Appetite 105 (2016) 567–574

Contents lists available at ScienceDirect

Appetite

journal homepage: www.elsevier.com/locate/appet

Taking control: Working memory training in overweight individuals increases self-regulation of food intake

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ARTICLE INFO

Article history:
Received 7 April 2016
Received in revised form
22 June 2016
Accepted 23 June 2016
Available online 25 June 2016

Keywords:
Obesity
Working memory
Training

ABSTRACT

Working memory (WM) plays a critical role in cognitive control by shielding self-regulatory goals from distraction by desire-related thoughts and emotions. This study examined whether training WM increases self-regulation in overweight participants. It was hypothesized that WM training would decrease psychopathological eating-related thoughts, (over)consumption of food in response to emotions and external cues, food intake and body weight. Overweight participants ($n = 50$) performed 20–25 sessions of WM training or control/sham training. The dependent measures were self-reported eating-related psychopathology, self-reported emotional/external eating behavior, food intake during a bogus taste test, and body weight, assessed before training, immediately following training, and at one-month follow-up. Relative to control, WM training reduced psychopathological eating-related thoughts and emotional eating (but not external eating). These effects were still present at follow-up, one month later. Food intake and body weight did not show an overall effect of training, though WM training did reduce food intake among highly restrained participants. WM training effectively reduced eating-related thoughts, overeating in response to negative emotions, and food intake among participants with strong dietary restraint goals. Hence, these findings indicate that WM training may strengthen self-regulation by shielding dieting goals from distraction by unwanted eating-related thoughts and emotions.

1. Introduction

In the last three decades, the prevalence of obesity has nearly doubled (Finucane et al., 2011; Flegal, 2005; Wang & Beydoun, 2007), placing more and more individuals at risk of developing cardiovascular diseases, diabetes, musculoskeletal disorders and cancer (World Health Organization, 2009). In 2010, overweight and obesity were estimated to cause 3.4 million deaths worldwide (Lim et al., 2012). Research further shows that, unabated, the increase in obesity will lead to dramatic falls in future life expectancy (Olshansky et al., 2005). A key contributor to the rapid weight gain that occurred over the past 30 years is our obesogenic environment, which encourages over-consumption of widely-available, inexpensive, energy-dense food and discourages expenditure of energy though physical activity (Hill, Wyatt, Reed, & Peters, 2003). The solution to the obesity problem therefore may lie in identifying feasible ways to cope with the current food-rich environment and adhere to the simple principles of the energy balance equation.

One strategy to reduce over-consumption could be to strengthen cognitive control of consumption and body weight. Cognitive control (or executive functioning) is an umbrella term that refers to three basic cognitive functions that allow for goal-directed action amid the endless possibilities afforded to us in real-life situations (Miyake et al., 2000): Maintaining and updating relevant information ('updating'), inhibition of prepotent impulses ('inhibition'), and mental set shifting (task-switching). According to contemporary dual-process models, overconsumption of palatable, energy-dense foods is the result of unintentional, fast-acting impulses that are not or insufficiently regulated via top-down cognitive control (Hofmann, Friese, & Strack, 2009; Strack & Deutsch, 2004): Individuals with both strong behavioral impulses to consume palatable food and low levels of cognitive control are particularly susceptible to over-consumption (Friese, Hofmann, & Wänke, 2008; Hofmann & Friese, 2008; Hofmann, Friese, & Roefs, 2009; Hofmann, Gschwender, Friese, Wiers, & Schmitt, 2008; Hofmann, Rauch, & Gawronski, 2007) and weight gain (Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010) compared

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http://dx.doi.org/10.1016/j.appet.2016.06.029
0195-6663/

to individuals with effective cognitive control. Hence, individual differences in cognitive control may explain why some people do not succeed in resisting the lure of palatable, energy-dense foods and achieving a healthy weight.

It has been argued that working memory (WM) may very well lie at the heart of successful cognitive control (Engle, Tuholski, Laughlin, & Conway, 1999; Kane, Bleckley, Conway, & Engle, 2001). WM is closely connected to the construct of 'updating' and refers to the ability to maintain an active mental representation of (self-regulatory) goals, and shield those goals from distraction (Engle et al., 1999; Hofmann, Schmeichel, & Baddeley, 2012; Kane et al., 2001). Moreover, this ability to focus on goal-relevant information should also relate to people's ability to regulate their own thoughts and emotions (Hofmann et al., 2012). Indeed, increased WM capacity is related to less thought intrusions and mind-wandering (Brewin & Beaton, 2002; Brewin & Smart, 2005; Kane et al., 2007) and better emotion-regulation (Schmeichel & Demaree, 2010; Schmeichel, Volokhov, & Demaree, 2008). Importantly, overweight and obesity have been associated with reduced cognitive control, including WM (Smith, Hay, Campbell, & Trollor, 2011), which begs the question whether training cognitive control, and WM in particular, may translate into better behavioral self-regulation in overweight and obese individuals.

Previous studies showed that WM can be improved via adaptive training and that such training is effective in reducing clinical symptoms (for reviews see Klingberg, 2010; Morrison & Chein, 2011). It is important to note, however, that there has also been criticism on the effectiveness of WM training claiming that there is yet insufficient evidence of its efficacy. Specifically, it has been argued that more scientific evidence is needed to support both near transfer of WM training to untrained WM tasks, and far transfer to WM-related abilities and behavior (e.g., Shipstead, Redick, & Engle, 2012). In the present study, it was examined whether WM training decreases over-consumption and body weight in a sample of overweight participants. Participants either performed WM training or control tasks (sham training) for 25 days. It was expected that WM training would increase self-regulation and cognitive control as evidenced by (1) reduced pathological eating-related thinking, (2) decreased (over-)consumption of food in response to emotions and external cues, (3) reduced consumption of palatable, energy-dense foods, and (4) a decrease in body weight.

2. Materials and methods

2.1. Participants

Participants were recruited via advertisements in local newspapers about the possibility to participate in research exploring WM training as an intervention for overweight. The advertisements specifically asked for individuals who had overweight and who were motivated to lose weight. Eligibility required that participants were aged 18–65, and had a Body Mass Index (BMI) higher than 25 (i.e., A BMI above 25 indicates overweight). Of the 67 participants who responded to the advertisements and met the eligibility criteria, 62 participants completed the pretest. Twelve participants dropped out after missing too many training sessions.[1] The remaining 50 (37 female) participants completed at least 20 training sessions, the pretest, posttest and follow-up. Of the final sample, 6% received primary education, 66% received secondary education, and 28% received higher education. See also Table 1 for participant characteristics. The study was approved by the Ethical Review Committee Psychology and Neuroscience.

2.2. Materials & measures

2.2.1. Working memory training

The WM training (Houben, Wiers, & Jansen, 2011; Klingberg, Forssberg, & Westerberg, 2002) consisted of three tasks: A visuospatial WM task, a backward digit span task, and a letter span task (presented in this order). During the visuospatial WM task, a sequence of squares in a 4×4 grid changed in color on the computer screen. Participants had to reproduce this sequence by clicking the squares that had changed color in the correct order using the computer mouse. During the backward digit span, a sequence of numbers was presented on the computer screen, which participants had to reproduce in reversed order, using either the computer mouse or the keyboard. In the letter span task, a sequence of letters was presented on the computer screen in a circle. One of the positions in this circle was then indicated and participants had to reproduce the corresponding letter using the keyboard. All three tasks consisted of 30 trials (one block).

In the training condition, the difficulty level of all three WM tasks was automatically adjusted on a trial-by-trial basis (cf. Houben et al., 2011; Klingberg et al., 2002): Each task initially started with a sequence of three items. When participants correctly reproduced this sequence two times in a row, one item was added to the sequence on the next trial. When participants could not correctly reproduce the sequence on two consecutive trials, the sequence in the next trial was reduced by one item. In the control condition, the difficulty level of the WM tasks remained on the initial easy level (three items in a sequence; cf. Houben et al., 2011; Klingberg et al., 2002). Before and after training, WM was measured using the same three tasks, but these assessment tasks ended when participants were unable to reproduce a sequence on two consecutive trials. The outcome measure for each WM task was the amount of items in the sequence that could be correctly reproduced. These three scores were averaged to calculate a total WM score.

2.2.2. Eating Disorder Examination Questionnaire (EDE-Q)

The EDE-Q (Fairburn & Beglin, 1994; Fairburn & Cooper, 1993) is a 36-item self-report measure of eating disorder psychopathology. The EDE-Q contains 23 items assessing eating disorder psychopathology over the previous 28 days. These items are answered on a 7-point Likert scale (0 = 'not one day'; 6 = 'every day'). The 23 items together comprise one global score (Cronbach's $\alpha = 0.90$) as well as four subscales: Restrained eating (Cronbach's $\alpha = 0.73$), preoccupation with food (Cronbach's $\alpha = 0.67$), weight concern (Cronbach's $\alpha = 0.78$) and body shape concern (Cronbach's $\alpha = 0.88$). Higher scores indicate stronger eating disorder psychopathology.

2.2.3. Dutch Eating Behaviour Questionnaire (DEBQ)

The DEBQ (Van Strien, 2005; Van Strien, Frijters, Bergers, & Defares, 1986) is a 33-item self-report measure of emotional eating (Cronbach's $\alpha = 0.96$), external eating (Cronbach's $\alpha = 0.77$) and restrained eating (Cronbach's $\alpha = 0.90$). All items are scored on a 5-point Likert scale (1 = 'Never'; 5 = 'Very often'). Item examples: 'Do you have a desire to eat when you are irritated?' (emotional eating), 'If foods smells and looks good, do you eat more than usual?' (external eating) and 'Do you try to eat less at mealtimes than you would like to eat?' (dietary restraint). Means are calculated for the three subscales with higher scores indicating increased emotional, external or dietary restraint.

[1] Of the 12 participants who dropped out, 9 participants were in the training condition and 3 participants were in the control condition. The participants who dropped out did not differ from the participants who finished the study in terms of age, or scores on WM, DEBQ, EDE-Q and RS (all $F < 1$). Participants who dropped out, however, did have a lower BMI ($M = 28.84$, $SD = 2.58$, $F(1, 60) = 5.72$, $p = 0.02$, compared to the rest of the sample ($M = 31.56$, $SD = 3.72$).

Table 1
Participant characteristics per training condition. Means and standard deviations for baseline characteristics are provided per condition.

	Training (N = 24)	Control (N = 26)	Range	F/χ^2	p
Age	36.08 (11.28)	37.62 (10.65)	18–62	0.24	0.62
Baseline BMI (kg/m^2)	31.76 (3.79)	31.38 (3.72)	26.50–41.58	0.13	0.72
Gender (% female)	79.2%	69.2%	–	0.64	0.42
Dietary restraint (RS)	17.50 (3.71)	16.69 (5.19)	3–27	0.40	0.53
Working memory (WM) – baseline	6.15 (1.54)	6.06 (1.32)	3.00–9.67	0.05	0.83

2.2.4. Bogus taste test

Food consumption was measured using a bogus taste test. Participants were presented with four bowls containing different palatable energy-dense foods: salted potato chips (541 kcal/100 g), chocolate cookies (465 kcal/100 g), milk chocolate (530 kcal/100 g), coated peanuts (535 kcal/100 g). Participants were told that we were interested in their taste perception of a number of food products. Participants were instructed that they were allowed to consume as much or as little of the food as they wished while completing food ratings: Participants first indicated how much they experienced hunger and desire to eat the food on a 100 mm Visual Analogue Scale (0 = 'no desire/not hungry'; 100 = 'strong desire/very hungry'). Next, they compared and rated the different food products on a number of taste dimensions. After 15 min, the experimenter removed the bowls of food and the amount of food consumed was measured outside the test room. Total amount of calories was calculated as an index of food intake.

2.2.5. Dietary restraint

Dietary restraint was measured using the revised Restraint Scale (RS; Herman & Polivy, 1980). The RS is a self-report questionnaire consisting of 10 items that measure dieting concern/intentions and weight fluctuations (Cronbach's $\alpha = 0.70$). Higher scores indicate an increased intention to restrict food intake.

2.2.6. Body mass index

Participants' weight and height were assessed in order to calculate participants' Body Mass Index (kg/m^2; BMI).

2.3. Procedure

After giving consent, participants performed the bogus taste test and the assessment WM tasks. Next, they filled out the Restraint Scale, EDE-Q and DEBQ, and their weight and height were measured. Participants were then randomly assigned to the training or control condition and were informed that they would perform a WM training consisting of 25 sessions via the Internet (so they did not have to come to the lab for the training sessions; participants were sent invitations for each training session via email together with a personalized link to start the session). Participants were given two days to complete a training session. Each session lasted about 30 min in total. If participants did not complete a session in time, that session was marked as missed, and participants moved on to the next session. In total, participants could miss up to 5 training sessions. Hence, the total number of training sessions varied between 20 and 25 ($M = 23.02$, $SD = 1.80$; the training sessions were on average completed within 33.92 days, $SD = 8.23$, range: 25–66).[2] Upon completing the training, the posttest session was scheduled in the lab (on average 9.52 days, $SD = 6.19$, after the last training session). At posttest, participants again performed the bogus taste test and the WM assessment, they filled out the EDE-Q and DEBQ, and their weight was measured. The follow-up session was scheduled one month after the posttest and included the same measures. Upon completing the experiment, participants received a gift certificate of 50€ as remuneration for their participation.

2.4. Design & statistical analyses

Participants were randomly allocated to one of two groups: Active working memory training ($n = 24$) or control training ($n = 26$). Randomization checks showed no significant differences between conditions for any potential confounding factors (Table 1). Data were analyzed using mixed-effects ANOVA with condition as between-subjects factor (training versus control) and time as within-subjects factor (pretest, posttest and follow-up).[3]

3. Results

3.1. Manipulation check

In the control condition, the difficulty of the training tasks always remained on the easiest level with only three to-be-remembered items in each task. Consequently, the performance of participants in the control condition remained at the same level over the course of the training period (see Fig. 1). In the training condition, in contrast, the training was adjusted adaptively to participants' performance. As can be seen in Fig. 1, participants in the training condition showed a steady increase in working memory performance during the training period.

3.2. Working memory

A mixed ANOVA on WM task performance showed significant main effects of time, $F(2,96) = 67.31$, $p < 0.001$, $\eta^2_p = 0.58$, and condition, $F(1,48) = 7.19$, $p = 0.01$, $\eta^2_p = 0.13$, as well as a significant time × condition interaction, $F(2,96) = 17.29$, $p < 0.001$, $\eta^2_p = 0.27$ (see Fig. 2). Follow-up analyses per condition showed a significant increase over time in WM performance in both the control condition, $F(2,50) = 17.86$, $p < 0.001$, $\eta^2_p = 0.42$, and the training condition, $F(2,46) = 57.14$, $p < 0.001$, $\eta^2_p = 0.71$. Contrasts indicated that, in both the training and control condition, the increase in WM performance from pretest to posttest was significant, $F(1,23) = 98.68$, $p < 0.001$, $\eta^2_p = 0.81$, and $F(1,25) = 28.20$, $p < 0.001$, $\eta^2_p = 0.53$, respectively, with a larger increase in the training condition than in the control condition, $F(1,48) = 6.13$ $p = 0.02$, $\eta^2_p = 0.11$. In addition, both conditions also improved in WM performance from pretest to follow-up, $F(1,23) = 66.63$, $p < 0.001$,

[2] Note that the range normally should have been 25–50 days because participants were only allowed to do one session per day and had to complete a session every two days. However, two participants were given some extension to these rules due to personal issues.

[3] We also performed an Intention To Treat (ITT) analysis on all dependent variables using the "last observation carried forward method". In the ITT analyses, all participants were included, rather than including only the participants who completed the study as in the Per Protocol analyses. Including all participants in the ITT analyses did not change any of the effects compared to the Per Protocol analyses.

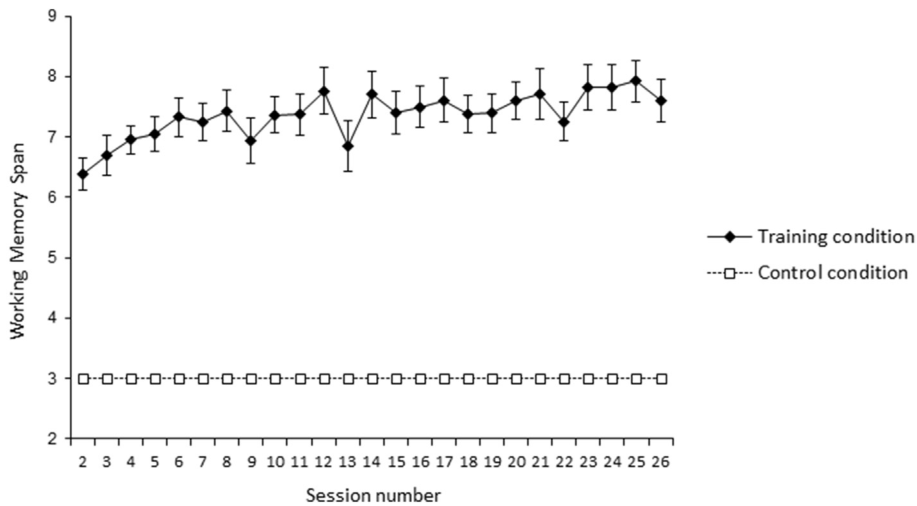

Fig. 1. The number of items that could be correctly recalled in a WM sequence at the end of each training/control session, averaged across the three training tasks (working memory span), separately for the training condition and the control condition.

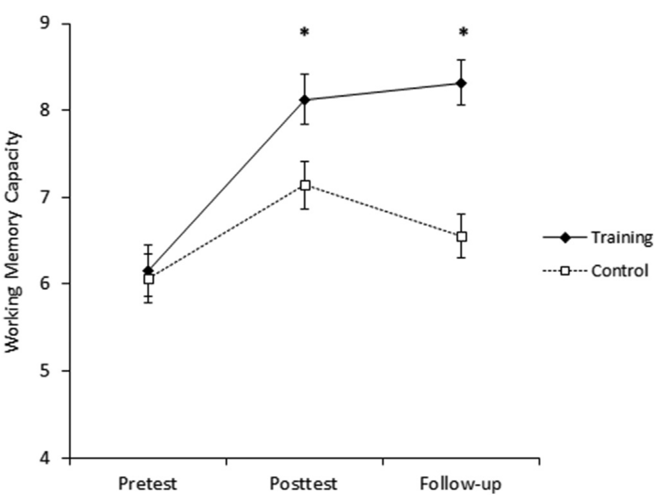

Fig. 2. Means and standard errors for WM performance at pretest, posttest and one-month follow-up, per condition. Note: * indicates significant differences at $p < 0.05$.

$\eta^2_p = 0.74$, and $F(1,25) = 6.36$, $p = 0.02$, $\eta^2_p = 0.20$, respectively. At follow-up, WM performance of the training condition was still significantly higher compared to control, $F(1,48) = 23.38$, $p < 0.001$, $\eta^2_p = 0.33$.

3.3. Eating psychopathology

For the EDE-Q, separate analyses were performed for the global EDE-Q score, and for the four separate subscales: Eating concern, shape concern, weight concern, and dietary restraint. For eating concern, results showed a significant main effect of time, $F(2,96) = 9.54$, $p < 0.001$, $\eta^2_p = 0.17$ (but no effect of condition, $F(1,48) = 0.14$, $p = 0.71$, $\eta^2_p < 0.01$), and a significant time × condition interaction, $F(2,96) = 3.08$, $p = 0.05$, $\eta^2_p = 0.06$. Follow-up analyses indicated a significant decrease in eating concern over time in the training condition, $F(2,46) = 7.47$, $p < 0.01$, $\eta^2_p = 0.25$, but not in the control condition, $F(2,50) = 2.47$, $p = 0.10$, $\eta^2_p = 0.10$ (see Table 2). Contrasts confirmed a significant decrease in the training condition from pretest to posttest, $F(1,23) = 16.26$, $p < 0.01$, $\eta^2_p = 0.41$, that was still significant at one month follow-up, $F(1,23) = 4.27$, $p = 0.05$, $\eta^2_p = 0.16$.

Similarly, analyses for the shape concern subscale also showed a significant time effect, $F(1.77, 84.88) = 10.59$, $p < 0.001$, $\eta^2_p = 0.18$ (but not of condition, $F(1,48) = 0.52$, $p = 0.48$, $\eta^2_p = 0.01$) that was qualified by a significant time × condition interaction, $F(1.77, 84.88) = 5.17$, $p = 0.01$, $\eta^2_p = 0.10$ (see Table 2).[4] Follow-up analyses indicated a significant decrease in shape concern following training, $F(2,46) = 12.68$, $p < 0.001$, $\eta^2_p = 0.36$, indicating a significant decrease in shape concern from pretest to posttest, $F(1,23) = 19.81$, $p < 0.001$, $\eta^2_p = 0.46$, and to follow-up, $F(1,23) = 12.47$, $p < 0.01$, $\eta^2_p = 0.35$. In the control condition, there was no significant change in shape concern over time, $F(2,50) = 0.65$, $p = 0.53$, $\eta^2_p = 0.03$.

A similar pattern emerged for the weight concern subscale of the EDE-Q (see Table 2), but here the interaction between time and condition did not reach significance, $F(2,96) = 2.02$, $p = 0.14$, $\eta^2_p = 0.04$. There was a significant effect of time, $F(2,96) = 5.56$, $p < 0.01$, $\eta^2_p = 0.10$, indicating an overall decrease in weight concern. The main effect of condition was not significant, $F(1,48) = 0.14$, $p = 0.71$, $\eta^2_p < 0.01$. For the dietary restraint subscale of the EDE-Q, no effects reached significance (time: $F(1.65, 79.26) = 2.10$, $p = 0.13$, $\eta^2_p = 0.04$; condition: $F(1,48) = 0.40$, $p = 0.53$, $\eta^2_p = 0.01$; time × condition: $F(1.65, 79.26) = 0.73$, $p = 0.48$, $\eta^2_p = 0.02$).[4]

This pattern of results was also illustrated in the analysis of the total EDE-Q score: In addition to a significant main effect of time, $F(1.71, 82.25) = 14.34$, $p < 0.001$, $\eta^2_p = 0.23$ (no significant effect of condition, $F(1,48) = 0.25$, $p = 0.62$, $\eta^2_p = 0.01$), the time × condition interaction was significant, $F(1.71, 82.25) = 3.99$, $p = 0.02$, $\eta^2_p = 0.08$ (see Table 2),[4] indicating an overall decrease in EDE-Q scores over time in the training condition, $F(1.50, 34.42) = 16.71$, $p < 0.001$, $\eta^2_p = 0.42$, that was significant at posttest, $F(1,23) = 23.88$, $p < 0.001$, $\eta^2_p = 0.51$, as well as at follow-up one month later, $F(1,23) = 15.53$, $p < 0.01$, $\eta^2_p = 0.40$. No effect of time emerged in the control condition, $F(2,50) = 2.13$, $p = 0.13$, $\eta^2_p = 0.08$.

3.4. Emotional and external eating

Separate analyses were performed for the three subscales of the

[4] Due to violation of the sphericity assumption, degrees of freedom were Greenhouse-Geisser adjusted.

Table 2
Means and standard deviations for the dependent measures at pretest, posttest and one-month follow-up, per condition.

	Training (N = 24)			Control (N = 26)		
	Pretest	Posttest	Follow-up	Pretest	Posttest	Follow-up
DEBQ emotional eating	2.90 (0.86)	2.66 (0.86)*	2.63 (0.98)*	2.73 (1.04)	2.80 (1.01)	2.70 (1.18)
DEBQ external eating	3.07 (0.54)	2.97 (0.51)	2.87 (0.59)	3.10 (0.63)	2.94 (0.51)	2.91 (0.64)
DEBQ dietary restraint	3.08 (0.82)	3.07 (0.66)	2.93 (0.63)	3.08 (0.78)	2.96 (0.75)	2.95 (0.89)
EDE-Q eating concern	1.10 (0.89)	0.57 (0.56)*	0.74 (0.75)*	0.96 (0.82)	0.84 (0.78)	0.79 (0.65)
EDE-Q shape concern	3.04 (1.52)	2.14 (1.28)*	2.23 (1.39)*	2.31 (1.33)	2.18 (1.30)	2.14 (1.44)
EDE-Q weight concern	2.65 (1.37)	2.10 (1.26)	2.02 (1.38)	2.22 (1.42)	2.07 (1.31)	2.08 (1.42)
EDE-Q dietary restraint	2.00 (1.41)	1.70 (0.98)	1.80 (1.17)	1.84 (1.05)	1.71 (1.03)	1.45 (1.09)
EDE-Q global	2.19 (1.01)	1.63 (0.78)*	1.70 (0.89)*	1.83 (0.98)	1.70 (0.88)	1.61 (0.97)
Food intake (kcal)	243.72 (203.60)	309.67 (289.46)	296.83 (233.39)	266.83 (138.19)	299.37 (174.61)	345.40 (348.40)
BMI (kg/m^2)	31.76 (3.79)	31.62 (3.76)	31.63 (3.84)	31.38 (3.72)	31.31 (3.94)	31.25 (3.96)

Note. * = Significantly different from pretest at $p < 0.05$.

DEBQ: emotional eating, external eating and dietary restraint. For emotional eating,[4] the significant main effect of time, $F(1.73, 83.19) = 3.60$, $p = 0.04$, $\eta^2_p = 0.07$, was qualified by a significant time × condition interaction, $F(1.73, 83.19) = 3.63$, $p = 0.04$, $\eta^2_p = 0.07$ (see Table 2). The main effect of condition was not significant, $F(1,48) < 0.01$, $p = 0.97$, $\eta^2_p < 0.01$. Follow-up analyses per condition showed a significant decrease in emotional eating over time in the training condition, $F(2,46) = 5.87$, $p < 0.01$, $\eta^2_p = 0.20$, but no effect of time in the control condition, $F(2,50) = 0.81$, $p = 0.45$, $\eta^2_p = 0.03$. Contrasts confirmed that in the training condition, emotional eating was significantly reduced at posttest, $F(1,23) = 9.35$, $p < 0.01$, $\eta^2_p = 0.29$, and at follow-up, $F(1,23) = 7.37$, $p = 0.01$, $\eta^2_p = 0.24$, compared to pretest. For external eating only the main effect of time reached significance, $F(2,96) = 7.86$, $p < 0.01$, $\eta^2_p = 0.14$, indicating a decrease in external eating across both conditions (condition: $F(1,48) = 0.01$, $p = 0.93$, $\eta^2_p < 0.01$; time × condition: $F(2,96) = 0.27$, $p = 0.77$, $\eta^2_p = 0.01$). For dietary restraint there were no significant effects (time, $F(1.70, 81.43) = 2.63$, $p = 0.09$, $\eta^2_p = 0.05$; condition, $F(1,48) = 0.02$, $p = 0.89$, $\eta^2_p < 0.01$; time × condition, $F(1.70, 81.43) = 0.66$, $p = 0.49$, $\eta^2_p = 0.01$).[4]

3.5. Food intake

Results showed no differences between the training and control condition with respect to hunger (condition: $F(1, 48) = 0.04$, $p = 0.84$, $\eta^2_p = 0.00$; time: $F(2, 96) = 1.42$, $p = 0.25$, $\eta^2_p = 0.03$; condition × time: $F(2, 96) = 0.74$, $p = 0.48$, $\eta^2_p = 0.02$) or craving (condition: $F(1, 48) = 0.01$, $p = 0.91$, $\eta^2_p = 0.00$; time: $F(2, 96) = 0.61$, $p = 0.54$, $\eta^2_p = 0.01$; condition × time: $F(2, 96) = 1.06$, $p = 0.35$, $\eta^2_p = 0.02$). Food intake during the bogus taste test showed no significant time × condition interaction, $F(1.62, 77.52) = 0.38$, $p = 0.64$, $\eta^2_p = 0.01$, nor significant main effects (time, $F(1.62, 77.52) = 2.04$, $p = 0.15$, $\eta^2_p = 0.04$; condition, $F(1,48) = 0.13$, $p = 0.72$, $\eta^2_p < 0.01$).[4]

It is important to note here that research in other areas of cognitive control training (i.e., inhibitory control training) indicates a moderating role of dietary restraint on training effects with larger effects on food intake in participants with high levels of dietary restraint (e.g., Houben & Jansen, 2011; see also; Jones et al., 2016). Theoretically, stronger cognitive control should result in greater concordance between one's current goals and behavior (Hofmann et al., 2009). Hence, it is unlikely that increasing cognitive control will lead to behavior change when there is no concurrent dieting goal present. Similarly, WM is critical for sustained attention to one's goals (Engle et al., 1999; Hofmann et al., 2012; Kane et al., 2001). Training WM should therefore translate into lower food intake especially for participants with strong dieting goals but not for participants without active dieting goals.

We therefore also a post-hoc analysis to examine the effect of baseline dietary restraint (measured with the RS), condition and their interaction on food intake at pretest, posttest and at follow-up. Restraint scores were z-standardized and entered as a continuous predictor in the ANOVA (Aiken & West, 1991). One influential outlier (Cook's > 1.5) was excluded from the analyses. For food intake at pretest, none of the effects reached significance (restraint: $F(1,45) = 0.48$, $p = 0.49$, $\eta^2_p = 0.01$; condition: $F(1,45) = 2.58$, $p = 0.12$, $\eta^2_p = 0.05$; condition × restraint: $F(1,45) = 0.23$, $p = 0.63$, $\eta^2_p = 0.01$). At posttest, the expected interaction between dietary restraint and condition was significant, $F(1,45) = 3.91$, $p = 0.05$, $\eta^2_p = 0.08$. The main effects of restraint and condition did not reach statistical significance (restraint: $F(1,45) = 0.04$, $p = 0.83$, $\eta^2_p < 0.01$; condition: $F(1,45) = 0.28$, $p = 0.60$, $\eta^2_p = 0.01$). We analyzed the effect of training separately for participants scoring high and low on the RS (respectively 1 *SD* above and 1 *SD* below the mean score; Cohen, Cohen, West, & Aiken, 2003). For participants with lower dietary restraint (−1 *SD*), there was no significant difference between training and control with respect to food intake, $F(1,45) = 1.26$, $p = 0.27$, $\eta^2_p = 0.03$, but among high restrained participants (+1 *SD*), food intake was reduced in the training condition compared to control, $F(1,45) = 3.49$, $p = 0.07$, $\eta^2_p = 0.07$ (see Fig. 3). Consumption at follow-up showed a similar pattern of results, though the interaction between dietary restraint and condition was not significant, $F(1,45) = 2.11$, $p = 0.15$, $\eta^2_p = 0.05$ (restraint: $F(1,45) = 0.43$, $p = 0.52$, $\eta^2_p = 0.01$; condition: $F(1,45) = 0.61$, $p = 0.44$, $\eta^2_p = 0.01$).

3.6. BMI

None of the effects of time or condition were significant for BMI (time: $F(1.50, 71.87) = 1.00$, $p = 0.35$, $\eta^2_p = 0.02$; condition: $F(1,48) = 0.11$, $p = 0.74$, $\eta^2_p < 0.01$; time × condition: $F(1.50, 71.87) = 0.09$, $p = 0.86$, $\eta^2_p < 0.01$),[4] indicating no significant change in body weight over time.

4. Discussion

Given the prominent role of cognitive control in self-regulatory behavior like food intake, the aim of the present study was to examine whether boosting WM via training would lead to better self-regulation in overweight individuals. As expected, participants who received WM training, relative to participants in the control condition, reported overall less eating-related concerns (especially less concern about eating and shape), and less emotional eating (but not external eating), immediately following training and at one-month follow-up. Food intake and body weight did not show an overall effect of training. Results, however, did show the expected effect of WM training on food intake in highly restrained participants, indicating that WM training increased

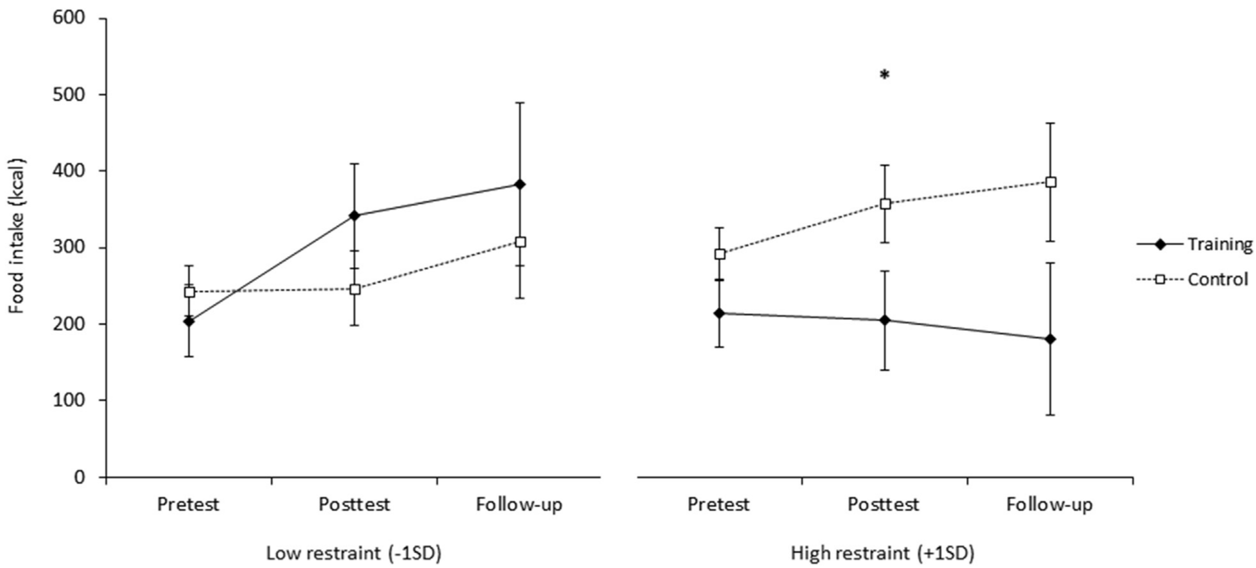

Fig. 3. Estimated marginal means (with standard errors) for caloric intake at pretest, posttest and one-month follow-up, per condition. Means are shown separately for low restrained versus highly restrained eaters (respectively 1 *SD* below or above the mean restraint score). Note: * indicates significant differences at $p < 0.05$.

correspondence between dietary goals and food intake.

WM supports self-regulation by enabling individuals to resist the attentional capture of tempting stimuli at early stages of information processing, thereby shielding self-regulatory goals from competing goals and distraction (Hofmann et al., 2012; Kane et al., 2001). As such, WM relates to the ability to regulate one's own thoughts and emotions, by focusing attention on goal-relevant information and ignoring irrelevant, distracting information (Hofmann et al., 2012). In line with this idea, WM training reduced pathological ruminative thoughts about food, weight, and body shape. This finding fits with previous research showing an association between preoccupying cognitions and WM impairment in dieters: Preoccupying thoughts about food, weight and body shape seem to consume WM resources with detrimental effects on WM performance (Green, Elliman, & Rogers, 1997; Kemps & Tiggemann, 2005; Kemps, Tiggemann, & Marshall, 2005; Vreugdenburg, Bryan, & Kemps, 2003). The present results add to these findings by demonstrating that WM training alleviates distraction by preoccupying cognitions related to dieting, weight, food, and body shape.

Further, WM training decreased self-reported emotional eating indicating that participants who received WM training were better able to regulate their emotions in other ways than by (over)eating compared to participants in the control condition. This finding is consistent with previous studies showing that individuals with higher WM capacity, as opposed to individuals with lower levels of WM, are better able to regulate emotions and appraise emotional stimuli in an unemotional manner (Schmeichel & Demaree, 2010; Schmeichel et al., 2008). It was also expected that WM training would increase the resilience to temptation by food cues. Unexpectedly, self-reported external eating was reduced over time in both conditions. Previous research, however, has indicated that the external eating subscale of the DEB-Q (but not the emotional eating subscale or the dietary restraint subscale) is affected by visceral states and may thus be a state rather than a trait measure (Evers et al., 2011). It is possible that such fluctuations in visceral states over time have caused this slight, albeit significant, decrease in external eating across conditions.

These findings thus indicate that WM training might help overweight and obese individuals to create a more healthy style of thinking about their body and eating behavior. Nevertheless, the present findings did not show the expected effects of WM training on body weight, and effects on food intake were only found among highly restrained eaters. Specifically, highly restrained eaters who received WM training showed a reduction in food intake relative to participants in the control condition. Perhaps this finding is not surprising given that high WM capacity increases the correspondence between dieting goals and eating behavior (Hofmann et al., 2007). Without (dieting) motivation, it is unlikely that cognitive control training will lead to behavioral change. Thus, the strongest effects on food intake are to be expected for participants who hold strong dietary restraint standards. It is interesting to note that training studies which have targeted a different cognitive control ability, namely response inhibition, have also shown stronger effects of inhibition training on food intake among highly restrained eaters (Houben & Jansen, 2011; Veling, Aarts, & Papies, 2011; see also; Jones et al., 2016), indicating that cognitive control training may indeed be more effective for participants with high levels of dietary restraint.

While WM training did not influence body weight in the present study, it should be noted that inhibition training has been shown to reduce both food intake (e.g., Houben & Jansen, 2011, 2015; Veling, Aarts, & Stroebe, 2013; Veling et al., 2011; Lawrence, Verbruggen, Morrison, Adams, & Chambers, 2015) and body weight (e.g., Lawrence et al., 2015; Veling, van Koningsbruggen, Aarts, & Stroebe, 2014). As such, inhibition training effects appear to be stronger and more robust compared to effects of WM training. Perhaps this is due to differences in terms of the behavioral-specificity of the training. Inhibition training has been shown to be effective only when the training is focused on strengthening inhibition over food-related responses, but not when general response inhibition is targeted during training (Allom, Mullan, & Hagger, 2016). It might therefore be interesting for future research to contrast the present findings for general WM training with more applied, diet-relevant WM training.

A limitation to the present findings is that we did not measure dieting motivations, and as explained above, it is unlikely that WM training will translate into weight loss when participants are unmotivated to lose weight. Future research should therefore screen participants for dieting motivations and test whether WM training might be more effective among overweight participants who are committed to losing weight. A second limitation is that we did not measure beliefs regarding the training in the two conditions. While both conditions received the same instructions, we cannot rule out that participants in the control condition may have become suspicious and did not believe that they were receiving WM training. It is therefore important to include measures of expectancies and beliefs regarding the training and the purpose of the study in future studies to rule out demand artefacts. Another limitation to this study concerns the fact that we did not measure transfer effects of the WM training to other non-trained tasks of executive functions (WM, task-switching, inhibition). Earlier research has shown transfer effects to non-trained tasks (see Klingberg, 2010 for a review), though the generalization to non-trained tasks has also raised considerable debate (e.g., Shipstead et al., 2012). Further, it is possible that WM training in isolation is not effective as a weight loss intervention and will only be effective in reducing weight in combination with additional (lifestyle) interventions. In this way, overweight individuals who are highly motivated to diet and who are provided with dieting strategies might profit the most from WM training that boosts self-regulatory abilities. Future research should thus further examine the effectiveness of WM training on weight in combination with other weight loss interventions.

In conclusion, WM training successfully reduced emotional eating and psychopathological eating-related concerns in a sample of overweight participants. Moreover, WM training also reduced food intake, but only among highly restrained eaters, underscoring the need to further examine the effectiveness of WM training in target groups of overweight individuals who are highly motivated to lose weight.

Acknowledgements

The authors declare that they have no conflicts of interest.

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