Executive function training with game elements for obese children: A novel treatment to enhance self-regulatory abilities for weight-control.

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Abstract

For obese children behavioural treatment results in only small changes in relative weight and frequent relapse. The current study investigated the effects of an Executive Functioning (EF) training with game-elements on weight loss maintenance in obese children, over and above the care as usual in an inpatient treatment program. Forty-four children (aged 8-14 years) who were in the final months of a 10-months inpatient treatment program in a medical paediatric centre were randomized to either the 6 week EF-training condition or to a care as usual only control group. The EF-training consisted of a 25-session training of inhibition and working memory. Treatment outcomes were child performances on cognitive tasks of inhibition and working memory and childcare worker ratings on EF-symptoms as well as weight loss maintenance after leaving the clinic. Children in the EF-training condition showed significantly more improvement than the children in the care as usual only group on the working memory task as well as on the childcare worker reports of working memory and meta-cognition. They were also more capable to maintain their weight loss until 8 weeks post-training. This study shows promising evidence for the efficacy of an EF-training as weight stabilization intervention in obese children.

Keywords: obesity, childhood, executive functioning, working memory, inhibition, cognitive training

The dramatic rise in childhood obesity in recent decades is well established (Ogden, Carrol, Curtin, Lamb, & Flegal, 2010). The major health problems and psychosocial consequences associated with this rise make the development of an effective treatment for obese children imperative. Multidimensional treatment programmes including diet, exercise and behaviour change have demonstrated their efficacy, showing positive outcomes in the short term as well as some evidence of long term maintenance of treatment effect (Luttikhuis et al., 2009). However, with severely obese children these interventions suffer from high drop-out rates or result in significant weight regain at follow-up (Levine, Ringham, Kalarchian, Wisniewski, & Marcus, 2001; Braet, Tanghe, Decaluwé, Moens, & Rosseel, 2004; Goossens, Braet, Van Vlierberghe, & Mels, 2009). More effective tailoring of treatment to underlying core deficits involved in obesity may be one promising approach for enhancing long-term weight maintenance.

Recent investigations suggest that weight gain results, at least in part, from the inability to resist temptations and inhibit automatic responses (Smith, Hay, Campbell, & Trollor, 2011). Impressive longitudinal research has shown that children between two and five years old with limited impulse control are more likely to be above average weight at the age of 5, 11 or 12 (Francis, & Susman, 2009; Graziano, Calkins, & Keane, 2010; Seeyave et al., 2009). Cross-sectional studies have found that overweight children act more on impulse than children of normal weight (Braet, Claus, Verbeken, & Van Vlierberghe, 2007; Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006) and one prospective study has shown that impulsivity hinders weight loss in therapy (Nederkoorn, Jansen, Mulkens, & Jansen, 2007).

Executive function deficits have often been proposed as underlying core deficits in impulse control (Barkley, 1997). Executive Functions (EFs) allow individuals to regulate their behaviour, thoughts and emotions, and thereby enable self-control. Weight-loss and weight-loss maintenance clearly require executive functioning. First, cognitive control such as the inhibition of automatic responses and approach behaviour is highly indicated when, for example, a child needs to resist palatable snacks. Second, adequate memory capacity (‘remembering what I was doing or what I have to do to reach a current goal’) is also seen as a necessary self-regulation ability. It is assumed that enhanced working memory may facilitate planning, monitoring, and self-instruction, which, in turn, can improve impulse control in eating behavior and consequently can help in weight management. Today, there is already some evidence that working memory is necessary for learning new skills and that sufficient working memory capacity is required to be able to transfer the new skills to a long-term behavioral repertoire (Bickel, Jarmolowicz, Mueller, Gatchalian, & McClure, 2012). Evidence in children with cognitive control deficits suggest that in general it may be that visuo-spatial working memory is more related to impulsivity/self-regulation than verbal working memory (e.g. Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005). Moreover, the two EFs are related since the cognitive capacity to inhibit automatic responses and forego temptations is limited and depends upon the deployment of sufficient working memory capacity (Hofmann, Gschwender, Friese, Wiers, & Smitt, 2008).

Advances in neuro-imaging research suggest that impairment in cognitive inhibition may indeed lead to a failure in deactivating food reward circuits and consequently facilitate overeating (Wang, Volkow, Thanos, & Fowler, 2009), resulting in a higher body mass index (BMI) (Volkow et al., 2009; Batterink, Yokum, & Stice, 2010). Conversely, higher prefrontal cortex (PFC) activation has been shown to be associated with dietary restraint (DelParigi et al., 2007) and lower BMI (Batterink et al., 2010). Similarly, behavioural studies in obese children suggest that they have problems with behavioural inhibition, as assessed with a well-validated computerized measure (Stop-signal Task; e.g. Nederkoorn et al., 2006; Verbeken, Braet, Claus, Nederkoorn, & Oosterlaan, 2009). Additionally, the association between weight control and working memory has been clearly shown in a study by Li, Dai, Jackson, and Zhang (2008) that included over 2000 children and an impressive number of covariates. This study found that compared to children of average weight, obese children performed significantly poorly on a visual spatial working memory test.

Today, treatment programmes for severely obese children already focus on improving impulse control by means of learning self-regulation skills such as self-observation, self-instruction, self-evaluation and self-reward (Duffy & Spence, 1993; Braet et al., 2004). Nevertheless, for some obese children, these vital skills seem hard to implement in daily life and are not very effective in the long term as children often relapse. It seems likely that, as long as children do not strengthen their EF, the acquired impulse self-control skills remain of limited capacity. In this context, studies on how to modify the supposed underlying core neurocognitive processes of poor impulse control could be helpful for achieving sustained weight loss. Therefore, the aim of the present study is to evaluate an intensive cognitive training programme for obese children developed specifically to strengthen their EF.

Convincing evidence has been found for the trainability of executive functions in samples of children characterized by poor executive functioning such as ADHD samples (Klingberg et al., 2005; Klingberg, Forssberg, & Westerberg, 2002; Van der Oord, Ponsioen, Geurts, Ten Brink, & Prins, in press) and samples of children with low working memory (but no ADHD) (Holmes, Gahercole, & Dunning, 2009; Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009). For example, Klingberg and colleagues (2005) showed that in a sample of children with ADHD, individually adaptable computerized working memory training not only improved the trained working memory; training effects also generalized to other non-trained executive functions such as response inhibition and complex reasoning. Further, not only did the core EFs improve but also objective behaviour; as there was a significant reduction of parent-rated inattention and hyperactivity/impulsivity symptoms and positive effects were maintained at three months follow-up. In another study with low working memory samples using the same training, not only did working memory performance improve but also relevant and objective school results, including performance in maths at 6 month's follow-up (Holmes et al., 2009), again suggesting the generalisability of results to objective behaviour.

Fewer studies have been conducted on the trainability of inhibition through cognitive training. Preschool children trained in inhibition showed a significant improvement on most of the trained tasks, but there was no generalization effect of this training to tasks measuring other executive functions like working memory (Thorell et al., 2009; White & Shah, 2006). This may have been due to the training task used, in which the level of inhibition was not adapted to the level of the child. An individually adaptable task is deemed crucial for improving executive functioning through training (Klingberg, 2010). Recently, Dovis and colleagues (2008b) have developed a format that enables individual differentiation in task difficulty in an inhibitory control task (*see* method section) by individually adapting the window of responding for each child.

Training of EF is time-consuming and needs prolonged concentration. Adding game elements to a potentially boring task may enhance the intrinsic motivation because their addition makes the task more interesting and engaging (Dovis, Van der Oord, Wiers, & Prins, 2011).Moreover, also extrinsic reinforcement contingencies have a positive impact on the task performance and motivation of all children, but this is more pronounced in children with disturbed sensitivity to rewards (Dovis et al., 2011; Haenlein & Caul, 1987; Luman, Oosterlaan, & Sergeant, 2005). Disturbed sensitivity to rewards is also found in children with obesity. Research showed that compared to average weight, obese children exhibit a hyper-responsivity to reward (Stice, Yokum, Burger, Epstein, & Small, 2011; Van den Berg et al., 2011; Verbeken, Braet, Lammertyn, Moens, & Goossens, 2012) and prefer immediate over delayed gratification (Verbeken, Braet, & Lammertyn, in prep). A feature that may increase children's motivation is adding computer game-elements to tasks. This was already suggested in children with ADHD. Parents, teachers and clinicians have reported that children with ADHD, when playing a computer game, can sustain attention, concentrate for longer periods of time and behave less impulsively (Barkley, 2006). Studies also show enhanced cognitive performance on EF-tasks when gaming elements are added to these tasks (Dovis et al., 2011; Prins, Dovis, Ponsioen, Ten Brink & Van der Oord, 2011). In the current study, we use executive functioning training to which game-elements are added, in order to optimize children's motivational state and potentially optimize their cognitive performance during training.

In sum, current treatments for childhood obesity are not always effective, and do not target possible core deficits of executive functioning. In other samples characterized by executive functioning deficits, EF-training has been shown to be effective. Therefore, the purpose of this treatment study is to evaluate the effectiveness and acceptability of a 6 week intensive cognitive EF-training programme for obese children embedded in a game-world above the effects of an intensive 10-month inpatient treatment programme. Obese children in the final months of the inpatient treatment programme were randomized to either the EF-training condition or the care-as-usual-only (CAU) condition. The training aimed to improve working memory capacity and response inhibition by directly training both core cognitive processes. Outcomes were child performances on cognitive EF-tasks and childcare worker ratings on different cognitive components of executive functioning as well as weight loss maintenance after leaving the clinic. Since this is to our knowledge the first study of the effects of EF- training in obese children, hypotheses were mainly exploratory. We expected more improvement in EF in children who were randomized to the EF- training condition than those randomized to the CAU control condition. After the end of the inpatient treatment programme, confrontation with the daily food environment at home enabled the study of long-term effects of treatment in the natural environment characterized by a high risk of relapse. We expected better weight loss maintenance at 8 and 12 weeks after leaving the clinic in those randomized to the EF-training condition than in those in the CAU condition.

Method

Participants

All overweight children in the final phase of a 10-month inpatient treatment program in a medical paediatric centre (Belgium) were invited to participate. Inclusion criteria for participation in the study were: primary obesity determined by a medical doctor of the clinic, age between 9 and 14 years, an IQ within the normal range as established with the Raven Progressive Matrices (RPM; Raven, 1938), and absence of pervasive development disorders as determined by a child psychiatrist of the clinic. Fifty children and their parents received an information letter about the research project (see Figure 1). Two children were too young (seven years old). The remaining 48 children were invited to attend an information session and were asked to participate. Parents of 44 children gave their written informed consent (age *M*=9.79, *SD*=1.04; boys: 50%)

Description of interventions

Inpatient treatment as usual. All children were morbid obese at entrance, with a minimum of 60 % overweight. The inpatient treatment consisted of a 10-month non-diet healthy lifestyle program. The aim was achieving a healthy body weight through learning the children to make healthy food choices at fixed times during the day, and providing daily physical activities. Cognitive Behavioral Techniques (CBT) are integrated as part of the program. The program is described and evaluated in detail in Braet, et al. (2004) and consists of three phases of approximately 3 months each: introduction phase, maintenance phase and termination phase. Results show that treated children lost a significant amount of overweight (with a mean loss of 50%) over the 10-month period, whereas their non-treated case-controls continued to gain weight (Braet, Tanghe, De Bode, Franckx, & Van Winckel, 2003). Results show that, in the last phase, when children were prepared for ‘returning home’ (termination phase), a mean of 10% additional weight loss is achieved and at discharge overweight is reduced to 20%-30 %. However, follow-up data showed that after leaving the clinic, children regain some of their overweight and at the 14-month follow-up, the children have about 44.1% overweight (Braet et al., 2004). At the 6 year follow-up overweight returned in to 53% (Goossens, Braet, Verbeken, Decaluwe, & Bosmans, 2011).

Executive function training. The intervention is a training of cognitive EF, embedded in a game-world (Prins, et al., 2011; Van der Oord et al., submitted). The game is called ‘Braingame Brian’, named after the main character of the game “Brian”. The game consists of 25 training sessions of about 40 minutes. Each session contains two blocks (of about 20 minutes) of two training tasks in a fixed order. The first training task is a working memory training task, and the second an inhibition training task. Over a period of 6 weeks, the child trains about 4 times a week on fixed days (Monday, Tuesday, Wednesday, Thursday). Each day, the child does not play more than one session of 40 minutes. After each block of training tasks, the difficulty level of the training task is adjusted to the child’s level of performance. To enhance motivation, each completed block of training tasks results in an elaboration of the game-world or extra powers for the main character, Brian. Before, after and in between the training tasks the child can walk around in the elaborated game-world. With his extra powers Brian can create inventions, to help people in his village, resulting in happier village-people (the more Brian helps them the more they smile). Thus, completing sessions does not only result in a more elaborated game world, more powers for Brain, but also in happier people in the village. The child plays the computer-game in the clinic after school hours. Every session a research assistant watches the child play and answers possible questions about the game.

Further, the child keeps a diary of his/her experiences with the game and receives a daily token for playing the 40-minutes session.

The Working Memory Training. The working memory training, embedded in the game world, combines different types of working memory tasks (Dovis et al., 2008a). It consists of five levels: (1) short term memory, (2) short term memory, updating and keeping information online, (3) short term memory and manipulation/updating, (4) short term memory and keeping information online during a delay and finally (5) short term memory + keeping information online + manipulation of information/ updating. In each level, the training consists of a 4 x 4 grid of equally sized rectangles (Figure 1). The rectangles light up in a random sequence. The rectangles light up for 900 *ms*, and after 500 *ms* the next rectangle lights up. After each sequence of rectangles the child has to reproduce the sequence by clicking the right rectangles in the right order with the computer mouse. The child finishes a session if it has reproduced 110 correct rectangles. Sequence length is adapted during the training to the level of the child's performance.

The Inhibition Training. This task was designed to train prepotent response inhibition (Dovis et al., 2008b). The task was visually designed as a factory, in which the child had to respond as quick and accurately as possible to an arrow on a machine. In the first block of trials, a stimulus lights up on the left or right side of the computer screen (Figure 2). If the stimulus lights up on the left, the child has to press the left button (Q key), and if the stimulus lights up on the right, the child has to press the right button (P key). It is not a matter of responding as quick as possible, but to respond within a certain range; a stimulus at the top of the screen shows the range within which the child has to respond (a bar which is colored green between 700 and 1000 *ms* and red before 700 *ms* and after 1000 *ms*). These are go trials. In the next block the stop trials are introduced: 25% of the trials are stop trials and 75% are go trials. In the stop trials, after presentation of the stimulus a stop-signal is given (a tone and the stimulus turns red). The child has to inhibit his or her ongoing response. The time a child needs to stop his/her response is the stop signal reaction time (SSRT); in the present training the SSRT time is progressively shortened; the presentation of the stop signal is adjusted to the individual level of the child. A block has to be re-played if the child has 20% errors on the go trials and more than 30% errors on the stop trials.

Selection measures

Body weight. The Body Mass Index (BMI) (weight/height^2) was determined for each child pre-training, post-training, and at 8 weeks and 12 weeks follow up. In order to make BMI comparisons between children of different ages, this study uses the adjusted BMI (actual BMI/ Percentile 50 of BMI for age and gender) x 100). The 50th percentiles of the BMI for age and gender are based on normative data (Fredriks, van Buuren, Wit, & Verloove-Vanhorick, 2002). An adjusted BMI score equal to or greater than 120% is considered as overweight (Van Winckel, & Van Mil, 2001).

Estimated IQ. The estimated IQ was based on the Raven Progressive Matrices (RPM, 1938), a widely used test of nonverbal reasoning ability. This is a multiple-choice paper and pencil test, which consists of a series of visual pattern matching. There are 60 items and these are grouped into five series of 12 items (A–E) (Raven & Court, 1998). The validity of the RPM is comparable with conventional tests. Various studies conducted among children and adolescents showed good to excellent correlation, ranging from .70 to .98, to conventional tests of intelligence such as the Wechsler Intelligence Scale for Children (Barratt, 1956).

Outcome measures

Behavior Rating Inventory of Executive Functioning [BRIEF] (Goia, Isquith, Guy, & Kenworth, 2000). Childcare workers of the clinic filled in a Dutch teacher-rated version of the BRIEF (Smidts, & Huizinga, 2009), here used as outcome measure. The 75-item BRIEF assesses cognitive components of executive functions and contains 8 subscales: inhibit, shift, emotional control, initiate, working memory, plan/organize, organization of materials and monitor. The first three scales form the “behavior regulation factor” and the remaining five the “meta-cognition index”. Also, a total score is computed. Higher scores indicate more impaired executive functioning. The BRIEF differentiates between different psychiatric disorders (Gioia, Isquith, Kenworthy, & Barton, 2002) and internal consistency and test-retest reliability are good (Smidts, & Huizinga, 2009). For this study, we used the subscales inhibition, working memory, the meta-cognition index and the total scale as dependent variables.

The Corsi Block-Tapping Task - forward and backward version (Corsi, 1972; Milner, 1971) is a nonverbal paradigm used to assess visuo-spatial working memory. This task has widely been adopted in neurpsychological research (De Renzi & Nichelli, 1975; Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000), and has been claimed to be a valid measure of the visuo-spatial sketchpad (Milner, 1971). The task consists of nine cubes that are positioned on a square board. The blocks are labeled with numbers, one through nine, that are only visible to the experimenter. The experimenter taps a sequence of blocks (starting with a sequence of 3 blocks), after which the participant has to repeat this in the same order (forward version) or in the reversed order (backward version). The same sequence length is presented three times, if the participant produces at least one of the three sequences correctly, the block sequences increase in length with one block to a maximum of eight blocks. After three errors within the same sequence length, the test is stopped. The score that is obtained for both versions is the number of correctly remembered sequences (maximum = 18).

*The Stop Task (*Logan & Cowan, 1984; Logan, Cowan, & Davis, 1984). This computer task provides an index of the child’s ability to inhibit a prepared motor response. The task was presented as a game in which the child had to perform the tasks of an air traffic controller. First, the child was taught to respond to airplanes appearing on the computer screen by pressing the response button that was on the same side as the airplane (a two-choice reaction time task). Then, the child was told to withhold responding whenever he or she saw a big white cross (the ‘stop’ trials), but otherwise to keep on responding to the planes as quickly as possible (the ‘go’ trials). Each trial began with a 350 milliseconds presentation of a fixation point (‘+’-sign presented at the centre of the screen). The presentation of the stimulus (an airplane), displayed for 1500 milliseconds then followed. The inter-trial interval was 1000 milliseconds. The stimuli appeared equally often on either side of the screen within each block. The stop signals (white crosses) appeared at the centre of the screen, c.q. on top of the airplane. They were presented equally often after left- and right-sided presentations of the stimuli. A go trial always followed a stop trial, except once in each block where two stop signals were presented in succession. The percentage of stop trials was 25%. A tracking algorithm (for a detailed description of this procedure, see Scheres et al., 2003) was applied to vary dynamically the onset of the stop-signal in response to a participant’s performance, such that it is increased after a previously unsuccessful inhibition trial (making the next stop trial less difficult). This one-up/one-down tracking procedure ensures that a child has approximately 50% chance of response inhibition and controls for difficulty level across participants (Congdon et al., 2012).

All children performed two practices and four experimental blocks (each consisting of 64 trials) on this task and were given short breaks between blocks. The main dependent variable in this task was the stop signal reaction time (SSRT). The speed of the stopping process, the SSRT cannot be observed, because the response to a stop signal is a covert one. The SSRT can be estimated using the race model (Logan et al., 1984). According to this model the probability of inhibiting the response depends on the outcome of a race between the "go" process and the stopping process. The process that finishes first wins the race. If the go process is faster than the stopping process, the child emits the response; if the stop process finishes first, the response is inhibited. The outcome of the race depends on the speed and the variability of the go process, the delay between the go stimulus and stop signal, and the speed and the variability of the stop process. SSRT can be calculated by subtracting the mean delay from the mean go signal reaction time (Scheres et al., 2003; for a more detailed description see also Oosterlaan & Sergeant, 1998).

Treatment acceptability. A diary was completed by each child during the training. The diary inquired daily about the acceptability and enjoyment of the training in general. Both closed and open-ended formats were utilized. In particular, children were asked why they kept training and how much they liked the training sessions (visual analogue scale 1-10 from not fun to very fun). The scores < 5 were recoded as Less Fun (LF) and the scores >5 were recoded as Fun (F). Furthermore, the children were asked if they tried hard enough to score well (visual analogue scale 1-5 from a little to very much). The scores < 2.5 were recoded as Little Hard (LH) and scores > 2.5 were recoded as Hard (H).

Procedure

At the start of the 'returning home phase' after 6 months of inpatient treatment and after pretest, participants ($N = 44$) were randomly assigned to either a care-as-usual only condition (CAU, $n = 22$) or to an active cognitive EF-training condition (CAU + EF-training, $n = 22$). Randomization (using random number generator by person blind to the study) was stratified on gender and age. Children who were randomized to the EF-training condition were provided with a computer. It was ensured that this computer was placed at a location in the clinic with limited distractions. Further, to limit distraction during the playing of the game children wore headphones and no contact with the Internet or other software was possible on the computer. The training time was kept equal for all children in the training condition (25 times 40 minutes) to prevent variability in exposure.

Before the beginning of the EF- training, the pre-test was conducted. The children (*n*=44) were assessed in the clinic with the Raven, the Stop task and the Corsi Block Tapping task – forward and backward (counterbalanced). Furthermore childcare workers living daily with the children were asked to complete the BRIEF-questionnaire assessing behavior of the child more or less as a stand-in parent. One week after the 6-week training, participants in both conditions and childcare workers received the same post-test measures, BMI was determined, and one week later the children left the clinic. One child was unable to complete the posttest due to illness. A follow-up was conducted 8 weeks ($n = 33$) and 12 weeks ($n = 36$) after the treatment program, children returned to the clinic for BMI determination. The assessors for the post-test and follow-up measures of our primary outcome measure BMI were blind to treatment condition. The Ethics Committee of the Ghent University approved the study.

Statistical Analyses

First, baseline differences between both the EF-training condition and the care-as-usual condition were tested using chi-square tests for categorical and ANOVAs for continuous variables. Then, a mixed factorial ANOVA model was fit to test pre-post differences between treatment conditions. We used repeated measures ANOVA with time of assessment as within factor (pre-test, post-test) and treatment condition as between factor (EF-training or CAU). Then to assess long-term effects, ANOVAs for repeated measures analyses were conducted with time as within factor (pre - post- 8-weeks follow-up – 12-weeks follow up) and condition as between factor. Effect sizes (Cohen's η^2, Cohen, 1988) are reported for all analyses. Following Cohen's guidelines effect sizes smaller than 0.06 were considered small, effect sizes between 0.06 and 0.14 were considered medium and effect sizes above 0.14 were considered large.

All data were available for 80% of the children at both follow ups. Analyses showed no significant baseline differences between participants with complete versus incomplete data at follow up. Moreover, comparison of means and covariances using Little's (1988) MCAR test revealed that data were missing completely at random ($\chi^2_{888} = 923.84$, *ns*). Therefore, missing bodyweight values were estimated using maximum likelihood estimation (Schafer, 1997) and the expectation maximization algorithm.

Results

Descriptive characteristics

ANOVAs and chi-square analyses tested for differences in demographic variables and baseline differences on outcome measures between participants of both treatment conditions (see Table 1 & 2). There were no significant differences between the two conditions on any of the variables. Outlier analysis showed no outliers on any of the dependent variables.

Evaluation of the EF-training on executive functioning

Regarding child outcome measures, for both the Corsi Block Tapping Task forward and Corsi Block Tapping Task backward there were significant interaction effects. Children in the EF-training condition showed more improvement in working memory than children in the care as usual only condition. The Stop Task did not show significant time effects nor interaction effects (see Table 3).

Time effects were observed for some childcare worker outcome measures as described in Table 3. Comparing pretest –posttest data on the BRIEF inhibition subscale did not show a significant interaction effect. However, comparing the BRIEF working memory subscale and the BRIEF meta-cognition subscale showed significant interaction effects, with medium effect sizes. A trend-significant interaction effect was found on the BRIEF-total score (*p*= .075). The scores of the children in the EF-training group remained stable, while children in the care as usual only condition showed increased deficits in working memory and meta-cognition as measured by the BRIEF.

Long-term weight control effects

Repeated measures ANOVAs were conducted on adjusted BMI with 4 time points (pretest-posttest-8 weeks follow up- 12 weeks follow up) as within group factor and treatment condition as between factor (EF-training or CAU-only). There was a significant time by condition effect for adjusted BMI qualified by a large effect size (see Table 4). Children in the EF-training condition showed better weight loss maintenance compared to the children in the CAU- only condition. Time by condition contrasts showed significant better weight loss maintenance in the EF-training group specifically from posttest to 8 weeks follow up, qualified by a large effect size. This effect decreased to a non-significant difference at the 12 weeks follow up (see also Figure 2).

Treatment acceptability.

Of the 22 children in EF training condition, 19 completed the diaries. Among these children, 94.74% tried hard to score well during the training tasks (mean VAS = 4.18, SD = .82) and 44.4% reported to experience the training sessions as fun (mean VAS = 5.95; SD = 2.72).

To explore possible gender differences and to control for possible age effects, analyses were also run with gender as between factor and age as covariate. Results were similar as described above (data available from first author).

Discussion

This study is the first evaluation of the acceptability and effectiveness of adding cognitive EF-training with game elements to a 10-month inpatient treatment programme for obese children in the 'returning home phase'. Overall, the training sessions were well tolerated and had reasonable acceptability ratings from the children. The impact of the intervention was explored on two measures of executive functioning and on weight loss and weight-loss maintenance after discharge from the clinic. Not only did the EF-training improve the children's executive functioning skills, mainly working memory, but also, compared to the children in the CAU condition, the children who completed the EF-training appeared to be more capable of maintaining their weight-loss at 8 weeks' post-training. These results are noteworthy, especially since to date evidence shows that treatment for obesity is typically followed by weight regain. Therefore, strengthening in the patient the skills that enable better long-term weight control may be the main challenge in the treatment of obesity (Latner et al., 2000).

We can speculate as to why this EF-training may have a surplus value in improving weight-loss maintenance. After leaving the clinic, the children are assumed to maintain the learned healthy lifestyle behaviours aimed at keeping a healthy weight over their lifespan. Research has provided some evidence that neurocognitive factors may be implicated in these patterns of healthy behaviour over the lifespan (Deary, Whiteman, Starr, Whalley, & Fox, 2004; Gottfredson, & Deary, 2004), especially executive functions (Hall, Elias, & Crossley, 2006). In line with previous research (e.g. Klingberg et al., 2005; Thorell et al., 2009), our data suggest that specifically *working memory* capacity can be expanded through targeted EF-training, with a significant increase in performance over 6 weeks and also notably better weight maintenance when returning home at 8 weeks' follow-up.

Other studies in ADHD samples did show generalization of the effects of WM training to other executive functions such as inhibition (Klingberg, 2010). We could not find such effects on inhibition as measured with the Stop Task. It may be that our task was not sensitive enough to measure subtle advances in inhibition abilities or that inhibition is not trainable with this programme. However, analyses of the inhibition scores of the training task indicated significant improvement in all participants from the first to the last session suggesting promising potential also for the training of inhibition (data available from first author). Therefore it seems reasonable to assume that the present 25 session-intervention may have trained both executive functions to some degree, but not enough to observe significant changes on the Stop Task.

Weight maintenance effects were no longer visible at 12 weeks' follow-up. This is in line with other training studies in children and adults showing that training-related gains were stable for a number of weeks but were lost thereafter (Holmes et al., 2010; Buschkuehl et al., 2008). It seems likely that EF functions need permanent training and therefore it would be worthwhile testing whether a reasonable schedule of "maintenance" EF-training could further help children control their weight.

The study produced an expected finding on the BRIEF- data obtained by the childcare workers. While children from the EF-training group demonstrated maintenance of their pre-test level, at post-test a significant reduction in executive functioning was observed in the CAU control group. This seems at first sight somewhat surprising. We assume that these results must be interpreted in the light of the new challenges these children were faced with during the third phase of the inpatient programme. In the final weeks of this treatment, the rigid structure is gradually attenuated and more frequent home visits are implemented, which include more food temptations to overcome. Furthermore, anticipating the departure from the clinic and the upcoming summer holiday may have caused more arousal and emotions, thereby limiting the capacity for inhibited behaviour. This in turn was reflected in the reduction of observed executive functioning in the CAU group. The maintenance of a good level of executive functioning may therefore in itself be interpreted as a good progression in the children as a result of the EF training.

There are a number of strengths and weaknesses of this study that need to be considered in interpreting it. The strengths of this study include the use of a novel intervention, based on a theoretical model of causal and maintenance mechanisms of overweight and obesity in children. Additionally, we used different cognitive tasks and ratings to assess EF-functioning. Estimates of efficacy are often based only on assessments made by individuals likely to be aware of study allocation and who are in some way or another biased (e.g. participate in the treatment), which may inflate effect sizes. In the current study large effects were found on the most objective, clinically relevant and 'blind' outcome measure: BMI. Although weight loss is the most important outcome measure, the fact that it was not possible to assess EF at follow-up must be seen as a limitation of this study. Furthermore, future research should try to unravel mechanisms of change and how this EF-training works precisely in obese samples. Dismantling research is necessary to examine whether the positive effects of the EF-training are accounted for by the working memory component, the inhibition training component or the combination of the two. We also wonder, for example, whether the trained capacity in working memory is related to weight loss through self-controlled food-intake. More specifically, we need also more data that evidenced the assumed link between working memory and weight-control behaviors, which could significantly strengthen the theoretical basis for this treatment program

This study is somewhat limited in power. Larger randomized controlled trials are worth considering. This way it would be possible to identify potential moderators in order to determine which obese children might respond best to this intervention. Nevertheless, even with only 44 inpatient and severely clinical disturbed patients and with a care-as-usual-only control group, we did find moderate to large effects on the most clinical relevant measures.

For this first study of EF-training in obese children, we deemed an active control group (e.g. non-adaptive computer tasks) as used by Klingberg et al (2005) not feasible. First, non-adaptive computer tasks contain little to no challenges for children, and would have lead to possible motivational problems. Second, the staff of the clinic anticipated that installing an equally attractive intervention for the control group could have led to organisational problems, mitigation and more drop-outs. Therefore, non-specific treatment effects in the EF-training condition (such as the attention of the childcare workers) were not controlled for. However, the significant long-term effects on weight-loss maintenance found in the EF-training condition do in fact provide indications towards true unbiased effects of the training.

In order to tackle the mentioned feasibility problems, in future research an active control group can consist of children in the residential setting playing tetris on a hand computer 40 minutes each training day. As the current sample was a clinical sample receiving inpatient treatment, the findings may not be generalizable to outpatient clinical groups. It is recommended that future research replicate the findings in an outpatient setting of obese children, for example. as homework in the termination phase of an ambulant treatment. Nowadays, most children have a computer at home where it is easier to organize the daily screen time for each child. Furthermore possible motivational problems are easier to deal with in a one-to-one situation..

In sum, the intervention tested in this study may serve as the basis for future research which examines interventions targeting overweight and obesity in children. Although treatment programmes already attest to the importance of self-regulatory *skills* for weight-control, consideration of self-regulatory *abilities* represent a fascinating new area of research. This study shows promising evidence of the efficacy of EF-training in obese children. Future studies should replicate and disentangle these positive treatment effects in order to explore specific effects for each EF-task, motivational aspects of the gaming environment and, ultimately, which EF-training component would be most effective for each specific child, with their specific executive (dis)functioning profile.

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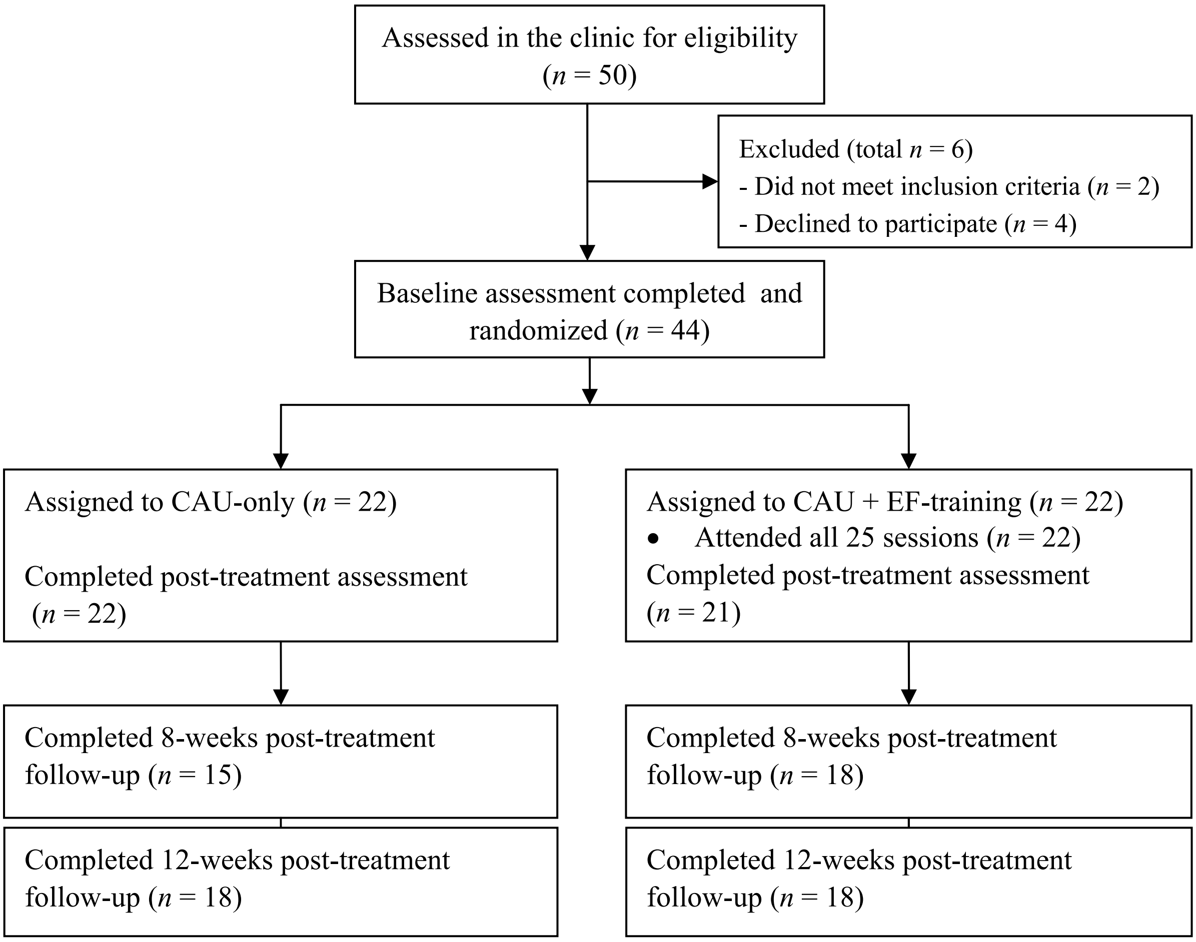
Figure 1. Flow of participants through the trial.



Note. CAU-only = care as usual only; CAU + EF-training = care as usual and the executive functioning training.

Table 1. Differences in demographic characteristics between children in the EF-training condition and the care-as-usual condition

	EF-training (*n*=22)		Care-as-usual (*n*=22)		F/χ^2
Age (*Mean/SD*)	11.50	1.60	11.41	1.93	*F*=.036
Raven (*Mean/SD*)	36.32	6.40	34.06	7.43	*F*=.960
Gender (*n*/%)					X^2=.54
Girls	11	50	9	40.9	
Boys	11	50	13	59.1	
Admission adjusted BMI *(Mean/SD)*	181.88	32.65	185.67	25.06	*F*=.186
Pre-test adjusted BMI *(Mean/SD)*	131.58	21.70	132.91	15.98	*F*=.054

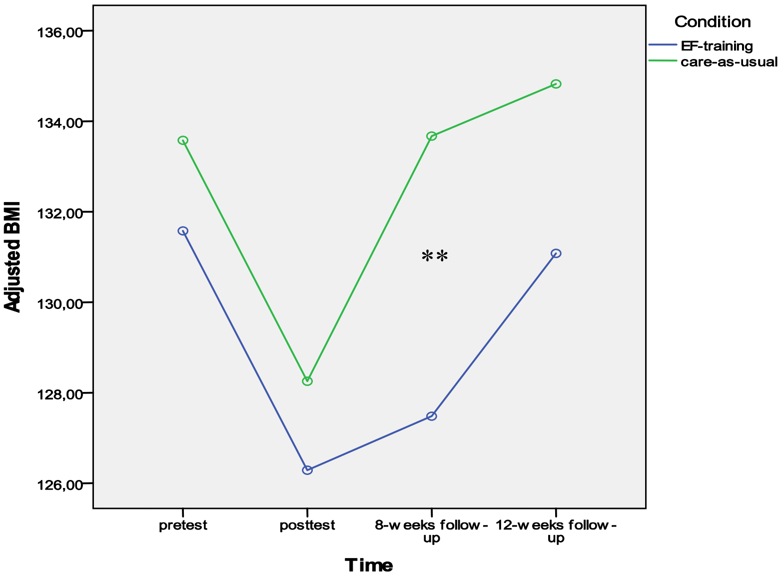
Note: Adjusted BMI: BMI adjusted for age and gender

Table 2. Baseline comparisons between children in the EF-training condition and the care-as-usual condition

	EF-training (*n*=22)		Care-as-usual (*n*=22)		*F*
	Mean	*SD*	*Mean*	*SD*	
BRIEF childcare worker					
Inhibition	7.22	6.22	7.16	4.90	.001
WM	6.57	4.62	7.42	4.48	.377
Metacog	26.82	17.85	27.87	14.42	.045
Total	44.63	27.25	46.65	23.19	.068
Corsi Block-Tapping Task					
FW	4.86	.94	5.21	1.23	1.046
BW	8.55	1.97	8.89	2.77	.221
STOP Task					
SSRT	271.26	79.33	250.04	60.73	.902

Note: BRIEF = Behavior Rating Inventory of Executive Functioning, WM = Working Memory, Metacog = Meta-cognition, FW = forwards, BW = backwards, SSRT= stop signal reaction time (msec).

Figure 2. Weight control effects for overweight children during and after and intensive treatment with or without adding an EF-training



Note: Adjusted BMI: BMI adjusted for age and gender; $**p \leq .01$

Table 3. Scores at pre-test, post-test for children in the EF-training condition and the case-as-usual condition.

	Pretest				Posttest				Time	ŋ^2	Time by Group	ŋ^2
	EF-training		Care-as-usual		EF-training		Care-as-usual					
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*				
CW-outcomes												
B-Inhibition	7.22	6.22	7.16	4.90	6.82	5.49	8.00	6.03	*F*(1,41)=.07	.00	*F*(1,41)=.57	.01
B-WM	6.57	4.62	7.42	4.48	6.25	5.29	9.62	3.65	*F*(1,41)=2.51	.06	*F*(1,41)=4.54*	.10
B-Metacog	26.82	17.85	27.87	14.42	27.26	19.47	39.99	15.84	*F*(1,41)=6.45*	.02	*F*(1,41)=5.57*	.12
B-Total	44.63	27.25	46.65	23.19	45.43	27.99	61.72	29.86	*F*(1,41)=4.12*	.09	*F*(1,41)=3.33^2	.08
Child-outcomes												
Corsi-FW	8.62	2.38	8.71	2.78	10.19	2.21	8.29	2.95	*F*(1,40)=1.88	.04	*F*(1,40)=5.75*	.13
Corsi-BW	8.62	1.99	8.81	2.71	9.71	1.71	8.62	2.46	*F*(1,40)=2.58	.06	*F*(1,40)=5.22*	.12
SSRT	261.42	55.03	257.95	68.87	268.33	105.33	269.43	67.69	*F*(1,40)=.40	.01	*F*(1,40)=.02	.00

Note: CW-outcomes: Childcare worker outcomes, B-Inhibition= Inhibition scale of the Behavior Rating Inventory of Executive Functioning, B-WM= Working Memory scale of theBehavior Rating Inventory of Executive Functioning, B-Metacog= Meta-cognition index of theBehavior Rating Inventory of Executive Functioning , B-Total= total scale of theBehavior Rating Inventory of Executive Functioning, Corsi-FW = Corsi Block Tapping Task forwards, Corsi-BW= Corsi Block Tapping Task backwards, SSRT= stop signal reaction time.

**p*≤.05, ***p*≤.01, ****p*≤.001; ^{2}trend p= .075

Table 4 Adjusted BMI at pretest, posttest and follow up for children in the EF-training condition and the care-as-usual condition.

	Pretest		**Posttest**		**8-weeks follow up**		**12-weeks follow up**		**Time** F(1.38)	**ŋ²**	**Time by condition** F(1.38)	**ŋ²**	**Time by condition contrasts** F(1,40)					
	EF-training	Care-as-usual	EF-training	Care-as-usual	EF-training	Care-as-usual	EF-training	Care-as-usual					Pre-post	ŋ²	Post-FU1	ŋ²	Post-FU2	ŋ²
	M(SD)	*M(SD)*	*M(SD)*	*M(SD)*	*M(SD)*	*M(SD)*	*M(SD)*	*M(SD)*										
Adjusted BMI	131.58 (21.70)	132.91 15.98)	126.29 (20.36)	127.69 (15.85)	127.48 (20.30)	132.73 (15.87)	131.08 (20.19)	134.11 (17.39)	30.13***	.70	3.56*	.22	.00	.00	7.75**	.16	.54	.01

Note: BMI adjusted for age and gender; FU1= 8-weeks follow up, FU2= 12-weeks follow up. **p*≤.05, ** *p*≤.01, ****p*≤.001