Affective Control Training (AffeCT) Reduces Negative Mood in Depressed Individuals

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This work was funded by the UK Medical Research Council (Grant Reference: SUAG/043 G101400) awarded to Tim Dalgleish. The research was partly supported by the National Institute for Health Research Cambridge Biomedical Research Centre.

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Introduction

Depression is now the leading cause of disability worldwide (Patel et al., 2016; WHO, 2018), with prevalence rates increasing, especially in young people (Erskine et al., 2015; *Adult Psychiatric Morbidity Survey*, 2016; Patel et al., 2018). Yet, despite the scale of the problem, available pharmacological and psychological interventions only have limited efficacy, leaving 40-50% of patients unremitted or with significant residual symptomatology (Cuijpers et al., 2016). There is, therefore, an urgent need for novel intervention targets and approaches. To address this need we adopted the National Institute of Health's Science of Behaviour Change framework (Nielsen et al., 2018). The framework proposes to capitalise on insights from basic science by focusing on target mechanisms when developing and evaluating novel interventions, with the goal to better understand how and why interventions work (Nielsen et al., 2018). Here we evaluate a computerized programme targeting affective control (Schweizer et al., 2013), a mechanistic target involved in both risk and maintenance of depression (Grahek et al., 2018; Joormann & Tanovic, 2015).

Affective control refers to the capacity to flexibly engage and disengage from affective information depending on its goal-relevance (Schweizer et al., 2020). That is, the application of cognitive control in affective contexts. Affective control has been proposed to contribute to risk of depression by biasing cognition and impairing emotion regulation (Grahek et al., 2018; Joormann & Tanovic, 2015)[1]. An accumulating body of research demonstrates an association between the experience and risk for depressive symptoms and impairments in affective control and altered functional activation in affective control's

[1] While these theoretical pieces refer to cognitive rather than affective control, the processes discussed encompass what we refer to as affective control including, affective updating, disengaging attention and responses from affective information.

neural substrates in the frontoparietal control network (Bertocci et al., 2012; Kilford et al., 2015; Murphy et al., 2012; Tavitian et al., 2014; Wen & Yoon, 2019). The combined theoretical and empirical evidence makes affective control a promising target for a behavioural change intervention.

To evaluate affective control's utility as a target mechanism, the Science of Behaviour Change framework takes an experimental medicine approach (Nielsen et al., 2018). That is, after establishing the putative mechanism of change, here affective control, valid measures of the target are required to assess the mechanism. The framework outlines four criteria for developing successful interventions: (1) verifiable engagement of the target that shows promise to deliver behaviour changes across different clinical endpoints; (2) intervention evaluation based on appropriate assays that index target engagement; (3) putative targets of change evaluated across clinical endpoints in pilot-testing; and (4) systematic improvement of the trial design to continuously assess target engagement throughout the intervention-target-clinical endpoint pathway.

Support for the first criterion stems from both the literature reviewed above, which demonstrates the centrality of affective control in depression as well as research investigating the malleability of affective control using a computerized affective control interventions. Affective control interventions have been shown to successfully modify affective control components (specifically, affective updating, affective inhibition and affective interference resolution; Cohen et al., 2016; Schweizer et al., 2011) and applications of affective control (specifically, emotion regulation; Cohen et al., 2015; Daches & Mor, 2014; Schweizer et al., 2013) in psychologically healthy individuals (however see: de Voogd et al., 2016) as well as individuals with dysregulated affective states across disorders (du Toit et al., 2020; Krause-Utz et al., In Press; Schweizer et al., 2017). Pre- to post-intervention changes in affective control's neural substrates in the

ventrolateral prefrontal cortex mediated these improvements in emotion regulation (i.e., clinical endpoint) following a computerized affective control intervention (Schweizer et al., 2013). This same region emerged in a subsequent meta-analysis as central to affective control processing (Schweizer et al., 2019). The reviewed literature then suggests that affective control interventions may constitute a promising tool to modify affective control deficits in depression and identifies a range of potential assays of affective control.

Before discussing the potential of affective control further, it should be noted that there is accumulating evidence (for a review see: Koster et al., 2017) that cool cognitive control training – without an explicit affective component – can successfully reduce the onset of depressive symptoms in adolescence (Beloe & Derakshan, In Press) and improve mood, as well as other clinical endpoints dependent on good affective control (e.g., depressive rumination), in those experiencing depressive symptomatology (Calkins et al., 2015; Hoorelbeke et al., 2015, In Press; Onraedt & Koster, 2014; Owens et al., 2013; Siegle et al., 2007). Given the efficacy of cool cognitive training, is there a need for affective control training in depression? Affective control has been shown to be uniquely – that is, over and above cool cognitive control – associated with clinical endpoints that are central to the onset, relapse and maintenance of depression such as rumination (Hilt et al., 2014, 2017; Hilt & Pollak, 2013). Meta-analytic evidence supports this notion showing that affective control uniquely differentiates between psychologically healthy individuals and those suffering from mental health disorders (Schweizer et al., 2019). Targeting affective control, then, may show benefits over and above those observed for cool cognitive control interventions.

The current study aimed to evaluate the potential clinical benefits of increasing affective control in individuals suffering from depression, through a pilot trial comparing an Affective Control Training (AffeCT) paradigm to a placebo training (P-Training)

group. We first established the profile of deficits exhibited in our sample by comparing the entire depressed sample (n = 48) to never-depressed controls (n = 16). The identified affective control difficulties were then used as indices of the target mechanism. Pre- to post-intervention changes on these target mechanisms were predicted to be associated with benefits to the clinical end-points of interest, incl. positive and negative affect as well as depressive symptoms. We included three putative indices of affective control: 1) the affective GoNogo task (Erickson et al., 2005), which has shown reliable differences in individuals who are clinically depressed as well as those at-risk for depression, compared to healthy individuals (Kilford et al., 2015; Ladouceur et al., 2006; Murphy et al., 2012; Wang et al., 2008); 2) the affective Stroop task (Preston & Stansfield, 2008), which has previously been shown to change as a function of AffeCT (Schweizer et al., 2011); and finally, 3) the affective reading span task, which appears unmodulated as a function of depressive state (Schweizer et al., 2018). We predicted that performance on the affective GoNogo and Stroop tasks, but not performance on the affective reading span task, would be poorer in depressed individuals compared to the never-depressed group. The reading span task therefore is intended to act as a plausible control to verify that AffeCT does not simly improve cognitive performance across the board. Post-training improvements in affective control performance on any index emerging from phase one, were hypothesised to be associated with greater improvements on a range of clinical endpoints (i.e., lower negative mood and fewer symptoms of depression) following AffeCT but not P-Training. Finally, the trial aimed to provide effect sizes for any effects of the intervention to inform future definitive randomised control trials (Whitehead et al., 2016).

Methods

Participants

Sixty-four participants were recruited to the study. Including 16 never-depressed controls and 48 depressed individuals (Table 1). The study was powered to detect a training effect on clinical outcomes based on our previous work using AffeCT, which has shown moderate to large effect sizes (*Cohen's ds*: 0.84-2.17; Schweizer et al., 2013, 2017). Healthy controls were recruited from the Medical Research Council Cognition and Brain Sciences Unit (MRC CBSU) volunteer panel and individuals with depression were recruited through the MRC CBSU clinical volunteer panel (n = 45) and self-referral following a mention of the study on a national radio programme (n = 3). To be included, participants needed to be over 18 years, speak English with native fluency, have normal (or corrected to normal) vision and be neurologically healthy (no history of neurological disorders or head injuries). The depressed group needed to also present with a current episode of major depressive disorder (APA, 2013). Twenty-two depressed participants in the P-Training group and 24 participants in the AffeCT group completed the training, the two non-completing participants did not differ in demographic characteristics from completing participants.

Table 1. Demographic and clinical participant characteristics

	Never-depressed	Depressed		Never-depressed vs. Depressed		P-Training vs. AC-Training	
		P-Training	AC-Training				
	n = 16	*n* = 22	*n* = 24	F / X^2	R^2 / Cramer's V	F / X^2	R^2 / Cramer's V
Demographic							
Age *M* (*SD*)	30.5 (12.56)	39.4 (14.42)	39.75 (13.09)	5.30*	.08	0.03	< .001
Range							
Female *n* (%)	9 (56)	17 (74)	18 (75)	1.12	.13	< 0.001	< .001
Education *M* (*SD*)	3.44 (0.51)	2.70 (1.15)	2.71 (0.81)	8.24**	.12	0.002	< .001
Clinical							
Symptoms of depression	2.12 (2.99)	30.09 (7.91)	30.25 (11.23)	129.8***	.12	0.003	< .001
Trait positive affect	35.88 (5.70)	23.35 (9.49)	25.29 (8.26)	23.71***	.28	0.56	0.01
Trait negative affect	13.06 (4.14)	27.35 (8.16)	26.50 (8.86)	39.5***	.39	0.12	.003
Trait anxiety	32.88 (7.55)	57.39 (12.28)	60.97 (8.17)	84.96***	.59	1.28	.03
Positive mood	34.19 (8.46)	19.13 (6.63)	20.83 (6.94)	46.08***	.43	0.74	.02

Negative mood	14.88 (6.11)	28.26 (8.10)	31.96 (7.13)	50.95***	.46	2.77	.06
State anxiety	29.75 (7.20)	50.43 (12.13)	51.12 (12.18)	43.08***	.41	0.03	< .001

Table 1. Education = (0 – "no formal education"; 1 – "GCSE"; 2 – "Higher education/ A-levels" 3 – "university graduate"; 4 – "post-graduate education"); Symptoms of depression = total score on Beck Depression Inventory-II (Beck et al., 1996); Trait positive affect = total score on the positive affect subscale of the trait version of the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988); Trait negative affect = total score on the negative affect subscale of the trait version of the Positive and Negative Affect Schedule; Trait anxiety = total score on the State-Trait Anxiety Inventory-Trait measure (STAI; Spielberger et al., 1970); Positive mood = total score on the positive affect subscale of the PANAS with reference to the previous two weeks; Negative mood = total score on the negative affect subscale of the PANAS with reference to the previous two weeks; State anxiety = total score on the STAI-State measure. * $p \leq .05$, ** $p \leq .01$ *** $p < .001$.

Clinical measures

History of depression. Clinical diagnosis and history of depression was assessed with the mood module from the Structured Clinical Interview for the DSM-IV (First et al., 1995). Interviews were administered by SCID-I trained researchers.

Symptoms of depression. Self-reported depressive symptomatology was assessed with the BDI-II (Beck et al., 1996), a well-validated 21-item inventory of affective, cognitive and physical symptoms of depression (Arnau, Meagher, Norris, & Bramson, 2001).

Self-reported trait affect and recent mood. Enduring (trait) tendency toward positive and negative affect were assessed with the Positive and Negative Affect Schedule (Watson et al., 1988) at the pre-training assessment only. Recent (past two weeks) levels of positive and negative affect – Positive and Negative Mood – were assessed at the pre- and post-training assessments. The scale requires participants to indicate the extent to which they endorse ten positive and ten negative adjectives over the reference time period .

Symptoms of anxiety. Anxiety was assessed with the Spielberger State and Trait Anxiety Inventory (Spielberger et al., 1970). Again the Trait subscale was only administered at pre-training. The subscales consist of 20-items each, with participants indicating how much they agree with statements describing symptoms of anxiety (e.g., “I am tense”) right now (state) or generally (trait).

Measures of cognitive and affective functioning

Cool cognitive control. The backward digit span (Lezak, 1995) from the Wechsler Adult Intelligence Scale (Wechsler, 1999) was administered as a measure of cool cognitive control. The task requires participants to repeat serially presented digits in reverse presentation order.

Affective control. As noted, three measures of affective control were included: the affective GoNogo task (Erickson et al., 2005), the affective Stroop task (Preston & Stansfield, 2008) and the affective reading span task (Schweizer et al., 2018).

Affective GoNogo. The affective GoNogo task requires participants to respond to negative or positive target words (trait adjectives) in the context of either neutral distractors or distractors of the opposite valence. Stimuli were presented in blocks of 20 adjectives including 50% targets. Affective inhibition was assessed with reaction time for correctly identified target stimuli.

Affective Stroop. The task requires participants to categorize adjectives as either angry, happy or sad, while ignoring the valence of the expression on a face upon which the adjective is superimposed. This leads to three different trial types: 1) neutral trials, where the background face has a neutral expression; 2) congruent trials, where the background face depicts the same emotion as the superimposed adjective; and 3) incongruent trials, when the background face depicts an expression that is incongruent with the superimposed adjective. There were eight adjectives in each emotion category (e.g., jolly, gloomy, bitter). Each adjective was presented once across each trial type, resulting in a total of 96 trials. The congruency and incongruency indices were computed by subtracting reaction time in neutral trials from reaction times in congruent and incongruent trials, respectively. The congruency index represents individuals' capacity to benefit from task-irrelevant affective information. While the incongruency index is a metric of how much individuals were distracted by task irrelevant information.

Affective reading span. The affective reading span task requires the storage and recall of words, in tandem with an operation component (evaluating sentences on their semantic accuracy) that potentially disrupts participants' ability to memorize the words. Valence is manipulated by including blocks of neutral and negative sentences. The negative sentences were derived from the 100-item Dysfunctional Attitude Scale (DAS; Weissman & Beck, 1978). The task comprised between 4 and 7 (trial size) sentence-word

pairings within each trial. Each trial size was presented twice for each valence. This resulted in 44 neutral and 44 depressogenic pairings, across eight trials for each valence. Affective working memory was measured as the proportions of words recalled correctly in the neutral and depressogenic conditions separately.

Training tasks

Affective control training (AffeCT). The training paradigm for AffeCT is presented in Figure 2. The training is based on single (visuospatial and auditory) and dual modality *n*-back tasks. The basic principle of the *n*-back task is that it requires participants to report whether the stimulus/i they are currently seeing and/or hearing are the same as the one/s *n* positions back. The level of *n* starts as one and increases with performance. Affective control is measured as the maximum level on *n*-back achieved during a session. Task specific descriptions for each version of the *n*-back task are provided below.

Visuospatial n-back. In the visuospatial *n*-back task faces appear for 500ms on a 4x4 grid. The task requires participants to indicate within 2.5s whether the face they are seeing in the current trial is presented in the same location as the face presented *n* trials back. Responses are provided via key press (left arrow).

Auditory n-back. In the auditory version of the training task participants are presented with words over headphones. On each trial they have 2.5s to indicate via key press (right arrow), whether the word presented in the current trial is the same as they heard *n* trials back.

Dual n-back. The dual version of the task presented participants with the visuospatial and auditory *n*-back simultaneously. The task requires participants to indicate whether the location in which the face is appearing on the current trial is the same as the location in which a face appeared *n* trials back. At the same time, they indicate whether the word they are hearing on the current trial is the same as the word *n*-trials back. Target

responses were indicated with the appropriate key press (left arrow = visuospatial target; right arrow = auditory target; both keys = visuospatial and auditory target. One third of the target trials are visuospatial targets, one third auditory targets, and one third dual targets.

Stimuli. Each of the training versions included 20% neutral stimuli and 80% negative stimuli to train the flexible engagement and disengagement from affective information. Thirty per cent of the trials constituted target trials. The words included in AffeCT were derived from the Affective Norms for English Words database (Bradley & Lang, 1999). The face stimuli were selected from the NimStim faces database (Tottenham et al., 2009). The emotion expression of the faces included were angry, fearful, sad, and neutral. In each training session, 50% of the faces were female.

Figure 2. Affective control training (AffeCT) tasks

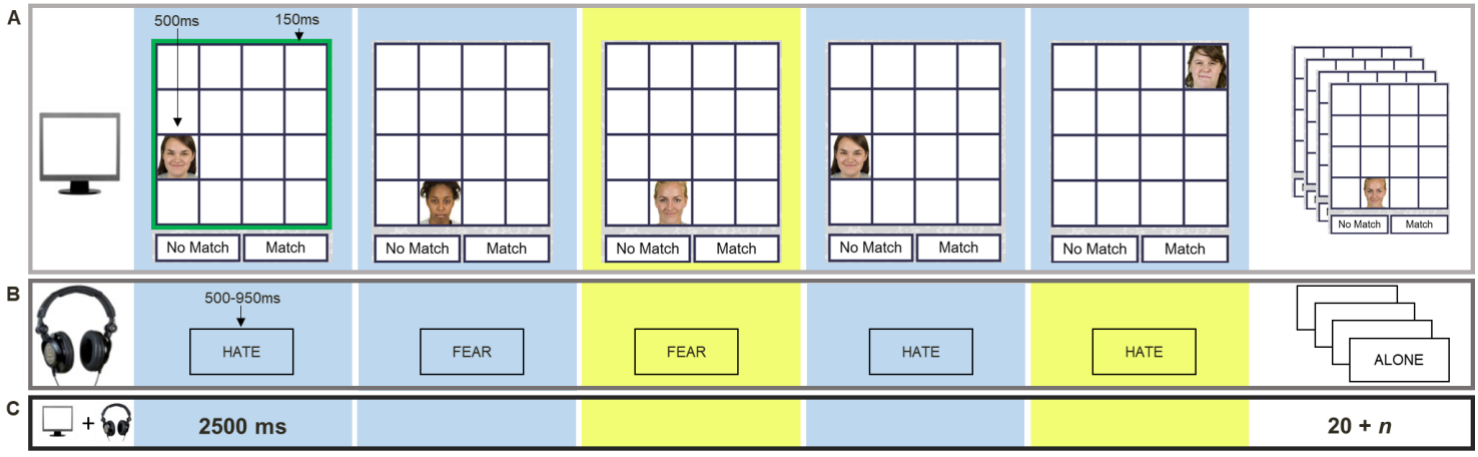

Figure 2. The figure depicts sample trials for each of three training tasks: A) visuospatial *n*-back, B) auditory *n* –back, and C) dual *n*-back. The example block in Figure 2 is depicted for *n* = 1. Match trials for the visuospatial *n*-back training task are trials where the current face is presented in the same location as the face *n* positions back. For auditory

n-back match trials, the same word is presented as the one *n* trials back. The dual *n*-back training task includes both modalities and both types of target trials (for additional buttons appearing on screen with the dual *n*-back see the task description below). Trials depicted with a light blue background require a "No Match" (i.e., not a target) button press, whereas yellow backgrounds indicate "Match" (i.e., target) trials in the respective modality. The green border provides feedback to participants, where green indicates the response was correct, whereas a red border appears for incorrect trials. Feedback is provided after each response or when a trial times out. 2500ms = the maximal (duration is self-paced up to 2500ms) time between onset of one stimulus and the next (i.e., total trial time); 500ms = face presentation time; 150ms = feedback presentation time; 500-950ms = word presentation time. 20 + *n* = each block consists of 20 + *n* trials.

Placebo training. The P-Training task requires participants to indicate via button press ("Match", "No Match") whether two panels display the same stimuli in the same positions on the grid. The stimuli are the same faces as those presented in the AffeCT. Each trial is self-timed up to a maximum of 90s after which participants are asked to respond more quickly. This trial involves minimal affective control as attention to the emotion expressions does not need to be inhibited, but rather attended to for successful task completion. However, minimal affective control may be required to regulate any affective responses to the faces, during the training.

Procedure

The study was approved by the Cambridge Local Research Ethics Committee (CPMS ID 10120).

Phase I (all participants). After providing informed consent, all participants completed the mood module of the SCID-I (all depressed participants had additionally

been administered a full SCID-I at a previous database intake session and depression was established as the primary diagnosis). Participants then completed the questionnaires, the assessment versions of the training tasks and the cognitive and affective functioning tasks. Participants were then compensated with £6/h. The total session took approximately 2 hours and participants had the option to complete all assessments in one session or to split them across two sessions. For never-depressed participants the study was completed after Phase I.

Phase II (depressed participants only). After completing Phase I, depressed participants were randomly allocated to either the P-Training or AffeCT groups. Group assignement was based on entry time into Phase I, simply alternating between the two groups (i.e., the first depressed individual to enter the study was assigned to AffeCT, the second to P-Training, third to AffeCT, fourth to P-Training etc…). All participants received a study rationale tailored to their training condition describing the benefits of training the control of affective information processing (P-Training) and affective control (AffeCT). The training groups did not differ on any clinical or demographic characteristics (Table 1). Participants then completed 14 days of training followed by a post-training assessment that was identical to the Phase I assessment. Experimenters were blind to participants' condition until the end of the training session when the condition was unmasked by the study coordinator and all participants were offered indefinite access to the AffeCT training. Participants were then compensated with £2 for each training day completed and £6/h for the post-training assessment session.

Statistical analyses

All comparisons between the depressed and never depressed groups in Phase I included age and education as covariates, to account for the group differences on these two demographics (Table 1). Clinical symptoms and cool cognitive control were

compared across groups using a general linear model. Performance on the affective control tasks was compared across groups using repeated measures mixed (i.e. with between- and within-subjects factors) linear models. The between-subjects factor was always depression group (never depressed vs. depressed) and within-subjects factors for the GoNogo were distractor (positive/negative vs. neutral) and target (positive/negative vs. neutral) valence. For the Stroop task, within-subjects factors were trial type (neutral vs. congruent vs. incongruent) and trial emotion (happy vs. sad vs. angry). For the affective reading span task, the within-subjects factor was valence (negative vs. neutral).

For the analyses in phase two, all analyses were repeated measures mixed linear models. The between-subjects factor was always training group (AffeCT vs. P-Training) and within-subjects factors were as for phase I with additionally all analyses including a within-subject factor of time (pre- vs. post-training).

Results

Cognitive and affective functioning in depressed compared to never-depressed individuals (Phase I)

Clinical symptoms. As expected, the depressed group reported significantly more symptoms of depression, anxiety, negative affect and less positive affect compared to the never depressed group (Table 1).

All means and standard deviations for cool cognitive and affective control are reported in Table S1.

Table S1. Cognitive and affective control across groups and time

Never-depressed	P-Training		AffeCT	
Pre	Pre	Post	Pre	Post
M (*sd*)	*M* (*sd*)	*M* (*sd*)	*M* (*sd*)*M*	*M* (*sd*)

Cognitive control					
Digit backward	7.81 (1.87)	7.44 (2.94)	7.78 (3.21)	7.47 (2.14)	7.05 (2.42)
Affective control					
GoNogo Pos/Neg	574.38 (92.13)	548.44 (47.50)	540.32 (49.57)	537.11 (56.65)	546.74 (763.46)
GoNogo Pos/Neu	577.81 (50.38)	546.04 (51.85)	566.81 (54.44)	537.36 (42.54)	549.88 (68.18)
GoNogo Neg/Pos	600.03 (81.69)	545.64 (46.73)	564.29 (54.42)	546.26 (42.70)	568.37 (64.13)
GoNogo Neg/Neu	595.19 (69.01)	558.25 (54.95)	560.36 (50.01)	553.26 (48.11)	550.32 (62.31)
Stroop Neutral-H	727.16 (127.53)	817.22 (179.32)	798.70 (242.03)	719.14 (135.34)	695.36 (111.63)
Stroop Neutral-S	894.84 (199.68)	918.63 (231.66)	898.13 (257.21)	844.94 (207.93)	766.98 (139.36)
Stroop Neutral-A	820.44 (144.47)	853.28 (190.81)	844.84 (229.20)	764.11 (126.52)	719.04 (111.53)
Stroop Congruent-H	710.03 (117.93)	801.44 (170.59)	781.11 (236.53)	705.75 (138.14)	686.06 (120.56
Stroop Congruent -S	873.94(171.47)	913.36 (217.05)	875.78 (213.64)	815.66 (203.95)	789.09 (180.16)
Stroop Congruent -A	828.91 (156.73)	848.52 (213.50)	830.32 (245.80)	769.96 (122.10)	711.90 (110.16)
Stroop Incongruent-H	732.88 (115.27)	827.38 (174.37)	846.32 (321.51)	731.49 (141.06)	710.99 (133.96)
Stroop Incongruent -S	870.31 (170.72)	922.40 (221.80)	890.62 (246.61)	835.13 (187.22)	770.45 (124.84)
Stroop Incongruent -A	823.18 (137.83)	885.72 (199.22)	830.78 (245.54)	790.00 (149.35)	747.38 (154.20)
% correct Neutral	.50 (.18)	.49 (.20)	.53 (.22)	.51 (.16)	.61 (.20)
% correct Negative	.53 (.17)	.53 (.20)	.56 (.21)	.58 (.21)	.58 (.16)

Table S1. GoNogo Pos/Neg = trials with positive targets and negative distractors; GoNogo Pos/Neu = trials with positive targets and neutral distractors; GoNogo Neg/Pos = trials with negative targets and positive distractors; GoNogo Neg/Neu = trials with negative targets and neutral distractors. H = Stroop trials including happy adjectives; S = Stroop trials including sad adjectives; A = Stroop trials including angry adjectives;

Neutral = Stroop trials including a neural background face; Congruent = Stroop trials including a background face that is congruent in emotional expression with the super-imposed adjective; Incongruent = Stroop trials including a background face that is incongruent in emotional expression with the super-imposed adjective. % correct Neutral = percentage words recalled correctly that followed neutral sentences; % correct Negative = percentage words recalled correctly that followed negative sentences.

Cool cognitive control. The depressed group did not differ from never-depressed individuals on cool cognitive control measured with the backward digit span, F (1, 62) < 1, p = .639, d = 0.12.

Affective control. On the first index of affective control, the affective GoNogo task, there was a main effect of diagnostic group F (1, 55) = 9.76, p = .003, d = 0.84, but not distractor valence, F (1, 55) < 1, p = .737, d = 0.08 nor target valence, F (1, 55) < 1, p = .424, d = 0.20 effects. In contrast with our predictions, depressed individuals showed moderately faster overall response rates compared to never-depressed controls. This was not at the cost of reduced accuracy, with no significant group differences in accuracy, F (1, 54) = 2.85, p = .097, d = 0. 46 where again the moderate effect was in favour of the depressed group showing higher accuracy. There were no significant interactions between diagnostic group and target or distractor valence.

Similarly, there was no significant effect of trial type (congruent, neutral, incongruent) F (2, 55) = 1.86, p = .221, d = 0.52, trial emotion (happy, sad, and angry), F (2, 55) = 2.98, p = .059, d = 0.66, nor diagnosis, F (1, 56) < 1, p = .840, d = 0.06 on our second index of affective control: affective Stroop response times. Though the moderate effect of type showed the expected pattern with response times being fastest in the congruent condition, intermediated for neutral trials and slowest for incongruent trials.

There was, however, a significant interaction of emotion and diagnostic group, F (2, 55) = 5.02, p = .010, d = 0.85. Unpacking the interaction revealed no significant paired-comparison group differences ($p \geq .360$). The effect sizes showed a small difference with depressed individuals being slower to categorise happy adjectives (d = 0.23). In contrast, depressed individuals were faster than never-depressed controls when responding to sad (d = 0.06) and angry (d = 0.00) trials but these differences were negligible in effect size. Interestingly, accuracy on the affective Stroop was again lower in the never depressed group (M = .92 SD = .01) compared to depressed individuals (M = .96 SD = .01), F (1, 56) = 7.31, p = .003, d = 0.72.

Finally, the third index of affective control, affective reading span, as anticipated showed no significant effect of valence, F (1, 49) < 1, p = .931, d = 0.00, diagnosis F (1, 49) = 2.44, p = .124, d = 0.44 or interaction F (1, 49) < 1, p = .937, d = 0.00.

Interim results summary Phase I

In contrast to our predictions, the depressed group was overall higher functioning than the never depressed group, even after statistically adjusting for the depressed group's older age and lower levels of education. The only difference observed was a relative slowing on the Stroop task for happy compared to negative words in the depressed group compared to never-depressed individuals. In line with the Science of Behaviour Change framework we therefore took this index, Stroop performance across trials of different emotions as an index marker of our intervention target, affective control.

Section comparing the two depressed groups on task performance at baseline?

Training outcomes across groups

All means and standard deviations for training task performance at pre- and post-training and test statistics for within group changes are reported in Table S2.

There was no significant differences between the groups in the average number of training days completed (P-Training: M = 12.18, sd = 3.36; AffeCT: M = 11.54, sd = 6.01), F (1,46) < 1, p = .662, d = 0.12 or average number of minutes spent training during a session (P-Training: M = 17.02, sd = 4.15; AffeCT: M = 20.03 min, sd = 6.00), F (1,31) = 2.59, p = .118, d = 0.59.

Placebo training. The P-training group showed improved performance on their training task. This improvement, however, was not significantly greater than the AffeCT group's pre- to post-training improvement on the same feature match (placebo training task) task. That is, there was no significant training group x time interaction, F (1,41) = 2.86, p = .099, d = 0.53.

Affective control training. The AffeCT group significantly improved on their training task, F (3, 16) = 10.61, p < .001, d = 2.82 across all three versions. That is, they improved on the single, F (1, 20) = 9.45, p = .006, d = 1.34, dual neutral, F (1,20) = 18.06, p < .001, d = 1.90 and dual affective, F (1,22) = 17.35, p < .001, d = 1.78 versions of the dual *n*-back task.

There was no significant interaction of time x training group for the single version of the affective *n*-back, F (1, 40) = 2.98, p = .092, d = 0.54. There was, however, a significant time x training group interaction for both the neutral, F (1, 40) = 8.39, p = .006, d = 0.91 and affective F (1, 43) = 11.72, p = .001, d = 1.04 dual *n*-back., with the AffeCT group showing greater pre- to post-training improvements. There was no significant valence x time x training group interaction, F (1, 40) < 1, p = .837, d = 0.06.

Table S2. Pre- to post-training in training task performance.

	P-Training	Pre-Post change	AC-Training	Pre-Post change

	n = 23	*F*	*d*	*n* = 24	*F*	*d*
Placebo training task						
ΔTask performance	34.60 (7.93)	19.05***	2.00	11.09 (12.57)	1.02	0.43
Affective control training task						
ΔSingle affective *n*-back	0.62 (0.03)	1.01	0.45	2.29 (0.18)	9.45**	0.57
ΔDual neutral *n*-back	0.19 (0.02)	< 1	0.27	1.62 (0.96)	18.06***	1.90
ΔDual affective *n*-back	−0.09 (0.15)	< 1	0.07	1.48 (0.69)	17.35***	1.78

Table S2. Δ = pre- to post-training change, Single affective *n*-back = visuospatial *n*-back including emotional faces; dual neutral *n*-back = dual *n*-back task including only neutral stimuli; dual affective *n*-back = dual *n*-back task including only affective stimuli. ** $p \leq .01$ *** $p < .001$

Training-related changes in clinical outcomes

All means and standard deviations for clinical outcomes at pre- and post-training and test statistics for within-group changes are reported in Table S3.

Unsurprisingly, there was no difference in incidence of depression (P-Training 65% vs. AffeCT 64%) across the two training groups at post-training, $X^2 = 0.03$, $p = .855$, $R^2_{Nagelkerke} = .00$. The logistic regression analysis confirmed no effect of training group on post-training diagnosis controlling for pre-training diagnostic status, $\beta = 0.26$, $W = 0.64$, $p = .425$ as none of the participants had remitted. Similarly, there was no significant training group by time interaction for self-reported symptoms of depression, F (1, 39) < 1, $p = .354$, $d = 0.30$, with both groups showing a significant pre- to post-training reduction in symptom levels. There were also no significant changes in pre- to post-training levels of state anxiety ~~symptoms~~ for either training group, and there was no significant training group by time interaction, F (1, 39) < 1, $p = .538$, $d = 0.20$.

There was, however, a significant training group by time interaction on the PANAS evaluation of Positive and Negative Mood over the previous two weeks (Watson et al., 1988), F (2, 38) = 4.57, p = .017, d = 0.98. Follow up analyses showed that this was due to the AffeCT group showing a larger pre- to post-training decrease in Negative Mood over the previous two weeks, compared to the P-Training group.

Exploratory analyses showed that the reduction in Negative Mood in the AffeCT group showed a non-significant small association with improved performance on the trained affective control measure affective *n*-back task (single and dual combined), r (20) = −.25, p = .280.

Table S3. Pre- to post-training changes in clinical symptoms conflated across groups.

	P-Training	Pre-Post change		AffeCT	Pre-Post change	
		F	*d*		*F*	*d*
Clinical						
ΔSymptoms of depression	−4.89 (1.16)	17.90**	2.00	−7.27 (2.13)	11.67**	1.49
ΔState anxiety	−3.42 (2.29)	2.23	0.70	−1.73 (1.56)	1.18	0.47
ΔPositive Mood	3.58 (1.25)	8.18*	1.34	1.46 (1.42)	1.05	0.44
ΔNegative Mood	−2.89 (1.19)	5.92*	1.15	−5.91 (1.34)	19.53***	1.93

Table S3. Δ = pre- to post-training change. Symptoms of depression = total score on BDI-II; State anxiety = total score on the STAI state version; Positive Mood = total score on the positive affect subscale of the PANAS with reference to the previous two weeks; Negative Mood = total score on the negative affect subscale of PANAS with reference to the previous two weeks. * $p \leq .05$, ** $p \leq .01$ *** $p < .001$.

Training-related changes in cognitive outcomes

Present these data somewhere? Table?

Cool cognitive control. The was no significant training group by time interaction for cool cognitive control, F (1, 37) = 1.20, p = .280. d = 0.36.

Affective control. The index of interest for affective control in this group of individuals with a current diagnosis of depression was affective Stroop performance. For a summary of pre- to post-training changes for the other affective control indices (no significant time x group interactions), which showed no deficits compared to the never-depressed group, please see the supplementary results section (SM1).

For the affective Stroop task there was a main effect of trial type, trial emotion and time (for statistics see Table S4), but not training group. These main effects were qualified by a significant 4-way interaction of time x training group x type x emotion interaction, F (4, 35) = 2.99, p = .032, d = 1.17. To break-down the interaction we looked at the effects of time, type and emotion in each training group separately. For neither group was there a significant time x trial type x trial emotion interaction, (P-Training: F (4, 14) = 1.79, p = .187, d = 1.43; AffeCT: F (4, 18) = 1.49, p = .246, d = 1.15). There was, however, a significant interaction for time x trial emotion in the AffeCT group only, F (2, 20) = 3.92, p = .037, d = 1.25 not in the P-Training group, F (2, 16) < 1, p = .513, d = 0.59. Interestingly, individuals in the AffeCT training group were faster at post-training to categorise negative adjectives, (sad: F (1, 21) = 8.23, p = .009, d = 1.25; anger: F (1, 21) = 19.50, p < .001, d = 1.93) but not happy adjectives, F (1, 21) = 1.63, p = .216, d = 0.56.

This effect was not due to group differences in overall accuracy, which showed no main effect of time, F < 1, p = .709, d = 0.12, nor interactions of time with type, emotion or condition (p = .412 – .932).

Table S4. Pre- to post-training in affective Stroop task performance.

	F	*df*	*d*

Within-subject effects			
Time	7.73**	1, 38	0.90
Type	10.20***	2, 37	1.48
Emotion	48.56***	2, 35	3.29
Between-subjects effects			
Training group	3.53	1, 38	0.55

Table S4. Time = main effect of time (pre vs. post); Type = main effect of type (neutral vs. congruent vs. incongruent); Emotion = main effect of emotion (happy vs. sad vs. angry); Training group (P-Training vs. AffeCT). ** $p \leq .01$ *** $p < .001$.

Finally, the sample was underpowered to investigate whether pre- to post-training changes in Stroop reaction times for sad or angry adjectives mediated reductions in Negative Mood. We therefore explored the association between Stroop reaction times in sad and angry trials with Negative Mood at post-training in each training group separately. In the P-training group Negative Mood at post-training showed trivial associations with reaction times on sad, r (17) = −.12 and angry r (17) = −.11 trials. In the AffeCT group, Stroop reaction times on sad, r (22) = .30 and angry, r (22) = .30 trials showed a small-moderate non-significant (p = .181) association with Negative Mood. Given these effects we further explored the association with our other clinical endpoints of interest, there were non-significant trivial to small associations with state positive affect (sad: r (22) = −.04; angry, r (22) = −.06 and state anxiety, sad: r (22) = .12; angry, r (22) = .20). Stroop reaction times on sad, r (22) = .49 and angry, r (22) = .48 trials were significantly associated to symptoms of depression at post-training in the AffeCT group. Again, none of these associations was significant in the P-Training group (p = .190 – .874).

SM1: Supplementary results affective control

Affective GoNogo task. There was no main effect for training group, time or trial distractor (p = .173 – .721). There was a main effect of trial target, F (1, 38) = 5.96, p = .019, d = 0.79. None of the interactions of time x training group were significant (p = .114 – .965).

Affective reading span task. There was a main effect of trial valence, F (1, 31) = 6.21, p = .018, d = 0.90, with words following negative sentences being recalled better compared to those following neutral sentences. There was also a main effect of time, F (1, 31) = 7.06, p = .012, d = 0.94, with more words being remembered at post-training. However, there was no time x training group interaction nor a three-way interaction of time x training group x trial valence (report values?).

Discussion

The Science of Behavioural Change framework (Nielsen et al., 2018) highlights the importance of determining and assaying the predicted mechanisms of change, when developing and evaluating interventions. Here, we showed that a high functioning group of depressed individuals out-performed younger and more highly educated individuals on two of our three measures of affective control, the affective GoNogo task and the affective reading span. We therefore did not evaluate our affective control intervention against these indices, but instead used the index that showed significantly poorer performance for depressed individuals in our sample, the affective Stroop task. This index, subsequently showed significant post-training differences across the training groups, with the AffeCT group showing faster reactions for negative trials compared to the P-training group. The AffeCT group further showed greater reductions from pre- to post-training in negative mood but not on wider symptoms of depression. Importantly, post-training negative mood showed a small-moderate (r = .30) association with post-training reaction times in sad and angry trials.

Applying the Science of Behavioural Change framework ensured that the study population was meaningfully profiled in terms of affective control. The very high levels of overall cognitive and affective control performance in the depressed sample are noteworthy. This is in contrast with commonly observed deficits in cognitive (Snyder, 2013) and affective control (Grahek et al., 2018). However, the lack of deficits in the affective reading span are in line with our initial finding of a maintained affective enhancement effect in depressed individuals on this task (Schweizer et al., 2018). We included the task to demonstrate that affective control training would not moderate areas of no deficits. The lack of evidence for poorer performance on the GoNogo task were more surprising. However, in line with our results, Lewis et al. (2019) recently reviewed the relevant literature on the affective GoNogo in depressed individuals and reported mixed findings. The relative slowing in positive relative to negative trials on the Stroop task of depressed compared to never-depressed individuals demarked a unique affective control deficit in this population. Encouragingly, the affective control training specifically reduced reaction times on the Stroop task, though in particular the negative (sad and angry) trials.

When subsequently observing Stroop performance from pre- to post-training there was relatively less (compared to negative trials) reduction in reaction times on positive trials. The absence of improved affective control in positive contexts was mirrored in the absence of significant training effects on Positive Mood. This is likely due because affective control training is unlikely to modify reward processing abnormalities observed in depression (Ng et al., 2019), associated with altered functioning of the reward circuitry. Moreover, beyond the effect on negative mood, affective control training did not reduce broader self-reported symptoms of depression or shift depressed participants out of episode, with all individuals still meeting a diagnosis of depression after two weeks of

training. However, both groups training groups showed a significant reduction in broader self-reported depressive symptoms. Arguably a longer follow-up time would be required to see an impact of improved affective control on wider symptoms of depression, with improved affective control gradually impacting on habitual emotion regulation strategies (Joormann & Stanton, 2016) and reducing cognitive biases (Beck & Bredemeier, 2016).

The training-related reduction in negative mood was associated with improved affective control on our target marker identified at pre-training, specifically, reduction in reaction times that require the classification of angry and sad words. This suggest that affective control may indeed facilitate flexible disengagement from negative content. Importantly, and in line with our findings in psychologically healthy individuals (Schweizer et al., 2011), the training improved response times to negative adjectives on the affective Stroop task irrespective of the trial type. That is, affective control improvements facilitated situationally-appropriate (i.e., goal-dependent) engagement and disengagement from negative information.

The promising findings need to be interpreted with caution given the early-phase nature of the trial (MRC, 2008) and the corresponding limited sample size. However, importantly the aim of a pilot study is to provide effect size estimates to run a subsequent fully powered trial. Moreover, encouragingly drop-out was very low (4%) and participants opted to train for an average of 20 minutes on the affective control task, despite, having the option to quit the training session anytime from 10 minutes onward. However, there was no follow-up period included in the current study leaving the question open whether the improvements in affective control and associated improvements in mood are transient or more stable. A final, point of note is the current sample's relative cognitive resources. The sample may have been particularly motivated during the tasks, as

suggested by the evidence that they outperformed a younger and more highly educated control sample. However, this was true for both the active and placebo training groups.

In sum, a computerized affective control training led to improved affective control and a concomitant reduction in negative affect. These initial findings are promising and warrant replication in a larger more diverse sample. The study importantly highlighted the need to profile our samples under-investigation in terms of specific deficit patterns.

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