From surviving to thriving in the face of threats: the emerging science of emotion regulation training
Noga Cohen¹,²,³ and Kevin N Ochsner¹

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.

Addresses
¹ Department of Psychology, Columbia University, New York, NY, USA
² Department of Special Education, University of Haifa, Haifa, Israel
³ Edmond J. Safra Brain Research Center for the Study of Learning Disabilities, University of Haifa, Haifa, Israel

Corresponding authors: Cohen, Noga (noga.cohen@edu.haifa.ac.il), Ochsner, Kevin N (ko2132@columbia.edu)

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 [4,5,6] 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) versus at home (less effective) [13**,14,15]. 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 whether 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**,14,15,16*,17,18,19*].

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**,22**,23,24] 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 interpersonal 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).
### Table 1

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

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample</th>
<th>Training and control tasks</th>
<th>Training stimuli</th>
<th>Trained function</th>
<th>Training length</th>
<th>Outcome measures/transfer tasks</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reappraisal</td>
<td>Denny and Ochsner, Emotion [21]**</td>
<td>N = 99 (mean age = 23, 67 female)</td>
<td>Reappraisal (distancing) versus reappraisal (reinterpretation) versus passive viewing</td>
<td>Reappraisal</td>
<td>Four sessions spread 2–5 days apart</td>
<td>Self-reported emotion and perceived stress</td>
<td>Reappraisal can be trained. Distancing training can be generalized and result in a reduction in perceived stress. Providing reappraisal support decreased depression via increase in reappraisal. Perspective-taking (use of second-person pronouns) enhanced training-related benefits.</td>
</tr>
<tr>
<td></td>
<td>Finkel et al., Psychological Science [27]</td>
<td>N = 120 married couples (mean age = 40 years)</td>
<td>Reappraisal versus no-reappraisal</td>
<td>Emotional (marriage conflict)</td>
<td>Reappraisal</td>
<td>Six times over two years</td>
<td>Reappraisal intervention that targets marriage conflicts protects against declines in marital quality over time.</td>
</tr>
<tr>
<td></td>
<td>Halperin et al., Psychological Science [28]</td>
<td>Experiment 1: N = 39 (mean age = 25, 13 female)</td>
<td>Reappraisal versus control (passive watching)</td>
<td>Emotional (anger inducing pictures)</td>
<td>Reappraisal</td>
<td>Single session</td>
<td>The effect of reappraisal training on support for conciliatory policies was mediated by self-report anger (Exp 1) and negative emotions (Exp 2).</td>
</tr>
<tr>
<td></td>
<td>Morris et al., Journal of Medical Internet Research [31]**</td>
<td>N = 166 (age range 18–35, 119 female)</td>
<td>Reappraisal (receiving and providing) versus expressive writing</td>
<td>Emotional (personal stressful situations)</td>
<td>Reappraisal</td>
<td>Three weeks</td>
<td>Social reappraisal training is helpful for depressed individuals and for low reappraisers. Individuals (including those with high neuroticism) could effectively use reappraisal to reduce their negative emotions.</td>
</tr>
<tr>
<td></td>
<td>Ng and Diener, Journal of Social and Clinical Psychology [26]</td>
<td>N = 82 (students, 55 female)</td>
<td>Reappraisal versus control versus focusing</td>
<td>Emotional (personal negative event)</td>
<td>Reappraisal</td>
<td>One week</td>
<td>Daily diary measures (negative affect after writing event/ reappraising the event/focusing on the event)</td>
</tr>
</tbody>
</table>
Table 1 (Continued)

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample</th>
<th>Training and control tasks</th>
<th>Training stimuli function</th>
<th>Training length</th>
<th>Outcome measures/transfer tasks</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raio et al., PNAS</strong> [62]</td>
<td>N = 78 (mean age = 23, 39 females)</td>
<td>Cognitive regulation training (includes reappraisal)</td>
<td>Emotional (conditioned stimuli)</td>
<td>Single session</td>
<td>Fear conditioning task following stress manipulation (CPT) or following no-stress manipulation</td>
<td>Acute stress impairs the ability of reappraisal to control fear responses Non-explicit reappraisal training can prevent intrusive memories and may have implications for the treatment of PTSD Non-explicit reappraisal training can prevent trauma-related symptomatology</td>
</tr>
<tr>
<td><strong>Woud et al., Emotion</strong> [24]</td>
<td>N = 74 (mean age = 23, 37 female)</td>
<td>Non-explicit reappraisal — positive versus negative sentence completion task</td>
<td>Emotional (sentences)</td>
<td>Single session</td>
<td>Intrusive memories on a stressful film presented before the training</td>
<td></td>
</tr>
<tr>
<td><strong>Woud et al., Journal of Behavior Therapy and Experimental Psychiatry</strong> [23]</td>
<td>N = 47 (mean age = 29, 31 female)</td>
<td>Non-explicit reappraisal — positive versus negative sentence completion task</td>
<td>Emotional (sentences)</td>
<td>Single session</td>
<td>Intrusive memories on a stressful film presented after the training</td>
<td></td>
</tr>
<tr>
<td><strong>Selective Attention</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cohen et al., Clinical Psychological Science [34**]</td>
<td>N = 91 (mean age = 24, 58 female)</td>
<td>80% of negative stimuli preceded by an incongruent stimulus versus 20% of negative stimuli preceded by an incongruent stimulus</td>
<td>Emotional (IAPS pictures)</td>
<td>Single session</td>
<td>State reappraisal following the recall of a personal upsetting event; negative mood following reappraisal induction</td>
<td>Selective attention training increases the propensity to use reappraisal as well as the effectiveness of instructed reappraisal as measured by reduction in negative mood Selective attention training reduces ruminative thinking</td>
</tr>
<tr>
<td>Cohen et al., Clinical Psychological Science [32**]</td>
<td>N = 68 (mean age = 24, 42 female)</td>
<td>90% of negative stimuli preceded by an incongruent stimulus versus 10% of negative stimuli preceded by an incongruent stimulus</td>
<td>Emotional (IAPS pictures)</td>
<td>Single session</td>
<td>Mood, state rumination following the recall of a personal upsetting event</td>
<td></td>
</tr>
<tr>
<td><strong>Working memory</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bomyea and Amir, Cognitive Therapy and Research [38]</td>
<td>N = 40 (mean age = 19, 59% female)</td>
<td>Rspan with high proactive interference versus Rspan with low proactive interference</td>
<td>Non-emotional (words)</td>
<td>Single-session training</td>
<td>Anxiety, depression, trauma history, PTSD, working memory capacity, thought suppression, memory</td>
<td>WM training increases the ability to inhibit unwanted thoughts tDCS augments the clinical effects of CCT in older individuals, particularly in those who improve in the training task WM training can improve attentional control and resilience, and reduce worry</td>
</tr>
<tr>
<td>Brunoni et al., Journal of Affective Disorders [70]</td>
<td>N = 37 depressed patients (age range 18–65: 11 females)</td>
<td>PASAT versus PASAT + DLPFC tDCS</td>
<td>Non-emotional (digits)</td>
<td>10 sessions over 4 weeks.</td>
<td>Depression</td>
<td></td>
</tr>
<tr>
<td>Course-Choi et al., Behaviour Research and Therapy [37]</td>
<td>N = 60 high worriers (mean age = 29, 15 male)</td>
<td>Dual n-back task versus dual n-back + mindfulness versus 1-back task (control)</td>
<td>Non-emotional (letters)</td>
<td>Working memory</td>
<td>Anxiety, resilience, ruminative, positive and negative affect</td>
<td></td>
</tr>
<tr>
<td>de Voogd et al., Australian Journal of Psychology [49]</td>
<td>N = 168 adolescents (mean age = 14, 60.1% female)</td>
<td>Emotion working memory (chessboard task) versus control training (nonadaptive chessboard task)</td>
<td>Emotional (angry, fearful, or sad faces)</td>
<td>Working memory</td>
<td>Self-esteem, anxiety, depression, perseverative thinking, test anxiety, social-emotional and behavioral problems, stressful life events</td>
<td>Findings are inconclusive, more research is needed to examine the effects on emotional WM training</td>
</tr>
<tr>
<td>Study</td>
<td>Sample</td>
<td>Training and control tasks</td>
<td>Training stimuli</td>
<td>Trained function</td>
<td>Training length</td>
<td>Outcome measures/transfer tasks</td>
</tr>
<tr>
<td>-------</td>
<td>--------</td>
<td>-----------------------------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>----------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>Hitchcock and Westwell, the Journal of Child Psychology and Psychiatry [48]</td>
<td>N = 148 primary school children (mean age = 12, 80 female)</td>
<td>Cogmed Working Memory Training versus nonadaptive Cogmed WM training</td>
<td>Non-emotional (verbal and visual-spatial)</td>
<td>Working memory</td>
<td>Every school day for five weeks</td>
<td>Reading comprehension, mathematical ability, attention, WM, questionnaire assessing social, emotional and behavioral difficulties</td>
</tr>
<tr>
<td>Hoorelbeke et al., Behaviour Research and Therapy [39]</td>
<td>N = 47 high ruminators (37 for the follow-up results, mean age = 21, 4 male)</td>
<td>CCT (adaptive PASAT) versus VST (Visual search task)</td>
<td>Non-emotional (letters)</td>
<td>Working memory</td>
<td>10 sessions over a period of 14 days, maximum one session a day</td>
<td>WM (O-Span), stress induction that followed a mood assessment, questionnaires assessing depression, rumination, and positive and negative affect</td>
</tr>
<tr>
<td>Iacoviello et al., Depression and Anxiety [40]</td>
<td>N = 61 (mean age = 21, 9 male)</td>
<td>Emotional n-back task (EMFT) versus neutral n-back task</td>
<td>Emotional (faces)</td>
<td>Working memory</td>
<td>8 sessions over 4 weeks</td>
<td>Rumination, short-term memory for positive and negative self-descriptors, attention and working memory, and depression symptoms</td>
</tr>
<tr>
<td>Onraedt and Koster, PLoS One [50]</td>
<td>Experiment 1: N = 72 (mean age = 20, 63 female); Experiment 2: N = 45 (mean age = 21, 7 female)</td>
<td>Exp1: Dual n-back versus single 1-back versus no training. Exp2: Dual n-back versus single 1-back</td>
<td>Non-emotional (letters)</td>
<td>Working memory</td>
<td>6 days</td>
<td>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</td>
</tr>
<tr>
<td>Sari et al., Biological Psychology [47]</td>
<td>N = 33 high anxious, low attentional control (mean age = 25, 8 male)</td>
<td>Dual n-back training versus dual 1-back training</td>
<td>Non-emotional (letters)</td>
<td>Working memory</td>
<td>Once a day for 3 weeks</td>
<td>Anxiety and worry questionnaires, brain activity (rest EEG), flanker task, antisaccade task</td>
</tr>
<tr>
<td>Schweizer et al., PLoS One [44]</td>
<td>N = 45 (mean age = 25, 28 female)</td>
<td>Emotional dual n-back task versus neutral dual n-back task versus feature match task</td>
<td>Emotional (faces and words)</td>
<td>Working memory</td>
<td>20 days (four five-day training blocks followed by two rest days)</td>
<td>Cognitive transfer tasks (GF and WM); affective transfer task (emotional Stroop)</td>
</tr>
<tr>
<td>Vanderhasselt et al., Progress in Neuro-WM training reduces depressive symptoms</td>
<td>N = 33 MDD patients (mean age= 44, 73% female)</td>
<td>PASAT versus PASAT + DLPFC tDCS</td>
<td>Non-emotional (digits)</td>
<td>Working memory</td>
<td>Five sessions a week, for two weeks</td>
<td>Rumination, depression</td>
</tr>
</tbody>
</table>

Table 1 (Continued)
### Table 1 (Continued)

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample Description</th>
<th>Training and control tasks</th>
<th>Training stimuli</th>
<th>Trained function</th>
<th>Training length</th>
<th>Outcome measures/transfer tasks</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wannmaker et al., Depression &amp; Anxiety [42]</td>
<td>N = 61 dysphoric students (mean age = 21, 23% male)</td>
<td>Adaptive versus non-adaptive WM task</td>
<td>Non-emotional (squares, letters, numbers, colored figures)</td>
<td>Working memory</td>
<td>3 times a week over 3 weeks</td>
<td>Depression, anxiety, rumination, working memory (Spanboard Task)</td>
<td>WM training may be ineffective for depression, anxiety and rumination</td>
</tr>
<tr>
<td>Xiu et al., Physiology &amp; Behavior [36]</td>
<td>N = 40 (mean age = 22, 7 male)</td>
<td>Running memory task versus no training</td>
<td>Non-emotional (letters)</td>
<td>Working memory</td>
<td>Each day for 20 days</td>
<td>Heart rate variability (HF-HRV) during an emotion regulation task</td>
<td>Working memory training could contribute to emotion regulation</td>
</tr>
</tbody>
</table>

#### Response inhibition

Reviews and meta-analyses of response inhibition training in addiction and food consumption: Adams et al., Appetite [57]; Allom et al., Health Psychology Review [58]; Goldstein et al., American Journal of Psychiatry [51]; Jones et al., Appetite, [56]; Smith et al., Drug and Alcohol Dependence, [52]

#### Training involving more than one component

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample Description</th>
<th>Training and control tasks</th>
<th>Training stimuli</th>
<th>Trained function</th>
<th>Training length</th>
<th>Outcome measures/transfer tasks</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sanchez et al., Emotion [71]</td>
<td>N = 40 (age range 18–29, 33 female)</td>
<td>Reappraisal (attention focus on positive words versus unscrambling sentences)</td>
<td>Emotional (scrambled sentences)</td>
<td>Reappraisal + attention towards positive information</td>
<td>Single session (eight blocks of six randomly presented sentences)</td>
<td>Attention bias (fixation time on positive and negative stimuli, assessed using eye-tracking), emotional dot-probe task, emotion regulation task</td>
<td>Training attentional control influence the use of reappraisal strategies and its impact on negative emotions</td>
</tr>
<tr>
<td>Calkins et al., Behavioural and Cognitive Psychotherapy [61]</td>
<td>N = 48 depressed individuals (age range = 18–68, 26 female)</td>
<td>Cognitive Control Training (CCT; PASAT + ACI) versus Peripheral Vision Training (PVT)</td>
<td>Non-emotional (numbers, sounds)</td>
<td>Selective attention + WM</td>
<td>3 sessions within a 2-week period</td>
<td>Mood, depression</td>
<td>CCT training is effective in altering depressed mood</td>
</tr>
<tr>
<td>Siegle et al., Cognitive Therapy and Research [72]</td>
<td>N = 31 depressed patients (age range 18–55)</td>
<td>Treatment as usual + Cognitive Control Training (CCT; PASAT + ACI) versus treatment as usual</td>
<td>Non-emotional (numbers, sounds)</td>
<td>Selective attention + WM</td>
<td>6 sessions over two weeks</td>
<td>Depression, rumination, brain activity (fMRI) and pupil dilation during a digit sorting task and an emotional task</td>
<td>CCT can be an effective intervention for depression</td>
</tr>
<tr>
<td>Segrave et al., Brain Stimulation [73]</td>
<td>N = 27 depressed adults (mean age = 40, 10 female)</td>
<td>Antidepressant outcomes from anodal DLPFC tDCS may be potentiated via delivery of concurrent CCT</td>
<td>tDCS + CCT (WAT + PASAT), sham tDCS + CCT or tDCS + sham CCT</td>
<td>Non-emotional (digits and sounds)</td>
<td>Selective attention + WM</td>
<td>Depression, rumination, brain activity (fMRI) and pupil dilation during a digit sorting task and an emotional task</td>
<td>CCT can be an effective intervention for depression</td>
</tr>
<tr>
<td>Depression, 2-back emotional WM task</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moshier et al., International Journal of Cognitive Therapy [74]</td>
<td>N = 69 individuals with depressed or euthymic mood (age range 18–85, 43 female)</td>
<td>CCT depressed versus CCT euthymic versus Control depressed versus Control euthymic</td>
<td>Non-emotional (numbers, sounds)</td>
<td>Selective attention + WM</td>
<td>Three visits across a two-week period</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meta-memory and accuracy following repeated checking</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>Sample</td>
<td>Training and control tasks</td>
<td>Training stimuli</td>
<td>Trained function</td>
<td>Training length</td>
<td>Outcome measures/transfer tasks</td>
<td>Conclusion</td>
</tr>
<tr>
<td>-------</td>
<td>--------</td>
<td>-----------------------------</td>
<td>------------------</td>
<td>------------------</td>
<td>----------------</td>
<td>-------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td><strong>Reappraisal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Denny et al., Psychological Science [22**]</td>
<td>N = 17 (mean age = 24, 12 female)</td>
<td>Repeated reappraisal versus single reappraisal (within-subjects design)</td>
<td>Emotional (IAPS pictures)</td>
<td>Reappraisal</td>
<td>3 sessions over 9 days</td>
<td>Self-report emotion, brain activity (fMRI)</td>
<td>Amygdala response 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 conclude that reappraisal training can exert long-lasting effects on emotional responses</td>
</tr>
<tr>
<td><strong>Selective attention</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cohen et al. NeuroImage [35**]</td>
<td>N = 26 (mean age = 26, 14 female)</td>
<td>Flanker task with 80% incongruent trials versus Flanker task with 20% incongruent trials</td>
<td>Non-emotional (arrows)</td>
<td>Selective attention</td>
<td>6 days, 3 times a day (18 sessions)</td>
<td>Brain activity and connectivity (task and rest fMRI), RT in a forced-choice discrimination task following negative versus neutral pictures</td>
<td>The training 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 conclude that selective attention training can reduce emotional reactions</td>
</tr>
<tr>
<td><strong>Working memory</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Li et al., Scientific Reports [43**]</td>
<td>N = 34 college students with high/low social anhedonia</td>
<td>Dual n-back task</td>
<td>Non-emotional (square location)</td>
<td>Working memory</td>
<td>20 sessions (5 times a week over 4 weeks)</td>
<td>Brain activity (fMRI) during an Affective Ancentive Delay task (AID), Monetary Incentive Delay (MID), Letter-Number-Span Task (LNS), self-report measures of emotional feelings and emotional expressivity Brain activity (fMRI), emotion regulation task</td>
<td>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 for the treatment of schizophrenia. Training-related benefits were associated with greater activity in frontoparietal regions. The authors conclude that emotional WM training improves affective control</td>
</tr>
<tr>
<td>Schweizer et al., The Journal of Neuroscience [45**]</td>
<td>N = 34 (mean age = 23, 20 female)</td>
<td>emotional dual n-back task versus feature match task</td>
<td>emotional (faces and words)</td>
<td>working memory</td>
<td>Each day for 20 days</td>
<td>Brain activity (fMRI), emotion regulation task</td>
<td></td>
</tr>
<tr>
<td><strong>Response inhibition</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beauchamp et al., SCAN [53**]</td>
<td>N = 60 (age range 18-30, 33 female)</td>
<td>Stop-signal task (SST) versus forced-choice reaction time task</td>
<td>Non-emotional (arrows)</td>
<td>Response inhibition</td>
<td>10 sessions across 3 weeks</td>
<td>Brain activity (fMRI) and self-report rating to negative pictures during reappraisal versus look</td>
<td>The training group showed reduced activation in the left inferior frontal gyrus (lIFG) and supramarginal gyrus during the emotion regulation task. The authors conclude that inhibitory control training may generalize to an untrained emotion regulation task</td>
</tr>
</tbody>
</table>
Insight into the mechanisms mediating such effects comes from studies manipulating the nature of training. For example, Denny and 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 reduction in amygdala response to aversive images and an increase in 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 [36–38,39,40–42,43**,44**,45**,46*], while others report either no beneficial or mixed outcomes [47*,48*,49,50].

For example, in two studies Schweizer et al. [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*,57*,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 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 five imaging studies have investigated regulation training [22**,35**,43*,45*,53** 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 versus 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 ruminate
tive 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*,57*,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 ruminate 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.

Conflict of interest statement
Nothing declared.

Acknowledgements
Completion of this manuscript was supported by Fulbright, ISF 61/16, and Israel Council for Higher Education Fellowships awarded to N.C. and grants AG057202 and AG043463 from NIA.

References and recommended reading
Papers of particular interest, published within the period of review, have been highlighted as:

- of special interest
- ** of outstanding interest


A review paper that proposes that any instance of emotion regulation should be examined as an interaction of person, situation and strategy.


A review paper discussing methodological and theoretical issues in ABM paradigms.
From surviving to thriving in the face of threats: the emerging science of emotion regulation training Cohen and Ochsner 153


A review paper suggesting that ABM may be dependent on interactions between salience-driven and goal-directed processes.


A review paper arguing that ABM may be dependent on top-down processes involved in threat-evaluation, orienting and inhibitory control.


A paper showing that reappraisal training results in a reduction in perceived stress.


A neuroimaging paper showing that amygdala responses are attenuated for images that had been repeatedly reappraised during training.


A diary study showing that reappraisal training can be beneficial for individuals with social anxiety.


An online social-regulation training study demonstrating that providing reappraisal support decreases depression via increase in reappraisal.


An online social-regulation training study demonstrating that providing reappraisal support is helpful for depressed individuals and for low reappraisers.


A single-session training study showing that selective attention training reduces ruminative thinking and the association between trait rumination and negative mood.


35. A single-session training study showing that selective attention training increases the propensity to use reappraisal and the effectiveness of instructed reappraisal.


37. A neuroimaging study showing that a six-day selective attention training results in a reduction in amygdala activity in response to unpleasant pictures and increases amygdala-prefrontal connectivity.


A multiple-session WM training study that found reduction in rumination following training.


A neuroimaging study that assessed brain activity following a multiple-session WM training and found increased activity in frontoparietal regions among individuals with social anhedonia.


A neuroimaging paper showing greater activity in frontoparietal regions following an emotional WM training.


A paper showing that affective WM training, but not non-emotional WM training, can improve emotional behavior.


A multiple-session WM training study showing that working memory training can increase resilience to depression in an at-risk populations.


A multiple-session WM training study that offers that working memory training can improve attention control deficits typically associated with anxiety.


A multiple-session WM training study that found no support for a positive impact of WM training on everyday school functioning among primary school children.


A neuroimaging study that assessed effects of a multiple-session response inhibition training on brain activity during an emotion regulation task.


A meta-analytic examination of studies assessing the effects of response inhibition training on appetitive behavior.


A response inhibition training study that did not find conclusive effects regarding training ability to change appetitive behavior.


A meta-analysis of response inhibition training studies suggesting that certain training paradigms can lead to a reduction in harmful behaviors.


64. Daches S, Mor N, Hertz P: Rumination: cognitive consequences of training to inhibit the negative. J Behav Ther Exp Psychiatry 2015, 46:76-83 http://dx.doi.org/10.1016/j.jbtep.2015.01.010.


