Total Anxiety subscale of the Revised Child Anxiety and Depression Scale (RCADS i.e., Beloe & Derakshan, 2019), the 20-item Trait Anxiety subscale of the Beck Youth Inventory (BYI i.e., Rough & Hadwin, 2011), and the 30-item Children's Test Anxiety Scale (CTAS i.e., Hadwin & Richards, 2016; Roughan & Hadwin, 2011), and parent-reported anxiety was measured using the 34-item Preschool Anxiety Scale (PAS i.e., Grunewaldt et al., 2013) and the 8-item Anxious/Shy subscale of the Conners Parent Rating Scale (CPRS i.e., Lomas, 2001). Self-reported depressive symptomology was

assessed using the 27-item Children's Depression Inventory (CDI i.e., Lomas, 2001) and the 15-item Negative Affect subscale of the Positive and Negative Affect Schedule for Children (PANAS-C i.e., Shanok et al., 2021). The CDI was also used as a parent-reported measure of depression in a younger sample of children (de Voogd et al., 2016). Other psychological factors related to anxiety and depression were captured using parent/teacher reported measures, namely the Internalizing and Anxious/Depressed subscales from the Child Behaviour Checklist (CBCL i.e., Bigorra et al., 2015; Corti et al., 2020; Hitchcock & Westwell, 2017), the Anxious/Depressed subscale from the Teacher Rating Scale (TRS i.e., Bigorra et al., 2015), the Emotional Symptoms subscale of the Strengths and Difficulties Questionnaire (SDQ i.e., Roberts et al., 2016; Roughan & Hadwin, 2011), and the self-reported Cognitive Emotion Regulation Questionnaire; CERQ; i.e., Schweizer et al., 2017).

Studies also differed depending on whether anxiety and/or depression were their primary or secondary outcomes. Five studies investigated anxiety and/or depression as their primary outcome; three focused on both measures (Beloe & Derakshan, 2019; de Voogd et al., 2016; Shanok et al., 2021), whereas the other two targeted anxiety only (Hadwin & Richards, 2016; Roughan & Hadwin, 2011). It is worth noting all studies with anxiety and/or depression as the primary outcome used self-reported symptom-specific scales. Studies outlining anxiety and/or depression as secondary outcomes used parent and/or teacher rating scales to assess symptoms. Moreover, three studies examining emotional and internalizing symptoms, and emotion regulation have listed these as primary outcomes, using teacher-report and self-report respectively (Hitchcock & Westwell, 2017; Roberts et al., 2016; Schweizer et al., 2017). Due to the high level of heterogeneity within all identified studies, in Section 3.5 the study findings are summarised separately for anxiety (10 studies), depression (6 studies), and other psychological factors (3 studies).

3.4 Population

The populations investigated in the 12 studies were also heterogeneous. We grouped studies by population into four different categories of young people: typically developing, neuro-developmental problems, neurological disorders, and psychological disorders. We examined samples to determine whether baseline characteristics of anxiety and depression were reported and if they were at normal levels, at-risk, subclinical, or clinical. We also analysed the samples according to the age of participants due to a significant divergence between studies, with participants ranging from 5 – 18 years old, as well as the ranges within the studies fluctuating amongst 1 – 8 year-difference between same study participants. Furthermore, the number of participants in experimental conditions was highly variable within different studies, ranging from 9 – 226 subjects.

Typically developing children were sampled most often (Beloe & Derakshan, 2019; de Voogd et al., 2016; Hitchcock & Westwell, 2017; Shanok et al., 2021). Considering the convenience of the sample, studies with healthy children and adolescents generally had most CCT group participants (e.g., de Voogd et al. (2016), n = 129; Beloe and Derakshan (2019), n = 128; Hitchcock and Westwell (2017), n = 54; with the exemption of Shanok et al. (2021), n = 28). Young people with neuro-developmental problems were classified as those with ADHD with or without comorbidities (Bigorra et al., 2015; Lomas, 2001), social, emotional, and behavioural disorders (SEBD; Roughan & Hadwin, 2011) and memory problems (Roberts et al., 2016) with these studies comprising n = 35, n = 18, n = 7 and n = 226 in their CCT condition, respectively. Children and adolescents with neurological disorders were sampled in two studies and contained smaller numbers of participants in the CCT group; preterm/very low birth rate children aged 5 – 6 years (Grunewaldt et al., 2013; n = 9) and adolescents with acquired brain injury (Corti et al., 2020; n = 24). Fewer subjects were also evident in the CCT groups of the two studies with young people with psychological disorders:

children with high anxiety (Hadwin & Richards, 2016; *n* = 20) and adolescents with post-traumatic stress disorder (PTSD; Schweizer et al., 2017; *n* = 15).

Samples varied on baseline levels of anxiety and depression, with some falling within the normal range for emotional symptoms (i.e., Beloe & Derakshan, 2019; Bigorra et al., 2015; Corti et al., 2020; de Voogd et al., 2016; Grunewaldt et al., 2013; Hitchcock & Westwell, 2017; Lomas, 2001; Roberts et al., 2016), while others demonstrating elevation of anxiety, depression and other psychological factors (i.e., Hadwin & Richards, 2016; Roughan & Hadwin, 2011; Schweizer et al., 2017; Shanock et al., 2021).

Age varied across studies. The youngest participants investigated were 5 – 6 year-old pre-school children (Grunewaldt at al., 2013). In primary-school children the ages sampled ranged between 6 – 7 years (Roberts et al., 2016), 7 – 9 years (Lomas, 2001), 7 – 12 years (Bigorra et al., 2015), and 8 – 12 years (Shanok et al., 2021). In secondary-school adolescents the ages studied ranged from 10 – 14 years (Hadwin & Richards, 2016; Hitchcock & Westwell), 10 – 18 year (Beloe & Derkshan, 2019), 11 – 14 years (Roughan & Hadwin, 2011), 11 – 16 years (Corti et al., 2020), 11 – 18 years (de Voogd et al, 2016), and 14 – 18 years (Schweizer et al., 2017).

3.5 Study findings

Table 1 describes the characteristics of the studies and respective findings. As shown in the table, nine studies investigated anxiety symptom changes, five examined changes in depressive symptoms and three measured outcomes of other psychosocial symptoms. All 12 studies reported various effects of cognitive transfer (i.e., other training effects). The synthesis of findings is presented by outcome measures (i.e., Anxiety, Depression, Other psychological factors) and type of CCT intervention.

INSERT TABLE 1 ABOUT HERE

3.5.1 Anxiety

3.5.1.1 Cognitive control training using neutral stimuli

Two studies investigated transfer following CCT using neutral stimuli on anxiety with typically developing children and adolescents; an adaptive dual *n*-back (Beloe & Derakshan, 2019) and an adaptive Go/No-Go task (Shanok et al., 2021). Both articles reported beneficial emotional transfer effects of CCT. Utilising an adaptive dual *n*-back task, Beloe and Derakshan (2019) found a significant reduction in anxiety symptoms on the Total Anxiety subscale score of the RCADS in adolescents. Specifically, the analysis conducted on the intention to treat (ITT) sample was significant for the Group x Time interaction, revealing a reduction in anxiety symptoms for the CCT group relative to controls, which was sustained at 1-month follow-up. A similar pattern of results was found for Total Internalizing scores of RCADS between CCT and control groups. Importantly, Beloe and Derakshan also reported effects of cognitive transfer, namely improved WM (*n*-back) performance in the CCT group who trained using the adaptive *n*-back, relative to controls who trained on a modified (non-adaptive) *1*-back. Using an adaptive Go/No-Go task with neutral stimuli, Shanok et al. (2021) again found a significant reduction in self-reported anxiety indexed by the SCARED in a sample of children, where participants in the emotional training condition demonstrated a significantly larger reduction in anxiety compared to the waiting list control condition. Moreover, Shanok and colleagues reported cognitive transfer pre- vs. post-training. Specifically, improved inhibitory effectiveness on the Go/No-Go and better inhibitory effectiveness and efficiency on the flanker task was demonstrated by the CCT group relative to controls in a waitlist group.

3.5.1.2 Cognitive control training using affective stimuli

Two studies investigated the effect of affective WM training on anxiety symptoms in typically developing children: Shanok et al., 2021 (aged 8-12 year-olds) and de Voogd et al., 2016 (11-18 year-olds). de Voogd and colleagues (2016) showed general decreases in self-reported anxiety (SCARED) from pre-training to 3-, 6-, and 12-month follow-up, yet these effects were common to both the CCT (adaptive emotional WM training) and control (non-adaptive WM training) groups. Furthermore, de Voogd et al. reported cognitive transfer effects (i.e., increased WM performance). Shanok et al. (2021) used an adaptive emotional Go/No-Go task as CCT and found a significant reduction in self-reported anxiety (SCARED) and cognitive transfer (i.e., improved inhibitory efficiency), pre vs post, relative to controls. It is noteworthy that the affective CCT was as effective as the non-emotional CCT in terms of emotional transfer, suggesting no added effects of using emotional content during CCT.

3.5.1.3 Commercial working memory training

Commercial WM training software was used as a CCT intervention in six studies that investigated changes in anxiety symptoms, of which five employed CWMT (Bigorra et al., 2015; Grunewaldt et al., 2013; Hadwin & Richards, 2016; Hitchcock & Westwell, 2017; Roughan & Hadwin, 2011), while Lomas (2001) used LocoTour software. Results of studies using commercial WM training as a CCT intervention are mixed. Four studies showed some promise for a positive effect of CCT on anxiety (Bigorra et al., Grunewaldt et al., Hadwin & Richards, Roughan & Hadwin), and two studies showed no differential effects (Hitchcock & Westwell, 2017; Lomas, 2001). Reconciliation of findings was complicated by differences in populations, baseline levels of emotional symptoms and outcome measures.

Grunewaldt et al. (2013) found a significant reduction in parent-reported anxiety indexed by the PAS in a CCT group of pre-term born and low birthweight pre-schoolers, relative to waitlisted controls. Grunewaldt and colleagues also noted cognitive transfer (i.e.,

improved attention and WM). Bigorra et al. (2015) investigated changes in parent- and teacher-reported symptoms (CBCL & TRS, respectively) in a sample of ADHD children. Upon request, unpublished Anxiety and Depression subscale scores were provided by the authors. Bigorra and colleagues' data showed a trend towards reduction of anxiety symptoms for the CCT group at post-training and 3-months follow-up relative to baseline, with no observable changes in the control group. Bigorra et al. also noted cognitive transfer (i.e., improved WM) in the CCT group who trained using CWMT titrated to performance vs. the control group who used a non-adaptive CWMT training procedure. A similar trend showing lower self-reported anxiety symptoms was noted by Roughan and Hadwin (2011) who used CWMT as a CCT intervention in adolescents with SEBD. Roughan and Hadwin, however, reported reduced test anxiety (CTAS scores), but not trait anxiety (BYI), pre vs. post, yet these effects were not sustained at 3-month follow-up. Interestingly, no test anxiety differences were noted between young individuals in the CCT (CWMT) and control (no-training) groups at baseline yet both groups reported anxiety symptom reduction at post-training, nevertheless the effect was more profound in the CCT group. Roughan and Hadwin also noted cognitive transfer in the CCT group but not controls (e.g., increased WM, attention, inhibition). Importantly, comparing the effectiveness of CCT (using CWMT) with CBT, Hadwin and Richards (2016) noted parallel reductions in self-reported anxiety (RCMAS-2 & CTAS scores) and improvements in cognition (inhibitory control, attentional bias for threat) of highly anxious adolescents, with these changes noted pre- to post-training and sustained at 3-month follow-up. These findings suggested CWMT to be as effective as targeted interventions such as CBT in reducing anxiety symptoms.

Interestingly, two studies which used commercial WM training failed to find beneficial effects of CCT on indicators of anxiety, both of which also did not observe cognitive transfer. For instance, Lomas (2001) reported no differential effects of CCT on

parent-reported anxiety of their children (Anxious/Shy subscale scores on CPRS), both the CCT and control groups in children with ADHD showed a reduction over time. Interestingly, Lomas also reported no cognitive transfer effects and no differences between groups pre vs. post (e.g., vigilance, attention). Similarly, Hitchcock and Westwell (2017) investigated CCT in typically developing adolescents and found no differences in symptoms of anxiety captured by parent-reported Internalizing subscales of the CBCL, between the CWMT and no-training control groups across time (pre- vs. post- vs. 3-month follow-up). Further, Hitchcock and Westwell found no meaningful cognitive transfer effects (e.g., no differences in WM or attention).

3.5.2 Depression

No studies exclusively investigated the effects of a CCT intervention on depressive symptoms in children or adolescents. However, five studies investigated changes in anxiety (see 3.5.1) and depression. To assist with interpretability, the cognitive transfer effects are repeated along with any changes in depression (see also 3.5.1).

3.5.2.1 Cognitive control training using neutral stimuli

Utilising a sample of typically developing adolescents, Beloe and Derakshan (2019) reported a significant decrease in self-reported depression (RCADS scores) along with cognitive transfer (i.e., improved WM performance) in the CCT group (adaptive dual *n*-back training). Neither depression nor cognitive transfer effects were noted in controls (non-adaptive dual *1*-back training) when comparing pre- to post-training, and this result was sustained at 1-month follow-up. In accord, Shanok et al. (2021) reported significant reduction in self-reported depressive symptoms (CDI & PANAS-C Negative Affect scores) and evidence of cognitive transfer (i.e., improvements in inhibition effective and efficiency) in the

CCT group (adaptive non-emotional Go/No-Go training) compared to the waitlisted controls comprising typically developing children.

3.5.2.2 Cognitive control training using affective stimuli

Two studies explored effects of affective WM training on depressive symptoms in a sample consisting of typically developing youth (de Voogd et al., 2016, 11 - 18 year-olds; Shanok et al., 2021, 8 - 12 year-olds). Shanok et al. (2021) reported a significant reduction in self-reported depressive symptoms (CDI & PANAS-C Negative Affect scores) compared to wait list controls. In terms of cognitive transfer, the CCT group (adaptive emotional Go/No-Go) showed improvements in inhibitory control efficiency from pre- to post-training relative to controls. de Voogd et al. (2016) found general decreases in self-reported depression (CDI scores) between adolescents in the CCT (adaptive emotional WM training) and control (non-adaptive emotional WM training) groups, yet no between group differences (i.e., both groups reported similar reductions in depression over time). de Voogd et al (2016) also reported no differential effects of training condition on cognitive transfer (i.e., WM improvements).

3.5.2.3 Commercial working memory training

Two studies used commercial WM training as a CCT intervention for depression and deployed CWMT (Bigorra et al., 2015; Hitchcock & Westwell, 2017). In a sample of children with ADHD, Bigorra and colleagues (2015) noted a trend for reduction in parent- and teacher-reported depression (Depression subscale scores of the CBCL & TRS, respectively) and cognitive transfer effects (i.e., improvements in WM) in CCT group compared to no changes in the Control group, pre- vs. post-training and effects maintained at 6-month follow-up. Conversely in typically developing adolescents, Hitchcock and Westwell (2017) reported no changes to parent-reported depression (Internalizing subscales of the CBCL) and no cognitive transfer effects between the CCT and Control groups, or across time.

3.5.3 Other psychosocial measures

Four CCT studies examined changes in psychological factors related to anxiety and depression and due to the limited number of studies available using children and adolescents we – in line with our pre-registration – included them in the present review. Specifically, CCT methodology was used by Schweizer et al. (2017) to examine changes in emotional regulation in typically developing children (8 - 12 year-olds), de Voogd et al. (2016) to examine changes in self-esteem in typically developing adolescents (11 - 18 year-olds), Corti et al. (2020) to investigate the influence on internalizing symptoms in children with acquired brain injury (11 - 16 year-olds), and Roberts et al. (2016) to explore effects on emotional symptoms in children with WM difficulties (6 - 7 year-olds). Schweizer et al. found significant increases in self-reported adaptive emotional regulation (CERQ scores) in the CCT group (adaptive emotional WM training) relative to the active control group (non-adaptive sham training), pre- vs. post-training. Schweizer et al., however reported no change in use of maladaptive emotional regulation strategies (e.g., rumination) over training for either group. The CCT group showed some evidence of cognitive transfer with improvements in inhibitory effectiveness but not efficiency pre- vs. post-training, compared to controls. de Voogd et al. (2016) found marginally significant Group × Time interaction on self-esteem (RSES scores), reflecting improvements for CCT group relative to Controls over time, in the absence of cognitive transfer. Two studies found no beneficial emotional transfer effects. Corti et al. found no significant reduction in parent-reported internalizing symptoms (CBCL scores) in adolescents in the CCT (Luminosity training) compared to waitlist group, across time. Increases in visual-spatial WM were found in both groups, with greater improvements noted in the CCT group. Roberts et al. reported no changes in parent-reported emotional symptoms (SDQ scores) between CCT (CWMT) and control (no-training) groups, and no indication of cognitive transfer.

3.6 Methodological quality

We used the Downs and Black (1998) quality checklist to assess methodological quality (see Table 2). As shown, all studies included in the present review obtained levels in the *good* and *excellent* range that is, all studies had a control group. There was, however, a lack of information regarding concealment of randomisation for some studies (i.e., Beloe & Derakshan, 2019; Grunewaldt et al., 2013; Roughan & Hadwin, 2011).

INSERT TABLE 2 ABOUT HERE

Following Lowther and Newman (2014), we adapted the question on 'power' to a single (0 = No, 1 = Yes) response to whether any findings were due to chance. All studies scored 1, except Roughan and Hadwin (2011). To account for the lack of clarity of the question of power to detect a clinically important effect we conducted further investigation. Where effect sizes were not reported by the authors (see Table 2) these were calculated using the sensitivity analyses in G*Power. For each study, the strongest effect that could be detected was calculated based on the reported *N*, with a power of .80, and $\alpha = .05$: i.e., Bigorra et al. (2015), $f = .35$, $d = 0.70$; Corti et al. (2020), $f = .41$, $d = 0.82$; de Voogd et al. (2016), $f = .22$, $d = 0.44$; Hitchcock and Westwell, (2017), $f = .27$, $d = 0.54$; Lomas (2001), $f = .50$, $d = 1.00$; Roberts et al. (2016), $f = .13$, $d = 0.26$.

4.0 Discussion

The present review investigated changes in anxiety and depressive symptoms in children and adolescents following a CCT intervention (neutral, affective, multifaceted/commercial). We addressed aspects of the study design, measurements of anxiety and/or depression used and training effects on anxiety, depression and other related psychological factors, in addition to cognitive transfer effects between pre- and post-training and at follow-up (where available). Differences between study outcomes were elaborated. Taken together, this information provides valuable insights into the effects of CCT on anxiety

and/or depression vulnerability in children and adolescents and provides recommendations for directions for future research.

4.1 Type of cognitive control intervention

Eight of the 12 studies in the present review provide positive support for CCT to reduce symptoms of anxiety and depression or related risk factors in children and adolescents (Beloe & Derakshan, 2019; Bigorra et al., 2015; de Voogd et al., 2016; Grunewaldt et al., 2013; Hadwin & Richards, 2016; Roughan & Hadwin, 2011; Schweizer et al., 2017; Shanok et al., 2021). The pattern of findings across studies suggest that cognitive transfer might be a prerequisite for emotional transfer.

Two studies using neutral stimuli, namely adaptive dual *n*-back (Beloe & Derakshan, 2019) and adaptive Go/No-Go (Shanok et al., 2021), reported cognitive transfer effects relative to their control groups (i.e., improved WM and inhibitory control, respectively). Similarly, three studies using affective CCT reported cognitive transfer. Schweizer et al. (2017) and Shanok et al. (2021) observed improved inhibitory control after CCT using adaptive dual *n*-back and adaptive Go/No-Go tasks, respectively. De Voogd et al. (2016) reported general WM improvements across both CCT and control conditions. It is worth noting that we have assumed Schweizer et al.'s results to be favourable to CCT effecting emotional regulation processes using their findings of increase in use of adaptive emotional regulation strategies, however the same study noted no change in use of maladaptive emotional regulation strategies. It is plausible that these findings may be explained by Braet et al.'s (2014) observation that in adolescence the use of maladaptive emotional regulation does not necessarily increase, but rather the use of adaptive emotional regulation seems to decrease. Thus, Schweitzer et al.'s results look optimistic.

Four studies used CWMT (i.e., commercial WM training) demonstrated trends or weak effects of CCT to relieve symptoms of anxiety and depression (Bigorra et al., 2015; Grunewaldt et al., 2013; Hadwin & Richards, 2016; Roughan & Hadwin, 2011) and all showed evidence of cognitive transfer (e.g., improved WM, inhibition). Interestingly, those who studied young people with neurodevelopmental difficulties and neurological disorders showed a greater ability to detect differences between the CCT group and their control counterparts (Bigorra et al. with ADHD children; Roughan & Hadwin with adolescents with SEBD; Grunewaldt et al. with preterm, low birthweight preschoolers). In addition, in a sample of children with psychological problems, Hadwin and Richards (2016) demonstrated CWMT to be as effective as CBT.

Three studies failed to find a significant effect of CCT on anxiety, depression or other related psychological factors (Corti et al., 2020; Hitchcock & Westwell, 2017; Roberts et al., 2016). It is possible that these samples were not high enough in emotional symptoms before training. However, this is contradictory to other studies who found significant effects of CCT with lower levels of anxiety/depression (e.g., Beloe & Derakshan, 2019; Bigorra et al., 2015; Grunewaldt et al., 2013). Therefore, it is possible that the type of CCT intervention could explain the disparity in results. All three studies used commercial WM training packages (Corti et al used Lumosity; Hitchcock & Westwell and Roberts et al. used CWMT) and also showed mixed evidence of cognitive transfer. That is, Corti et al. (2020) reported no differential cognitive transfer effects between Lumosity and waitlist controls and only noted improved visual-spatial WM at post-training. Interestingly, Roberts et al. deployed CWMT and also found visuospatial WM to be the only cognitive transfer effect, while Hitchcock and Westwell noted no cognitive transfer of WM or attention. It is plausible that heterogeneity in transfer effects might rest with differences in the processes that the training task is targeting and therefore measuring. It is possible that CCT research requires more fundamental

understanding of the relationship between specific domains or tasks and emotional vulnerability prior to attempting to manipulate them.

Taken together, although based on a limited number of studies, the present findings indicate that adaptive CCT tasks which include neutral or affective stimuli offer promise with reducing anxiety/depression, and that cognitive transfer is needed to effect change in emotional outcome measures in children and adolescents. Undoubtedly, more research is called for to confirm these suggestions.

4.2 Duration and context

Across the eight studies that afforded some promise for CCT as an intervention for reducing anxiety and depression in children and adolescents, the average duration and dose was 4.5 weeks and 18.75 sessions, respectively. Separating studies by type of intervention, CCT using neutral stimuli relied on an average of 4 weeks and 11 sessions to reveal change, CCT using affective stimuli saw change following as few as 4 weeks and 14.7 sessions, and commercial WM training procedures used 5 weeks and 25 sessions.

Five studies supporting the efficacy of CCT to effect reduction in anxiety, depression, or related factors (e.g., emotion regulation, self-esteem) were conducted in the school setting (de Voogd et al, 2016; Lomas, 2001; Roughan & Hadwin, 2011; Schweizer et al, 2017; Shanok et al., 2021), two studies were undertaken at home with parental supervision (Bigorra et al., 2015; Grunewaldt et al., 2013), and two studies provided for participation at either school or home (Beloe & Derakshan, 2019; Hadwin & Richards, 2016). Moreover, CCT undertaken in school settings fulfills many of the recommendations for future treatments of anxiety/depression outlined by Kazdin (2017). Offering CCT as part of regular classroom routine affords reach, scalability, affordability, expansion of nonprofessional workforce,

expansion of settings where interventions are provided, feasibility and flexibility of delivery, and flexibility and choice of intervention.

4.3 Outcome measures

Interventions with self-reported measures had a higher rate of significant reduction in anxiety/depression symptoms in CCT groups than in studies utilising parent- and/or teacher-reporting instruments. The five studies with significant reductions in anxiety, depression and/or related factors utilised self-reported measures exclusively (Beloe & Derakshan, 2019; de Voogd et al., 2016; Hadwin & Richards, 2016; Schweizer et al., 2017; Shanok et al., 2021). Indeed, previous research has highlighted the difficulty associated with discrepancies between self and informant reports of child and adolescent psychopathology (Achenbach, 2006; De Los Reyes & Kazdin, 2004; 2006). Factors such as concealment of inner thoughts and feelings, trivialisation of symptoms and low informant understanding of psychopathological symptoms had led to discrepancies in reporting (Bidaut-Russell et al., 1995; Bowers et al., 2020). This may explain the high number of significant self-reported symptom reductions, as it is possible self-report provides a more precise measure that identifies nuanced changes. Roughan and Hadwin (2011) used self-report measures and found a weak trend for reduction in anxiety, but at the same time was underpowered (n = 7 vs. 8) to detect significant differences between CCT and control conditions. In this study, cognitive transfer was also established. Furthermore, it needs mention that no studies included samples of children/adolescents with elevated depressive symptoms, mainly because anxiety is more prevalent and the comorbidity between the two becomes more evident with age (Kessler et al., 2007). In summary, future research should deploy self-reported measures of anxiety and depression to accurately capture such internalizing symptoms.

4.4 Population

Interestingly, based on our narrative analysis of the literature, age does not seem to have a significant impact on symptom change of anxiety and/or depression, with significant reductions found in studies using samples aged 8-18 years. Since cognitive control develops at an accelerated rate between the ages of 5 - 11, with smaller improvements between the age of 11 - 15 (Gathercole et al., 2004), CCT positions itself to be a promising treatment option for anxiety and depression in children and adolescents. However, of the eight studies that resulted in reduction of anxiety/depression reviewed here, only two (Grunewaldt et al., 2013; Shanok et al., 2021) included children aged under 12 years and both deployed commercial WM packages. Two further studies with children revealing no change also used commercial WM training (Lomas, 2001; Roberts et al., 2016). To date, no studies investigating the use of targeted, adaptive CCT (i.e., training inhibition, shifting or update WM) have been conducted with children under 12. Nonetheless, as more research pertaining to the effectiveness of CCT in children and adolescents will become available in the years to come, this hypothesis, among the other observations mentioned above (e.g., pertaining training procedure), will require further investigation using a meta-analytic approach. In addition, in contrast to the CCT literature for adults in which the potential of CCT as a preventive intervention for depression has received more attention (for a review, see Koster et al., 2017), the impact of CCT on depression in youngsters with elevated levels of depressive symptomatology remains to be tested.

4.5 Quality

At a methodological level, some of the heterogeneity problems between studies are not unique to investigations with children and adolescents but relate more broadly to CCT research. For example, the sample characteristics, sample size, adequate control conditions, adequate blinding, and lack of open science practices are concerning. Many of the studies reviewed here were vague about their randomization process and whether they were single- or

double-blinded trials. Many studies also lacked use of an active control condition (e.g., Corti et al., 2020; Grunewaldt et al., 2013; Hitchcock & Westwell, 2017; Roberts et al, 2016; Roughan & Hadwin, 2011; Shanok et al., 2021). Use of passive, no-training or waitlist controls are problematic for the reason they are not sufficient to account for any gains due to a placebo effect in the CCT group. Most of the studies were not pre-registered, fell short of reporting a priori sample calculations and some had a very small *N*. Deviating from analytic plans adds additional bias for the effect size parameter, and as such, future studies would move the field forward by being fully transparent, use pre-registration (e.g., OSF), and investing in designs that are adequately powered to detect differential training effects.

4.6 Directions for future research

Although the most applicable databases were selected for the present review, and a systematic screening of the available literature was conducted, it is conceivable that a relevant study was missed. The scope and heterogeneity of included studies with regard to differences in type of CCT intervention, duration and context, outcome measures, and population variations meant we could only draw qualitative conclusions. Due to the small number of studies available we wanted to be inclusive and provide a breadth of research, thus we included studies with outcomes of other psychological factors (e.g., internalizing & emotional symptoms, emotion regulation).

Future research should investigate whether individual differences in baseline WM capacity, motivation, emotional vulnerability or other factors moderate CCT effects, examine the durability of these effects, and determine if top-up training procedures are beneficial. Larger scale, confirmatory work to support the initial promise of CCT for the treatment of anxiety and depression vulnerability in children and adolescents is critical. In addition, based on research in adults suggesting that individuals belonging to high risk or clinical populations

may benefit more from CCT than healthy individuals (Koster et al., 2017), future studies evaluating preventive effects of CCT in children would ideally pre-screen based on level of internalizing symptomatology or strongly related cognitive risk factors (e.g., repetitive negative thinking). Moreover, current studies show high heterogeneity in type of training procedure used (neutral, affective, multi-component/commercial) and training intensity. Future research should investigate how CCT could be ideally implemented, where based on age and at-risk status a differential training approach may be warranted. In addition, more longitudinal research determining the predictive power of cognitive control (Vijayakumar et al., 2016) and the ability for CCT to protect against emotional vulnerability later in adulthood, is much needed. It is the challenge for future work to tailor this treatment and optimize effect sizes. For this purpose, as a first step pre-registered high quality experimental psychopathological research with a strong mechanistic focus, linking changes in cognitive and affective processes in youngsters, will be crucial.

5.0 Conclusion

CCT research is an exciting and growing area and its utility for reducing emotional vulnerability in children and adolescents is promising. Thus far, empirical studies suggest that cognitive transfer is a necessary precondition for emotional transfer irrespective of CCT paradigm. In sum, there is support for CCT with the following specifications: (Type) adaptive, targeted inhibition, shifting, or updating WM tasks including neutral or affective stimuli; (Duration) 4 weeks and 11-15 sessions; (Context) in schools; and (Outcome measures) specific and sensitive measures of anxiety/depression appropriate for the sample. The evidence for such a ‘recipe’ for CCT with typically developing children under 12 years of age, however, is untested. Anxiety and depression are both attenuated by CCT using targeted WM (updating) tasks; the valence of the stimuli is less important. There is some support for commercial WM training with extended training sessions for anxiety, however, this approach

with depression is yet to be tested. We hope that this review will become the catalyst for further work.

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Conflicts of interest

The authors have no conflicts of interest to declare.

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References

Achenbach, T. M. (2006). As others see us: Clinical and research implications of cross-informant correlations for psychopathology. *Current Directions in Psychological Science, 15*(2), 94-98. https://doi.org/10.1111/j.0963-7214.2006.00414.x

Beloe, P., & Derakshan, N. (2020). Adaptive working memory training can reduce anxiety and depression vulnerability in adolescents. *Developmental Science, 23*(4), e12831–n/a. https://doi.org/10.1111/desc.12831

Bidaut-Russell, M., Reich, W., Cottler, L. B., Robins, L. N., Compton, W. M., & Mattison, R. E. (1995). The Diagnostic Interview Schedule for Children (PC-DISC v. 3.0): Parents and adolescents suggest reasons for expecting discrepant answers. *Journal of Abnormal Child Psychology*, *23*(5), 641-659. https://doi.org/10.1007/BF01447667

Bigorra, A., Garolera, M., Guijarro, S., & Hervás, A. (2016). Long-term far-transfer effects of working memory training in children with ADHD: A randomized controlled trial. *European Child & Adolescent Psychiatry, 25*(8), 853-867. https://doi.org/10.1007/s00787-015-0804-3

Boden, J. M., Fergusson, D. M., & Horwood, L. J. (2007). Anxiety disorders and suicidal behaviours in adolescence and young adulthood: Findings from a longitudinal study. *Psychological Medicine, 37*(3), 431-440. https://doi.org/10.1017/S0033291706009147

Bowers, M. E., Reider, L. B., Morales, S., Buzzell, G. A., Miller, N., Troller-Renfree, S. V., Pine, D. S., Hendersson, H. A., & Fox, N. A. (2020). Differences in parent and child report on the screen for child anxiety-related emotional disorders (SCARED): implications for investigations of social anxiety in adolescents. *Journal of Abnormal Child Psychology, 48*(4), 561-571. https://doi.org/10.1007/s10802-019-00609-3

Bowie, C. R., Gupta, M., Holshausen, K., Jokic, R., Best, M., & Milev, R. (2013). Cognitive remediation for treatment-resistant depression: effects on cognition and functioning

and the role of online homework. *The Journal of Nervous and Mental Disease, 201*(8), 680-685. https://doi.org/10.1097/NMD.0b013e31829c5030

Braet, C., Theuwis, L., Van Durme, K., Vandewalle, J., Vandevivere, E., Wante, L., Moens, E., Verbeken, S., & Goossens, L. (2014). Emotion regulation in children with emotional problems. *Cognitive Therapy and Research*, *38*(5), 493-504. https://doi.org/10.1007/s10608-014-9616-x

Calkins, A. W., McMorran, K. E., Siegle, G. J., & Otto, M. W. (2015). The effects of computerized cognitive control training on community adults with depressed mood. *Behavioural and Cognitive Psychotherapy*, *43*(5), 578-589. https://doi.org/10.1017/S1352465814000046

Campbell, M. (2006). Anxiety in early childhood. *Educating Young Children*, *12*(2), 31-33.

Clayborne, Z. M., Varin, M., & Colman, I. (2019). Systematic review and meta-analysis: adolescent depression and long-term psychosocial outcomes. *Journal of the American Academy of Child & Adolescent Psychiatry*, *58*(1), 72-79. https://doi.org/10.1016/j.jaac.2018.07.896

Cogmed. (2021, March 14). *Research*. https://www.cogmed.com.au/research

Cohen, J. D. (2017). Cognitive control: Core constructs and current considerations. *The Wiley Handbook of Cognitive Control*, (pp. 1-28). John Wiley & Sons Ltd. https://doi.org/10.1002/9781118920497

Cohen, N., Mor, N., & Henik, A. (2015). Linking executive control and emotional response: A training procedure to reduce rumination. *Clinical Psychological Science*, *3*(1), 15-25. https://doi.org/10.1177/2167702614530114

Cohen, N., & Ochsner, K. N. (2018). From surviving to thriving in the face of threats: The emerging science of emotion regulation training. *Current Opinion in Behavioral Sciences, 24*, 143-155. https://doi.org/10.1016/j.cobeha.2018.08.007

Corti, C., Urgesi, C., Poggi, G., Strazzer, S., Borgatti, R., & Bardoni, A. (2020). Home-based cognitive training in pediatric patients with acquired brain injury: Preliminary results on efficacy of a randomized clinical trial. *Scientific Reports, 10*(1), 1-15. https://doi.org/10.1038/s41598-020-57952-5

Course-Choi, J., Saville, H., & Derakshan, N. (2017). The effects of adaptive working memory training and mindfulness meditation training on processing efficiency and worry in high worriers. *Behaviour Research and Therapy, 89*, 1-13. https://doi.org/10.1016/j.brat.2016.11.002

Cummings, C. M., Caporino, N. E., & Kendall, P. C. (2014). Comorbidity of anxiety and depression in children and adolescents: 20 years after. *Psychological Bulletin*, *140*(3), 816-845. https://doi.org/10.1037/a0034733

De Los Reyes, A., & Kazdin, A. E. (2004). Measuring informant discrepancies in clinical child research. *Psychological Assessment*, *16*(3), 330-334. https://doi.org/10.1037/1040-3590.16.3.330

De Los Reyes, A., & Kazdin, A. E. (2006). Conceptualizing changes in behavior in intervention research: The range of possible changes model. *Psychological Review*, *113*(3), 554-583. https://doi.org/10.1037/0033-295X.113.3.554

Derakhshan, N. (2020). Attentional control and cognitive biases as determinants of vulnerability and resilience in anxiety and depression. In *Cognitive Biases in Health and Psychiatric Disorders* (pp. 261-274). Academic Press.

De Raedt, R., & Koster, E. H. (2010). Understanding vulnerability for depression from a cognitive neuroscience perspective: A reappraisal of attentional factors and a new conceptual framework. *Cognitive, Affective, & Behavioral Neuroscience*, *10*(1), 50-70. https://doi.org/10.3758/CABN.10.1.50

de Voogd, E. L., Wiers, R. W., Zwitser, R. J., & Salemink, E. (2016). Emotional working memory training as an online intervention for adolescent anxiety and depression: A randomised controlled trial. *Australian Journal of Psychology, 68*(3), 228-238. https://doi.org/10.1111/ajpy.12134

Dolcos, F., Katsumi, Y., Moore, M., Berggren, N., de Gelder, B., Derakshan, N., Hamm, A.O., Koster, E.H., Ladouceur, C.D., Okon-Singer, H. & Pegna, A.J., (2020). Neural correlates of emotion-attention interactions: From perception, learning, and memory to social cognition, individual differences, and training interventions. *Neuroscience & Biobehavioral Reviews, 108,* 559-601. https://doi.org/10.1016/j.neubiorev.2019.08.017

Downs, S. H., & Black, N. (1998). The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *Journal of Epidemiology & Community Health, 52*(6), 377-384. https://doi.org/10.1136/jech.52.6.377

Du Toit, S. A., Kade, S. A., Danielson, C. T., Schweizer, S., Han, J., Torok, M., & Wong, Q. J. (2020). The effect of emotional working memory training on emotional and cognitive outcomes in individuals with elevated social anxiety. *Journal of Affective Disorders, 261,* 76-83. https://doi.org/10.1016/j.jad.2019.09.085

Erskine, H. E., Moffitt, T. E., Copeland, W. E., Costello, E. J., Ferrari, A. J., Patton, G., Degenhardt, L., Vos, T., Whiteford, H. A., & Scott, J. G. (2015). A heavy burden on young minds: the global burden of mental and substance use disorders in children and youth. *Psychological medicine, 45*(7), 1551. https://doi.org/10.1017/s0033291714002888

Esteves, S. C., Majzoub, A., & Agarwal, A. (2017). The problem of mixing 'apples and oranges' in meta-analytic studies. *Translational Andrology and Urology*, *6*(Suppl 4), S412. https://doi.org/10.21037/tau.2017.03.23

Etherton, J. L., Oberle, C. D., Rhoton, J., & Ney, A. (2019). Effects of Cogmed working memory training on cognitive performance. *Psychological Research*, *83*(7), 1506-1518. https://doi.org/10.1007/s00426-018-1012-9

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, *7*(2), 336-353. https://doi.org/10.1037/1528-3542.7.2.336

Gathercole, S. E., Pickering, S. J., Ambridge, B., & Wearing, H. (2004). The structure of working memory from 4 to 15 years of age. *Developmental Psychology*, *40*(2), 177-190. https://doi.org/10.1037/0012-1649.40.2.177

Grol, M., Schwenzfeier, A. K., Stricker, J., Booth, C., Temple-McCune, A., Derakshan, N., Hirsch, C., Becker, E., & Fox, E. (2018). The worrying mind in control: An investigation of adaptive working memory training and cognitive bias modification in worry-prone individuals. *Behaviour Research and Therapy*, *103*, 1-11. https://doi.org/10.1016/j.brat.2018.01.005

Grunewaldt, K. H., Løhaugen, G. C. C., Austeng, D., Brubakk, A. M., & Skranes, J. (2013). Working memory training improves cognitive function in VLBW preschoolers. *Pediatrics*, *131*(3), e747-e754. https://doi.org/10.1542/peds.2012-1965

Hadwin, J. A., & Richards, H. J. (2016). Working memory training and CBT reduces anxiety symptoms and attentional biases to threat: A preliminary study. *Frontiers in Psychology*, *7*, 47–47. https://doi.org/10.3389/fpsyg.2016.00047

Headley, C., & Campbell, M. (2013). Teachers' knowledge of anxiety and identification of excessive anxiety in children. *Australian Journal of Teacher Education, 38*(5), 48-66. https://doi.org/10.14221/ajte.2013v38n5.2

Hinchliffe, K., & Campbell, M. (2016). Tipping points: Teachers' reported reasons for referring primary school children for excessive anxiety. *Journal of Psychologists and Counsellors in Schools, 26*(1), 84-99. https://doi.org/10.1017/jgc.2015.24

Hitchcock, C., & Westwell, M. S. (2017). A cluster-randomised, controlled trial of the impact of Cogmed working memory training on both academic performance and regulation of social, emotional and behavioural challenges. *Journal of Child Psychology and Psychiatry, 58*(2), 140-150. https://doi.org/10.1111/jcpp.12638

Hooper, P., Jutai, J. W., Strong, G., & Russell-Minda, E. (2008). Age-related macular degeneration and low-vision rehabilitation: A systematic review. *Canadian Journal of Ophthalmology, 43*(2), 180-187. https://doi.org/10.3129/i08-001

Hoorelbeke, K., Koster, E. H., Vanderhasselt, M. A., Callewaert, S., & Demeyer, I. (2015). The influence of cognitive control training on stress reactivity and rumination in response to a lab stressor and naturalistic stress. *Behaviour Research and Therapy, 69*, 1-10. https://doi.org/10.1016/j.brat.2015.03.010

Hoorelbeke, K., & Koster, E. H. (2017). Internet-delivered cognitive control training as a preventive intervention for remitted depressed patients: Evidence from a double-blind randomized controlled trial study. *Journal of Consulting and Clinical Psychology*, *85*(2), 135-146. http://dx.doi.org/10.1037/ccp0000128

Hoorelbeke, K., Van den Bergh, N., De Raedt, R., Wichers, M., & Koster, E.H.W. (2021). Preventing recurrence of depression: Long-term effects of a randomized controlled trial on cognitive control training for remitted depressed patients. *Clinical Psychological Science*. https://doi.org/10.1177/2167702620979775

Hotton, M., Derakshan, N., & Fox, E. (2018). A randomised controlled trial investigating the benefits of adaptive working memory training for working memory capacity and attentional control in high worriers. *Behaviour Research and Therapy, 100*, 67-77. https://doi.org/10.1016/j.brat.2017.10.011

Iacoviello, B. M., Wu, G., Alvarez, E., Huryk, K., Collins, K. A., Murrough, J. W., Iosifescu, M. D., & Charney, D. S. (2014). Cognitive-emotional training as an intervention for major depressive disorder. *Depression and Anxiety*, 31(8), 699-706. https://doi.org/10.1002/da.22266

Joormann, J., & D'Avanzato, C. (2010). Emotion regulation in depression: Examining the role of cognitive processes: Cognition & Emotion Lecture at the 2009 ISRE Meeting. *Cognition and Emotion, 24*(6), 913-939. https://doi.org/10.1080/02699931003784939

Kazdin, A. E. (2017). Addressing the treatment gap: A key challenge for extending evidence-based psychosocial interventions. *Behaviour Research and Therapy, 88*, 7-18. https://doi.org/10.1016/j.brat.2016.06.004

Kertz, S. J., Belden, A. C., Tillman, R., & Luby, J. (2016). Cognitive control deficits in shifting and inhibition in preschool age children are associated with increased depression and anxiety over 7.5 years of development. *Journal of Abnormal Child Psychology, 44*(6), 1185-1196. https://doi.org/10.1007/s10802-015-0101-0

Kessler, R. C., Berglund, P., Demler, O., Jin, R., Merikangas, K. R., & Walters, E. E. (2005). Lifetime prevalence and age-of-onset distributions of DSM-IV disorders in the National Comorbidity Survey Replication. *Archives of General Psychiatry, 62*(6), 593-602. https://doi.org/10.1001/archpsyc.62.6.593

Koster, E. H., Hoorelbeke, K., Onraedt, T., Owens, M., & Derakshan, N. (2017). Cognitive control interventions for depression: A systematic review of findings from training

studies. *Clinical Psychology Review, 53*, 79-92. https://doi.org/10.1016/j.cpr.2017.02.002

Lengvenyte, A., Coppola, F., Jaussent, I., Courtet, P., & Olié, E. (2020). Improved functioning following computerized working memory training (COGMED®) in euthymic patients with bipolar disorder and cognitive complaints: An exploratory study. *Journal of Affective Disorders*, 262, 414-421. https://doi.org/10.1016/j.jad.2019.11.062

Locutour. (2021, March 14). *Attention*. https://www.locutour.com/software/overview.php?p=Attention

Lomas, K. M. (2001). *Computer-assisted cognitive training with elementary school-age children diagnosed with attention-deficit/hyperactivity disorder and mild/moderate comorbidity: A short-term prospective study on attention, planning and behavior.* (Doctoral dissertation, Howard University).

Lotfi, S., Ward, R. T., Ayazi, M., Bennett, K. P., Larson, C. L., & Lee, H. J. (2020). The effects of emotional working memory training on worry symptoms and error-rRelated negativity of individuals with high trait anxiety: A randomized controlled study. *Cognitive Therapy and Research*, 1-17. https://doi.org/10.1007/s10608-020-10164-7

Lowther, H., & Newman, E. (2014). Attention bias modification (ABM) as a treatment for child and adolescent anxiety: A systematic review. *Journal of Affective Disorders, 168*, 125-135. https://doi.org/10.1016/j.jad.2014.06.051

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, *24*(1), 167-202. https://doi.org/10.1146/annurev.neuro.24.1.167

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49-100. https://doi.org/10.1006/cogp.1999.0734

Morimoto, S. S., Wexler, B. E., Liu, J., Hu, W., Seirup, J., & Alexopoulos, G. S. (2014). Neuroplasticity-based computerized cognitive remediation for treatment-resistant geriatric depression. *NatureCommunications, 5*(1), 1-7. https://doi.org/10.1038/ncomms5579

Nelson, T. D., Kidwell, K. M., Nelson, J. M., Tomaso, C. C., Hankey, M., & Espy, K. A. (2018). Preschool executive control and internalizing symptoms in elementary school. *Journal of Abnormal Child Psychology, 46*(7), 1509-1520. https://doi.org/10.1007/s10802-017-0395-1

Nigg, J. T. (2017). Annual research review: On the relations among self-regulation, self-control, executive functioning, effortful control, cognitive control, impulsivity, risk-taking, and inhibition for developmental psychopathology. *Journal of Child Psychology and Psychiatry, 58*(4), 361-383. https://doi.org/10.1111/jcpp.12675

Orwin, R. G., & Vevea, J. L. (2009). Evaluating coding decisions. In H. Cooper, L. V. Hedges, & J. C. Valentine (Eds.), *The handbook of research synthesis and meta-analysis* (p. 177–203). Russell Sage Foundation.

Ochsner, K. N., & Gross, J. J. (2005). The cognitive control of emotion. *Trends in Cognitive Sciences, 9*(5), 242-249. https://doi.org/10.1016/j.tics.2005.03.010

Page, M. J., McKenzie, J., Bossuyt, P., Boutron, I., Hoffmann, T., Mulrow, C., Shamseer, L., Tetzlaff, J. N., & Moher, D. (2020). Updating guidance for reporting systematic reviews: development of the PRISMA 2020 statement. *Journal of Clinical Epidemiology, 134*, 103–112. https://doi.org/10.1016/j.jclinepi.2021.02.003

Rethlefsen, M. L., Kirtley, S., Waffenschmidt, S., Ayala, A. P., Moher, D., Page, M. J., & Koffel, J. B. (2021). PRISMA-S: an extension to the PRISMA Statement for Reporting Literature Searches in Systematic Reviews. *Systematic Reviews, 10*(1), 1-19. https://doi.org/10.1186/s13643-020-01542-z

Roberts, G., Quach, J., Spencer-Smith, M., Anderson, P. J., Gathercole, S., Gold, L., Sia, K., Mensah, F., Ainley, J., & Wake, M. (2016). Academic outcomes 2 years after working memory training for children with low working memory: A randomized clinical trial. *JAMA Pediatrics*, *170*(5), e154568. https://doi.org/10.1001/jamapediatrics.2015.4568

Roughan, L., & Hadwin, J. A. (2011). The impact of working memory training in young people with social, emotional and behavioural difficulties. *Learning and Individual Differences, 21*(6), 759–764. https://doi.org/10.1016/j.lindif.2011.07.011

Routledge, K. M., Williams, L. M., Harris, A. W., Schofield, P. R., & Gatt, J. M. (2021). The impact of online brain training exercises on experiences of depression, anxiety and emotional wellbeing in a twin sample. *Journal of Psychiatric Research*, 134, 138-149. https://doi.org/10.1016/j.jpsychires.2020.12.054

Sadeghi, M., McAuley, T., & Sandberg, S. (2020). Examining the impact of motivation on working memory training in youth with ADHD. *Journal of the Canadian Academy of Child and Adolescent Psychiatry, 29*(1), 4-14.

Sari, B. A., Koster, E. H., Pourtois, G., & Derakshan, N. (2016). Training working memory to improve attentional control in anxiety: A proof-of-principle study using behavioral and electrophysiological measures. *Biological Psychology*, *121*, 203-212. https://doi.org/10.1016/j.biopsycho.2015.09.008

Schweizer, S., Gotlib, I. H., & Blakemore, S. J. (2020). The role of affective control in emotion regulation during adolescence. *Emotion, 20*(1), 80-86. https://doi.org/10.31234/osf.io/asq9j

Schweizer, S., Hampshire, A., & Dalgleish, T. (2011). Extending brain-training to the affective domain: increasing cognitive and affective executive control through emotional working memory training. *PloS one*, *6*(9), e24372. https://doi.org/10.1371/journal.pone.0024372

Schweizer, S., Samimi, Z., Hasani, J., Moradi, A., Mirdoraghi, F., & Khaleghi, M. (2017). Improving cognitive control in adolescents with post-traumatic stress disorder (PTSD). *Behaviour Research and Therapy, 93*, 88-94. https://doi.org/10.1016/j.brat.2017.03.017

Shamseer, L., Moher, D., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P. & Stewart, L. A. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. *British Medical Journal, 349*. g7647. https://doi.org/10.1136/bmj.g7647

Shanok, N. A., Meltzer, K., Frank, C., Lugo, V., & Jones, N. A. (2021). Computerized inhibitory control training reduces anxiety in preadolescent students. *Applied Neuropsychology: Child*, 1-16. https://doi.org/10.1080/21622965.2021.1884984

Siegle, G. J., Ghinassi, F., & Thase, M. E. (2007). Neurobehavioral therapies in the 21st century: Summary of an emerging field and an extended example of cognitive control training for depression. *Cognitive Therapy and Research, 31*(2), 235-262. https://doi.org/10.1007/s10608-006-9118-6

Siegle, G. J., Price, R. B., Jones, N. P., Ghinassi, F., Painter, T. & Thase, M. E. (2014). You gotta work at it: Pupillary indices of task focus are prognostic for response to a neurocognitive intervention for rumination in depression. *Clinical Psychological Science, 2,* 455-471. https://doi.org/10.1177/2167702614536160

Sportel, B. E., Nauta, M. H., de Hullu, E., de Jong, P. J., & Hartman, C. A. (2011). Behavioral inhibition and attentional control in adolescents: Robust relationships with anxiety and

depression. *Journal of Child and Family Studies, 20*(2), 149-156. https://doi.org/10.1007/s10826-010-9435-y

Swainston, J., & Derakshan, N. (2018). Training cognitive control to reduce emotional vulnerability in breast cancer. *Psycho-oncology*, *27*(7), 1780-1786. https://doi.org/10.1002/pon.4727

Vijayakumar, N., Whittle, S., Yücel, M., Byrne, M. L., Schwartz, O., Simmons, J. G., & Allen, N. B. (2016). Impaired maturation of cognitive control in adolescents who develop major depressive disorder. *Journal of Clinical Child & Adolescent Psychology*, *45*(1), 31-43.

Woodward, L. J., & Fergusson, D. M. (2001). Life course outcomes of young people with anxiety disorders in adolescence. *Journal of the American Academy of Child & Adolescent Psychiatry*, *40*(9), 1086-1093. https://doi.org/10.1097/00004583-200109000-00018

Appendix

Database searches

Search Date	Database	Search String	Explanation	Number Retrieved
10/12/2020	Web of Science	TI=("cognitive control therapy" OR "cognitive control tr aining" OR "cognitive control task" OR "neurocognitive training" OR "cognitive training" O R "executive control training" OR "working memory training" OR "cognitive emotional trai ning" OR "cognitive remediation" OR "neurobehavioral therapy") AND AB=(child* OR ad ol* OR you*)	Title for intervention and abstract for population (child, adolescents, youth)	392
11/12/2020	Medline	TI ("cognitive control therapy" OR "cognitive control training" OR "cognitive control task" OR "neurocognitive training" OR "cognitive training" OR "executive control training" OR "working memory training" OR "cognitive emotional training" OR "cognitive remediation" OR "neurobehavioral therapy") AND AB (child* OR adol* OR you*)	Same as above	343
11/12/2020	APA PsycINFO	Title: "cognitive control therapy" *OR* Title: "cognitive control training" *OR* Title: "cognitive control task" *OR* Title: "neurocognitive training" *OR* Title: "cognitive training" *OR* Title: "executive control training" *OR* Title: "working memory training" *OR* Title: "cognitive emotional training" *OR* Title: "cognitive remediation" *OR* Title: "neurobehavioral therapy" *AND* Abstract: child* *OR* Abstract: adol* *OR* A bstract: you*	Same as above	422
12/12/2020	EMBASE	('cognitive control therapy':ti OR 'cognitive control training':ti OR 'cognitive control task':ti OR 'neurocognitive training':ti OR 'cognitive training':ti OR 'executive control training':ti OR 'working memory training':ti OR 'cognitive emotional training':ti OR 'cognitive remediation':ti OR 'neurobehavioral therapy':ti) AND (child*:ab OR adol*:ab OR you*:ab)	Same as above	476
15/12/2020	CINAHL	TI ("cognitive control therapy" OR "cognitive control training" OR "cognitive control task" OR "neurocognitive training" OR "cognitive training" OR "executive control training" OR "working memory training" OR "cognitive emotional training" OR "cognitive remediation" OR "neurobehavioral therapy") AND AB (child* OR adol* OR you*)	Same as above	116
15/12/2020	PubMed	("cognitive control therapy"[Title] OR "cognitive control training"[Title] OR "cognitive control task"[Title] OR "neurocognitive training"[Title] OR "cognitive training"[Title] OR "executive control training"[Title] OR "working memory training"[Title] OR "cognitive emotional training"[Title] OR "cognitive remediation"[Title] OR "neurobehavioral therapy"[Title]) AND (child*[Title/Abstract] OR adol*[Title/Abstract] OR youn*[Title/Abstract] OR yout*[Title/Abstract])	Title for intervention and title and abstract for population	366

Table 1

Characteristics of Included Studies

Author	Participants	CCT Type (process)	CCT group	Control group	Duration (dose)	Training effects on anxiety/depression	Other training effects
Beloe & Derakshan (2019)	Typically developing adolescents; 10-18 years (*N* = 254)	CCT with neutral stimuli (updating WM)	Adaptive dual *n*-back WM training (*n* = 128)	Non-adaptive dual *1*-back training (*n* = 126)	4 weeks, 20 sessions (5 x week) However, data was analysed on ≥6 sessions (*N* = 120)	CCT group showed decreased scores on RCADS Total Anxiety (*d* = 0.37), Depression (*d* = 0.52), and Total Internalizing (Anxiety + Depression; *d* = 0.41) scales pre vs. post and sustained at 1-month follow-up. Controls demonstrated no differences across the training period.	CCT group showed improved WM (*n*-back) performance across training period. Controls revealed no changes in WM performance across the training period.
Bigorra et al. (2015)	Children with ADHD +/- comorbid disruptive behaviour disorders; 7-12 years (*N* = 65)	Commercial WM training (mixed WM)	CWMT (RM) (*n* = 35)	Non-adaptive CWMT (RM) (*n* = 30)	5 weeks, 25 sessions (5 x week)	CCT group revealed a trend for reduction in CBCL and TRF Anxious/Depressed subscales pre vs. post and maintained at 6-month follow-up. Controls showed no noticeable difference across the training period.	CCT group showed improved WM performance pre vs. post and sustained at follow-up; improved BRIEF teacher version on the initiate, metacognition index, WM index, monitoring and shifting pre vs. post and maintained at 6-month follow-up; and decreased ADHD symptoms across time. Control group showed no noticeable differences across the training period.
Corti et al. (2020)	Adolescents with acquired brain injury; 11-16 years (*N* = 48)	Commercial WM training (mixed WM)	Lumosity (*n* = 24)	Waitlist (*n* = 24)	8 weeks, 40 sessions (5 x week)	No significant differences on CBCL Internalizing scale between CCT groups or across time.	Both groups showed improved visual-spatial WM, with CCT group demonstrating greater improvement relative to Control group.
de Voogd, et al. (2016)	Typically developing adolescents; 11-18 years (*N* = 168)	CCT with affective stimuli (updating WM)	Adaptive affective WM training (*n* = 129)	Non-adaptive affective WM training (*n* = 39)	4 weeks, 8 sessions (2 x week)	No group differences of SCARED Anxiety or CDI Depression scores across time, despite general decreases in anxiety and depression symptoms pre-training to follow-up in both groups.	No group differences in WM performance across time, however both groups showed equivalent increases in WM performance pre-training to follow-up. Equivalent group decreases in perseverative negative thinking, test anxiety, and social-emotional and behavioural problems from pre-training to follow-up. Marginally significant Group × time interaction on RSES self-esteem scores, reflecting improvements for CCT group relative to Controls over time.

Grunewaldt et al. (2013)	Pre-term born very low birth weight preschool children; 5-6 years (*N* = 20)	Commercial WM training (mixed WM)	CWMT (JM) (*n* = 9)	Waitlist (*n* = 11)	5 weeks, 25 sessions (5 x week)	The waitlist condition also completed CWMT. Authors analysed effects of CCT on anxiety combining both groups. CCT was associated with significant reduction in parent-reported PAS Separation Anxiety (*d* = 1.15) and Total Anxiety (*d* = 1.06), but not OCD, Social, Physical Injury Fears or Generalised Anxiety.	CCT was associated with improved performance on measures of sustained auditory attention, phonological processing, sentence repetition, narrative memory, memory for faces and both trained and non-trained WM tasks.
Hadwin & Richards (2016)	Highly anxious adolescents; 11-14 years (*N* = 40)	Commercial WM training (mixed WM)	CWMT (RM) (*n* = 20)	CBT -FRIENDS for Life (*n* = 20)	5 weeks, 25 sessions (5 x week)	No group differences on RCMAS-2 Total Anxiety scores across time. Equivalent group decreases in anxiety (*d* = 1.50) from pre- to post- and maintained at follow-up. Conceptually similar pattern for CTAS Test Anxiety (*d* = 0.81).	No group differences on inhibitory control or attentional bias for threat, which improved (higher inhibitory control and lower threat bias) from pre- to post- and maintained at follow-up.
Hitchcock & Westwell (2017)	Typically developing adolescents; 10-14 years (*N* = 148)	Commercial WM training (mixed WM)	CWMT (RM) (*n* = 54) Non-adaptive CWMT (*n* = 45)	No-training (*n* = 49)	5 weeks, 25 sessions (5 x week)	No group differences of CBCL Internalizing subscale across time.	No group differences on Internalizing or Externalising behaviours (aggression, social problems, hyperactivity, rule breaking behaviour, somatic complaints), WM or attention over time. All groups showed fewer task-unrelated thoughts and improved reading comprehension from pre-training to follow-up; improved mathematics performance from pre- to post-training, but not sustained at follow-up.
Lomas (2001)	Children with ADHD and mild/moderate comorbidity; 7-9 years (*N* = 33)	Commercial WM training (mixed WM)	LocuTour (*n* = 18)	Non-adaptive sham training (*n* = 15)	14 weeks, 42 sessions (2-3 x week)	Both groups showed a trend for reduction in CPRS Anxious/Shy subscale from pre vs. post. However, authors noted CCT group reported higher anxiety than Controls at pre-training when measured using CPRS, yet matched for Anxiety and Depression when assessed using RCMAS and CDI, respectively.	No group differences on sustained attention and vigilance, nor parent ratings of multi-dimensional functioning from pre- to post-training.
Roberts et al. (2016)	Children with WM in the bottom 25th percentile; age 6-7 years (*N*=452)	Commercial WM training (mixed WM)	CWMT (RM) (*n* = 226)	No-training (n = 226)	25 sessions, 5 weeks (5 x week)	No group differences between SDQ Emotional Symptoms pre vs. post or at 12- or 24-month follow-up. There was also no difference when examining whether students were within the top 10% of the scores, representing an 'at risk' group.	No group differences in child cognitive, academic or behavioural domains. Examination of predictors of training effects showed no characteristics, including child internalizing behaviour at baseline, predicted outcomes at 6 months.

Roughan & Hadwin (2011)	Adolescents with SEBD in school; 11-14 years (*N* = 17)	Commercial WM training (mixed WM)	CWMT (RM) (*n* = 7)	No-training (*n* = 8)	5 weeks, 25 sessions (5 x week)	CCT group showed no differences in BYI Trait Anxiety, a trend for reduction in teacher reported CTAS Test-Anxiety (*d* = 0.41) and significant reduction in SDQ Emotional Symptoms (*d* = 1.54) between pre vs. post. Control group showed no differences in BYI Trait Anxiety, trend for reduction in teacher-reported CTAS yet not as great a reduction as CCT group, no changes in Emotional Symptoms (SDQ) between pre vs. post. Nonetheless, no effects were sustained at 3-months.	CCT group showed increases in WM relative to Controls pre vs. post and improvements remained at 3-month follow-up. CCT group showed improved inhibition, IQ, attentional control and reduced behavioural difficulties compared to controls between pre vs. post, yet effects were not sustained at 3-month follow-up.
Schweizer et al. (2017)	Adolescents with PTSD; 14-18 years (*N* = 30)	CCT with affective stimuli (updating WM)	Adaptive affective dual *n*-back (*n* = 15)	Non-adaptive sham training (*n* = 15)	4 weeks, 20 sessions, (5 x week)	CCT group showed greater increases in CERQ Adaptive Emotional Regulation from pre vs. post relative to Controls (*d* = 1.67). Yet, no change in CERQ maladaptive emotional regulation strategies (e.g., rumination) over time for both groups.	CCT groups showed improvements in cognitive control effectiveness (Go/No-Go performance), but not efficiency (RTs) pre vs. post, relative to the Controls.
Shanok et al. (2021)	Typically developing children; 8-12 years (*N* = 42)	CCT with affective stimuli (inhibition) CCT with neutral stimuli (inhibition)	Adaptive affective Go/No-Go training (*n* = 15) Adaptive non-emotional Go/No-Go training (*n* = 14)	Waitlist (*n* = 13)	4 weeks, 16 session (2-3 x week)	Both CCT groups (Adaptive affective and Adaptive non-emotional CCT) reduced self-reported SCARED Anxiety (*d* = 1.38). , CDI Depression (*d* = 2.30). and PANAS-C Negative Affect (*d* = 1.34). pre vs. post, relative to Controls. Most profound effect for depression noted in non-emotional CCT, whereas for negative affect in emotional CCT. Inhibitory control accuracy predicted self-reported SCARED Anxiety and parent-reported SCARED Anxiety and CDI Depression.	Non-emotional CCT revealed greatest improvement in inhibitory control effectiveness pre vs. post, compared to controls, however this effect was shown for Go/No-Go and flanker, but not Stroop. Both CCT conditions were associated with improvements in inhibitory control efficiency (on flanker task alone) from pre vs. post, relative to Controls.

Notes: ADHD = Attention-Deficit/Hyperactivity Disorder; BYI = Beck Youth Inventory; CBCL = Children's Behaviour Checklist; CBT = Cognitive Behaviour Therapy; CCT = Cognitive Control Training; CDI = Children's Depression Inventory; CERQ = Cognitive Emotion Regulation Questionnaire; CPRS = Conner's Parent Rating Scale; CTAS = Children's Test Anxiety Scale; CWMT = Cogmed Working Memory Training; ITT = Intention to Treat; LocuTour = LocuTour™ Multimedia Cognitive Rehabilitation Training Software; PANAS-C = Positive and Negative Affect Schedule for Children; PAS = Preschool Anxiety Scale; PTSD = Posttraumatic Stress Disorder; RCADS = Revised Children's Anxiety Depression Scale; RCMAS-2 = Revised Children's Manifest Anxiety Scale 2nd edition; RSES = The Rosenberg Self-Esteem Scale; SCARED = Screen for Child Anxiety Related Emotional Disorders; SDQ = Strengths and Difficulties Questionnaire; SEBD = Social Emotional and Behavioural Difficulties; TAU = Treatment as Usual; TRF = Teacher Report Form of the CBCL; Effect sizes reported as η^2 were converted to Cohen's *d* for easy of interpretability using the formula: $d = 2 \times f$, where $f = \text{sqr}(\eta^2/1-\eta^2)$.

Table 2

Methodological Quality of Included Studies Based on Downs and Black (1998)

Author, (year)	Reporting (0-11)	External validity (0-3)	Bias (0-7)	Confounding (0-6)	Power (0-1)
Beloe & Derakshan (2019)	11	3	6	5	1
Bigorra et al. (2015)	11	3	7	5	1
Corti et al. (2020)	11	3	7	6	1
de Voogd et al. (2016)	10	3	7	6	1
Grunewaldt et al. (2013)	11	3	5	5	1
Hadwin & Richards (2016)	11	3	5	6	1
Hitchcock & Westwell (2017)	11	3	6	6	1
Lomas (2001)	11	3	6	5	1
Roberts et al. (2016)	10	3	6	6	1
Roughan & Hadwin (2011)	10	3	5	4	0
Schweizer et al. (2017)	11	3	6	5	1
Shanok et al. (2021)	11	3	5	3	1