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From Surviving to Thriving in the Face of Threats: The Emerging Science of Emotion Regulation Training

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Abstract

A key survival skill is the ability to regulate your emotions so as to respond adaptively to life's challenges. As such, it is essential to understand how we can improve this ability through training. While this is still a new area of research, to date, behavioral and brain studies have taken one of two approaches: either training individuals to implement strategies that directly impact current emotional responses, or training a cognitive control ability (like working memory, selective attention, response inhibition) to strengthen or tune control processes that can support regulation to subsequently encountered events. Behavioral data highlight the importance of tailoring training to an individual and their emotional situation. Brain data suggest that training impacts domain general cognitive control systems and their interaction with subcortical regions (mainly the amygdala). Future progress will depend on systematic examination of the mechanisms involved in training effectiveness and the populations that may benefit from training.

Introduction

How we respond to life's emotional challenges is a major determiner of both subjective and physical well-being. When we are confronted with a situation that threatens our survival or well-being, the brain prioritizes available resources for coping with the threat at the expense of current task or goals [1]. This survival mechanism, however, is not inevitable and is influenced by modulatory systems [2]. The nature of this modulation has implications for surviving the grind of the everyday, warding off psychiatric and substance abuse disorders [3], and ensuring our ultimate survival and chances for reproduction.

A powerful tool for meeting emotional challenges is our capacity to use these modulatory systems to regulate emotion and methods for learning to be better at regulation could have great theoretical and practical importance. In the past five years, there has been an exciting rise of basic behavioral studies designed to test the effects of regulation training on emotional well-being. In some cases, these methods have been ported into the clinical domain as well.

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In general, this research has taken one of two kinds of approaches. The first trains individuals in strategies that engage cognitive control processes to directly impact their current emotional responses. The second trains participants in a cognitive ability, like working memory, in a non-emotional context and then measures indirect effects of this training on subsequent emotional reactions. The goal of this paper is to review these two types of studies, integrate their key findings, highlight their limitations, and suggest directions for future work. In order to make reading less taxing, specific details (sample size, stimuli type, etc) of the reviewed work appear in Table 1 for behavioral studies and in Table 2 for brain imaging studies.

Direct training: Enhancing adaptive responding by practicing the implementation of specific emotion regulation strategies

Studies of this type are informed by models of emotion and emotion regulation [4–6] that differentiate classes of regulation strategies in terms of the stage of a putative emotion generation sequence that they impact. Specifically, emotion regulation involves attempts to change the nature, intensity or duration of emotion and these models offer two main steps in which these changes occurs: an early attentional control step and a later cognitive step [7]. In the current paper we review recent studies providing training in these two classes of emotion regulation -training that impact attention to emotional stimuli, and training that target the subsequent appraisal of the meaning of stimuli.

Attention deployment

Attention deployment strategies either overtly (e.g. moving gaze) or covertly (e.g. internally controlling the focus of attention without necessarily moving one's eyes) shift attention towards or away from stimuli. Attention deployment training therefore provides practice in overt or covert shifts of attention away from stimuli that elicit undesired responses and towards stimuli that elicit desired responses. The most commonly studied exemplar is attention bias modification (ABM), which has been shown to reduce anxiety symptoms.

Commonly used in clinical populations, ABM is based on the idea that individuals with a given disorder may be biased to attend to disorder-relevant negative information [8,9]. ABM seeks to disrupt and alter that bias using variants of the dot-probe task, which presents two images/words on a computer screen – one negative and one neutral. Participants are asked to respond to a target probe (e.g., small dot or a letter), that on most of the trials (e.g., 90%) appears in the location previously occupied by the neutral stimulus. Over time, participants learn to direct their attention away from negative stimuli [10].

Recent meta-analyses [11,12] conclude that the effect of ABM is relatively small and mainly driven by reductions in anxiety symptoms. ABM effectiveness seems to be dependent on task characteristics, such as whether the training was administered in the controlled context of a lab/clinic (more effective) vs. at home (less effective) [13–15]. Furthermore, in numerous studies the control group also showed anxiety reductions after completing a control task not intended to tax key processes of interest. It is therefore unclear ABM's effects are mediated by changes in attention towards negative information or from overall improvements in attention control [13,16,17]. Careful and systematic examination of the processes underlying ABM and the specific populations that may benefit from such training is needed [9,13–19].

Cognitive reappraisal

Once attention has gated some stimuli for focal processing, cognitive reappraisal can draw on a combination of domain general cognitive control processes to change the way one appraises – or interprets – the meaning of those stimuli, thereby changing one's emotional response [20]. In general, reappraisal training reduces negative responses to laboratory stimuli in typically-developing individuals [21–24] and responses to disorder-relevant stimuli/situations in social phobics and neurotic individuals [25,26]. In interpersonal contexts, training in reappraising marital conflicts mitigates declines in marital quality [27] and reappraising pictures related to inter-group conflict increases support for conciliatory policies toward out-group members for up to five months after training [28] (but see [29] for no effect on altruistic behavior).

Insight into the mechanisms mediating such effects comes from studies manipulating the nature of training. For example, Denny & Ochsner [21] reported training-related improvements in the ability to either reinterpret the meaning of negative images or to psychologically distance oneself from them. But only distancing led to benefits beyond the lab – reducing reports of daily life stress – possibly because distancing training offers more 'time on task' than does reinterpretation training: whereas distancing involves maintenance of a consistent mindset across all stimuli, reinterpretations are tailored to individual stimuli. In keeping with this interpretation, offering support to others by repeatedly helping them reappraising life events increased provider's tendency to reappraise in their own lives, which in turn led them feel less depressed [30,31].

The sole imaging study asked participants to reappraise sets of aversive images either once or four times. Whereas both conditions diminished amygdala responses during active regulation, only repeatedly reappraising images led to a week-long reduction in amygdala responses - in the absence of on-going prefrontal engagement [22] - suggesting that repeated reappraisals can cause lasting reductions in the emotional impact of specific stimuli.

Indirect training: Training facilitates cognitive disruption of emotion

There is increasing evidence that training in *selective attention, working memory, and response inhibition* can impact responses to emotional stimuli encountered outside of training. While the mechanisms underlying these indirect effects need further study – as discussed below – current work suggests that this type of training strengthens cognitive control processes that can be used to regulate responses to emotional stimuli when they are encountered at some other time.

Selective attention

Studies of selective attention training follow the basic logic of Attention Control studies described in the prior section, with the exception that participants respond to targets and ignore distractor stimuli that are all affectively neutral. For example, Cohen et al. [32]

trained participants using a variant of the classic Eriksen flanker task [33] that inserted negative images after trials that required engagement of selective attention (i.e. incongruent trials). After training, reactivity to aversive images was reduced and participants were less likely to ruminate about a personally significant event. Two studies using variants of this training method support the idea that it strengthens cognitive control processes used to support other forms of emotion regulation: a behavioral study found that flanker task training increased both lab-based reappraisal success and the frequency of self-reported everyday reappraisals [34] and an imaging study that extended training over six days showed subsequent reductions in amygdala responses to aversive images and increased amygdala-prefrontal connectivity [35].

Working memory

Working memory (WM) enables the active maintenance, processing, and manipulation of information, thereby enabling us to keep in mind goal-relevant information despite the interference of distractions. Therefore, it might be expected that WM training would reduce distraction by irrelevant negative information and alleviate depression and anxiety symptoms such as rumination and worry. However, findings from WM training studies are equivocal: some report that WM training improves emotion regulation and reduces symptoms of anxiety and depression [36–46], while others report either no beneficial or mixed outcomes [47–50].

For example, in two studies Schweizer and colleagues [44,45] trained participants for 20 days on an adaptive n-back task that required keeping in mind either emotional or neutral word-image pairs. Critically, how long participants had to keep these pairs in mind was titrated based on their performance. In the first study, after training, participants were scanned while completing a reappraisal task with aversive films. Emotional – but not neutral – WM training enhanced reappraisal success, and this relationship was mediated by increased activity in frontoparietal regions thought to support control processes common to WM and reappraisal [45]. In the second study, emotional – but not neutral – training enhanced performance on an emotional Stroop Task [44], which can be thought of as assessing the ability to use the Attentional Control emotion regulation strategy. Consistent with these data, WM training with neutral stimuli may have less consistent effects: it had no impact on reports of rumination and depression [50]; it decreased anxiety in high trait anxious individuals but didn’t change performance of an overt selective attention task with emotional faces [49]; and it didn’t impact teacher reports of children’s social and emotional behaviors in the classroom [48]. Together, these data support the idea that WM training with emotional stimuli strengthens the ability of domain-general control systems to support the implementation of emotion regulation strategies.

Response inhibition

Response inhibition involves withholding a pre-potent response. To the extent that response inhibition training tunes core cognitive control systems used to regulate emotional responses, it would be predicted to improve the ability to control unwanted affect-driven behaviors such as binge eating and addiction [51,52]. Current data support these predictions.

For example, Beauchamp et al. [53] trained participants with either 10 sessions of the stop signal task [54] or a control task not tapping inhibitory control ability, and then had both groups complete a reappraisal task in the scanner. Although training didn't improve behavioral indices of reappraisal success, it did lead to reductions in recruitment of inferior frontal and parietal regions associated with cognitive control, suggesting that training may have enhanced the efficiency with which these regions could be deployed during reappraisal.

Several other training studies have used an emotional version of the go no-go task [55] in which participants are trained to inhibit their response to emotionally-valenced (usually appetitive) images. These training procedures can improve the ability to inhibit responses to appetitive items (food, alcohol, drugs) in the task, and critically, can reduce consumption of such items [56–58]. While these findings may be promising for the understanding and treatment of emotion dysregulation and addictive behaviors, some studies failed to observe changes in behavior following the training [56].

Conclusions

Research on emotion regulation training promises new avenues for understanding ways that individuals can not only survive but learn to thrive in the face of emotional challenges. Specifically, emotion regulation training may promote well-being by enhancing the modulatory (i.e., regulatory or control) systems responsible for tuning-down or reducing the need for survival behaviors [2], presumably by strengthening amygdala-prefrontal circuits [35]. Enhancing these modulatory systems reduces vigilance for goal-irrelevant emotional information and may result in better survival decisions. This applies to stimuli that the brain detects as a threat to survival (e.g., spider to a spider-phobic individual), as well as for appetitive stimuli (e.g., high calorie food for a person on a diet). Over time, practicing in emotion regulation, either directly (ABM, reappraisal) or indirectly (by enhancing cognitive control), could re-configure our survival circuits [1], such that events or stimuli that were once considered as a threat to survival (or alternatively highly hedonic) loses their ability to trigger survival behaviors. This being an important – but relatively new area of research – for every initial insight gained there are many more questions raised. In part these questions surround the certainty with which conclusions can be drawn given that data for virtually every type of training is limited and sometimes is inconsistent. Future research is needed to clarify which training elements are most effective, why, and for whom.

In addition to limited data and inconsistent findings, there are several other limitations that should be addressed in future work. First, most of the studies reviewed here had a relatively small sample size and future work with large populations is needed. Furthermore, there is a lack of data on test-retest reliability or data showing poor reliability for some of the training tasks used [59,60]. This is essential if we are to understand how training changes performance. Third, the large variability in the types of stimuli used during training, the number of training sessions, sample characteristics and outcome measures makes it hard to generalize the findings and may partially underlie the inconsistencies found between different studies.

That said, two clear patterns have emerged. The first concerns the way in which training impacts the neural circuits supporting emotion regulation – and all that entails for making people better at using them to survive disruptions to their emotional equilibrium, whether large or small. As noted at the outset, the ability to regulate emotion is known to depend on interactions between (often lateral but also medial) prefrontal systems that implement domain general cognitive processes and (typically subcortical) systems that trigger emotional responses. To date, only 5 imaging studies have investigated regulation training [22,35,43,45,52 see Table 2]. All report findings consistent with the idea that training can either alter the effectiveness/efficiency with which prefrontal systems are engaged [45,53], reduce the responsivity or affect triggering systems [22,35] or change the way these regions communicate [35].

A second factor concerns the specifics of the training regime. In theory, differences in the frequency and timing of training should impact success (as they are known to impact learning and memory, in general), although such factors have yet to be investigated systematically. It appears, however, that training may be more effective when it includes emotional information/stimuli – which is always the case for direct training, but is optionally the case with indirect training (e.g. practicing holding in mind emotions vs. neutral information to train WM [44,45]). In addition, training might be most effective when it titrates task parameters so as to be moderately difficult, perhaps because this more effectively engages attentional, motivational and learning systems [13,18]. Similarly, training conducted in the lab/clinic is usually more successful than home-based training, possibly because lab participants are more engaged in the task and less distracted [13]. Moreover, training that targets more than one process (e.g., selective attention & WM [61]) can be more effective than interventions that target only one component, although they are less suitable for assessing the specific mechanisms that drive training success. Situational factors, such as current stress, may also interact with training effectiveness [62].

Future research should examine how the interaction between different factors determines training success. While more research is needed to confirm this, we suggest that training effectiveness is dependent on the fit between the individual (their life history, genes, etc.), the emotions being targeted by training, and the strategy being trained [5]: Training may be more successful when it targets person/disorder-specific deficits or biases. For instance, attention deployment training (e.g. ABM) should be more effective for anxious individuals as it presumably targets their bias to attend to threat-related information. Individuals prone to depression and ruminative thinking may benefit more from training that teaches them to ignore irrelevant negative thoughts, which can be done by enhancing their reappraisal skill or improving their WM or selective attention abilities [32,34,40,63,64]. And response inhibition training may be beneficial mainly for individuals suffering from an inability to suppress unwanted behaviors such as compulsive eating and substance use [56–58].

In terms of training effectiveness and training ability to create long-lasting changes in people lives, training work may benefit from knowledge gained from more developed fields such as the study of learning and memory. Learning and memory are modulated by internal and external factors [65] such as incentives [66], arousal [67] and attentional processes [68]. As such, we postulate that training may benefit from adding incentives during training, as well as from manipulating attention or arousal states that may increase participants' engagement in the training task.

Another goal for future work concerns the way in which we measure training success. Some outcome measures, such as self-report questionnaires assessing global levels of anxiety and depression symptoms, may lack the sensitivity to detect training effects. Measures that are more specific may be more sensitive, such as using lab-based tasks to assess the efficacy in which one implements specific emotion regulation strategies (like reappraisal), or self-report measures of specific types of thinking or emotion – like ruminative thinking or worry [69].

The challenge for future work, therefore, is to systematically explore the interactions between specific training parameters, emotional responses and individual characteristics [5]. New discoveries in this gradually-evolving field are expected to provide new insights into the mechanisms underlying the full range of human emotion – from everyday ups and downs to profound threats to well-being and survival – paving the way for the ultimate development of person-specific interventions.

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Highlights

- Learning to be better regulators is essential for survival
- Training impacts the neural circuits supporting emotion regulation
- Training may be more successful when it is tailored for an individual and their situation

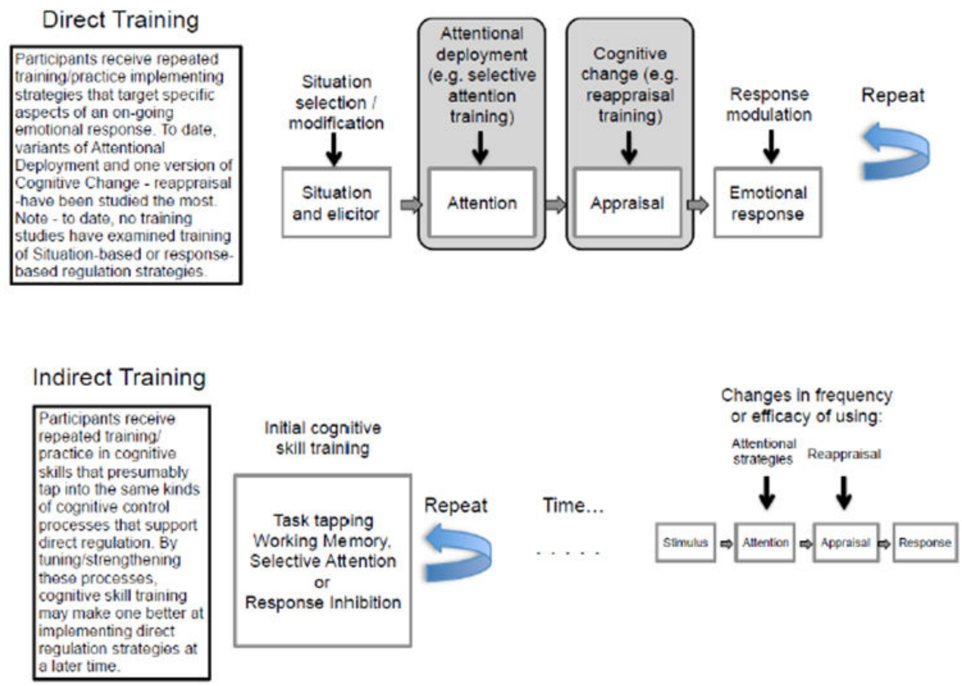

Fig 1.

Illustration of the two training approaches. Direct Training includes strategies that have direct impact on current emotional responses. Indirect Training includes training tasks the enhance core cognitive control abilities.

Table 1.

Behavioral studies that assessed changes in emotion reactivity, mood, depression/anxiety symptoms or other behavioral outcomes following training.

Study	Sample	Training and control tasks	Training stimuli	Trained function	Training length	Outcome measures/transfer tasks	Conclusion
ABM							
Meta-analyses and reviews: Bar-Haim et al., Psychological Bulletin, 2007; Cristea et al., The British Journal of Psychiatry, 2015; Hakamata et al., Biological Psychiatry, 2010; Heeren et al., Frontiers in Human Neurosicence, 2013; Kuckertz et al., Current Psychiatry Reports, 2015; Linetzky et al., Depression and Anxiety, 2015; Mogg & Bradley, Behaviour Research and Therapy, 2016; Mogg & Bradley, Trends in Cognitive Sciences, 2018; Mogoase et al, Journal of Clinical Psychology, 2014; Shechner & Bar-Haim, Current Directions in Psychological Science, 2016							
Reappraisal							
Denny & Ochsner, Emotion, 2014	N = 99 (mean age = 23, 67 female)	Reappraisal (distancing) vs reappraisal (reinterpretation) vs passive viewing	Emotional (IAPS pictures)	Reappraisal	Four sessions spread 2–5 days apart	Self-reported emotion and perceived stress	Reappraisal can be trained. Distancing training can be generalized and result in a reduction in perceived stress.
Dore et al., Personality and Social Psychology Bulletin, 2017	N = 82 (age range 18–35, 62 female)	Reappraisal (receiving and providing) vs expressive writing	Emotional (personal stressful situations)	Reappraisal	3 weeks	Questionnaires assessing depression and habitual reappraisal; text analysis (LIWC)	Providing reappraisal support decreased depression via increase in reappraisal. Perspective-taking (use of second-person pronouns) enhanced training-related benefits
Finkel et al., Psychological Science, 2013	N = 120 married couples (mean age = 40 years)	Reappraisal vs noreappraisal	Emotional (marriage conflict)	Reappraisal	6 times over two years	Self-report measures of marital quality	Reappraisal intervention that targets marriage conflicts protects them against declines in marital quality over time
Halperin et al., Psychological Science, 2013	Experiment 1: N = 39 (mean age = 24.51, 13 female) Experiment 2: N = 60 (mean age = 17.94, 36 female)	Reappraisal vs control (passive watching)	Emotional (anger inducing pictures)	Reappraisal	Single session	Exp 1:Self-report anger and rage toward out-group members following a 4-minute anger inducing presentation, attitudes toward conciliatory and aggressive political policies Exp 2: self-report emotional and political reactions	The effect of reappraisal training on support for conciliatory policies was mediated by self-report anger (Exp 1) and negative emotions (Exp 2)

Study	Sample	Training and control tasks	Training stimuli	Trained function	Training length	Outcome measures/transfer tasks	Conclusion
Kivity & Huppert, Journal of Consulting and Clinical Psychology, 2016	N = 124	Reappraisal-high social anxiety vs monitoring-high social anxiety vs monitoring-low social anxiety	Emotional (personal stressful social situations)	Reappraisal	One week	Daily self-report following reappraisal, questionnaires assessing social anxiety and habitual emotion regulation	Reappraisal training can be beneficial among individuals with social anxiety
Morris et al., Journal of Medical Internet Research, 2015	N = 166 (age range 18–35)	Reappraisal (receiving and providing) vs expressive writing	Emotional (personal stressful situations)	Reappraisal	3 weeks	Questionnaires assessing depression, reappraisal, and preservative thinking	Social reappraisal training is helpful for depressed individuals and for low reappraisers
Ng and Diener, Journal of Social and Clinical Psychology, 2013	N=101 (students)	Reappraisal vs control vs focusing	Emotional (personal negative event)	Reappraisal	One week	Daily diary measures (negative affect after writing event/reappraising the event/focusing on the event)	Individuals (including those with high neuroticism) could effectively use reappraisal to reduce their negative emotions.
Raio et al., PNAS, 2013	N = 78 (mean age = 23.2, 39 females)	Cognitive regulation training (includes reappraisal)	Emotional (conditioned stimuli)	Reappraisal	Single session	Fear conditioning task following stress manipulation (CPT) or following no-stress manipulation	Acute stress impairs the ability of reappraisal to control fear responses.
Woud et al., Emotion, 2012	N = 74 (mean age = 22.47, 37 female)	Non-explicit reappraisal - positive vs negative sentence completion task	Emotional (sentences)	Non-explicit reappraisal	Single session	Intrusive memories on a stressful film presented before the training	Non-explicit reappraisal training can prevent intrusive memories and may have implications for the treatment of PTSD
Woud et al., Journal of Behavior Therapy and Experimental Psychiatry, 2013	N = 47 (mean age = 29.06, 31 female).	Non-explicit reappraisal - positive vs negative sentence completion task	Emotional (sentences)	Non-explicit reappraisal	Single session	Intrusive memories on a stressful film presented after the training	Non-explicit reappraisal training can prevent trauma-related symptomatology.
Selective Attention							
Cohen et al., Clinical Psychological Science, 2017	N = 91 (mean age = 24, 58 females)	80% of negative stimuli preceded by incongruent trial vs 20% of negative stimuli preceded by incongruent trial	Emotional (IAPS pictures)	Selective attention (Flanker task)	Single session	State reappraisal following the recall of a personal upsetting event; negative mood following reappraisal induction	Selective attention training increased the propensity to use reappraisal as well as the effectiveness of instructed reappraisal as measured by reduction in negative mood

Study	Sample	Training and control tasks	Training stimuli	Trained function	Training length	Outcome measures/transfer tasks	Conclusion
Cohen et al., Clinical Psychological Science, 2015	N = 68 (mean age = 24, 42 female)	90% of negative stimuli preceded by incongruent trial vs 10% of negative stimuli preceded by incongruent trial	Emotional (IAPS pictures)	Selective attention (Flanker task)	Single session	Mood, state rumination following the recall of a personal upsetting event	Selective attention training can reduce ruminative thinking
Working memory							
Bomyea & Amir, Cognitive Therapy and Research, 2011	N = 50 (mean age = 19, 60% female)	Rspan with high proactive interference vs Rspan with low proactive interference	Non-emotional (words)	Working memory	Single-session training	Anxiety, depression, trauma history, PTSD, working memory capacity, thought suppression, memory	WM training increases the ability to inhibit unwanted thoughts
Brunoni et al., Journal of Affective Disorders, 2014	N = 37 (age 18–65)	PASAT vs PASAT + DLPFC tDCS	Non-emotional (digits)	Working memory	10 sessions over 4 weeks.	Depression	tDCS augment the clinical effects of CCT in older individuals, particularly in those who improve in the training task
Course -Choi et al., Behaviour Research and Therapy, 2017	N = 60 (mean age = 29, 15 male)	Dual n-back task vs dual n-back + mindfulness vs 1-back task (control)	Non-emotional (letters)	Working memory	Once a day for 7 consecutive days	Anxiety, resilience, rumination, positive and negative affect	WM training can improve attentional control and resilience, and reduce worry
de Voogd et al., Australian Journal of Psychology, 2016	Adolescents (N=168, 11–18 year olds)	Emotion working memory (chessboard task) vs control training (nonadaptive chessboard task)	Emotional (angry, fearful, or sad faces)	Working memory	Twice a week for 4 weeks	Questionnaires assessing self-esteem, anxiety, depression, perseverative thinking, test anxiety, social-emotional and behavioral problems, stressful life events	Findings are inconclusive, more research is needed to examine the effects on emotional WM training
Hitchcock & Westwell, the Journal of Child Psychology and Psychiatry, 2016	N = 148 primary school children (mean age = 12; 80 females)	Cogmed Working Memory Training vs nonadaptive Cogmed WM training	Non-emotional (verbal and visual-spatial)	Working memory	Every school day for 5 weeks	Reading comprehension, mathematical ability, attention, WM, questionnaire assessing social, emotional and behavioral difficulties	No support was provided for a positive impact of WM training on everyday school functioning
Hoorelbeke et al., Behaviour Research and Therapy, 2015	N = 47 high ruminators (37 for the follow-up results; 4 males).	CCT (adaptive PASAT) vs VST (Visual search task)	Non-emotional (letters)	Working memory	10 sessions over a period of 14 days, maximum one session a day	WM (O-Span), stress induction that followed a mood assessment. Questionnaires assessing depression, rumination, and positive and negative affect	Working memory training can increase resilience to depression in an at-risk population
Hoorelbeke et al., Emotion, 2016	N = 61 (mean age = 21; 9 males)	CCT (adaptive PASAT) vs PASAT without the WM component	Non-emotional (letters)	Working memory	10 sessions over a period of 14 days, maximum one session a day	Dual n-back task, affect following a reappraisal task, affective state during a period of 7 days following training	Cognitive control plays a stronger role in maladaptive emotion regulation compared with

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Study	Sample	Training and control tasks	Training stimuli	Trained function	Training length	Outcome measures/transfer tasks	Conclusion
							adaptive emotion regulation
Iacoviello et al., Depression and Anxiety, 2014	N=21, with MDD in current episode (age range ages 18 – 55	Emotional n-back task (EMFT) vs neutral n-back task	Emotional (faces)	Working memory	8 sessions over 4 weeks	Questionnaires assessing rumination, short-term memory for positive and negative self-descriptors, attention and working memory, and depression symptoms	Emotional WM training may serve as an effective interventions in MDD
Onraedt & Koster, PLOS ONE, 2014	Experiment 1: N=72 (mean age = 20; 63 females); Experiment 2:	Exp1: Dual n-back vs single 1-back vs no training. Exp2: Dual n-back vs single 1-back	Non-emotional (letters)	Working memory	6 days	Exp1: Running memory Span Task (R-Span), Internal Shift Task (IST), questionnaires assessing depression and rumination; Exp2: R-Span, O-Span, emotional 2-back task, depression, rumination, positive and negative metacognitive beliefs about rumination	No evidence for transfer effects of a six day non-emotional dual n-back training on emotional and non-emotional working memory performance, and measures of rumination and depressive symptoms
Sari et al., Biological Psychology, 2016	N = 33 high anxious, low attentional control (mean age = 25, 8 male)	Dual n-back training vs dual 1-back training	Non-emotional (letters)	Working memory	Once a day for 3 weeks	Anxiety and worry questionnaires, brain activity (rest EEG), flanker task, antisaccade task,	Working memory training can improve attention control deficits typically associated with anxiety
Schweizer et al., PLOS ONE, 2011	N=45 (mean age = 25; 27 female)	Emotional dual n-back task vs neutral dual n-back task vs feature match task	Emotional (faces and words)	Working memory	20 days (four five-day training blocks followed by two rest days)	Cognitive transfer tasks (Gf and WM); affective transfer task (emotional Stroop)	Affective WM training, but not non-emotional WM training, can improve emotional behavior
Vanderhasselt et al., Progress in NeuroPsychopharmacology and Biological Psychiatry, 2015	N = 37 MDD patients	PASAT vs PASAT + DLPFC tDCS	Non-emotional (digits)	Working memory	5 sessions a week, for two weeks	Rumination, depression	WM training reduces depressive symptoms
Wanmaker et al., Depression & Anxiety, 2014	N=61 dysphoric students (Mean age = 21, 23% male).	Adaptive vs non-adaptive WM task	Non-emotional (squares, letters, numbers, colored figures)	Working memory	3 times a week over 3 weeks	Depression, anxiety, rumination, working memory (Spanboard Task)	WM training may be ineffective for depression, anxiety and rumination
Xiu et al., Physiology & Behavior, 2016	N=40 (mean age = 22, 7 male).	Running memory task vs no training	Non-emotional (letters)	Working memory	Each day for 20 days	Heart rate variability (HF-HRV) during an emotion regulation task	Working memory training could

Study	Sample	Training and control tasks	Training stimuli	Trained function	Training length	Outcome measures/transfer tasks	Conclusion
							contribute to emotion regulation
Response inhibition							
Reviews and meta-analyses of response inhibition training in addiction and food consumption: Adams et al., Appetite, 2017; Allom et al., Health psychology review, 2016; Goldstein et al., American Journal of Psychiatry, 2002; Jones et al., Appetite, 2016; Smith et al., Drug and Alcohol, 2017.							
Training involving more than one component							
Sanchez et al., Emotion, 2016	N = 40 (18–29 years, 33 female)	Reappraisal (attention focus on positive words) vs unscrambeling sentences	Emotional (scrambled sentences)	Reappraisal + attention toward positive information	Single session (8 blocks of 6 randomly presented sentences)	Attention bias (fixation time on positive and negative stimuli, assessed using eye-tracking). Emotional dot-probe task, emotion regulation task.	Training attentional control influence the use of reappraisal strategies and its impact on negative emotions
Calkins et al., Behavioural and Cognitive Psychotherapy, 2015	N = 48 with high depression scores.	Cognitive Control Training (CCT; PASAT + ACI) vs Peripheral Vision Training (PVT)	Non-emotional (numbers, sounds)	Selective attention + WM	3 sessions within a 2-week period.	Mood, depression	CCT training is effective in altering depressed mood
Siegle et al., Cognitive Therapy and Research, 2007	N = 31 depressed patients (age range 18–55)	Treatment as usual + Cognitive Control Training (CCT; PASAT + ACI) vs treatment as usual	Non-emotional (numbers, sounds)	Selective attention + WM	6 sessions over 2-weeks	Depression, rumination, brain activity (fMRI) and pupil dilation during a digit sorting task and emotional task	CCT can be an effective intervention for depression
segrave et al., Brain Stimulation, 2014	N = 27 depressed adults (mean age = 40, 10 female).	tDCS + CCT (WAT + PASAT), sham tDCS + CCT or tDCS + sham CCT	Non-emotional (digits and sounds)	Selective attention + WM	5 consecutive week days	Depression, 2-back emotional WM task	Antidepressant outcomes from anodal DLPFC tDCS may be potentiated via delivery of concurrent CCT
Moshier et al., International Journal of Cognitive Therapy, 2015	N = 69 (age range 18 – 65) depressed or euthymic mood	CCT depressed vs CCT euthymic vs Control depressed vs. Control euthymic	Non-emotional (numbers, sounds)	Selective attention + WM	3 visits across a two-week period	Meta-memory and accuracy following repeated checking	Cognitive Control Training is not effective in reducing the memory distrust following repeated checking

Table 2.

Neuroimaging studies that examined training-induced changes in brain activity and connectivity.

Study	Sample	Training and control tasks	Training stimuli	Trained function	Training length	Outcome measures/transfer tasks	Conclusion
Reappraisal							
Denny et al., Psychological Science, 2015	N=17(mean age= 24, 12 female)	Repeated reappraisal vs single reappraisal (within-subjects design)	Emotional (IAPS pictures)	Reappraisal	3 sessions over 9 days	Self-report emotion; brain activity (fMRI)	Amygdala responses remained attenuated for images that had been repeatedly reappraised. Prefrontal activation was not selectively elevated for repeatedly reappraised images and was not related to long-term attenuation of amygdala responses. The authors concluded that reappraisal training can exert long-lasting effects on emotional responses
Selective attention							
Cohen et al. NeuroImage, 2016	N = 26 (mean age = 25, 14 female)	Flanker task with 80% incongruent trials vs Flanker task with 20% incongruent trials	Non-emotional (arrows)	Selective attention	6 days, 3 times a day (18 sessions)	Brain activity and connectivity (task and rest fMRI); RT in a forced-choice discrimination task following negative vs neutral pictures	The training led to reduced amygdala activity and this reduction predicted behavioral (RT) changes. The training strengthened the connectivity between the amygdala and the right inferior frontal gyrus (rIFG). The authors concluded that selective attention training can reduce emotional reactions
Working memory							
Li et al., Scientific Reports, 2016	N=34 individuals with high/low social anhedonia	Dual n-back task	Non-emotional (square location)	Working memory	20 sessions (5 times a week over 4 weeks)	Brain activity (fMRI) during an affective incentive delay task (AID), Monetary incentive delay (MID); Letter-Number-Span Task (LNS), self-report measures of emotional feelings and emotional expressivity,	WM training enhanced brain activations among individuals with social anhedonia in the ACC, the dorsal striatum and the precuneus for the AID task, and the dorsolateral prefrontal cortex and parietal regions for the MID task during reward anticipation, this may have implications to the treatment of schizophrenia
Schweizer et al., The Journal of Neurosience, 2013	N= 34 (mean age= 23, 20 female);	emotional dual n-back task vs feature match task	emotional (faces and words)	working memory	Each day for 20 days	Brain activity (fMRI); Emotion regulation task	Training-related benefits were associated with greater activity in frontoparietal regions. The authors concluded that emotional WM training improves affective control
Response inhibition							
Beauchamp et al., SCAN, 2016	N = 60, 33 females, aged 18–30 years.	Stop-signal task (SST) vs forced-	Non-emotional (arrows)	Response inhibition	10 sessions across 3 weeks	Brain activity (fMRI) and self-report rating to negative pictures during reappraisal vs look	The training group showed reduced activation in the left inferior frontal gyrus (lIFG) and supramarginal

Study	Sample	Training and control tasks	Training stimuli	Trained function	Training length	Outcome measures/transfer tasks	Conclusion
		choice reaction time task					gyrus during the emotion regulation task. The authors conclude that inhibitory control training may generalize to an untrained emotion regulation task