Special Issue

Emotional working memory training as an online intervention for adolescent anxiety and depression: A randomised controlled trial

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Abstract

Objective: Anxiety and depression are highly prevalent disorders in adolescence. They are associated with deficits in working memory (WM), which also appears to increase rumination, worry, and negative mood. WM training, especially in an emotional context, might help in reducing or preventing these disorders. The current study investigated the direct effects of online emotional WM training on WM capacity, and short- and long-term effects on symptoms of anxiety and depression, and secondary measures of emotional functioning. **Methods:** Unselected adolescents ($n = 168$, aged 11–18) were randomised over an active or placebo emotional WM training. WM was assessed before and after 4 weeks of bi-weekly training. Emotional functioning was assessed pre- and post-training and at 3, 6, and 12 months follow-up. **Results:** Improvements in WM capacity and both short- and long-term emotional functioning were found in both training groups, with the only group difference being a trend for a larger increase in self-esteem in the active group compared to the placebo group. **Conclusions:** The general improvements irrespective of training condition suggest non-specific training or time effects, or some shared active ingredient in both conditions. Future research is necessary to detect potentially effective components of (emotional) WM training and to increase adolescent engagement with online training.

Key words: adolescents, anxiety, cognitive control, depression, working memory training

What is already known about the topic?

- Anxiety and depression are associated with deficits in working memory (WM) functioning.
- There are indications that WM training could improve WM capacity and emotional functioning.
- For transfer to emotional functioning, training in an emotional context appears important.

What this topic adds?

- An emotional WM training was provided to unselected adolescents aimed at improving WM capacity and reducing anxiety and depressive symptoms.
- Emotional WM training did not have any short- or long-term effects on WM capacity or emotional functioning over and above a placebo control training.
- Specific effective ingredients of emotional WM training have to be identified and training tasks should be made more engaging.

Prevalence of anxiety and depression peaks in adolescence (Kessler et al., 2012). Given the detrimental influence of these disorders on social and academic functioning and the associated risk of adult psychopathology, early prevention is highly important. Online interventions are attractive here, especially for adolescents, as they could be offered anonymously and at low cost. Recent years have witnessed a

growth of innovative approaches, where underlying mechanisms of anxiety and depression are directly targeted by (online) cognitive training (Becker, Vanderhasselt, & Vrijsen, 2015; MacLeod & Clarke, 2015).

Anxiety and depression are associated with deficiencies in cognitive control (Joormann & Vanderlind, 2014), and various studies have shown impaired working memory (WM) functioning in both depression (Demeyer, De Lissnyder, Koster, & De Raedt, 2012; Joormann, Levens, & Gotlib, 2011) and anxiety (Amir & Bomyea, 2011; Schweizer & Dalgleish, 2011). WM could be defined as 'the cognitive

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mechanism that supports active maintenance of task-relevant information during the performance of a cognitive task' (Jaeggi, Buschkuehl, Shah, & Jonides, 2014). In anxiety and depression, especially the ability to control the access and removal of negative material to and from WM appears impaired (Gustavson & Miyake, in press; Joormann et al., 2011). Such deficits in inhibiting irrelevant negative emotional information have been related to ruminative thinking and negative mood states (De Lissnyder et al., 2012; Mor & Daches, 2015). Training WM capacity might improve the ability to focus on task-relevant information and suppress irrelevant emotional information, thus promoting effective emotion regulation.

Various training paradigms have been developed targeting WM. Research in both adults and youth has provided mixed evidence regarding its effectiveness in changing executive functioning, with a number of studies showing improvements in various WM-tasks, whereas others did not find any transfer effects (for reviews, see Au et al., 2015; Karbach & Unger, 2014; Melby-Lervåg & Hulme, 2013; Morrison & Chein, 2011). An important next question is whether WM training also affects behaviour or emotional functioning. There are some indications that this might work: a multi-session WM training improved attentional control in a high anxious sample and reduced anxiety in those participants that improved most on the training task (Sari, Koster, & Pourtois, in press). However, both in a sample with high rumination tendencies (Onraedt & Koster, 2014) and in depressed patients (Wanmaker, Geraerts, & Franken, 2015), a comparable WM training did not have any effects on rumination, depression, or anxiety compared to an active control group.

In order to effectively improve cognitive control over emotional information processing, it might well be necessary to train WM also in the context of emotional information (Iacoviello & Charney, 2015). Indeed, in a study where WM training with emotional stimuli was directly compared to training with neutral stimuli, only the emotional training improved cognitive control over affective information and emotion regulation (Schweizer, Grahn, Hampshire, Mobbs, & Dalgleish, 2013; Schweizer, Hampshire, & Dalgleish, 2011). In a pilot study, emotional WM training also reduced depressive symptoms in patients (Iacoviello et al., 2014). In addition, several studies have employed the adaptive Paced Auditory Serial Addition Task, a WM task with neutral stimuli that elicits frustration and thus could also be seen as an emotionally laden training (Siegle, Ghinassi, & Thase, 2007), which affected depressive symptoms, stress-reactivity, and rumination in clinical and subclinical samples (Calkins, McMorran, Siegle, & Otto, 2015; Hoorelbeke, Koster, Vanderhasselt, Callewaert, & Demeyer, 2015; Siegle et al., 2007). In sum, while the evidence regarding both cognitive and emotional

effects of WM training is mixed, the most promising findings in the context of anxiety and depression have been obtained with training tasks in an emotional context (e.g., stress) or with emotional stimuli (emotional faces or words). As far as we know, such training paradigms have not yet been investigated in youth, although adolescents appear especially responsive to cognitive training in general (Crone, 2009). Applying training at an early stage might prevent the development of full-blown anxiety or depressive disorders.

In the current study, we investigated the effects of an emotional WM training (EmoWM) on WM capacity, anxiety and depression, and emotional functioning in unselected adolescents. Participants were randomised over an experimental or placebo version of the EmoWM training, consisting of eight online sessions. WM capacity was assessed during training (training performance), and pre- and post-training (transfer task). Emotional measures were administered both pre- and post-training and, as long-term effects of WM training are largely unknown (Jaeggi et al., 2014), at 3, 6 and 12 months follow-up. For the EmoWM training, we employed an adaptation of the chessboard task (Dovis, Van der Oord, Wiers, & Prins, 2012). In this adaptive block-tapping task, visual information has to be manipulated in WM, and an emotional distractor (negative emotional stimuli: fearful, sad, or angry faces) was added in the current study. As this emotional component was expected to increase transfer effects, we employed a relatively small number of training sessions (eight) compared to previous WM training studies in a neutral context (e.g., 15–25 sessions: Morrison & Chein, 2011).

Our first hypothesis was that WM capacity would increase after EmoWM training compared to a non-adaptive placebo training. Second, we expected a reduction in anxiety and depressive symptoms in the EmoWM group compared to placebo. Third, this symptom change was expected to be larger in participants who showed more improvement in WM capacity. Our fourth hypothesis concerned factors that moderated training effectiveness. First, we expected stronger training effects in adolescents who had lower WM capacity at baseline (Karbach & Unger, 2014), as this would provide more room for improvement. Second, adolescents who experienced relatively many and high impact stressful life events were hypothesised to profit most from training, as especially the ability to cope with stressors might be affected (cf. Hoorelbeke et al., 2015). Finally, based on previously observed relations between amount of training and training gain (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008), stronger effects were expected in adolescents who completed a relatively large amount of training sessions. Finally, to further explore the potential of EmoWM training in improving adolescent emotional functioning, we assessed effects on stress-reactivity, self-esteem, perseverative

negative thinking, test anxiety, and social-emotional and behavioural problems.

METHODS

The current study was part of a larger randomised controlled trial on cognitive training, that compared four types of training paradigms (EmoWM training, interpretation bias modification, two types of attentional bias modification) with their respective placebo conditions (resulting in eight conditions). The methods and data of the other training paradigms are reported in de Voogd et al. (2015) and de Voogd, Wiers, de Jong, Zwitser, and Salemink (2016). The study was approved by the ethics committee of the psychology department of the University of Amsterdam, carried out in accordance with the provisions of the World Medical Association Declaration of Helsinki, and registered in the Dutch trial register with number NTR3950 (http://www.trialregister.nl/trialreg/admin/rctview.asp?TC=3950).

Participants

In total, participants were recruited from 14 regular high schools in the Netherlands between January and September 2013. Of the 2,312 adolescents invited, 733 adolescents and parents provided written informed consent and were randomised over one of eight conditions (4:4:4:4:1:1:1:1 ratio). Less participants were allocated to the specific placebo conditions to make the study more appealing and because we
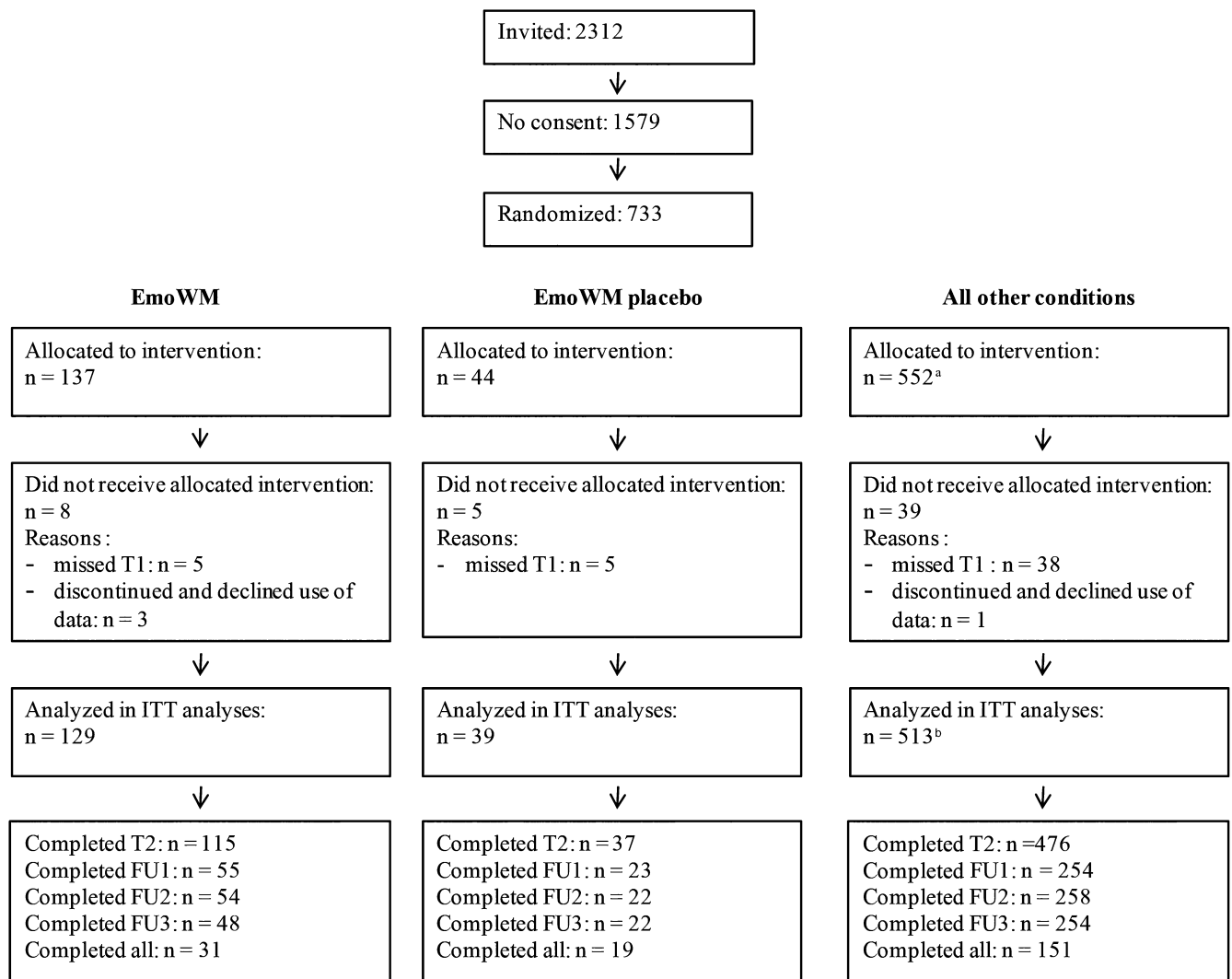
Figure 1 Flow chart of the full study.
Note. The full study also included three other experimental and placebo conditions.
[a]Visual search attention training (VS): $n = 140$, VS placebo: $n = 41$, Dot Probe attention training (DP): $n = 137$, DP placebo: $n = 50$ Interpretation training (CBM-I): $n = 142$, CBM-I placebo: $n = 42$.
[b]VS: $n = 126$, VS placebo: $n = 38$, DP: $n = 128$, DP placebo: $n = 48$, CBM-I: $n = 134$, CBM-I placebo: $n = 39$.

Table 1 Demographic characteristics per training condition

	EmoWM (n = 129)		Placebo (n = 39)	
	Mean/n	*SD/%*	*Mean/n*	*SD/%*
Age, mean (*SD*)	14.33	1.17	14.40	1.14
Female, n (%)	77	59.7	24	61.5
School level, n (valid %)				
Lower	33	25.6	7	17.9
Middle	26	20.2	10	25.6
Higher	70	54.3	22	56.4
Sessions, mean (*SD*)	4.74	2.37	5.26	2.71
High life events group, n (valid %)	35	29.9	14	36.8

initially planned to combine these groups into one control condition. Randomisation was stratified by school, gender, and age group (below/above 15 years). Both participants and test-assistants were blind to condition. Overall, 681 participants remained for intention-to-treat analyses, after excluding those who missed the first assessment or requested removal of data (see Fig. 1). For the current study, analyses were performed on the 168 participants (60.1% females, mean age = 14.35, SD = 1.16) who were randomised to the EmoWM group (n = 129) and EmoWM placebo group (n = 39). Group sizes of n = 39 provided 80% power to detect a Condition (2 groups) × Time (5 levels) interaction effect size of $f = 0.12$ at an alpha of .05. Chi-square tests and analyses of variance (ANOVAs) indicated no differences between these two groups on demographic characteristics (see Table 1) or baseline scores on outcome measures (see Table 2), all p's > .112.

Cognitive and primary outcome measures

WM capacity was assessed with a computerised version (Peeters, Monshouwer, Janssen, Wiers, & Vollebergh, 2014) of the Self Ordered Pointing Task (SOPT, Petrides & Milner, 1982). Concrete or abstract pictures (increasing from four to 12) were presented and participants had to click on each picture only once. Each time a participant selected a picture, the pictures were randomly reordered. Participants had to remember which pictures they already selected and were not allowed to select the same location twice in a row. The total number of correct clicks was used as an index of WM capacity.

The Screen for Child Anxiety Related Emotional Disorders (SCARED, 41-item version, Birmaher et al., 1999) and the Children's Depression Inventory (CDI, Kovacs, 1985) were used to assess anxiety and depressive symptoms respectively.

Secondary outcome measures

Stress reactivity was investigated by assessing mood responses to Cyberball (Williams, Cheung, & Choi, 2000; Williams, Yeager, Cheung, & Choi, 2012), a social stress

task. Here, participants are led to believe that they play an online ball-tossing game with two other participants. The 3-min game is programmed such that after two own tosses, the participant is excluded from the game. Before and after the stress task, participants had to indicate how happy, confident, enthusiast, anxious, nervous, and sad they felt on a scale from 0 to 100 (*not at all* to *very much*). Ratings were combined into a positive and negative mood scale.

To explore emotional functioning, the Rosenberg Self-Esteem Scale (RSES, Rosenberg, 1965), the Perseverative Thinking Questionnaire (PTQ, Ehring et al., 2011), the negative test anxiety subscale of the Dutch 'performance motivation test for children' (Prestatie Motivatie Test voor Kinderen, PMT-K, Hermans, 1983), and the total difficulties scale of the Strengths and Difficulties Questionnaire (SDQ, Goodman, 1997, self-report and parent version) were used to assess self-esteem, perseverative thinking, test-anxiety, and social-emotional and behavioural problems.

Internal consistency for all these questionnaires was adequate to excellent in the current sample (SCARED α = .92, CDI α = .86, positive mood α = .72, negative mood α = .65, RSES α = .86, PTQ α = .95, SDQ α = .71, SDQ-parent α = .71).

Stressful life events as potential moderator were assessed with the Dutch 'TRAILS events scale' (TRAILS Gebeurtenissen vragenlijst', Bouma, Ormel, Verhulst, & Oldehinkel, 2008). Participants had to indicate whether 25 stressful life events (e.g., parental divorce, severe illness/death of a family member) had occurred during the previous 2 years and how stressful (0–3) the event was. Impact scores for all experienced life events were added to create a stressful life events index, which was dichotomised into 'high stress' (>6) or 'low or average stress' for each time point. Finally, groups were created separating those who had 'high stress' at least at one time point and those who never had.

EmoWM and placebo training

The chessboard task was developed by Dovis et al. (2012) and was extended with an emotional component for the current study. In both conditions (active and placebo training), participants were presented with a fixation cross, followed by a 4×4 matrix of green and blue squares in chessboard format. A sequence of squares lit up (900 ms each) and after a light signal participants had to reproduce this sequence by clicking these squares in the correct order, first all green squares in the order in which they were presented and then all blue squares. Squares lit up in random order, but to ensure that information had to be manipulated in WM, at least one blue square was presented before the last green square. The emotional component consisted of a negative emotional face (angry, fearful, or sad) which was presented randomly on one of the squares that lit up and

Table 2 Outcome measures per training condition

	Outcome measure[a]	T1[b]		T2		FU1		FU2		FU3	
		M	SD	M	SD	M	SD	M	SD	M	SD
EmoWM (*n* = 129)	SOPT	57.25	5.23	60.16	5.10	—	—	—	—	—	—
	SCARED	17.72	11.11	15.01	10.57	13.69	10.08	15.09	10.89	14.79	10.46
	CDI	8.43	6.05	7.80	5.70	6.47	6.37	6.15	4.82	6.10	4.91
	Positive mood	200.67	59.89	196.55	69.50	—	—	—	—	—	—
	Negative mood	35.02	46.07	36.35	49.88	—	—	—	—	—	—
	RSES	30.68	4.33	31.77	4.76	32.47	5.03	32.04	5.10	32.12	4.60
	PTQ	34.95	11.78	31.82	12.11	30.09	11.34	31.02	13.51	30.23	12.01
	PMT-K	6.99	3.47	6.26	3.90	6.20	4.16	6.31	4.06	6.54	3.89
	SDQ	9.87	5.28	9.42	5.26	8.24	5.73	7.96	4.40	7.94	4.36
	SDQ-parent	6.16	5.16	6.12	4.76	5.00	4.14	4.64	4.08	4.72	4.19
Placebo (*n* = 39)	SOPT	58.79	5.52	60.43	5.31	—	—	—	—	—	—
	SCARED	17.44	9.85	15.73	11.78	16.39	12.24	15.23	13.20	14.50	10.15
	CDI	8.49	5.81	9.05	7.86	7.96	6.37	6.95	6.25	6.73	5.24
	Positive mood	198.14	68.81	195.75	74.85	—	—	—	—	—	—
	Negative mood	39.62	56.57	38.36	61.60	—	—	—	—	—	—
	RSES	30.23	5.15	29.30	6.74	31.04	4.97	32.64	5.48	31.61	5.14
	PTQ	34.77	11.93	31.73	12.93	32.87	13.06	31.59	12.67	33.18	11.69
	PMT-K	6.90	3.60	6.49	3.79	6.70	3.84	6.23	3.41	7.09	3.94
	SDQ	10.64	5.51	10.32	6.34	8.87	5.16	8.50	4.38	8.36	5.08
	SDQ-parent	7.13	5.57	5.57	4.27	6.08	4.55	5.35	3.99	4.17	2.96

[a] SOPT = Self Ordered Pointing Task; SCARED = Screen for Child Anxiety Related Emotional Disorders; CDI = Children's Depression Inventory; RSES = Rosenberg Self-Esteem Scale; PTQ = Perseverative Thinking Questionnaire; PMT-K = Performance Motivation Test for children; SDQ = Strengths and Difficulties Questionnaire.

[b] T1 = pre-training assessment; T2 = post-training assessment; FU1 = 3 months follow-up; FU2 = 6 months follow-up; FU3 = 12 months follow-up. Note that for positive and negative mood, T1 and T2 refer to pre- and post-stressor mood respectively, both assessed at the post-training (T2) assessment session.

had to be omitted during reproduction. Faces were drawn from the NIMH Child Emotional Faces Picture Set (NIMH_ChEFS, Egger et al., 2011, for stimuli selection, see de Voogd, Wiers, Prins, & Salemink, 2014). In the first training session, four practice trials were presented.

In the active condition, sequence length was dependent on performance, with a minimum of three squares (including the face stimulus) and increasing or decreasing by one square after two consecutive correct or incorrect trials respectively. The task consisted of three training blocks of 12 trials. In the placebo condition, the task was non-adaptive and three squares (including the face stimulus) were presented in all trials. Since trials were shorter due to short sequences, each training block consisted of 15 trials.

For both conditions, feedback was provided after each trial, also indicating change in sequence length in the active condition. During the task, a progress bar indicated how many trials were left. Between training blocks and at the end of the sessions, participants received feedback on the number of points earned, based on performance. The duration of a training session was approximately 15 min.

Procedure

Participating school classes received information about the content and aim of the study, stated as 'investigating a training to make adolescents more resilient to stress and negative emotions, by learning to worry less and have a more positive view on the environment'. Both adolescents and a parent provided written informed consent. The first assessment (T1), the first training sessions and the post-training assessment (T2) were completed under supervision in computer classrooms during regular school hours. Assessments included the SOPT, three other computer tasks,[1] and online questionnaires, and took about 80 min. The parent version of the SDQ was sent by e-mail and had to be completed within 1 week. One to seven days after T1, the 4-week training period started. Twice a week, participants received an e-mail and text message to remind them of the next session, which had to be completed within 2 days. In case of two missed sessions, a reminder was sent, offering technical assistance when needed. At T2 (one to seven days after the last training session), the procedure from T1 was repeated, now also including Cyberball and mood scales. After T2, participants were fully debriefed on Cyberball and compensated with vouchers and lottery tickets, based on the number of sessions completed. Three, six, and twelve months after T2 (FU1, FU2, and FU3 respectively), participants received an invitation for the online follow-up assessment, and a reminder after 1 week. Again, vouchers and lottery tickets were sent to compensate participants. Non-responders were contacted by telephone after 2 weeks.

Data analyses

Mixed regression analysis was performed (using IBM Statistical Package for Social Sciences 20), as this method takes into account all available data, without excluding participants with missing data at specific time points.[2] For all outcome measures, a mixed model with Participant as the grouping variable and Time as a repeated measure variable was tested. School was not included as another grouping variable, as preliminary analysis indicated that this did not improve model fit. With regard to the covariance between time points, we have verified (based on AIC and BIC criteria) whether these were structured according to compound symmetry, or first-order autoregressive, or whether these were unstructured.

For our hypotheses regarding improvements in WM capacity and emotional functioning in the EmoWM group compared to Placebo, the basic model included the factorial predictors Time (two or five levels for short- or long-term measures respectively) and Condition, and their interaction. For training performance, we only tested the effect of Time (eight levels, one for each training session) for the EmoWM group, as the placebo group could not improve on the number of squares reproduced. Parameters were excluded from the model in a backward elimination procedure based on AIC and BIC criteria and significance levels. To test our hypotheses on moderating factors (change in WM capacity, baseline WM capacity, number of sessions completed, stressful life events), first a model was tested including Time, Condition, the moderator of interest and their interactions and again, parameters were excluded till the best model fit was obtained.

To control for Type I errors related to the number of outcome measures, Bonferroni-Holm correction was applied. Effects with $p < .05$ that did not survive correction were defined as marginal. Statistics of the original and final models for all hypotheses can be found in Table 3, and Table 4 shows the relevant parameter estimates.

RESULTS

Preliminary analyses

At baseline, WM capacity as assessed with the SOPT was not correlated with anxiety nor depression, $r < .001$, $p = .996$, and $r = -.13$, $p = .096$, respectively. Table 2 shows descriptive statistics of all outcome measures.

Cognitive and primary outcome measures

Our first hypothesis, that EmoWM training would result in a larger increase in WM capacity compared to Placebo, was not confirmed, as only a significant main effect of Time was observed for SOPT scores, indicating a general increase in WM capacity, and no Condition × Time interaction. For WM capacity assessed by performance on the training task (EmoWM group only), a significant effect of Time was observed. The number of squares participants could reproduce increased during training, with performance during the last session (5.37 squares) being significantly different from session one (4.06 squares), $p < .001$.

Our second hypothesis, that EmoWM training would result in reduced anxiety and depressive symptoms, was also not supported, as no significant Condition × Time interactions were observed for SCARED nor CDI scores. Significant main effects of Time were observed, indicating a general decrease in both anxiety and depressive symptoms from T1 to follow-up.

Contrary to our third hypothesis, training effects on anxiety and depression were not affected by pre- to post-training changes in WM capacity as assessed with the SOPT.

Moderation of training effects

Our fourth hypothesis, that training effects would be moderated by baseline WM capacity, stressful life events, or number of training sessions completed, was not supported, as no three-way interactions between Condition and Time and these potential moderators were observed.

Secondary outcome measures

Finally, the potential of EmoWM training for improving emotional functioning was explored. Contrary to our expectations, no significant differences were observed between pre- and post-stressor (Cyberball) positive or negative mood, nor was mood affected by training condition. For self-esteem, the expected Condition × Time interaction was marginally significant, indicating a larger increase in RSES scores in the EmoWM group compared to Placebo post-training. For perseverative negative thinking, test anxiety, and social-emotional and behavioural problems (self- and parent-report), only significant Time effects were found, indicating an improvement in emotional functioning irrespective of condition.

DISCUSSION

The aim of the current study was to investigate the short- and long-term effects of multiple sessions EmoWM training in unselected adolescents. We hypothesised that training WM with emotional distractors would improve WM capacity and thereby reduce anxiety and depressive symptoms (primary outcome) and improve emotional functioning (secondary outcome).

Contrary to our expectations, the EmoWM training did not result in a larger increase in WM capacity than the placebo training, although participants improved their

Table 3 Statistics of the original and final models for all hypotheses

Outcome measure[a]	Model[b]	Model fit		Time		Condition		Condition × Time		Condition* × Time* × moderator	
		AIC	BIC	F	df	F	df	F	df	F	df
SOPT	Condition* × Time (CS)[c]	1936.01	1958.62	20.30****	1,155.81	1.35	1,163.79	1.39	1,155.81	—	—
	Time (CS)	1934.83	1949.90	35.693*****	1,157.51	—	—	—	—	—	—
Training performance	**Time**	1442.90	1637.30	40.02****	7,68.08	—	—	—	—	—	—
SCARED	Condition × Time	3697.78	3805.28	7.15****	4,92.81	0.09	1,154.92	0.94	4,92.81	—	—
	Time	3691.53	3777.51	11.32****	4,100.47	—	—	—	—	—	—
	Condition × Time × WM change	3544.03	3692.99	6.80****	4,90.50	0.05	1,139.72	0.82	4,90.50	0.45	4,93.74
	Condition × Time × Baseline WM	3707.01	3857.47	7.44****	4,94.03	0.00	1,155.50	0.81	4,94.03	0.51	4,96.01
	Condition × Time × Stressful life events	3601.51	3751.13	5.99****	4,92.41	0.04	1,143.55	1.13	4,92.41	0.92	4,92.41
	Condition × Time × Sessions	3710.17	3860.64	7.67****	4,119.69	0.03	1,190.62	0.25	4,119.69	0.16	4,119.19
CDI	Condition × Time	3129.19	3236.66	3.08**	4,90.51	0.34	1,145.94	1.20	4,90.51	—	—
	Time	3124.12	3210.10	4.83***	4,99.49	—	—	—	—	—	—
	Condition × Time × WM change	2998.21	3147.16	3.12**	4,85.80	0.35	1,133.21	1.02	4,85.80	1.15	4,88.10
	Condition × Time × Baseline WM	3137.51	3287.98	3.62***	4,91.78	0.23	1,147.54	1.12	4,91.78	0.74	4,94.77
	Condition × Time × Stressful life events	3038.74	3188.35	3.04**	4,89.70	0.27	1,133.47	1.43	4,89.70	1.07	4,89.70
	Condition × Time × Sessions	3144.46	3294.92	2.24*	4,117.91	0.30	1,186.39	1.35	4,117.91	0.18	4,116.33
Positive mood	Condition × Time	3208.20	3234.08	1.33	1,146.11	0.00	1,151.37	0.28	1,146.11	—	—
	Time	3204.51	3222.99	2.72	1,146.15	—	—	—	—	—	—
Negative mood	Condition × Time	3028.51	3054.39	0.08	1,145.84	0.03	1,148.75	1.08	1,145.84	—	—
	Time					—	—	—	—	—	—
RSES	**Condition × Time**	3006.27	3113.83	3.81***	4,98.69	0.44	1,147.32	3.59***	4,98.69	—	—
PTQ	Condition × Time	3877.60	3985.07	6.94****	4,93.25	0.15	1,152.89	0.44	4,93.25	—	—
	Time	3869.39	3955.37	9.91*****	4,99.82	—	—	—	—	—	—
PMTK	Condition × Time	2554.43	2661.90	2.50**	4,89.88	0.14	1,159.74	0.90	4,89.88	—	—
	Time	2547.86	2633.84	4.32***	4,97.60	—	—	—	—	—	—
SDQ	Condition × Time	2955.30	3042.82	3.06**	4,89.02	0.47	1,145.04	0.04	4,89.02	—	—
	Time	2926.20	3012.22	3.64***	4,95.58	—	—	—	—	—	—
SDQ-Parent	Condition × Time	2899.79	3007.99	5.35***	4,107.20	0.19	1,142.31	1.70	4,107.20	—	—
	Time	2896.35	2982.91	4.56***	4,106.83	—	—	—	—	—	—

[a] SOPT = Self Ordered Pointing Task; SCARED = Screen for Child Anxiety Related Emotional Disorders; CDI = Children's Depression Inventory; RSES = Rosenberg Self-Esteem Scale; PTQ = Perseverative Thinking Questionnaire; PMT-K = Performance Motivation Test for children; SDQ = Strengths and Difficulties Questionnaire.

[b] Bold print = final model.

[c] CS = Compound Symmetry. For all other outcomes measures, covariance between time points was unstructured.

$*p < .10$, $**p < .05$, $***p < .01$, $****p < .001$.

Table 4 Parameters estimates of significant effects

Training effects		EmoWM[a]		T2		FU1		FU2		FU2		T2 EmoWM	
		B	SE	B	SE	B	SE	B	SE	B	SE	B	SE
SOPT[b]	Time	—	—	2.55****	0.43	—	—	—	—	—	—	—	—
SCARED	Time	—	—	−2.59****	0.47	−3.88****	0.70	−3.25**	0.96	−3.87****	0.91	—	—
CDI	Time	—	—	−0.45	0.28	−1.39***	0.45	−1.54***	0.53	−1.92****	0.51	—	—
RSES	Condition* × Time	0.45	0.82	−0.94	0.62	1.16*	0.67	2.42***	0.85	1.44	0.88	1.95***	0.71
PTQ	Time	—	—	−3.38****	0.59	−3.97****	−0.84	−3.75***	1.14	−4.13****	1.08	—	—
PMT-K	Time	—	—	−0.60****	0.16	−0.73***	0.25	−0.94***	0.31	−0.59*	0.30	—	—
SDQ	Time	—	—	−0.38*	0.21	−0.93**	0.38	−1.27***	0.40	−1.63***	0.48	—	—
SDQ-Parent	Time	—	—	−0.38	0.28	−0.67**	0.33	−0.90**	0.38	−1.46****	0.36	—	—

[a] Reference categories were the placebo condition, and pre-training assessment (T1). T2 = post-training assessment; FU1 = 3 months follow-up; FU2 = 6 months follow-up; FU3 = 12 months follow-up. Condition × Time interactions for RSES at FU1, FU2, and FU3 are not shown, since they were not significant: all p's > .222.

[b] SOPT = Self Ordered Pointing Task; SCARED = Screen for Child Anxiety Related Emotional Disorders; CDI = Children's Depression Inventory; RSES = Rosenberg Self-Esteem Scale; PTQ = Perseverative Thinking Questionnaire; PMT-K = Performance Motivation Test for children; SDQ = Strengths and Difficulties Questionnaire.

*p < .10, **p < .05, ***p < .01, ****p < .001.

performance on the training task itself. Both groups showed a significant increase in WM capacity, which might reflect practice or non-specific training effects, or an unexpected active ingredient in the placebo training (discussed below). Also, no differential training effects were found on anxiety or depressive symptoms or secondary outcomes measures, except for a trend of increased self-esteem after EmoWM training. Consistent with cognitive effects, on most emotional outcome measures, a significant improvement was observed in both groups. Training effects were not related to change in WM capacity, and not moderated by baseline WM capacity, number of sessions completed or stressful life events.

The absence of training effects in the EmoWM group above and beyond the placebo group might be related to the number of training sessions (n = 8) in the current study, and their relatively short duration. Although some promising effects on rumination and depressive symptoms have been obtained with brief cognitive training in an emotional context (e.g., Cohen, Mor, & Henik, 2015; Iacoviello et al., 2014), WM training without emotional context usually involves a considerably larger amount of training (e.g., 15–25 sessions: Morrison & Chein, 2011). Intensive training might be needed to improve WM capacity and especially to find transfer effects to emotional functioning. However, increasing the length of sessions should be considered carefully, as a recent meta-analysis showed marginally larger transfer effects with shorter session length (Au et al., 2015).

The fact that we found improvements on many measures regardless of training condition might reflect demand effects, or a natural decline of symptoms, but could also indicate that the experimental and placebo training share some effective ingredient. Although only the experimental training was adaptive, which we expected to be necessary

to improve WM capacity, both training-varieties included an emotional distractor, and thus activated inhibition processes. So, in retrospect, even though the WM load of the placebo training was low, the task of reproducing a simple sequence of two squares while inhibiting distracting negative emotional information, might have affected emotional information processing (cf. Cohen et al., 2015).

The lack of differential training effects, which contradicts some promising previous findings (Calkins et al., 2015; Hoorelbeke et al., 2015) could also be related to the tasks used to train and assess WM in the current study. Many different paradigms have been used in previous research, but until now, no preferential training task has been identified. Our training task has not been used before in its current form (the non-emotional variant has been found to affect WM capacity: Dovis, Van der Oord, Wiers, & Prins, 2015), but a training including a comparable task also had no effect in a sample of depressed patients, even though that program involved longer and more frequent training (Wanmaker et al., 2015). However, recent studies do suggest that a combination of cognitive control and emotional information processing makes the most effective task when targeting rumination and related emotional problems (e.g., Cohen et al., 2015; Iacoviello et al., 2014). Future research should further disentangle the effects of training 'neutral' executive control and emotional processing. For example, one could employ a mixed design, systematically varying adaptive and non-adaptive WM training and inclusion or exclusion of an emotional component.

Given the importance of the emotional context of WM functioning, the non-emotional SOPT might not have been the best task to assess training-related changes. We did not find a significant correlation between this measure and anxiety or depressive symptoms, and an emotional WM task

might be better able to pick up symptom relevant differences or changes in cognitive control (cf. Shi, Gao, & Zhou, 2014, for such an assessment in test anxiety). The absence of such a task in our study is a limitation, as we could not compare WM performance under neutral and emotional conditions. The SOPT was also quite different from the training task in other aspects, and could thus be considered a far transfer task, which might have made it difficult to observe subtle changes in WM capacity.

Some other limitations are also important to take into account. First, although online training has clear advantages in terms of accessibility, it is also vulnerable to problems related to a lack of experimental control, and to technical issues.[3] Given the monotonous nature of the task, it takes a lot of effort to keep up concentration and motivation for training at home, and especially adolescents who have difficulties with self-regulation (either due to low attentional control or strong emotional states) might not profit from training in this way (cf. Studer-Luethi, Bauer, & Perrig, 2015). The relatively short session length might have been an advantage here (Au et al., 2015), but methods to increase engagement should also be investigated, for example adding gaming elements or motivational interviewing techniques (cf. Boendermaker, Boffo, & Wiers, 2015). Second, the high drop-out rates at follow-up considerably reduced our power to observe long-term effects. This is especially unfortunate in combination with the relatively small placebo group, due to unbalanced randomization. As our placebo training might have contained some active ingredients, in retrospect, a placebo group matched in size to the experimental group would have been preferable.

To summarise, in a sample of unselected adolescents, we did not find any beneficial effects of a relatively short EmoWM training compared to placebo training, except for a trend-level increase in self-esteem. General improvements in WM capacity and emotional functioning were observed in both groups, suggesting either demand or practice effects or a natural decline in symptoms, or some shared active ingredient of both conditions. Given the theoretical importance of WM in emotional symptoms and the relatively new field of training WM in the context of internalising problems, further research in both healthy, at-risk, and clinical adolescents is needed to examine the potentially effective components of both neutral and emotional WM training and to find more engaging training paradigms.

ACKNOWLEDGEMENTS

NOTES

1. Also two attentional bias and one interpretation bias task were administered, but these data are presented in separate papers (de Voogd et al., 2015; de Voogd et al., 2016).
2. Short-term analyses were also performed for 'completers' (defined as completing both T1, T2, and six or more training sessions). Results were comparable and can be requested from the first author.
3. After completing data collection, a small bug was detected in the EmoWM training, that affected accuracy for some participants. However, the occurrence of errors due to this bug did not interact with Time ($p = .123$) in predicting the number of squares, and the Time effect remained significant ($p < .001$) after controlling for the bug effect.

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