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Resisting food temptation: Influence of context, impulsivity and coping

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“I can resist everything, except temptation.”

Oscar Wilde

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Sandra Verbeken, september 2012

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Chapter 1

General introduction

Research aims

Look, smell,…palatable food is everywhere. Why can some resist the constant temptation while others surrender and abandon themselves to hedonic overeating and weight gain? Worldwide there is a dramatic rise in childhood obesity, both in prevalence and in severity with devastating consequences for the child's physical and psychological health. The most prominent consequence of childhood obesity seems to be the significant increased risk of remaining obese into adulthood. In children between 10 and 15 years old, 80% of the obese children were obese by age 25 (Whitaker, Wright, Pepe, Seidel, & Dietz, 1997) and similar evidence emerged in 25 longitudinal studies from around the world, as reviewed by Singh, Mulder, Twisk, van Mechelen, and Chinapaw (2008). The finding that childhood obesity is not a transient developmental phenomenon is alarming given the association between adult obesity and several morbidities and given the fact that extremely obese children may suffer cumulative effects of their "pound-years" (Xanthakos & Inge, 2007). Therefore sustained research is needed to reverse this epidemic and help these children. The impact of the environment on the obesity epidemic is well documented although this has not yet lead to vital radical (policy) changes. Far less is known about the child characteristics that are crucial to resist the overabundance. A central question is to what extent obese children are able to self-regulate their food intake. People think that they lack willpower, but do they actually have enough essential individual abilities to successfully resist food temptation? The current research aims to fill this gap by studying central parts of self-regulation like levels of impulsivity in obese versus non-obese children: their ability to resist temptation and delay gratification.

The studies outlined in this dissertation were designed to investigate four important questions. First, since impulsivity is not a unidimensional construct, but involves a number of processes like inhibitory control, resisting rewards and decision making (Nigg, 2000), it is important to distinguish between the different processes of impulsivity. For this purpose, two studies were designed to measure the different processes of impulsivity, testing the hypotheses that overweight children show poor inhibitory control and hypersensitivity to reward (Chapter 2), and show more decision making deficits (Chapter 3). Second, we investigated the assumption that overweight children are less able to delay gratification due to insufficient cognitive coping strategies and higher levels of impulsivity. Therefore, we explored the mediating role of attention strategies and impulsivity on the link between bodyweight and delay of gratification in a classic delay of gratification paradigm in and outside a food context (Chapter 4). Third, to increase our understanding on the role of individual differences in reward sensitivity in the vulnerability to overeat and becoming overweight, we followed recent developments in the obesity literature suggesting a feed forward process of obesity (Davis, Strachan, & Berkson, 2004; Lowe, Van Steenburgh, Ochner, & Coletta, 2009; Stice, Yokum, Burger, Epstein, & Small, 2011). In order to test this model in children, we investigated the association between reward sensitivity and bodyweight in children (Chapter 5). Finally, to improve our understanding of how underlying processes of controlling impulsivity can be helpful for weight control we designed a treatment study to evaluate the effectiveness of an intensive cognitive executive functioning training for obese children (Chapter 6).

This general introduction provides an overview of what is currently known about childhood obesity. In the first section of this chapter, an overall picture is presented of the definition, assessment, prevalence and consequences of childhood obesity. Next, the multifactorial etiology, including genetic-, environmental influences and child characteristics, is reviewed. Particular attention is paid to the influence of impulsivity for the development of eating behavior and overweight in children. In a second section of this chapter, an overview is presented of the empirical studies in the present doctoral dissertation.

Definition, assessment and prevalence of childhood obesity

Obesity is defined as a condition where an excess of body fat is present which implicates a considerable health risk (Wabitsch, 2000). On the other hand, overweight is simply defined as an excess of body weight relative to one's length (Field, Barnoya, & Colditz, 2002). However, because body fat is difficult and expensive to measure directly, obesity is also usually assessed as excess of body weight after adjusting for height, using the Body Mass Index (BMI, calculated as weight in kg/height in m^2). Research shows that the BMI correlates good with excess body fat as well as with health risks (Freedman, Khan, Dietz, Srinivasan, & Berenson, 2001; Mei et al., 2002). The cut off points, as defined by the World Health Organization guidelines (WHO, 2000) are BMI >25 for overweight and BMI >30 for obesity. However because children are growing and BMI is not adjusted for child length for age nor for gender differences, the BMI cannot be reliably used until adulthood. The age and gender of the child should be taken into account to evaluate a child's weight status. The Center for Disease Control and Prevention (CDC, 2000) provides percentile distributions of BMI relative to gender and age. Overweight is classified as at or above 85^{th} percentile, and obesity as at or above 95^{th} percentile of BMI. The use of 2 cutoff points emphasizes the distinctiveness of the weight groups with increasing mortality and risk of disability above this value. Recently an Expert Committee also proposes recognition of the 99^{th} percentile BMI as definition of severe childhood obesity. The marked increase in risk factor prevalence at this percentile provides clinical justification for this additional cutoff point (Barlow & Expert C., 2011).

The use of the Adjusted BMI, another way to calculate appropriate BMI comparisons between overweight children of different ages and sexes, is recommended by Goldfried, Raynor and Epstein (2002) and Jelalian and Saelens (1999). The Adjusted BMI is calculated as the percentage of overweight: (Actual BMI/percentile 50 of BMI for age and sex) X 100. The 50^{th} percentiles are based on normative data of a Dutch reference group (Frederiks, van Buren, Wit, & Verloove-Vanhorick, 2000). A percentage equal to or greater than 120% is considered as the criterion for overweight, a score equal to or greater than 140% is considered as obesity, and a score equal to or greater than 160% is considered as severe obese (Van Winckel & Van Mil, 2001).

However, in studies the terms overweight and obesity are often used interchangeable which adds to confusion both in research and clinic. In this dissertation, a clear distinction between children with overweight and obesity will be made based on the Adjusted BMI classification. The additional cutoff point for severe obesity is not included in the current studies since the Expert Committee recognizes that much additional study with larger samples is needed to better characterize this category (Barlow & Expert C., 2011). It should be noted that overweight normally includes obesity.

The prevalence of childhood obesity has risen dramatically the past few decades along with concomitant medical and psychosocial problems (Freedman, Mei, Srinivasan, Berenson, & Dietz, 2007; Lien, Henriksen, Nymoen, Wind, & Klepp, 2010; Ogden, Carrol, Curtin, Lamb, & Flegal, 2010). Nationwide 17.1% of boys and 15.5% of girls aged 1 to 19 years are obese as defined by using a BMI-for-age ≥ 95^{th} percentile (Ogden, Carroll, & Flegal, 2008). Over 12 million US children are now obese. The National Health and Nutrition Examination Survey (NHANES) 2003-2004 data reported a three-fold rise in obese adolescents and a four-fold rise in obese children ages 6-11 years since 1970. International surveillance data suggests that a similar but delayed worldwide epidemic of pediatric obesity is following US trends (Orsi, Hale, & Lynch, 2011). Of particular concern are recent findings that the severity of overweight among children is also much greater (Freedman et al., 2006; Koebnick et al., 2010). As the prevalence of childhood obesity continues to worsen, the duration of excess adiposity is therefore expected to increase in future adult generations.

Etiology and maintenance of childhood obesity

In what follows we review some recent research advances that indicate factors influencing childhood overweight and obesity, and follow thereby an ecological model that acknowledges multicausal interaction of hereditary, environmental and child characteristics (Harrison et al., 2011). Without denying the importance of energy-expenditure, the review will mainly focus on the energy-intake side of the energy balance, in other words the focus is on factors which may interfere with the regulation of the food-intake.

Hereditary influences

Recent data from twins, adopted children, and population studies indicate that about 30% to 77% of BMI and obesity-related phenotypes such as fat mass, skinfold thickness, and adipose tissue distribution is heritable (Rankinen et al., 2006; Wardle, Carnell, Haworth, & Plomin, 2008). Seldom obesity is caused by the mutation in one gene; mostly it is attributed to multiple genes. However, the rapid increase of obesity over the past four decades underscores the complex role of socioeconomic, geographic and environmental factors which influence inherited components of body weight. Susceptibility genes exert their influence in a highly obesigenic environment, leaving some people more susceptible to these changes in the environment, and thus more prone to obesity than others (Buttle et al., 2006; Orsi et al., 2011).

Environmental influences

The impact of the western food-environment on the recent boom of childhood obesity is well-established. A greater food palatability, a wide variety of foods, the high and easy availability (in the home and workplace), the attractive stimulation by advertising, the food saliency, the larger portion sizes, and a higher energy density of prepared food, all contribute to an increased exposure and enhanced reinforcement by the reward value of foods encouraging a shift in children's food choices towards more energy-dense refined foods (Rolls, 2011).

The Ecological Systems Theory (EST) is an interesting framework that captures the multiple interacting contexts to place a child at risk for overweight (Davison & Birch, 2001). The theory considers an ecological niche in which the child is located to understand the development of overweight. For most children, the home-environment is the central socialization context, and parental obesity, feeding practices and household routines influence the risk of obesity in offspring. Parental obesity is one of the strongest risk factors for childhood obesity, especially in the mother (Whitaker, Jarvis, Beeken, Boniface, & Wardle, 2011). It was suggested that genetic vulnerable parents might create more ‘obesigenic environments’ for their offspring (Francis & Birch, 2005). Furthermore, parents adopt different feeding styles and strategies toward their offspring and it is reasonable to suggest that the way parents feed their children may be related to a child’s eating behavior and weight status. Many studies suggest that parental report of restrictive feeding is paradoxically associated with increased child BMI (Fisher & Birch, 2002; Johnson & Birch, 1994; Moens, Braet, & Soetens, 2007). Researchers often speculate that restriction diminishes children’s self-regulation abilities. Too much control over a child’s food choices prevents the child of responding to internal signals of hunger and satiety. However other studies contradict this ‘overcontrol’ hypothesis. Based on observations at mealtime a lack of parental control instead of self-reported overcontrolling over children’s nutrition emerged within overweight families (Moens, et al., 2007).

Additionally, studies on household routines showed that preschool children receiving a family evening meal, adequate sleep, and being exposed to limited screens have a 40% lower prevalence of obesity compared to children with none of these routines. (Anderson & Whitaker, 2009). The role of childhood television viewing on obesity is well documented (Hancox & Poulton, 2006). Several potential mechanisms have been proposed: television can be associated with slower metabolic rate, less physical activity, more exposure to attractive food advertising leading to greater energy intake and combined eating while viewing leading to greater energy intake (Jordan & Robinson, 2008). Not surprisingly, reducing screen time (total viewing including computer, video games, and TV) in overweight schoolchildren was linked to weight loss (Epstein et al., 2000) and should be certainly also considered as important factor in prevention programs.

Also low SES predicts pediatric obesity, but the relationship is highly complex. Many of the enviromental risks for obesity disproportionately impact children of lower SES: access to healthy foods, safe housing and safe places to play (Lieb, Snow, & DeBoer, 2009), making it difficult to sort out the effects of SES alone (Spruijt-Metz, 2011).

However much of this research on environmental influences is correlational, and direction of effects cannot be determined. For example, it is likely that the parent-child relationship is bidirectional, with children’s self-regulatory deficits altering parent’ feeding practices and parents’ feeding practices paradoxically decrease children’ s self-regulation. Many young children can self-regulate their eating in a 24h span by using internal signals to decide the food amount they will consume based on energy needs (e.g., Birch & Deysher, 1985), but individual differences exist (Tan & Holub, 2011). Furthermore, the observation that not everyone in the same high rewarding food-environment becomes overweight stresses also at the role of interacting child characteristics.

Child characteristics

Which child characteristics are crucial to resist the current food-overabundance? It is a major challenge for obesity research to identify the factors that foster one’s proneness to weight gain, or buffer another from the same fate. The ability to resist a hedonic impulse and choose to go for the more advantageous alternative and long-term standards depends upon one’s cognitive control ability challenged or sometimes overruled by impulsivity. There has been considerable confusion about the construct of impulsivity, both theoretically and empirically over the past decade. Nevertheless, most would agree now that impulsivity includes a composite of neurobehavioural processes influenced by biological and environmental forces. The current review focuses on three neurobehavioral processes that have been most consistently implicated in obesity and overeating: inhibitory control, reward processes and decision making (Appelhans, Whited, Kristin, & Pagoto, 2011). Further, the behavioural manifestation from these brain functions - self-regulation, and the ability to delay gratification - will be discussed in relationship to obesity.

Impulsivity

Many studies have already demonstrated a relation between impulsive behaviour and childhood overweight. Cross-sectional studies found that a subgroup of overweight children demonstrated an impulsivity prone personality, that this subgroup act more on impulse than normal weight children, and that impulsivity hinders weight loss in therapy (Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006; Nederkoorn, Jansen, Mulkens, & Jansen, 2007; but Pauli-Pott et al., 2010). Overweight children starting treatment for obesity in a paediatric centre were found to display personality traits frequently associated with impulsive behaviour. They were found to be more impulsive and hyperactive and less attentive compared to control children who showed more reflectivity (Braet, Claus, Verbeken, & Van Vlierberghe, 2007).

Indeed, there is a remarkable similarity between impulsive behaviour and obesogenic eating patterns such as the inability to eat on a regular basis, to postpone in-betweens and to resist urges to indulge in snacks (Lyke & Spinella, 2004). However, impulsivity is a multidimensional construct that has been defined and measured in many ways. Overall there is an agreement of two main aspects of impulsivity: reward related impulsivity refers to an individual’s variation in sensitivity to rewarding stimuli in the environment while insufficient inhibitory control reflects the tendency to react without consideration of the consequences of behaviour (Dawe et al., 2004; Solanto et al., 2001; Sonuga-Barke, 2002). These two aspects are in line with more recent dual-process models of self-regulation stating that behaviour is determined by two qualitatively different types of processes. A bottom up fast-acting “reward system or impulsive system or hot system” appraises stimuli automatically in terms of affective and motivational significance and predisposes individuals to either approach or avoid a stimulus (e.g. Starck & Deutsch, 2004). On the other hand, behaviour is also guided by long-term goals and personal standards that reside in a top down slow-acting, controlled “inhibitory system or reflective system or cold system” (e.g. Starck & Deutsch, 2004). On a neurological level both processes are reflected in different brain regions: (1) “Drive regions or reward circuits” (limbic system and ventral striatum) processing immediate rewards, and (2) “control regions” (PFC) processing long term goals (McClure et al., 2004; Sommerville & Casey, 2010). This theoretical model has been implicated in obesity research and in adults preliminary evidence exist for obese persons showing high automatic affective reactions toward tasty food combined with a weak inhibitory control over this motivational tendency which leads to difficulties in resisting the motivational drive to indulge these types of food (Appelhans, 2009; Davis, Levitan, Smith, Tweed, & Curtis, 2006; Dawe & Loxton, 2004).

Until now, mostly self-report measures of impulsivity are used to assess the impulsive personality or the sensitivity to reward. The UPPS impulsive Behaviour Scale (Whiteside and Lynam, 2001, 2003) is made up of four separate personality facets linked to impulsivity, each facet is supported by a specific cerebral network (Van der Linden, Rochat, & Billieux, 2006). To measure individual differences in reward processes the BIS/BAS scale (Carver & White, 1994) is frequently used. The scale reflects the general conceptualisation of BIS and BAS dimensions from Gray's Reward Sensitivity Theory (RST). However, self-report measures are susceptible to demand characteristics and it was assumed that impulsive individuals may give less considerations to responses than the non-impulsive individual (Verdejo-Garcia et al., 2008).

Laboratory measures of impulsivity have been developed in an effort to overcome these problems. These measures directly assess neurocognitive processes. Also here, we can distinguish between (1) measures of inhibitory control wherein three different forms of executive inhibition can be discerned: prepotent inhibition, sustained inhibition and interference control (Barkley, 1997; Nigg, 2000), as measured for example with the Stop Signal test (Logan & Cowan, 1984), Circle Drawing Task (Bachorowski & Newman, 1985, 1990), and Opposite Worlds Task (Manly et al., 2001). (2) Measures of sensitivity for reward: within the reward-directed paradigms, the focus is on evaluating motivated inhibition of behaviour or thought. Here, the study of reward processes operating in different incentive contexts has been performed in several ways. The delay aversion model (Sonuga-Barke, 1994) is one approach, which conceptualizes impulsive behaviour within a motivational framework. This model views an impulsive choice as the preference for a small immediate reward over a large delayed reward, because the child does not tolerate the delay necessary for the larger reward (Dougherty et al., 2003; Nichols & Waschbusch, 2004). Also the Maudsley Index of Childhood Delay Aversion taps this dimension. Finally, (3) impulsive decision making: another way to study motivational processes is by measuring 'gambling' behaviour, which is behaviour driven by the strong short-term effects of immediate reward, neglecting the negative long-term effects of an action. These measures include the Door Opening Task (Daugherty & Quay, 1991) and the Iowa gambling Task (IGT) (Bechara et al., 1994).

Until now, no comprehensive impulsivity research in overweight children has been conducted. Chapter 2 and 3 is designed to improve upon previous research by using an extensive battery of impulsivity measurements that covers the major inhibitory and reward processes. As a result, this type of research may help to understand what specific process hinders self-regulation in overweight children. Based on the few studies that have been conducted before in the field of childhood obesity, we hypothesize that the overweight group will exhibit greater impulsive responding than the control group across all tasks: they will show less executive inhibitory control, prefer to wait less, be more sensitive to reward and keep gambling longer than children with normal weight, thereby showing deficits in both the hot and cool system.

Defining inhibitory control

As depicted in figure 1 inhibitory control is one important factor of impulsivity and a research gap in childhood obesity research. Inhibitory control refers to processes for intentional control in the service of higher order or longer term goals (e.g. resisting temptations, delaying gratification), and is believed to be at the heart of impulsive behaviour (Barkley, 1997; Nigg, 2000). Inhibitory control contributes to the self-regulation of behaviour and creates a delay in which one can think before acting. It becomes particularly manifest in people's restraint standards, in other words if one apply long term standards about how behaviour should be regulated (e.g. standards for keeping a healthy diet). The fact that we can restrain our self in the presence of palatable food while still finding this food very tempting indicates that the capacity to resist from eating is a distinct process from food reward. This suggests that inhibiting food intake is not simply a matter of reducing the drive to eat: it involves active self-regulation of behaviour despite the strong drive to eat (Appelhans et al., 2011).

Behavioural studies in obese children suggest that compared to average weight children, obese children have problems with behavioural inhibition, as assessed with a well-validated computerized measure to assess behavioural inhibition: the Stop Signal Task (Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006). Research in adults also demonstrate that poor inhibitory control is associated with higher body weight (Gueirrieri, Nederkoorn, & Jansen, 2008; Nederkoorn, Guerrieri, Havermans, Roefs, & Jansen, 2009) and leads to more failure in resisting food temptations (Gueirrieri et al., 2007).

Inhibitory control is linked with specific executive functions situated in brain region's like the prefrontal cortex (PFC). The PFC prevents us from impulsive responding to our environment with automatic emotionally driven behaviours and fosters goal directed behaviour (Miller & Cohen, 2001). Advances in neuro-imaging research suggest indeed a role of the PFC in inhibiting reward-driven behaviour. Small, Zatorre, Dagher, Evans, and Jones-Gottman (2001) found an increased PFC activation in chocolate-lovers with a decreased motivation to consume additional pieces of chocolate. Others showed that impairment in inhibitory control may indeed lead to a failure in deactivating food reward circuits and consequently may facilitate overeating (Wang, Volkow, Thanos, & Fowler, 2009) and result in a higher BMI (Volkow et al., 2009; Batterink, Yokum, & Stice, 2010). Conversely, higher PFC activation was shown to be associated with dietary restraint (DelParigi et al., 2007) and lower BMI (Batterink et al., 2010). In contrast, a recent study reported that obese children (10 – 18 years) show higher activation of the PFC compared to average weight children in response to food images, suggesting increased inhibitory control in the obese group (Davids et al., 2010). The higher PFC activation was specific to food-stimuli, as it was not found for other pleasant rewards. The authors attribute this finding to the fact that food stimuli constitute a higher conflict situation in obese children requiring a stronger top down control to resist food temptation. The evidence suggests that inhibitory control may be a critical child factor in the vulnerability for overeating and becoming obese.

Inhibitory control occurs in relation to other executive functions, including attention and working memory, in a way that these functions are mechanism that helps arbitrating between competing demands by the outside world and from intern goals (Berger, Kofman, Livneh, & Henik, 2007; Fonagy & Target, 2002; Posner & Rothbart, 2000; Ruff & Rothbart, 1996). Children low in inhibitory control may be less able to direct their attention away from temptations or may use different strategies to redirect their attention (Mischel, Shoda, & Rodriguez, 1989). In the theoretical framework of self-regulation proposed by Mischel and Ayduk (2004), the cognitive-attention control strategies that are essential in the pursuit of delayed rewards depend upon the balanced interactions between a cognitive ‘cool’ inhibitory system and an emotional ’hot’ reward system. When the inhibitory system, is able to override the reward system, the individual will generate cognitive-attention cooling strategies, and thus be less controlled by whatever is salient in the immediate field of attention (Metcalfe & Mischel, 1999; Rodriguez, Mischel, & Shoda, 1989). The suggestion that the attentional control strategies may be important in the extent to which food stimuli overstimulates food intake was also already confirmed in neuro-imaging research. Grabenhorst and Rolls (2008) showed that selective attention to the rewarding properties of food stimuli versus the more abstract properties of food stimuli activates different brain areas. The authors suggest that distraction from food stimuli or drawing attention to the non-rewarding properties such as shape or nutritional value can reduce the activation in the reward circuits by the food (Rolls, 2011). Additionally, a recent study in healthy adults showed that attentional bias to food cues was related to inability to control impulsive responding and to more external eating, suggesting that impulsive individuals are more likely to allocate attention to reward stimuli than non-impulsive individuals (Hou, Mogg, Bradley, Peveler and Roefs, 2011). Research using ecological valid paradigms placing the child in the rewarding food context are needed to make a stronger case for the role of cognitive attentional strategies in the inhibition of overeating. Chapter 4. was designed to examine these strategies in overweight children during a delay task in food and non-food context.

Inhibitory control is also closely related to and depends upon working memory capacity (Hester & Garavan, 2005). The ability to maintain items actively in working memory while resisting interference is considered to be the essential determinant of working memory capacity. Furthermore, working memory is often regarded as a more fundamental function, underlying other executive functions (Engle et al., 1999; Kane and Engle, 2003; Klingberg et al., 2005). The association between weight control and working memory was clearly shown in a study by Li, Dai, Jackson, and Zhang (2008) that included over 2000 children and an impressive number of covariates. The findings indicate that compared to average weight children, obese children performed significantly poorly on a visual spatial working memory test. Otherwise it was suggested that dietary breakdown due to cognitive overload or stress may result from the fact that such challenges monopolize the working memory resources necessary to maintain inhibitory control over eating (Mann & Ward, 2004).

Inhibitory control begins to develop at preschool age and continues to improve throughout childhood and into early adulthood. Right from the early infancy individual differences in inhibitory control capability can be observed (Rothbart et al., 1992), with a significant stability across time (Shoda et al., 1990). The prefrontal cortex is among the last brain regions to mature (Casey et al., 2000). A recent theoretical model further states that in adolescents there is an uneven neurobiological development of brain regions: inhibitory processes show a protracted linear development throughout adolescence while reward-related processes appear to develop in a curvilinear manner with a peak during adolescence, leaving the adolescent with highly sensitive, reward-driven processes that can only be moderately regulated by external factors, experience or gradually developing inhibitory processes. This way adolescents are particularly susceptible to appetitive cues since there ability to inhibit the automatic reward drive is much weaker (see figure 2) (for a review, see Hardin, 2010; Casey, Jones, & Hare, 2008; Bruce et al., 2011; Sommerville et al., 2010). Moreover, since adolescence is also a critical periods for the development of obesity (Dietz, 1994; Dietz, 2004) it is very relevant to study self-regulation processes in adolescents. To contribute to this relevance all study samples in this dissertation cover the transition from childhood to adolescence.

Next to the considerable variability between individuals in inhibitory control there is also variability within individuals (Chambers et al., 2009). Even brief periods of practice on inhibitory control make individuals perform better and produce functional changes in the brain areas that underlie performance, suggesting rapid neural plasticity (Kelley et al., 2006). These results are clearly of clinical significance for prevention and treatment (see further). Therefore in the final chapter of this dissertation we aimed to examine the effectiveness of a cognitive training on weight control in overweight children.

Guerrieri et al., (2008) hypothesize based on their findings that whereas the interaction with inhibitory control will become visible only after a prolonged period of overeating and/or gaining weight, possibly the other mechanism, namely reward sensitivity, is the basic mechanism that can affect people to overeat in an obesogenic environment. This is in line with the view of Rollins, Dearing, and Epstein (2010) that reward sensitivity may be a more powerful independent predictor of food intake than ability to inhibit.

Defining reward processes

In the presence of rewarding stimuli it is reasonable to propose that individual differences in reward sensitivity (RS) or the tendency to engage in motivated approach behavior may be one of the individual factors that contribute to a vulnerability to overeat and become obese (Small, 2009). As indicated in brain imaging studies, this reflects differences in the meso-limbic network (Berthoud & Morrison, 2008).

Obese individuals find palatable foods more rewarding than non-obese (McGloin et al., 2002; Nicklas, Yang, Baranowski, Zakeri, & Berenson, 2003; Rissanen et al., 2002), but it remains unclear *why* this is so (Lowe et al., 2009). At least two models propose an explanation. (A) According to Gray's Reinforcement Sensitivity Theory (RST, Gray, 1994; Gray & McNaughton, 2000; McNaughton & Corr, 2004), reward sensitivity (RS) reflects functional outcomes of the behavioral activation system (BAS), which is conceptualized as a motivational system that is sensitive to signals of reward and that is important for engaging behavior toward a reward. The BAS is organized primarily by the dopaminergic neurotransmitter system (Di Chiara, 1995; Gray & McNaughton, 2000; Pickering & Gray, 1999). Brain dopamine plays an important role in reinforcement of response habits and conditioned preferences (Wise, 2008). Additionally, it has been postulated that dopamine (DA) deregulation contributes to development of obesity and binge eating (Davis et al., 2008; Davis et al., 2009; Geiger et al., 2009; Mathes et al., 2010). (B) The dual vulnerability theory of dopamine deregulation presents two opposing hypotheses as why RS leads to DA deregulation (Davis et al., 2008; Stice, Spoor, Janet, & Zald, 2009). The first hypothesis, the hyper-responsiveness model, states that hypersensitivity to reward due to increased dopaminergic functioning, may motivate individuals to seek rewarding stimuli simply because the reinforcement value of the reward is so great (Davis, Strachan, & Berkson, 2004; Davis et al., 2008; Dawe & Loxton, 2004). Alternatively, Reward Deficiency Syndrome (RDS), states that individuals with relative insensitivity to reward because of low dopaminergic functioning, seek more rewarding substances to increase endogenous dopamine levels and improve mood (Blum, et al., 2000; Noble et al. 1997; Spitz et al., 2000; Wang, Volkow, & Fowler, 2002; Volkow, Wang, Fowler, & Telang, 2008).

The **hyper-responsiveness model** fits with the clinical feeling that enhanced responsiveness of reward systems to palatable food would result in overeating and weight gain. The model was also supported by experimental research in healthy volunteers. Guerrieri, Nederkoorn, and Jansen (2008) identified high and low RS-children based on their performance on a behavioural task and measured their caloric intake via a Bogus Taste Test. Interestingly, when varied food was offered, the high RS children ingested significantly more calories than their less RS counterparts. When monotonous food was offered, RS did not really affect caloric intake. This finding was further supported in adults by Blundell et al. (2005). They showed that in a large group of individuals who habitually consume a high-fat diet, a strong hedonic attraction to palatable foods and to eating is an important factor to differentiate between individuals who gained weight and those who remained lean.

Similarly imaging research in adults found that RS as measured with the BIS/BAS self-report scale (Carver & White, 1994), significantly predicted activation to appetizing foods (relative to bland foods) in brain areas implicated in food reward (Beaver et al., 2006; Schienle, Schäfer, Hermann, & Vaitl, 2009). Additionally, fMRI data proved that obese children and adolescents versus their lean counterparts showed greater activation in brain reward areas in response to visual food stimuli (Bruce et al., 2010; Batterink, Yokum, & Stice, 2010) and in response to food consumption (Stice, Spoor, Bohan, & Small, 2008). Especially relevant is the fact that it was previously shown in mice that activation of these brain areas produces overeating and increases the preference for foods high in fat and sugar (Kelley, 2004).

The assumed initial vulnerability that increases risk for obesity may be a generalized hyper-responsiveness to various reward types as opposed to a more focal deficit within the eating domain (Stice, Yokum, Burger, Epstein, & Small, 2011). Stice et al. (2011) found that adolescents at high-risk versus low-risk for future obesity by virtue of parental obesity not only showed greater activation in reward regions in response to palatable food, but also to monetary reward. Similarly, compared to lean individuals, obese children continue to play a rewarded computer game longer (Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006; Verbeken, Braet, Claus, Nederkoorn, & Oosterlaan, 2009) and report higher generalized RS (Davis et al., 2004; Kane, Loxton, Staiger, & Dawe, 2003; Mobbs, Crépin, Thiéry, Golay, & Van der Linden, 2010). Furthermore, longitudinal research evidenced that children with higher generalized RS (measured with a self-regulation task) were more likely to be classified as overweight or obese several years later (Francis & Susman, 2009; Graziano, Calkins, Keane, 2009; Seeyave et al., 2010). However the paradigm used in these longitudinal studies provides a mixed measure of RS and inhibitory control, and therefore it is impossible to rule out the unique predictive value of RS.

The second hypothesis, here labeled as **Reward Deficiency Syndrome** (RDS) rests on the premise that palatable food can be used in the same manner as addictive drugs, and that risk for its overuse should therefore be greater among those at the anhedonic end of the RS continuum (Davis et al. 2004). Imaging data proved that compared to normal-weight children, obese children showed indeed a weaker appetitive or approach reaction in response to food cues (Davids et al., 2010) and to food receipt (Stice et al., 2008), as indicated by their significant lower activation of a part of the dopaminergic reward system. These findings imply that food may be experienced as less rewarding by obese children.To our knowledge, there is until now no evidence for this model based on behavioural measures or self-report data in children. Few studies in adults and adolescents found evidence for the relation between reduced self-reported RS and uncontrolled eating, emotional eating, binge eating, and obesity (Davis et al., 2004; Davis & Fox, 2008; Goldfield et al., 2010; Keränen, Rasinaho, Hakko, Savolainen, & Lindeman, 2010; Pagoto, Spring, Cook, McChargue, & Sneider 2006).

These seemingly opposing data leads to the suggestion that both must not be contradictory but can reflect a **dynamic vulnerability (DV) model** for obesity that may evolve and change over time in response to overeating (Stice et al., 2011). The DV-model states that it is possible that heightened generalized RS is an initial risk factor for excessive food intake among normal weight individuals resulting in a positive energy balance and weight gain.

However, the excessive food-intake can overload the DA system in such a way that it reduces the DA activity. Hence, excessive overeating is assumed in the long run to lead to an insensitive reward system which may drive further overeating to reach an acceptable level of hedonic satisfaction (Davis, et al., 2004; Lowe et al, 2009; Stice et al.,2011). This DV-model was already evidenced in adults showing a curvi-linear relationship between BMI and RS, based on self-report (Davis & Fox, 2008), but has never been examined in children. Although, since the decision-making process regarding food choices depends upon individual differences in reward sensitivity, such knowledge seems pivotal in unraveling differential mechanisms leading to overeating but also in tailoring early intervention. Chapter 5 was designed to fill this gap by analysing the association between self-reported RS and bodyweight in children. Based on the findings of Davis and Fox (2008), it was expected to find a positive association between self-reported RS and BMI, which will change to a negative association among children with obesity.

Defining decision-making

As can be seen in Figure A, a third process seems at play besides inhibitory control and reward sensitivity. After the reward evaluation of food, a decision has to be made regarding whether to seek for and consume the reward or not. The Iowa Gambling Task (IGT) has proved to be a well-validated measure for assessing the decision-making processes involved when people are exposed to the temptation of immediate big rewards (Bechara, Damasio, Damasio, & Anderson, 1994). The task was originally developed to detect decision-making deficits in patients with ventromedial prefrontal cortex (VMPFC) lesions, and it mimics real-life decision-making in the way it manipulates reward, punishment, and uncertainty of outcomes (Bechara, 2004; Crone & van der Molen, 2004). In this task, individuals choose cards that result in monetary gains or losses from four decks. Cards in two decks sometimes yield large immediate gains but produce long-term losses, whereas cards in the other two decks produce smaller immediate rewards but have the potential for long-term gain. The task is conceptually similar to delay discounting tasks in that it taps in to a decision-making process in which immediate rewards are favoured over more advantageous future rewards. Importantly, within this paradigm the choice is between an immediate certain reward and a future probable reward. This future uncertainty is relevant for a lot of health behaviours: an individual knows very well what to refrain from in the present, but doesn't know for sure this effort will lead to better health in the future (Madden, Petry, & Johnson, 2009).

Studies analysing decision-making processes have revealed that at least two different reward processes might account for 'myopia' for the future: hypersensitivity to reward or insensitivity to the future (Bechara et al, 1994). To examine which process underlies this 'myopia' for the future a second experiment is needed in which the schedules of reward and punishment are reversed (Bechara, Tranel, & Damasio, 2000). *Insensitivity to the future* can be concluded when people specifically make in the reversed version choices that result in immediate low punishment but due to small delayed rewards, in larger losses in the long run, compared with the choices that result in high immediate punishment but a net gain in the long run due to high delayed rewards. The opposite choice pattern indicates a *reward-focused strategy*.

Apart from patients with VMPFC lesion, greater decision-making impairments were found in people with a diversity of impulse-control problems, such as addictive disorders, borderline personality disorder, attention deficit disorder, behaviour disorder, and eating disorders, suggesting all that poor self-regulation leads to increased psychopathology (Bazanis et al., 2002;

Bechara & Damasio, 2002; Boeka & Lokken, 2006; Cavedini et al., 2004; Ernst et al., 2003; Goudriaan, Oosterlaan, de Beurs, & van den Brink, 2006; Grant, Contoreggi, & London, 2000; Malloy-Diniz, Fuentes, Leite, Correa, & Bechara, 2007).

There is an intuitive link between weight control and impulsive decision making. If individuals want to go for long term weight control and the large benefit of improved health, they have to forego immediately rewarding energy dense food. Surprisingly, a decision-making paradigm has seldom been applied in overweight research. Two studies applied the IGT and both showed evidence for a decision-making deficit in above-average weight adults (Davis, Levitan, Muglia, Bewell, & Kennedy, 2004; Pignatti et al., 2006), demonstrating the relevance of this approach for understanding failures in the regulation of eating behaviour. However, this evidence is inconclusive because both of the available studies examined the performance of above-average weight individuals using only the standard version of the IGT, not the reversed version. Moreover, although younger people appear to experience lower levels of self-regulation skills in general (Lyke & Spinella, 2004) to date there has been no systematic examination of decision-making abilities in above-average weight children.

Since *hypersensitivity to reward* makes it hard to resist high rewarding palatable food, it seems the most obvious account for the possible decision-making deficits in above-average weight people (Davis et al., 2007). However, research has shown evidence that reduced dopaminergic activity (decreased sensitivity to natural rewards, RDS) is linked to poor decision-making abilities on the IGT, characterised by *future insensitivity* (Sevy et al., 2006). This hypothesis suggests that obese may also show poor decision-making abilities, characterised by more *future insensitivity*. RDS may destabilise cognitive representations, resulting in a dominant attention for more recent events as compared to more distant events (de Wit, Enggasser, & Richards, 2002). In this way one can predict that a person would be less likely to be motivated to abstain from eating because the long-term negative consequences of overeating are less salient (Volkow, Wang, Fowler, & Telang, 2008).

Chapter 5 was designed to explore patterns of decision-making in children aged 9 to 15 years old with and without overweight or obesity. We compared the performance of these groups on a developmentally appropriate variant of the IGT, the Hungry Donkey Task. We hypothesised that overweight children may show poor decision-making on the HD task and aimed to explore the possible underlying processes: (1) overweight children may be so/too sensitive to reward that they ignore the punishment that goes along with it, or (2) overweight children may be insensitive to future outcomes, and therefore they choose options that are appetitive on a short-term basis. To examine these possibilities, the participants completed both the standard and the reversed version of the HD task.

Defining self-regulation/delay of gratification

As depicted in figure 1 the neurobiological processes are mirrored in self-regulatory behaviour. Self-regulation can be defined as “the cognitive ability to resist temptations” or “the ability to postpone immediately available rewards in order to attain a more valued long-term outcome” (Ainslie, 1974; Logue, 1988; Logue & King, 1991; Rachlin & Green, 1972). In this way, overeating can be seen as the result of self-regulation failure through which impulses and immediate reward will rule over long-term consequences. Two older studies have already found that above-average weight children are less able to delay gratification from food than children of average weight (Bonato

& Boland, 1983; Johnson, Parry, & Drabman, 1978; but Geller, Keane, & Scheirer, 1981). These findings have been confirmed in recent longitudinal research showing that children between two and five years old with limited ability to delay gratification were more likely to be above-average weight at the age of 5, 11 or 12 years. In addition, early self-regulation skills were stronger predictors than actual BMI for predicting overweight 3 years later (Francis & Susman, 2009; Graziano, Calkins, & Keane, 2010; Seeyave, et al., 2009).

A fundamental question whether self-control deficits of overweight children are specific to the eating domain or if they occur across contexts remains inconclusive. Bonato and Boland (1983) adapted the DGP paradigm for overweight children and they found that in comparison with normal weight children, the overweight children choose immediate rewards more often, but only when the incentive was edible. These results suggest that deficits in delay of gratification of overweight children are food-specific, which may be due to the stronger incentive value of these items for them. However, other research shows that the deficits in the ability to sustain gratification were non-specific (Bruce et al., in press; Francis & Susman, 2009; Graziano, et al., 2010; Seeyave et al., 2009; Johnson et al., 1978; Sigal & Adler, 1976). A recent study compared the ability to delay gratification in overweight children using an ecologically valid measure. During therapy, children received a token for completing their homework. This token could immediately be spend on a small toy or saved to receive a larger price later. The obese children choose significantly more the small immediate reward, even for non-food rewards (Bruce et al., in press).

These findings provide convincing evidence that early self-control skills constitute an important individual factor to be taken into consideration when examining the development of overweight. Some intriguing questions remain however, for example whether self-control deficits of overweight children are specific to the eating domain or if they occur across contexts and whether the observed deficits in toddlers reflect a developmental delay that some children master later in life than others. Also, unresolved is the question which processes lead to the observation that also some older children are still less able to delay gratification than others. Specifying the processes that children can use to cope with the pressures and influences of the overwhelming food-environment is a major challenge in overweight research. This has important implications for developing specific strategies within obesity prevention programs or obesity treatments aimed at improving delay of gratification. Chapter 3 was designed to explore individual differences in delay of gratification skills in overweight and non-overweight children in a classic delay of gratification paradigm in and outside a food context. It was expected that overweight middle school children and young adolescents are less able to delay gratification in general and focuses on attentional control processes to cope with the delay.

Treatment

We have proposed three neurobiological processes that fosters overeating and obesity: poor inhibitory control mediated by the PFC, disturbed reward processes mediated by dopamine pathways and disadvantageous decision making processes due to discounting the delayed rewards relative to the immediate rewards, reflecting the interaction between the reward system and the PFC. If we take into account the previous review and can further evidence the assumptions in obese children some advices for weight control can be inferred. First, stimulus control is one technique needed to minimize the activation of the reward circuits. The drive to eat can be spared by reducing the exposure to palatable food in the environment. On the other hand also the top down inhibitory control should be maximized to help individuals resisting temptation.

Today, treatment programs for severely obese children already focus on improving impulse control by means of learning self-regulation skills such as self-observation, self-instructions, self-evaluations 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. Probably, as long as children do not strengthen their EF, the acquired impulse self-control skills remain of limited capacity. 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 chapter 6 was to evaluate in obese children an intensive cognitive training developed specifically to strengthen children's 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 and samples of children with low working memory (but no ADHD) (Holmes, Gahercole, & Dunning, 2009; Klingberg, Forssberg, & Westerberg, 2002; Klingberg et al., 2005; Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009; Van der Oord, Ponsioen, Geurts, Ten Brink, & Prins, submitted). For example, Klingberg and colleagues (2005) showed that in a sample of children with ADHD, an individually adaptable computerized working memory training not only improved the trained working memory, but training effects also generalized to other non-trained executive functions such as response inhibition and complex reasoning. Further, not only the core executive functions improved, but also objective behavior improved; there was a significant reduction of parent-rated inattention and hyperactivity/impulsivity symptoms and positive effects were maintained at three months follow-up. In low working memory samples, not only working memory performance improved, but also relevant and objective school results; math performance at 6 month's follow-up was improved (Holmes et al., 2009), suggesting again generalizability of results to objective behavior.

Fewer studies have been conducted on the trainability of inhibition through cognitive training (Thorell et al., 2009; White & Shah, 2006). 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. This may be due to the training task used, since within the training task the level of inhibition was not adapted to the level of the child. An individually adaptable task is deemed crucial in improving executive functioning through training (Klingberg, 2010). Recently, Dovis and colleagues (2008b) 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.

Furthermore, findings suggest that with proper incentives, adolescents are able to improve inhibitory control (Geier et al., 2010; Hardin et al., 2009). The suggestion that inhibitory control and as a consequence self-regulation can be improved in adolescents is particularly encouraging since adolescence is a critical developmental period for uncontrolled, unhealthy decision making behaviour due to overactive reward processes relative to poor cognitive control.

To optimize the motivational state of the children, external incentives were added to a potentially boring task (Dovis, Van der Oord, Wiers, & Prins, 2011). A feature that may increase children's motivation is adding computer game-elements to tasks. This was already confirmed 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). Also, studies show enhanced cognitive performance on EF-tasks due to adding gaming elements to these tasks (Dovis et al., 2011; Prins, Dovis, Ponsioen, Ten Brink & Van der Oord, 2011). In chapter 6, we use an executive functioning training, in which game-elements are added, in order to optimize children's motivational state and potentially optimalize their cognitive performance on the training.

The present training under research aims to improve working memory capacity and response inhibition by directly training both core cognitive processes. Since this is to our knowledge the first study of the effects of EF-training in overweight children, hypotheses were mainly exploratory. We expected more improvement in EF in overweight children who were randomized to the EF- training condition than those that were randomized to the care as usual- only control condition and as a consequence better weight loss maintenance post-treatment.

Overview of the chapters

This doctoral dissertation consists of seven chapters, including an introduction, five empirical studies and a general discussion. In c*hapter 2* the performance of overweight children was compared to that of normal weight control children on several different tasks within two types of impulsivity paradigms to examine which processes are implicated in the vulnerability to become overweight. *Chapter 3* aims to explore individual differences in delay of gratification skills in overweight and non-overweight children in a classic delay of gratification paradigm in and outside a food context. It was expected that overweight middle school children and young adolescents are less able to delay gratification in general, due to both insufficient inhibitory control and higher levels of reward sensitivity.*Chapter 4* aims to explore patterns of decision-making in children with and without overweight or obesity. We hypothesised that overweight children may show poor decision-making on the HD task because: (1) overweight children may be so/too sensitive to reward that they ignore the punishment that goes along with it, or (2) overweight children may be insensitive to future outcomes, and therefore they choose options that are appetitive on a short-term basis. To examine these possibilities, the participants completed both the standard and the reversed version of the HD task. *Chapter5* aims to investigate the DV model in children by analysing the association between self-reported RS and bodyweight in children. Based on the findings of Davis and Fox (2008), we expect a positive association between self-reported RS and BMI, which will change to a negative association among children with obesity. Finally **c***hapter 6* aims to examine the effects of EF-training in obese children. We expected more improvement in EF in children who were randomized to the EF- training condition than those that were randomized to the CAU-only control condition. After ending the inpatient treatment program, the confrontation with the daily food environment at home enables the study of long-term effects of treatment in the natural environment characterized by high risk for relapse. We expected better weight loss maintenance at 8 and 12 weeks after leaving the clinic in those randomized to the EF-training condition as compared to the children in the care as usual only condition. In a final discussion we will integrate our findings and suggest some challenging areas for future research.

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Figures

Figure 1: working model

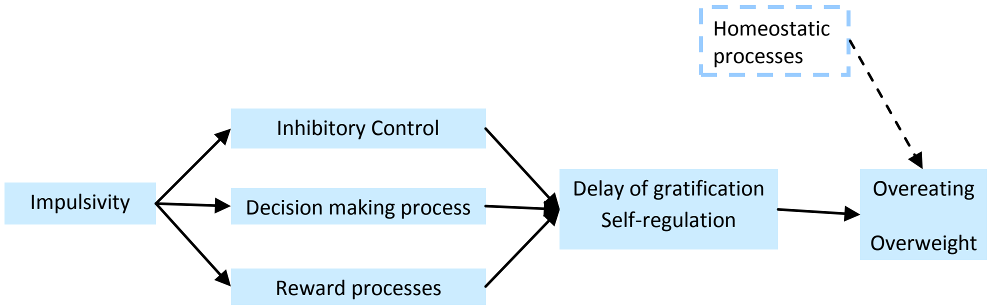
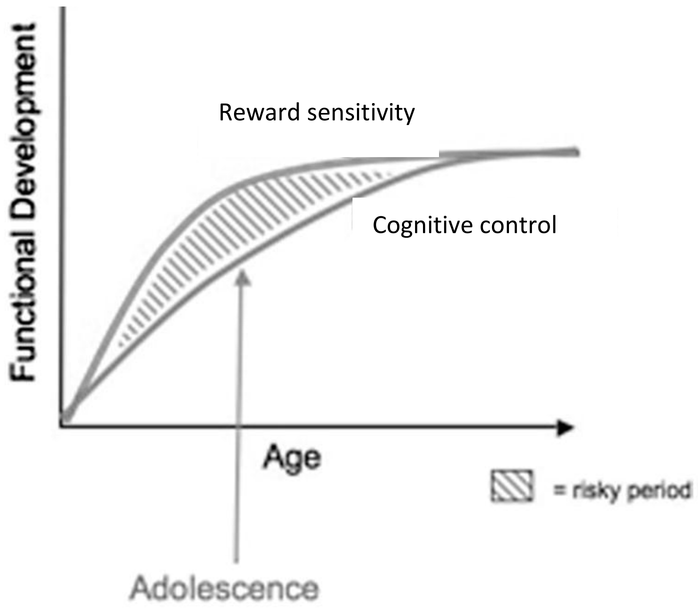


Figure 2



Note (modified from Casey et al., 2008) The traditional explanation of adolescent behavior has been that it is due to the protracted development of the prefrontal cortex. The model takes into consideration the development of the prefrontal cortex implicated in cognitive control together with reward regions implicated in risky choices and emotional reactivity.

Chapter 2

Childhood obesity and impulsivity:

An investigation with performance-based measures[1]

The study investigated whether obese children are more impulsive than lean children, taking into account the multidimensionality of the construct. Responses of 41 overweight children were compared to those of 40 lean children. The Stop Task, Circle Drawing Task and Opposite Worlds Task were administered to measure executive inhibitory control, and the Maudsley Index of Childhood Delay Aversion and the Door Opening Task were administered to measure motivational inhibitory control. On the Stop Task, the overweight children showed less inhibitory control. On the Opposite Worlds task, we found no significant difference, whereas on the Circle Drawing Task an unexpected group difference was found. Although, on the Door Opening Task, the overweight children showed greater reward sensitivity, they were equally motivated to wait on the Maudsley Index of Childhood Delay. It was concluded that the findings were different depending on the measure used, but that they suggest that overweight children can be characterized by a decrease in executive and motivational inhibitory control.

[1] Verbeken, S., Braet, C., Claus, L., Nederkoorn, C. & Oosterlaan, J. (2009). Childhood obesity and impulsivity. An investigation with performance-based measures. *Behaviour Change, 3*, 153-167.

Introduction

In adults, considerable research points at the relation between impulsivity and food intake (Guerrieri et al., 2007; Guerrieri, Nederkoorn, & Jansen, 2007; Nasser, Gluck, & Geliebter, 2004; van den Bree et al., 2006), between impulsivity and obesity (Fassino, Leombruni, Piero, Daga, Amianto, & Rovera, 2002; Gunstad, Paul, Cohen, Spitznagel, & Gordon, 2007; Ryden, Sullivan, Torgerson, Karlsson, Lindroos, & Taft, 2003; Nederkoorn, Smulders, Havermans, Roefs, & Jansen, 2006) and between impulsivity and boulimia nervosa (BN) and Binge Eating Disorder (BED) (Brewerton, Hand, & Bishop, 1993, Bullik, Sullivan, Weltzin, & Kaye, 1995; Engel et al., 2005; Fassino, Daga, Piero, Leombruni, & Rovera, 2001; Nederkoorn, Van Eijs, & Jansen, 2004; Rosval, Steiger, Bruce, Israël, Richardson, & Aubut, 2006). Furthermore, research shows parallels between obesity and other potentially addictive behaviour in adults, all characterised by impulsive behaviour and a rise in sensitivity to reward (Davis, Patte, Levitan, Reid, Tweed, & Curtis, 2007; Davis, Strachan, & Berkson, 2003; Dawe & Loxton, 2004).

Yet, the mechanisms of how impulsivity operates are less clear. Living under conditions of abundance means living with the continuous temptation of the immediately rewarding value of palatable, high-caloric foods. Resisting temptation requires self-regulatory resources. As a result, overeating may be promoted by a lack of self-regulation skills, allowing impulses and immediate reward to rule over long-term consequences (van den Bos & de Ridder, 2006). Indeed, there is a remarkable similarity between impulsive behaviour and obesogenic eating patterns such as the inability to eat on a regular basis, to postpone in-betweens and to resist urges to indulge in snacks (Lyke & Spinella, 2004).

Although younger people appear to experience higher levels of impulsivity in general, and therefore may be more likely to make impulsive choices related to food (Lyke & Spinella, 2004), the link between impulsivity and being overweight in children is far less studied. Some research found that a subgroup of overweight children demonstrated an impulsivity prone personality, that this subgroup act more on impulse than normal weight children, and that impulsivity hinders weight loss in therapy (Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006; Nederkoorn, Jansen, Mulkens, & Jansen, 2007). Overweight children starting treatment for obesity in a paediatric centre were found to display personality traits frequently associated with impulsive behaviour. They were found to be more impulsive and hyperactive and less attentive compared to control children who showed more reflectivity (Braet, Claus, Verbeken, & Van Vlierberghe, 2007). Furthermore, in a delay-of-gratification task, it seems to be more difficult for overweight children to wait since they more often choose the smaller immediate reward than the larger delayed reward (Bonato & Boland, 1983; Johnson, Parry, & Drapman, 1978; Lewitts, & Israel, 1978; but see Bourget & White, 1981; Wilson, 1980). Finally, studies point at the comorbidity between obesity and attention/hyperactivity disorder (ADHD) in children (Agranat-Meged et al., 2005; Holtkamp et al., 2004). Therefore, since the prevalence of childhood obesity is rising (Reilly, 2006; Reilly, 2007; Wang & Lobstein, 2006) and since children are the most important group for prevention to curb or even reverse the epidemic of obesity, it is a worthwhile group to study the possible influence of impulsivity on eating behaviour.

The study of impulsivity is complicated, since it is not a unidimensional construct, but involves a number of processes: the capacity to tolerate delay for reward, to inhibit an already initiated response, and to estimate the passage of time (Dougherty, Mathias, Marsh, & Jagar, 2005). Therefore, it is important to distinguish between the different processes of impulsivity which might be related to overeating. Two measurement paradigms seem to capture the different component processes related to the construct of impulsivity (1) the rapid-decision paradigms evaluating the executive inhibition effects and (2) the reward-directed paradigms evaluating motivational inhibition effects (Dougherty et al., 2003; Nigg, 2000; Sonuga-Barke, 2003). In the rapid-decision paradigms, executive inhibitions are defined as processes for intentional control in the service of higher order or longer term goals (Nigg, 2000). In this, three different forms of executive inhibition can be discerned: prepotent inhibition, sustained inhibition and interference control (Barkley, 1997; Nigg, 2000). Within the reward-directed paradigms, the focus is on evaluating motivated inhibition of behaviour or thought. The study of inhibitory processes operating in different incentive contexts has been performed in several ways. The delay aversion model (Sonuga-Barke, 1994) is one approach, which conceptualizes impulsive behaviour within a motivational framework. This theory views an impulsive choice as the preference for a small immediate reward over a large delayed reward, because the child does not tolerate the delay necessary for the larger reward (Dougherty et al., 2003; Nichols & Waschbusch, 2004). Another way to study motivational inhibitory control is by measuring ‘gambling’ behaviour, which is behaviour driven by the strong short-term effects of immediate reward, neglecting the negative long-term effects of an action.

Through the use of self-report questionnaires, the focus in previous studies on impulsivity in overweight children lies mainly on trait impulsivity (Braet & Claus, 2006; Lyke & Spinella, 2003; Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006; Ryden et al., 2003). Behavioural approaches or performance-based measures, on the other hand, may have the advantage of being sensitive to transient changes in impulsivity processes and are less subject to demand characteristics (Dougherty et al., 2003; Nederkoorn et al., 2006). The present investigation aims to compare the responding of overweight children to that of normal weight children on different performance-based tasks, measuring multiple kinds of inhibitory processes. All these measurements have shown good test-retest reliability in previous studies (Kindlon, Mezzacappa, & Earls, 1995; Kuntsi, Stevenson, Oosterlaan, & Sonuga-Barke, 2001; Manly, Anderson, Nimmo-Smith, Turner, Watson, & Robertson, 2001).

Within the rapid-decision paradigms, three different tasks were selected for they may each tap a different form of executive inhibition (Barkley, 1997; Nigg, 2000). First, the Stop Task (Logan & Cowan, 1984) is a measure of prepotent inhibition. The task examines a child's ability to stop a prepotent motor response, which means a response that is or has been previously associated with reinforcement. It is a unique measure of inhibition in that it permits an estimation of the latency of the inhibitory process (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006). Second, the Circle Drawing Task (Bachorowski & Newman, 1985, 1990), a measure of sustained inhibition, investigates the ability of the child to inhibit an ongoing response, which allows for a delay in the decision to continue responding. It is advantageous to include a continuous motor task because continuous motor sequences are quite different from discrete movements (Bachorowski & Newman, 1990). Finally, the Opposite Worlds Task (Manly et al., 2001) is a stimulus-incompatibility task, used to examine interference control. This task requires controlling an interfering prepotent or automatic verbal response to carry out an effortful primary response (Nigg, 2000). Investigators point at the value of these tasks for the assessment of impulsivity-related disorders as Attentiou Deficit/Hyperactivity Disorder (ADHD) and Oppositional Defiant Disorder (ODD) in children (Avila, Cuenca, Felix, Parcet, & Miranda, 2004; Geurts, Verté, Oosterlaan, Roeyers, & Sergeant, 2004; Lijffijt, Kenemans, Verbaten, & van Engeland, 2005; Oosterlaan & Sergeant, 1998; Schachar et al., 2007). In the field of eating disorders and obesity studies, the use of rapid decision tasks is scarce. One study using the Stop Task suggests that restrained eaters are worse in inhibiting their motor responses than unrestrained eaters (Nederkoorn, Van Eijs, & Jansen, 2004). Similarly, one study in obese children suggests that children with obesity inhibit less often on a Stop Task compared to children with normal weight (Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006).

To tap the motivational inhibitory processes, two different tasks were selected. The Maudsley Index of Childhood Delay Aversion (Kuntsi, Stevenson, Oosterlaan, & Sonuga-Barke, 2001) is a potential instrument used to measure impulsive responding resulting from delay aversion and second the Door Opening Task, which covers reward-directed behaviour with blindness for the long-term consequences of that behaviour (Daugherty & Quay, 1991). Recent investigations demonstrate the utility of reward-directed paradigms for measuring impulsive behaviour in children with ADHD and Conduct Disorder (CD) (Daugherty & Quay, 1991; Matthys et al., 1998; Matthijs, van Goozen, Snoek, & van Engeland, 2004; Neef et al., 2005; Nichols & Waschbusch, 2004; Solanto et al., 2001; Wilson & Evans, 2002). Furthermore, Nederkoorn and colleagues (2006) suggested, using the Door Opening Task, that obese children in treatment are indeed more sensitive to reward than children with normal weight.

To conclude, impulsivity is a multidimensional construct that has been defined and measured in many ways. Until now, no comprehensive impulsivity research in overweight children has been conducted. The current study improves upon previous research by using an extensive battery of impulsivity measurements that covers the major inhibitory processes. As a result, this type of research may help to understand what specific inhibitory process hinders self-regulation in overweight children.

The purpose of this investigation is to address this need by comparing the performance of overweight children to that of normal weight control children on several different tasks within the two types of impulsivity paradigms. Based on the few studies that have been conducted before in the field of childhood obesity, we hypothesize that the overweight group will exhibit greater impulsive responding than the control group across all tasks: they will show less executive inhibitory control, prefer to wait less, be more sensitive to reward and keep gambling longer than children with normal weight.

Method

Participants and procedure

Overweight children (N = 41 children, 16 boys and 25 girls) admitted in a medical paediatric centre for treatment for obesity were invited to participate. Nobody refused. Inclusion criteria were: diagnosed as primary obesity, displaying an adjusted BMI above 120 %, between 10 and 14 years old, attending regular schools corresponding with IQ within the normal range, and absence of Pervasive Development Disorder. The mean age was 12.0 years (SD = 1.46), the mean height and weight were 156.29 cm (SD = 9.55) and 78.9 kg (SD = 18.98) respectively. The adjusted BMI ranged from 125.42% to

273.92% (CDC BMI z-scores range from 1.16 to 2.83; Ogden et al., 2002). All socio-economic strata were represented in the overweight group (upper and upper-middle class: 23.4 %; middle class: 48.7 %; lower-middle and lower class: 17.9 %) (Hollinghead & Redlich, 1958, 1975).

The normal weight control children (*N* = 41, 17 boys and 23 girls) were selected from primary and secondary regular schools. They were matched on age and gender with the children in the experimental group. One girl was excluded from the analyses because her adjusted BMI was above 120% (136.66 %). The mean age was 11.6 years (SD = 1.36). Their mean height and weight were 149.99 cm (SD = 10.89) and 37.69 kg (SD = 6.86) respectively. The adjusted BMI ranged from 73.05% to 115.40% (CDC BMI *z*-scores range from -3.02 to 0.82; Ogden et al., 2002). All socio-economic strata were represented in the control group (upper and upper-middle class: 21 %; middle class: 50 %; lower-middle and lower class: 29 %) (Hollinghead & Redlich, 1958, 1975). Both samples did not differ according to age, gender and socio-economic background. The local research ethics committee approved the protocol of this study.

During a test session of approximately 2 hours, each child was tested individually in a low-stimuli room. The child completed the performance-based measures after answering the questions from the ADHD module of the KID-SCID interview. Standardized instructions were used for each of the tasks. The tasks were administered in three blocks: The Maudsley Index of Childhood Delay Aversion (block 1), Stop Task (block 2) and OW- TEA-Ch, Circle Drawing Task, Door Opening Task and MFFT (block 3). To minimize the potential for fatigue effects, the order of the blocks was counter-balanced over the children for each group. During a short break the children were offered a drink and at the end of the session, they were debriefed and all received the same reward.

Measures

Body overweight: The BMI (weight/height^2) was calculated for each child. In order to make BMI comparisons between obese children of different ages, the adjusted BMI was used in this study. The formula is [Actual BMI/ Percentile 50 of BMI for age and gender] x 100. The 50th percentiles of the BMI were based on European normative data (Fredriks, van Buuren, Wit, & Verloove-Vanhorick, 2000).

The Structured Clinical Interview for DSM-IV, Childhood version (KID-SCID; Hien et al., 1994, 1998; Dutch version: Dreessen, Stroux, & Weckx, 1998) was used to assess DSM-IV disorders in children. Similar to the adult version, the KID-SCID is a semi-structured instrument designed to generate childhood DSM-IV diagnoses for clinical research studies. In the current study, only the ADHD module which is part of the disruptive behaviour disorders section was assessed using the children as informants. The first part of the ADHD-module assesses 9 criteria referring to attention deficit problems. The second part of the module assesses hyperactivity (6 items) and impulsivity symptoms (3 items). Each criterion is scored as present ('1' score) or absent ('0' score). In case of doubt, the criterion in question is assigned a '0' score. In the study of Timbremont, Braet & Dreessen (2004) child-parent agreement rates varied between 88.7% and 100%, which indicates a good reliability of the interview. In addition, preliminary results of a study by Matzner and colleagues (1997) showed fair to excellent test-retest reliability for the disruptive behaviour disorders module (α between .63 and .84). Pilot data also indicated excellent interrater reliability for the disruptive behaviour module (α = 1.0 for

ADHD) (Matzner, 1994). In this study, Cronbach α internal consistency coefficients were 0.82 for the attentional deficit subscale, 0.74 for the hyperactivity and 0.63 for the impulsivity subscale respectively.

Opposite Worlds of the Test of Everyday Attention for Children (OW-TEA-Ch; Manly et al., 2001). This subtest of the TEA-Ch was used as a measure of verbal inhibition. It is a stimulus-incompatibility task, used here to examine interference control. The child was required to suppress an automatic or prepotent verbal response. There are two conditions in the OW-TEA-Ch. In the Same World (neutral) condition, the child names the numbers *1* and *2* in a snake-like trail. In the Opposite World (suppression) condition, the child is instructed to say 'two' when a *1* is designated and say 'one' when a *2* is designated on the trail. The experimenter pointed to each digit, only moving onto the next when a correct response was given. Each condition was performed twice. The dependent variable was the difference between the mean time needed to complete two neutral conditions and the mean time needed to complete two suppression conditions. This dependent variable will be referred to as the 'OW-TEA-Ch-Time Difference'. The smaller the OW-TEA-Ch-Time Difference, the better the participant was able to suppress the automatic verbal response.

The Circle Drawing Task (Bachorowski & Newman, 1990). The Circle Drawing Task was used as a measure of inhibition of an ongoing response. The task requires the subjects to trace a large printed circle with their index finger. The circle is 50.80 cm (20 in.) in diameter, drawn on a card-board square, and covered with plexiglass. The circle has a small line indicating the starting and the finishing point of the tracing. The task was administered under two conditions: first with neutral instructions ('trace the circle') followed by inhibition-instructions (‘trace the circle again, but this time as slowly as you can’). A maximum of 12 minutes was allowed for both tracing conditions. Participants were not informed of this fact. The dependent variable in this task was the time used to trace the circle in the slow condition minus the tracing time in the neutral condition. This dependent variable will be referred to as ‘Circle Time Difference’. The larger the Circle Time Difference, the better a participant was able to inhibit (slow down) the continuous tracing response.

*The Stop Task (*Logan & Cowan, 1984; Logan et al, 1984 – the original version; Oosterlaan et al., 1998). 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 the delay between the go and the stop signal. The longer this delay, the harder it is to inhibit the response.

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, Cowan, & Davis, 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. By using the tracking mechanism, success rate on inhibition trials is .5. This means that SSRT can be calculated by subtracting the mean delay from the mean go signal reaction time (Scheres et al., 2003).

The Door Opening Task (Daugherty and Quay, 1991; Nederkoorn, personal communication). The task provides a measure of motivational inhibition. It consists of a series of 100 doors presented sequentially on a laptop computer in a preprogrammed order of winning and losing doors. The probability of a winning door appearing, decreases by 10% with each succeeding set of 10 doors and starts at 90 % (thus from 90% to 0%). Within each set of 10 doors, losing doors are randomly sequenced among winning doors. In this game, the subject chooses either to open the next door or to stop playing and there is a steadily increasing ratio of punished responses (sad face behind door) to rewarded responses (happy face behind door). The dependent measures were the total number of doors opened (Doors Opened) and the total number of doors opened divided into three categories (Door Selection Strategies): (1) opening a total of 1 to 31 doors resulted in winning a suboptimal amount of points (10-29 points), due to a conservative selection approach; (2) 32 to 64 doors opened resulted in an optimal strategy, with a maximum gain of points (30-35 points); and opening of 65 to 100 doors resulted in a suboptimal amount of points earned (29-10 points), due to a perseverative selection strategy. A large number of doors opened are indicative of reward sensitivity and response perseveration. Subjects more sensitive to punishment will stop opening doors after a few punished responses.

The Maudsley Index of Childhood Delay Aversion (Kuntsi, Stevenson, Oosterlaan, & Sonuga-Barke, 2001). This computer task was originally designed to test the delay aversion hypothesis that children with ADHD choose immediate, small rewards over large, delayed ones, when this leads to less overall delay (Sonuga-Barke, Taylor, Sembi, & Smith, 1992). The child has to make a choice, on 20 occasions, between a small immediate reward (1 point involving a 2-second pre-reward delay) and a larger delayed reward (2 points involving a 30-second pre-reward delay). If the child chooses the small reward, the next trial started immediately afterwards. The task, administered on a laptop computer, was presented as a space game, in which the child, as a captain of a space ship, had to destroy enemy spacecraft (using the computer mouse). The aim of the game was to earn as many points as possible. Before the experimental trials, the child first practiced using the mouse and choosing each of the rewards. The tester also asked the child questions about the game in order to ensure that he or she understood the rules and aims of the game. The dependent variable used in the analyses was the percentage of choices for the 2-point delayed reward and will be referred to as 'Delay Aversion'.

Statistical analyses

First, correlations were calculated between the different impulsivity measures. Next, all correlations with age were explored.

Analysis of variance (ANOVA/MANOVA) and Chi-Square tests were used to assess differences between overweight children versus children with normal weight. We controlled for age because executive functions are still developing in the age range of 9-15 and this might influence the outcome despite the fact that there were no group differences for age. The analyses of the group contrast were repeated with gender as fixed factor. There were no significant differences found.

Two children in the control group received the diagnoses of ADHD. When the data of these children were excluded, the pattern of results of the group comparisons on the impulsivity measures did not alter. Therefore, the analyses on all subjects were reported.

Results

The results of the data analyses are presented in tables 1 and 2 and figure 1.

Correlations between dependent measures

Scores for some of the variables were reflected so that for all of the variables, the larger the score, the greater the level of impulsivity. The matrix reveals a pattern of low to moderate (r <.30), but not all positive, correlations among the various impulsivity measures. Overall, the correlations ranged from |.01| to |.31|. These results indicate that the individual impulsivity measures were not highly correlated with each other. None of the performance based measures of impulsivity were correlated with age.

Executive inhibitions

The Opposite Worlds of the Test of Everyday Attention for Children. There was no significant group difference for the verbal inhibition score (OW-TEA-Ch-Time Difference), $F(1,78) = .02$, $p = .89$.

Circle Drawing Task. This task showed a significant group difference for inhibition time (Circle Time Difference), $F(1,78) = 7.92$, $p <.01$; $\eta^2 = .09$, but in the unexpected direction. The normal weight controls had smaller difference scores, indicating more problems with inhibition of the continuous tracing response than the children in the overweight group.

Stop Task. A MANOVA with SSRT and RT as dependent variables showed a significant effect of group (Wilks' $\lambda = .91$, $F(2.70) = 3.58$, $p < .05$, $\eta^2 = .09$). As predicted, the overweight group had slower SSRTs compared to the control group, indicating less efficient inhibitory control ($F(2,70) = 9.75$, $p < .01$, $\eta^2 = .11$). There were no significant differences between the groups on reaction times on the go-trials ($F(2,70) < 1$), indicating that there were no impairments in responding itself.

Motivational inhibitions

The Door Opening Task. An ANOVA showed a significant effect of group for the total amount of doors openend (Doors Opened), $F\ (1,78) = 18.57$, $p < .001$. The proportion of children that opened doors in a conservative, optimal, or perseverative way is displayed in Fig. 1. A chi square analysis was performed with group as the independent variable and Door Selection Strategies as the dependent variable. The groups differed with regard to the selection of cards, χ^2 (2, N = 81) = 15.48, $p < .001$. Comparing either the conservative or the perseverative strategy with the optimal door selection strategy, indicated that compared to the normal controls, more children in the overweight group used a perseverative door selection strategy, χ^2 (1, N = 53) = 4.61, $p < .05$ and less a conservative door selection strategy, χ^2 (1, N = 66) = 6.04, $p < .05$.

The Maudsley Index of Childhood Delay Aversion. The group comparisons were nonsignificant for the percentage of choices for the larger reward, $F(1,78) = .24$, $p = .63$; $\eta^2 = .00$

Discussion

The main purpose of this study was to determine whether overweight children act more on impulse than normal weight controls. We examined performance based differences on five tasks, related to two behavioural measurement paradigms. It was hypothesized (1) that overweight children have less executive inhibitory control and (2) are more sensitive to reward than children with normal weight.

The results of the performance-based tasks showed that different processes seem to underlie the impulsive behaviour in overweight children, confirming the multidimensionality of the concept of impulsivity. Both the executive inhibitions and motivational inhibitions paradigms have demonstrated utility in the characterization of possible deficits in overweight children

The study first explored possible deficits in executive inhibitions via the Stop Task. The task seems to provide a remarkable differentiation between children who are or are not overweight. The overweight children showed longer SSRTs indicating less efficient executive inhibitory control.

Unlike our expectations, the overweight children performed equally well on the inhibition of a verbal response, an indication of interference control (Opposite Worlds Task). A possible explanation lies in the specification of the task. The current study examined the basic process of interference control with a regular stimulus-incompatibility task. However, Nigg (2000) points at the role of motivational systems moderating interference control for emotionally significant stimuli. Indeed, in previous research using an emotional Stroop task (Braet & Crombez, 2003), children with obesity displayed interference deficits and were slower in naming food words versus control words. Furthermore, the children with obesity showed no interference effect for negative-emotion words. These findings support the idea that possible self-regulatory deficits in overweight children are stimulus-specific.

Contrary to our hypotheses, the overweight children performed better on the inhibition of an ongoing, continuous motor response (Circle Drawing Task) than the children with normal weight. Since this result was not due to baseline differences, the normal children actually showed decreased inhibition compared to overweight children. We do not have a clear explanation for this unexpected finding. Bacharowski & Newman (1990) found that anxiety may have a restraining influence on motor speed in the presence of a goal (finishing point of the tracing). Possibly, the presence of anxiety may explain the superior performance of the children in the overweight group on the Circle Drawing Task. Preliminary studies (Vila et al., 2004) show that overweight children are indeed more vulnerable for emotional problems. However, we did not control for emotional functioning.

Within the reward-directed paradigm the Door Opening Task is a commonly used task. The present findings indicate that the task offers an effective means of discrimination between children with and without overweight. The overweight children kept gambling longer despite increasing losses, suggesting greater reward sensitivity and response perseveration. This endorses the observation that for overweight children it is more difficult to resist the temptation of tasty food than for lean children, despite the long-term negative consequences of overeating (van den Bos et al., 2006). Findings based on self-report have also confirmed the role of reward sensitivity in the development of obesity. It has been proposed that reward sensitivity may contribute to greater sensitivity and attention towards food-related cues (Dawe & Loxton, 2004) and a preference for sweet and fatty food (Davis et al., 2007). These findings stress the contribution of motivational inhibitory processes in overweight children.

Finally and unexpectedly, delay aversion measured with the Maudsley Index of Childhood Delay Aversion did not differ between the groups. The overweight children seem equally motivated to wait for a large reward than normal weight controls. Although this task was never used before in childhood obesity research, we hypothesised about possible explanations. Earlier research has pointed at the importance of effective attention deployment in the regulation of delay behaviour. Differences between children may be more remarkable when the task is long, thereby challenging their motivation. The overweight children tested here may have been able to persist in the short waiting periods in the present experiment. In real life situations, when gratification is typically delayed for longer periods, the strategies used by overweight children may not facilitate long-term self-control. Future research should be directed at determining the attention deployment strategies and the subjective experience of children in the delay task, particularly perceived task difficulty and reported level of frustration.

These results confirm the earlier findings from Nederkoorn and colleagues (2006). The Nederkoorn study assessed the same impulsivity paradigms, but looked within each at only one process. They also found that overweight children performed worse on both the inhibition of a prepotent response (Stop Task) and on the gambling task (Door Opening Task). The results of both the Nederkoorn study and the current investigation are of interest because they reveal which specific inhibitory processes display deficits and may burden the self-regulatory skills in overweight children.

Limitations of the current study hamper generalisation of the findings. First, the current findings may not be easily generalizable due to the potential risk of selection bias of a clinical-based sample. Second, the reward-directed tasks are never ‘pure’ measures of a *single* impulsivity process but are related to a number of processes. Third, since executive function measures are strongly related to IQ, controlling for IQ in future research is recommended. In general, performance improves with higher IQ (Mahone et al., 2002). Since all children attended regular schools, we assumed that none of them had severe intellectual deficits. Finally, the assumed link between lacking inhibitory processes and obesity related eating behaviour is not researched here. Now that the psychological processes associated with impulsivity in overweight children were identified, future research can explore how the eating behaviour of overweight children is related to impulsivity or lack of self control.

In sum, the present study was the first to use a multidimensional approach in the investigation of impulsivity in overweight children. It replicates and further elaborates the findings of Nederkoorn and collegues (2006). Interestingly, overweight children seem to show more reward-directed behaviour and lack inhibitory skills on some but not all tasks. Obesity treatment programs can develop specific techniques for helping overweight children to master effective and specific inhibitory skills as well as to strengthen their ability to resist temptation and delay gratification.

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Tables

Table 1. Pearson correlations between the dependent variables, age and IQ

	1	2	3	4	5	Age	IQ
1. OW-TEA-Ch-Time Difference	.12					-.17	.08
2. Circle Time Difference CD	-.08	.18				-.11	-.19
3. SSRT Stop task	.19	.31**	-.18			-.16	-.08
4. Doors Opened DOT	.15	-.01	-.14	.17		-.06	-.02
5. Delay Aversion MIDA	.11	-.17	.01	.17	-.14	-.16	-.14

Note. OW-TEA-Ch = Opposite Worlds of the Test of Everyday Attention for Children; SSRT = stop signal reaction time; DOT = Door Opening Task; MIDA = Maudsley Index of Childhood Delay Aversion. *p<.05, **p<.01, ***p<.001.

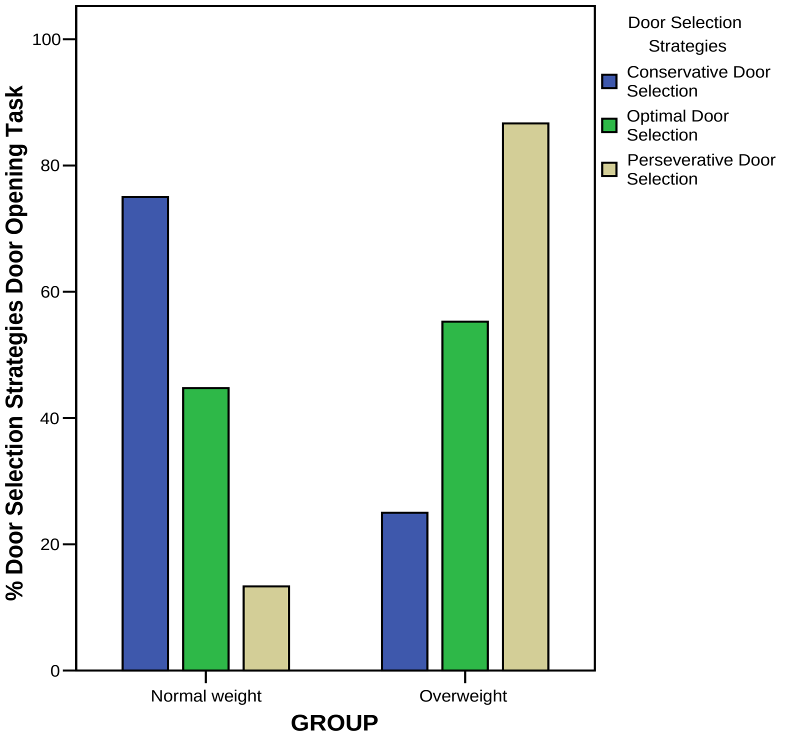
Table 2. Means, standard deviations, F-values for the two groups for the dependent variables.

	Control group M (SD)	Overweight group M (SD)	F(1,79)
Opposite Worlds Task			
OW-TEA-Ch-Time Difference	2.47 (1.42)	2.33 (2.07)	0.02
Circle Drawing Task			
Circle Time Difference	57.14 (43.91)	90.87 (58.11)	7.92**
Stop Task			
SSRT	227.00 (47.69)	261.93 (63.01)	9.75**
RT	546.45 (90.53)	543.65 (95.62)	0.08
Door Opening Task			
Doors Opened	29.70 (20.03)	51.27 (26.12)	18.57***
Maudsley Index of Childhood Delay Aversion			
Delay Aversion	68.56 (27.04)	72.20 (20.83)	0.24

Note. OW-TEA-Ch = Opposite Worlds of the Test of Everyday Attention for Children; SSRT = stop signal reaction time. *p<.05, **p<.01, ***p<.001.

Figures

Figure 1. Percentage of conservative, optimal, or perseverative door selection on the Door Opening Task by children with normal weight and overweight.



Chapter 3

Decision-making and the regulation of eating behaviour in children[1]

The current study addresses aspects of self-regulation skills in overweight and normal weight children, which may be related to their overeating problems. It is hypothesized that overweight children may show poor decision-making behaviour, and this may be due to several processes: hypersensitivity to reward or future insensitivity. Average weight children (n = 66) and overweight children (n = 64) between 11-16 years were tested with the developmentally appropriate analogue of the IOWA Gambling Task. The results reveal that overweight children show decision-making failure ensued from future insensitivity, suggesting that already in children the reward deficiency hypothesis or the anhedonic route to obesity is supported.

[1] Verbeken, S., Braet, C., Bosmans, G., & Goossens L. (2012). Decision-making and the regulation of eating behaviour in children. *Manuscript submitted for publication.*

Introduction

The prevalence of overweight and obesity in children has been increasing rapidly over the past three decades, along with the prevalence of concomitant medical and psychosocial problems (Lobstein, Baur, & Uauy, 2004; Jackson-Leach & Lobstein, 2006; Reilly et al., 2003; Reilly, 2006; Reilly, 2007). This massive increase is seen as the result of a mismatch between certain genes and modern environmental factors regulating food-intake and physical activity. However, the mechanisms underlying this process in human beings are less clear. In this study a cognitive psychological perspective regarding the regulation of food-intake will be adopted. From this perspective, it is assumed that human eating behaviour is not only stimulus-driven or determined solely by powerful physiological drives, but is also guided by cognitive and affective processes, both implicit and explicit (Berthoud, 2007). Acknowledging and studying these psychological processes in overweight children can contribute to an understanding of the complex process of regulating food-intake in humans.

In western societies, the modern environment calls for a permanent choice between immediately rewarding, highly palatable, and calorie-rich food and the long-term goal of health and slimness, especially for people who are concerned about their weight. This entails a strong challenge to a person's self-regulation ability, which can be defined as the cognitive ability to postpone immediately available rewards in order to attain a more valued long-term outcome (Ainslie, 1974; Logue, 1988; Logue & King, 1991; Rachlin & Green, 1972). In this way, overeating can be seen as the result of self-regulation failure through which impulses and immediate reward will rule over long-term consequences.

Although during childhood food-intake is primarily regulated by the parents, children gradually learn to self-regulate their food-intake. Individual differences in self-regulation ability have been found to emerge early in life and show clear stability over time as well as over a variety of life domains in children (Mischel, Shoda, & Peake, 1988; Mischel, Shoda, & Rodriguez, 1989; Tremblay, Boulerice, Arsenault, & Niscale, 1995). With regard to the study of overweight, two older studies have already found that overweight children are less able to delay gratification from food than children of average weight (Bonato & Boland, 1983; Johnson, Parry, & Drabman, 1978; but Geller, Keane, & Scheirer, 1981). These findings have been confirmed in recent longitudinal research showing that children with limited ability to delay gratification between three and five years old were more likely to be overweight at the age 11 or 12 years (Francis & Susman, 2009; Seeyave, et al., 2009).

Likewise, many studies have already demonstrated an association between impulsivity (here defined as a lack of self-regulation) and childhood overweight (Agranat-Meged et al., 2005; Agras, Hammer, McNicholoas, & Kraemer, 2004; Braet, Claus, Verbeken, & Van Vlierberghe, 2007; Carey, Hegvik, & McDevitt, 1988; Holtkamp et al., 2004; Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006; Nederkoorn, Jansen, Mulkens, & Jansen, 2007, Zeller, Boles, & Reiter-Purtill, 2008). The results of these studies indicate that overweight children seem to be more driven by an immediate need for food and be less able to control this need and make the right decisions, even when they know their behaviour can result in adverse physical and psychological consequences in the long-term.

Interestingly, studies analysing decision-making processes have revealed that at least two different processes might account for this ‘myopia’ for the future: hypersensitivity to reward or insensitivity to the future (Bechara, Damasio, Damasio, & Anderson, 1994) and can be identified by the Iowa Gambling Task. The Iowa Gambling Task (IGT) has proved to be a well-validated measure for assessing the self-regulation processes involved when people are exposed to the temptation of immediate big rewards (Bechara et al., 1994). The task was originally developed to detect decision-making deficits in patients with ventromedial prefrontal cortex (VMPFC) lesions, and it mimics real-life decision-making in the way it manipulates reward, punishment, and uncertainty of outcomes (Bechara, 2004; Crone & van der Molen, 2004). During the task, healthy individuals gradually learn to avoid choices with high immediate gains and long-term losses, by contrast, the performance of VMPFC patients suggests that these patients are oblivious to the consequences of their actions and that their decision-making is guided only by immediate prospects (Bechara et al., 1994; Crone, Bunge, Latenstein, & van der Molen, 2005; Crone & van der Molen, 2004). To examine which of the processes underlies a ‘myopia’ for the future two phases are needed in which the schedules of reward and punishment are reversed (Bechara, Tranel, & Damasio, 2000). *Insensitivity to the future* can be concluded when people specifically make choices that result in immediate low punishment but, due to small delayed rewards, in larger losses in the long run, compared with the choices that result in high immediate punishment but a net gain in the long run due to high delayed rewards. The opposite choice pattern indicates a *reward-focused strategy and* is measured with the standard IGT challenging choices with high immediate reward but a net loss in the long run, compared with advantageous choices of immediate low reward but significant gain in the long run.

Apart from patients with VMPFC lesion, greater decision-making impairments were found in people with a diversity of impulse-control problems, such as addictive disorders, borderline personality disorder, attention deficit disorder, behaviour disorder, and eating disorders, suggesting all that poor self-regulation is related with their problems (Bazanis et al., 2002; Bechara & Damasio, 2002; Boeka & Lokken, 2006; Cavedini et al., 2004; Ernst et al., 2003; Goudriaan, Oosterlaan, de Beurs, & van den Brink, 2006; Grant, Contoreggi, & London, 2000; Malloy-Diniz, Fuentes, Leite, Correa, & Bechara, 2007).

Surprisingly, a decision-making paradigm has seldom been applied in overweight research. Two studies applied the IGT and both showed evidence for a decision-making deficit in overweight adults (Davis, Levitan, Muglia, Bewell, & Kennedy, 2004; Pignatti et al., 2006), demonstrating the relevance of this approach for understanding failures in the regulation of eating behaviour. However, this evidence is inconclusive because both of the available studies examined the performance of overweight individuals using only the standard version of the IGT, not the reversed version measuring future insensitivity.

Moreover, although younger people appear to experience lower levels of self-regulation skills in general (Lyke & Spinella, 2004), to date there has been no systematic examination of decision-making abilities in overweight children. Hence, the goal of this study is to address these shortcomings by examining the performance of children with a broad range of body weight on both the standard and reversed version of a developmentally appropriate analogue of the IGT (Bechara et al., 2000; Crone & van der Molen, 2004). In this way this study aims to determine whether or not the hypothesised poor decision-making deficits in children with a higher BMI are mainly the result of hypersensitivity to reward or future insensitivity.

Since *hypersensitivity to reward* makes it hard to resist high rewarding palatable food, it seems the most obvious account for the possible decision-making deficits in overweight people (Davis, Patte, Tweed, & Curtis, 2007). Evidence for this account was already found in studies proving a significant positive association between high sensitivity to reward, as measured by self-report scales, and overeating, the preference for high fat and sweet food (Davis et al., 2007; Guerrieri, Nederkoorn, & Jansen, 2008), binge eating (Davis & Woodside, 2002; Loxton & Dawe, 2001), food cravings (Franken & Muris, 2005), and relative body weight (Davis, Strachan, & Berkson, 2004; Davis et al., 2007).

Alternatively, the hypothesis that a relative insensitivity to natural rewards (reward deficiency syndrome, RDS) is also a key factor in the etiology of obesity has already been demonstrated in neuro-imaging research (Wang et al., 2001; Haltia et al., 2007). RDS is assumed to be caused by a reduced dopaminergic activity and research has shown evidence that this was linked to poor decision-making abilities on the IGT, characterised by *future insensitivity* (Sevy et al., 2006). This hypothesis suggests that overweight individuals may also show poor decision-making abilities, characterised by more *future insensitivity*. RDS may destabilise cognitive representations, resulting in a dominant attention for more recent events as compared to more distant events (de Wit, Enggasser, & Richards, 2002; Robbins, 2005). In this way one can predict that a person would be less likely to be motivated to abstain from eating because the long-term negative consequences of overeating are less salient (Volkow, Wang, Fowler, & Telang, 2008). Furthermore, low sensitivity to reward may perpetuate overeating as a means of compensating for the decreased activation of reward circuits as a way to advance the anhedonic affect (Wang et al., 2001; Berridge & Robinson, 1998).

In conclusion, the current study aims to examine the role of self-regulation processes in average weight and above average weight children in a decision-making paradigm, thereby exploring the role of two possible but distinct processes assumed to underlie the supposed decision-making deficits: hypersensitivity to rewards or future insensitivity.

Method

Participants

The sample included 132 children (54.5% girls), with a mean age of 12.43 years (*SD* = 1.18), ranging from 11 to 16 years. The sample had a mean adjusted BMI (i.e. percent over ideal BMI) of 122.27 (*SD* = 25.42), ranging from 78.51 to 189.63 (CDC BMI z-scores range from -2.34 to 2.37). For the present research two weight groups are defined based on the criteria of Van Winckel and Van Mil (2001): (1) average weight children (*n* = 66) with an adjusted BMI < 120%; and (2) overweight children (*n* = 64) with an adjusted BMI > 120%. In the overweight group, 33.4% has an adjusted BMI between 120-140%; 53% between 140-160% and 6.8% > 160%.

Weight groups were compared on gender, age and weight differences. Analyses indicated that gender did not differ significantly between participants in the two weight groups, $\chi^2(1) = .703$; $p = .402$. Mean age was 12.42 (*SD*=1.16) for the average weight group and 13.59 (*SD*=1.62) for the overweight group. Analysis of variance (ANOVA) identified that this difference was significant, $F(1,128) = 22.44$, $p<.000$. Since neurocognitive functioning in children is age-dependent, this variable was added as covariate in all analyses.

The two weight groups also differed significantly in adjusted BMI (F(1,128) = 342.13, p<.000). The mean adjusted BMI of the average weight group was 102.56% (SD = 8.99) and ranged from 84.64% to 119.53% (CDC BMI z-scores range from -1.48 to .96). The mean adjusted BMI of the overweight group was 145.37% (SD = 16.27) and ranged from 120.53% to 189.63% (CDC BMI z-scores range from 1.14 to 2.37).

Procedure

The participants were recruited from community schools and from a pediatric obesity centre in Flandres, Belgium. Inclusion criteria for participation in the study were: age between 11 and 16 years, no underweight (adjusted BMI ≥ 85%) and following a regular academic track corresponding with IQ within the normal range. From the 216 eligible participants invited to come to the University lab, 134 were willing to participate. No significant differences in demographical data were observed between the children who participated in the study and those who did not. Informed consent was obtained from the children and their parents, and a test appointment was made. The computer task took approximately 30 minutes to complete. At the end of the study the children's height and weight were measured and they received two movie tickets for their participation. The local research ethics committee approved the protocol of this study.

Physical measurements.

Weight and height were measured by the investigator, using calibrated instruments (light clothing allowed but no shoes). The BMI (weight in kilograms/(height in meters)^2) was determined for each child. 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, 2000).

Gambling task.

Decision-making was assessed by the Hungry Donkey task (HD task; Crone & Van der Molen, 2004). This is a developmentally appropriate analogue of the IOWA Gambling Task (IGT) originally developed by Bechara et al. (1994). Participants were presented with 4 doors (A, B, C, D; presented in a row) on a computer screen. All doors were equal in size and appearance and below the doors sat a donkey. Participants were told to help the donkey to collect as many apples as possible by pressing one of four keys of the computer keyboard (A, S, K, and L) corresponding to the doors. Upon pressing one of the keys, the stimulus display was replaced with the outcome display showing the number of apples gained or the number of apples lost. The status of gain was indicated by a vertical bar presented at the right of the computer screen that was half red/half green at the beginning of the task. During the course of the task, the colour change of the bar corresponded to the total number of apples won or lost.

In the present study two versions of win/loss schedules were presented, the standard HD task and the reversed HD task. Both tasks contained 200 trials. All participants completed both versions of the task and the order was counterbalanced between participants. The important difference between the standard and the reversed version of the HD task is that in the former reward is presented up front and punishment is introduced later whereas in the latter punishment is presented up front and reward is introduced later.

Standard HD task (immediate reward/delayed punishment). In the standard HD task (see also Crone & Van der Molen, 2004), the immediate rewards for choice A and B were higher (four apples) than for choice C and D (two apples). However, the penalty amounts were higher at the high paying doors (A and B) and lower in the low paying doors (C and D). After selecting 10 A-doors the participant received 40 apples but also encountered five unpredicted losses of either 8, 10, 10, 10, or 12 apples, bringing the total cost to 50 apples, thus resulting in net loss of 10 apples. After selecting 10 B-doors, the subject received 40 apples but encountered one unpredicted loss of 50 apples, also resulting in a net loss of 10 apples. After selecting 10 C-doors, the subject received 20 apples, but encountered five unpredicted losses of 1, 2, 2, 2, or 3 apples, bringing the cost to 10 apples, resulting in a net gain of 10 apples. Finally, after selecting 10 D-doors, the subject received also 20 apples but encountered one unpredicted loss of 10 apples, also resulting in a net gain of 10 apples. In sum, doors A and B were disadvantageous in the long run, because they resulted in high immediate reward but a net loss in the long run, while doors C and D were advantageous in the long run because they resulted in immediate low reward but an overall gain.

Reversed HD task (immediate punishment/delayed reward). In the reversed HD task (see also Crone & Van der Molen, 2004), the immediate punishment for choice A and B were higher (four apples) than for choice C and D (2 apples). After selecting 10 A-doors the participant lost 40 apples but also encountered five unpredicted rewards of either 8, 10, 10, 10, or 12 apples, thus resulting in net gain of 10 apples. After selecting 10 B-doors, the subject lost

40 apples but encountered one unpredicted reward of 50 apples, also resulting in a net gain of 10 apples. After selecting 10 C-doors, the subject lost 20 apples, but encountered five unpredicted rewards of 1, 2, 2, 2, or 3 apples, resulting in a net loss of 10 apples. Finally, after selecting 10 D-doors, the subject lost 20 apples but encountered one unpredicted reward of 10 apples, also resulting in a net loss of 10 apples. In sum, in the reversed version choices A and B were advantageous, because they resulted in high immediate punishment but a net gain in the long run due to high delayed rewards, while choices C and D were disadvantageous, because they resulted in immediate low punishment but due to small delayed rewards, in larger losses in the long run.

Data preparation and Analysis

In line with the IOWA Gambling Task literature, the differences score between the advantageous choices and disadvantageous choices was calculated. For the standard HD task, the difference score was calculated between the total number of choices for doors C and D minus the total number of choices for door A and B [(C+D) – (A+B)]. For the reversed HD task, the difference score was calculated between the total number of choices for doors A and B minus the total number of choices for door C and D [(A+B) – (C+D)]. A positive score indicates an overall net gain while a negative score indicates an overall net loss, which indicates impaired decision making. Both the standard task and the reversed task consisted of a total of 200 trials. This can be divided in 5 blocks of 40 trials. The difference scores were calculated separately for the 5 blocks. In this way a possible strategy change during the course of the task performance could be examined.

First, differences between the two weight groups on the overall performance on the tasks was analysed using chi square analyses on impaired decision making (overall difference score < 0) and a MANCOVA with age as covariate. Second, repeated measures MANCOVAs were executed to detect overall group differences in decision making strategy between the two weight groups or group by factor interactions with age as covariate.

Results

Hungry Donkey Task Decision-making Performance

Chi square analyses comparing subjects with and without impaired decision making in both weight groups revealed a significant difference between the weight groups in the performance on both HD tasks. The overweight children showed more impaired decision making on the standard HD task ($\chi^2(1) = 8.76$, $p = .003$), and on the reversed HD task ($\chi^2(1) = 30.82$, $p = .000$). Results of the MANCOVA on the two difference score of both tasks as dependent variables with weight groups as between factor showed an overall difference between the weight groups in Decision-making performance, $F(2,114) = 10.91$, $p = .000$, $\eta^2 = .161$. Univariate analysis revealed a trend significant difference between the weight groups in their scores on the standard HD task, $F(1,115) = 3.40$, $p = .068$, $\eta^2 = .029$ and a significant difference on the reversed HD task, $F(1,115) = 20.83$, $p = .000$, $\eta^2 = .153$ (see Figure 1).

Hungry Donkey Task Decision-making Strategy

Repeated measure MANCOVAs on the difference scores, with Weight Group (average weight, overweight) as between subject factor, Blocks (5) as within-subject factors and age as covariate were performed for the two versions of the HD task to detect group differences between the two weight groups. All interactions with age failed to reach significance.

For the standard HD task a significant main effect of Task Block was found, $F(4,112) = 3.63$, $p = .008$, $\eta^2 = .115$, but the interaction effect between Weight Group and Task Block did not reach significance ($F(4,112) = 1.19$, $p = .320$, $\eta^2 = .041$). However, although not significant, the data were in the direction of the hypotheses: as depicted in Figure 2 the average weight children learned to adapt an advantageous decision-making strategy on the standard HD task during the 5 blocks in contrast with the overweight group who did not show a learning process.

For the reversed HD task, the main effect of Task Block was not significant, $F(4,119) = .78$, $p = .537$, $\eta^2 = .026$ but the interaction between Weight Group and Task Block was significant $F(4,119) = 6.76$, $p = .000$, $\eta^2 = .185$ (see Figure 3), indicating that the decision-making behaviour across the 5 blocks of the overweight children is poor compared with the average weight group. Post hoc t-tests for each block separately revealed that from block 2 on there was a significant difference between the weight groups in performance on the reversed HD ($p<.000$ for block 2,3,4 and 5).

Discussion

The present study explored patterns of decision-making in children aged 11 to 16 years old with and without overweight. We compared the performance of these groups on a developmentally appropriate variant of the IGT, the Hungry Donkey Task. With this paradigm we addressed aspects of self-regulation which may be related to developmental pathways that lead to overweight. We hypothesised that overweight children may show poor decision-making and aimed to explore the possible underlying processes: (1) overweight children may be so/too sensitive to reward that they ignore the punishment that goes along with it, or (2) overweight children may be insensitive to future outcomes, and therefore they choose options that are appetitive on a short-term basis. To examine these possibilities, the participants completed both the standard and the reversed version of the HD task.

In line with our expectations, the current findings reveal differences between the two weight groups in their decision-making performance. On both tasks, the overweight children showed more impaired decision-making compared to the average weight group. These finding is in line with considerable previous research evidencing diminished self-regulation in overweight children. Higher BMI in children is often associated with the inability to resist impulses and temptations (e.g. Seeyave et al.,2009; Verbeken, Braet, Claus, Nederkoorn, & Oosterlaan, 2009), while on the neurocognitive level they show a significantly worse response inhibition (Batternick, Yokum, & Stice, 2010).

Further analyses revealed that the overweight children showed mainly decision making deficits on the reversed version of the HD task. The data from the standard HD task did not reach significance, but the direction of the results suggest that children in the overweight group seem to be more influenced by immediate outcomes than by future consequences. The analysis of the performance pattern on the reversed version of the HD task was convincing that compared to average weight children, the overweight children significantly performed worse. These results suggest that the decision making behaviour of overweight children seemed to be more the result of insensitivity to future consequences then it is affected by hypersensitivity to reward.

The current findings are somewhat surprising and in contrast with previous research linking relative body weight and high sensitivity to reward (Davis et al., 2007; Davis et al., 2004; Davis & Woodside, 2002; Guerrieri et al., 2008; Loxton & Dawe, 2001; Franken & Muris, 2005). However, since poor decision-making abilities on the IGT, characterised by future insensitivity is linked to a reduced dopaminergic activity (Sevy et al., 2006) the findings suggests that already in children the RDS hypothesis or the anhedonic route to obesity is supported. The fact that a greater part of the children in the above average weight group were obese (*n* = 66.60%) may account for these observations. The dynamic vulnerability model for obesity (Davis, et al., 2004; Lowe, van Steenburgh, Ochner, & Coletta, 2009; Stice, Yokum, Burger, Epstein, & Small, 2011) states that it is possible that heightened generalized reward sensitivity is an initial risk factor for excessive food intake among normal weight individuals resulting in a positive energy balance and weight gain. However, the excessive reward can overload the DA system in such a way that it reduces the DA activity. Hence, once obese, these children may suffer from an insensitive reward system, which enhances further overeating to reach an acceptable level of hedonic satisfaction (Davis et al., 2004; Lowe et al., 2009; Stice et al., 2011). Previous evidence already showed a decrease of activation in reward areas in obese versus lean children, implying that food may be experienced as less rewarding by obese children (Davids et al., 2010; Stice, Spoor, Bohan, & Small, 2008).

Although the theory seems plausible, alternative explanations were still open. A dual process model presented by Appelhans (2009) posits that the decision to go for the immediate reward and eat palatable food or to strain for the larger future benefit of weight loss and improved health is the product of the balance between bottom up reward processes and active top down inhibitory control mediated by the prefrontal cortex. So, it is possible that in overweight children top down inhibitory control mechanisms were failing.

Despite our interesting findings, several limitations justify a cautious interpretation of our results. First, it seems noteworthy to justify in research the cut off points between overweight and obesity in children and to study if both groups are affected by different pathological routes. Secondly, in child research, it is generally accepted that children of different ages can react differently, specifically in the age range of 10-16 years. It is reasonable to assume that cognitive maturation can be of importance here. Therefore, following a regular academic track corresponding with IQ within the normal range was an inclusion criterion and age effects were controlled for in all analyses. Furthermore, given the known association between pubertal status and BMI, we made a good attempt to control for this variable via the use of the adjusted BMI controlling for age and gender. However, we recommend that future research should specifically control for IQ, pubertal status and for other factors as current dietary practices and unknown existing comorbidities which can affect weight or judgements about food-reward. Finally, the cross-sectional nature of this research prevents a causal interpretation of the relationships. Longitudinal research is needed to examine the suggested developmental pathways.

Obesity is caused by multiple factors, and specifically genetic factors play an important role by regulating the energy balance (Bouchard, 2009). Besides this, the study of biological differences in brain functioning is still in its infancy. Future research in this domain exploring for individual differences in cognitive control and self-regulation skills, is indicated and more specifically, the existence of a specific group of children characterised by a developmental VM brain dysfunction. Although this dysfunction alone does not lead to obesegenic eating habits, it may present a phenotypic characteristic of certain subjects that may succumb to excessive overeating. This is consistent with clinical experiences that some adolescents, despite great motivation to lose weight, report objective episodes of overeating not related to hunger or tasty food and consequently will not succeed in maintaining their weight loss. In this way, if future research can replicate the existence of decision-making deficits in obese children and create more homogeneous sub-groups, more specific treatment targets could be provided.

Furthermore, when estimating the implications of the detected 'myopia for the future' in overweight children, preventive interventions in childhood should focus more on creating a less tempting obesegenic environment. In public places, and particularly in schools, there should be little exposure, if any, to foods which are high in calories. Schools could remove junk foods form dispending machines where they seduce children into obesity and the food industry could make healthy foods more attractive, palatable, and less expensive (Volkow & Wise, 2005).

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Figures

Figure 1. Difference scores on the standard and reversed Hungry Donkey task for the two weight groups separately.

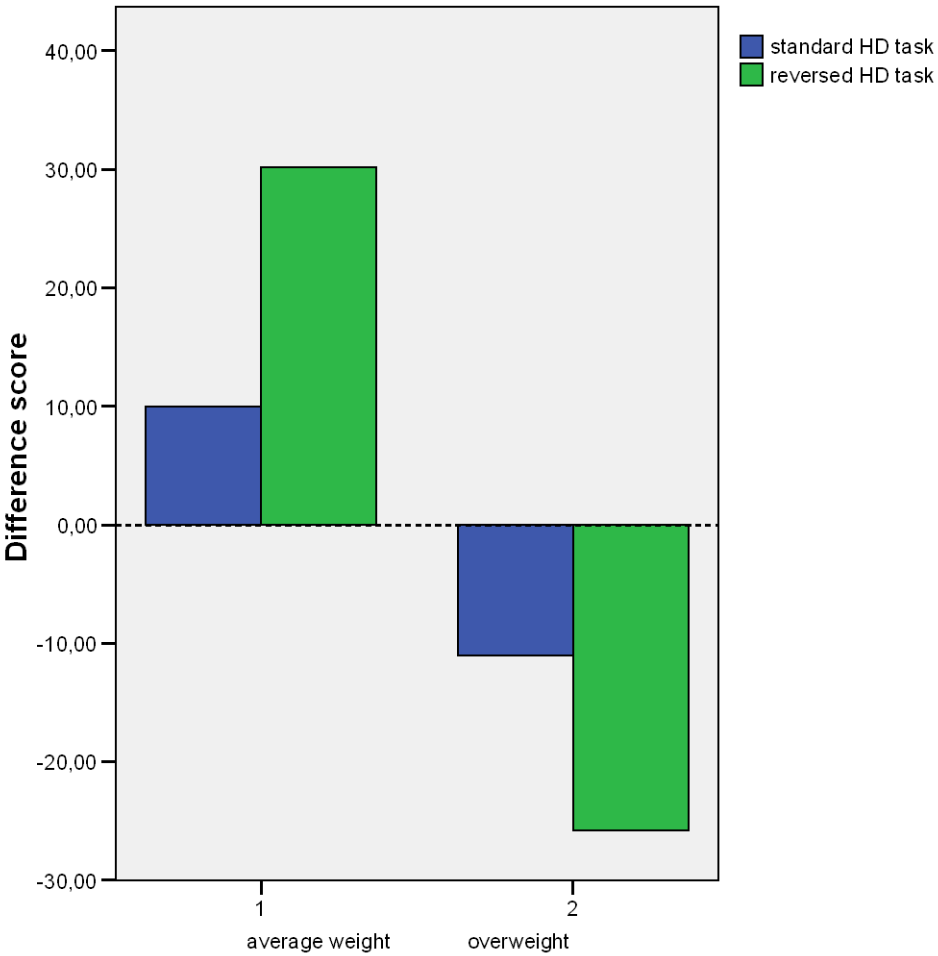


Figure 2. Difference scores as a function of trial block across the standard Hungry Donkey task for the two weight groups separately.

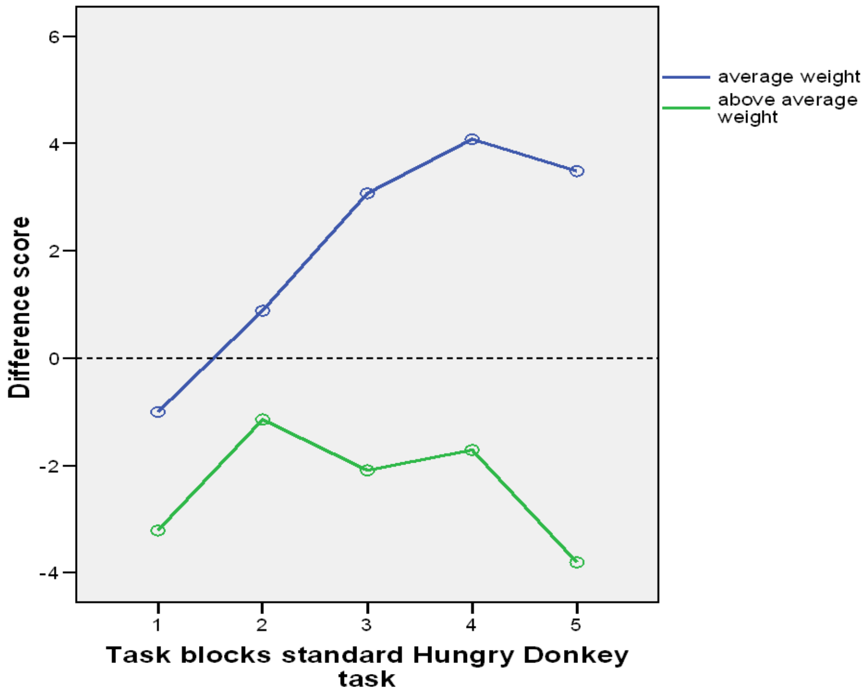
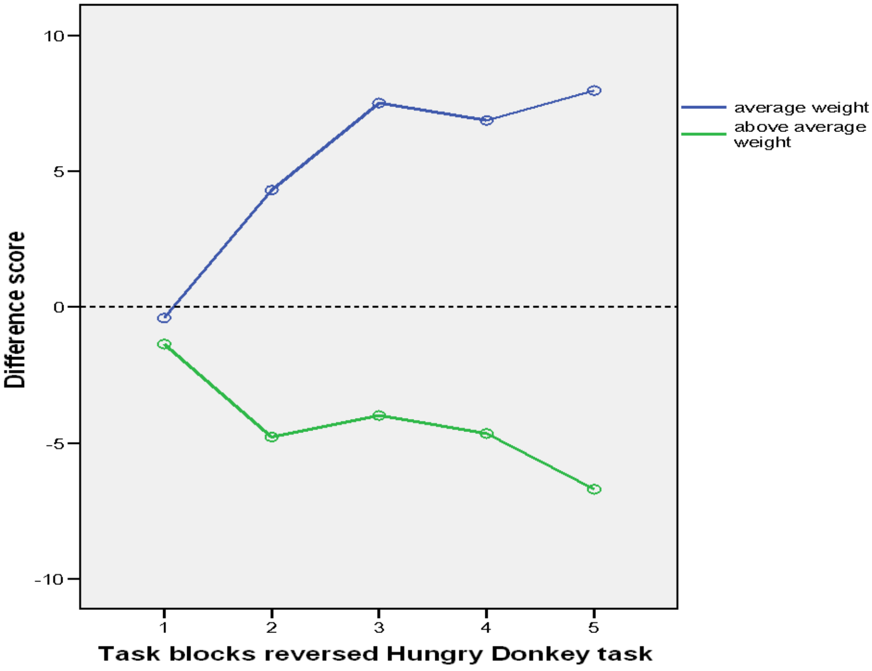


Figure 3. Difference scores as a function of trial block across the reversed Hungry Donkey task for the two weight groups separately.



Chapter 4

Delay of gratification in overweight children and adolescents1

Recent research stresses the importance of examining self-regulation skills as risk factors for the development of overweight in children. However, it remains unclear whether the poor self-regulation abilities in overweight toddlers linger into adolescence, what underlying processes are running and whether the poor self-regulation abilities are food-specific or general. The aim of the current study was to explore individual differences in self-regulation skills in overweight and non-overweight children in a classic delay of gratification paradigm in and outside a food context. It was found that overweight children and young adolescents are less able to delay gratification in general, due to both insufficient cognitive-attention strategies and higher levels of impulsivity. Weight-control interventions of overweight children should focus on enhanced self-control and so far cognitive-attention strategies.

[1] Verbeken, S., Braet, C., & Lammertyn, J. (2012). Delay of gratification in overweight children and adolescents. *Manuscript submitted for publication.*

Introduction

The prevalence of overweight in children has been increasing rapidly over the past three decades, along with the prevalence of concomitant medical and psychosocial problems (Lobstein, Baur, & Uauy, 2004; Jackson-Leach & Lobstein, 2006; Reilly et al., 2003; Reilly, 2006; Reilly, 2007). Besides the recognized genetic predisposition, the impact of the modern food-environment is well-established. The profuse exposure to the strongly rewarding food temptations in our environment challenges the self-regulatory system, which can be defined as the ability to override momentary gratification in exchange of long-term goals (Baumeister, Heatherton, & Tice, 1993; Metcalfe & Mischel, 1999). Consequently, overeating and weight-gain can be seen as the result of self-regulatory failure (Baumeister & Heatherton, 1996).

Indeed, recent longitudinal research shows that children between two and five years old with limited ability to delay gratification were more likely to be above-average weight at the age of 5, 11 or 12. In addition, early self-regulation skills were stronger predictors than actual BMI in determining which children were classified as overweight 3 years later (Francis & Susman, 2009; Graziano, Calkins, & Keane, 2010; Seeyave, et al., 2009). These findings provide convincing evidence that early self-regulation skills constitute an important individual factor to be taken into consideration when examining the development of overweight. Specifying the processes that children can use to cope with the pressures and influences of the overwhelming food-environment is a major challenge in overweight research. The present study aims to contribute to this research.

So far, most insights into the processes that enable self-regulation have come from research based on a specific standardized waiting task designed for use in young children: the delay of gratification paradigm (DGP) (Mischel, 1974; Mischel & Baker, 1975; Mischel & Ebbesen, 1970; Mischel, Ebbesen, & Zeiss, 1972; Mischel & Moore, 1973). During this procedure, children were faced with the dilemma of choosing one cookie immediately or waiting several minutes for two cookies. The situation creates a strong conflict between the temptation to stop the delay and take the immediately available – however smaller – reward or to continue waiting for the larger, more preferred choice. Extensive empirical evidence has shown that especially the children who are able to direct their attention away from the reward-related stimuli are able to wait longer than the children who direct their attention toward the reward-related stimuli (Eigsti, et al., 2006; Mischel, 1974; Mischel et al., 1989; Mischel, Shoda, & Rodriguez, 1989). The crucial effect of cognitive-attention control as underlying process behind all forms of self-regulation is well-documented (Fonagy & Target, 2002; Kopp, 1982; Posner & Rothbart, 1998; Ruff & Rothbart, 1996) and theoretically underpinned as well.

In the theoretical framework of self-regulation proposed by Mischel and Ayduk (2004), the cognitive-attention control strategies that are essential in the pursuit of delayed rewards depend upon the balanced interactions between a cognitive ‘cool’ system and an emotional ’hot’ system. When the cool system, which is a slow and contemplative ’known’ system, is able to override the hot system, which is a fast, impulsive, appetitive ‘go’ system, the individual uses cognitive-attention cooling strategies, and thus is less controlled by whatever is salient in the immediate field of attention (Metcalfe & Mischel, 1999; Rodriguez, Mischel, & Shoda, 1989).

Although we already know that overweight children fail on the DGP (Bonato & Boland, 1983; Johnson, Parry, & Drabman, 1978; but Geller, Keane, & Scheier, 1981), it remains uncertain if the assumed imbalance of these children is due to a lack of cognitive-attention competencies or to an overwhelming hot system. Research established already a strong relation between parameters of the hot system, such as impulsivity and childhood overweight (e.g. Braet, Claus, Verbeken, & Van Vlierberghe, 2007; Holtkamp et al., 2004; Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006; Verbeken, Braet, Claus, Nederdoorn, & Oosterlaan, 2009). Therefore, in overweight children the self-regulatory system can be out of balance due to a powerful hot system. This has been validated by research showing that especially children with weak delay of gratification abilities display more impulsivity and higher reward sensitivity (Evenden, 1999; Olson, Schilling, & Bates, 1999). Therefore we also expect that overweight children will report higher levels of impulsivity and that this will be associated with more difficulty to resist temptation during delay.

Further, an increasing amount of literature on neuropsychology of overeating, obesity and binge eating suggests that cognitive deficits are implicated (e.g. Cserjesi, Luminet, Poncelet, & Lenard, 2009; Cournot et al, 2006; Gunstad et al., 2007). We therefore assume that self-regulatory failure in overweight children can also be due to a weak cool system. This can be observed by poor use of cognitive-attention strategies helpful for maintaining the delay, such as purposeful self-distraction (Metcalfe & Mischel, 1999).

Remarkably, previous research on delay of gratification abilities was mainly conducted with toddlers. However, the examination of these abilities with an overweight population during the transition to early adolescence is particularly relevant, since it is a critical period for the persistence of overweight (Dietz, 1994, 2004). Recent longitudinal research proved the existence of delay of gratification deficits in overweight adolescents (Duckworth, Tsukayama, & Geier, 2010; Tsukayama, Toomey, Faith, & Duckworth, 2010). Unfortunately, in these interesting studies self-control was mainly assessed by means of questionnaires, which made the exploration of the underlying psychological processes that enable or constrain the ability to delay gratification impracticable. Therefore, this study aims to examine the self-regulatory ability of obese children and young adolescents during a DGP which allows us to specifically examine the underlying processes.

Furthermore, the fundamental question whether self-control deficits of overweight children are specific to the eating domain or if they occur across contexts remains inconclusive. Bonato and Boland (1983) adapted the DGP paradigm for overweight children and they found that in comparison with normal weight children, the overweight children choose immediate rewards more often, but only when the incentive was edible. These results suggest that deficits in delay of gratification of overweight children are food-specific, which may be due to the stronger incentive value of these items for them. However, other research shows that the deficits in the ability to sustain gratification were non-specific (Francis & Susman, 2009; Graziano, et al., 2010; Seeyave et al., 2009; Johnson et al., 1978; Sigal & Adler, 1976). Therefore, the current study aims to explore self-control skills of overweight children during a situation with delay of gratification using both food and non-food rewards.

In short it can be said that major recent longitudinal data stress the importance of examining self-regulation skills as risk factors for the development of overweight in children. However, it remains unclear whether the poor self-regulation abilities of overweight toddlers linger into adolescence, which underlying processes are running and whether the poor self-regulation abilities are food-specific or general. The purpose of this study was to explore individual differences in self-regulation skills in overweight and non-overweight children in a classic DGP in and outside a food context. It was expected that overweight middle school children and young adolescents are less able to delay gratification in general, due to both insufficient cognitive-attention strategies and higher levels of impulsivity. Therefore, we explored the mediating role of attention strategies and impulsivity on the link between bodyweight and delay of gratification in a classic delay of gratification paradigm.

Method

Participants

The sample included 55 girls and 48 boys, with a mean age of 12.30 years (*SD* = 1.35), ranging from 10 to 15 years. Due to missing data we were able to calculate the adjusted BMI for 97 children.

The overweight group consisted of 49 children, 19 boys and 30 girls, referred for treatment for obesity, with a mean age of 12.34 years (SD = 1.41). The mean adjusted BMI of the above average weight group was 166.20% (*SD* = 24.35) and ranged from 122.63% to 241.74% (CDC BMI z-scores range from 1.04 to 2.82; Ogden et al., 2002).

The average weight control group consisted of 48 children, 26 boys and 22 girls, selected from regular schools, with a mean age of 12.25 years (SD = 1.29). All controls were within the normal weight range. The mean adjusted BMI of the average weight group was 98.13% (SD = 10.71) and ranged from 78.03% to 116.84% (CDC BMI z-scores range from -2.42 to .83; Ogden et al., 2002).

Measures

Physical measurements. Weight and height were measured using calibrated instruments (light clothing allowed but no shoes). The BMI (weight in kilograms/(height in meters)^2) was determined for each child. 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 50^{th} percentiles of the BMI for age and gender are based on normative data (Fredriks, van Buuren, Wit, & Verloove-Vanhorick, 2000).

Socioeconomic Status. The Hollingshead index (Hollingshead, 1975) was used to assess socioeconomic status. This is a widely used measure of social and economic level based on career and education status. Higher scores on the Holingshead index (SES-index) reflect a lower socioeconomic status.

Delay of gratification task Participants were tested individually in a classroom containing a table with a desk bell, and a chair in front of the table, without any other distracting stimuli. The children were assigned randomly to a non-edible (toy) or an edible (candy) incentive condition. In order to construct for these older children a situation that includes both a contingency structure that gives the subject something tangible to gain through delay *and* a powerfully motivating, immediately available reward that must be resisted for delay to occur, the children were involved in the selection of the incentives (Funder & Block, 1989). This way, although the rewards were quite small, the motivational inducement would be sufficient (Hom & Fabes, 1984). They were asked to rate 10 rewards on a scale from 1 (the less preferred reward) to 10 (the most preferred reward). As indicated by the standard delay of gratification procedure (see Mischel et al., 1989), the experimenter offered the child afterwards the choice of either a small, less preferred reward (reward rated as 6) or a bigger, more preferred reward (reward rated as 10). The experimenter told the child that she had to go out of the room for a while and that the child would have to wait for the experimenter to return without leaving the chair to receive the most preferred reward. Children were also told that they could bring back the experimenter any time they wanted by ringing the bell in front of them; however then, they could only have the smaller, less preferred reward. After testing the child's comprehension of the contingency, the experimenter left the room, and returned when 20 min has elapsed, or as soon as the child rang the bell. This self-regulatory task have been shown to apply in diverse populations in middle school years, and to have meaningful correlates supporting their validity as predictors of diverse adaptive social, cognitive, and emotional outcomes (Ayduk et al., 2000; Rodriguez, et al., 1989).

Attention focus strategy During the delay period, children were videotaped and afterwards the tapes were analysed by two individual observers (psychology students) who were not informed of the aims of the current study. Comparison between them revealed a sufficient inter-rater reliability (.68). The ratings (see Peake, Heble & Mischel, 2002; Rodriguez, Mischel, & Shoda, 1989) was focused on the child's directly observable spontaneous attention focussing to the three most conceptually relevant foci of attention: the rewards, the terminating signal (the bell), and elsewhere (any distractions from these two temptations). Any looking, touching, or talking, directed at the rewards, the bell, or elsewhere, was coded by the observers in series of consecutive 5-s segments. To obtain a measure of how much attention children typically devoted to the particular foci during the delay period, we first calculated the frequency of a particular attentional activity and then calculated the relative frequencies across the total delay time (e.g. if a child attended to the rewards in 20 of the 5-s segments and rang the bell after 15 minutes which are 180 5-s intervals, the child would receive a relative 'attention focus rewards' score of

20/180 *100 = 11). Note, that because we used such small segments (5-s), the average relative frequencies for a specific focus are virtually equivalent to the proportion of time spent attending to each task.

UPPS Impulsive Behaviour Scale (Whiteside & Lynam, 2001). The UPPS consists of 45 items that evaluate four different facets of impulsivity, labelled Urgency, lack of Premeditation, lack of Perseverance, and Sensation Seeking. Items on the scale are scored on a 4-point Likert scale ranging from “I agree strongly” to “I disagree strongly”. Across all items a high score reveals more impulsivity. In accordance with previous research (Avila, 2001; Bechara, Dolan, & Hindes, 2002; Mobbs et al., 2010), the Urgency scale is the main focus in the current study. This research supposes that relative to the other facets, Urgency is the best predictor of impulsive behaviour in a conflict situation. Urgency is defined as “the tendency to experience strong impulses, frequently under conditions of negative affect” and may be reflected in difficulty resisting temptation and controlling overeating (Bechara, Dolan, & Hindes, 2002; Mobbs et al., 2010). The facet lack of premeditation is defined as “the difficulty to think and reflect on the consequences of an act before engaging in the act” (Whiteside & Lynam, 2001), and could be related to the inability to take into account the positive or negative consequences of a decision (Mobbs et al., 2010). This facet is less implicated because in the DGP the processes underlying the ability to sustain self-imposed delay of gratification are *after* the initial choice has been made. Similarly, the facet Sensation Seeking, associated with seeking new rewarding experiences as opposed to rewards in the immediate environment, and the facet lack of Perseverance, associated with difficulties inhibiting irrelevant thoughts, are less implicated in the current study. Whiteside and Lynam (2001) presented information on the internal consistency, as well as the divergent and external validity of the UPPS. The alpha reliabilities in the present sample for the different subscales were respectively .83, .78, .74, and .70.

Appetite was rated on self-report scales at the beginning and at the end of the delay task on a scale ranging from 0 (no hunger at all) to 10 (very hungry).

Subjective experience of resisting the temptation during the delay (“how difficult was it for you to resist the reward during the delay period?”) was rated on a self-report scale at the end of the delay task ranging from 0 (not difficult at all) to 10 (very difficult).

Procedure

The adjusted BMI for the children (Actual BMI/ Percentile 50 of BMI for age and gender X 100) was used in the analyses. Children’s overweight and obese status was identified in relation to the Dutch body mass index values in 0-21 year olds (Frederiks, van Buuren, Wit, & Verloove-Vanhorick, 2002). Because we are specifically interested in examining differences between normal weight and overweight children, we used a widely accepted cut-off for defining overweight (adjusted BMI > 120% indicating overweight; Troiano & Flegal, 1998) to divide the sample into the two weight-groups. In addition, to compare the degree of overweight of the present European sample with US-studies on overweight, BMI z-scores were calculated using a program provided by the Centers for Disease Control and Prevention (CDC) (Centers for Disease Control and Prevention, 2000).

Children with overweight in a medical paediatric centre were invited to participate. Inclusion criteria were: primary obesity, adjusted BMI above 120 %, age between 10 and 15 years, attending regular schools corresponding with

IQ within the normal range, and absence of pervasive development disorders. The normal weight control children were selected from primary and secondary regular schools. The same inclusion criteria were used except for adjusted BMI (< 120%).

Delay of gratification ability was measured using the classic delay of gratification paradigm (Mischel, 1974; Mischel, Shoda, & Rodriguez, 1989) - at the clinic before the beginning of treatment for the overweight children, and at the university laboratories for the control children. Children were individually assessed on the RAVEN Standard Progressive Matrices (Raven SPM; Raven, 1938, 1998) and self-report measures, in separate sessions before and after the delay task. The children also scored their feelings of hunger just before and after the delay task. Their parents were questioned on their own education and profession, in order to measure their socio-economic status (SES, Hollingshead index, Hollinghead, 1975). At the end of the study the children's height and weight were measured and they received two movie tickets for their participation. The local research ethics committee approved the protocol of this study.

Analytic plan

Between-group comparisons were performed using one-way (ANOVA) and multi-way (MANOVA) analyses of variance with weight group (average weight versus overweight) and condition (food reward versus non-food reward) as factors and appetite (pre and post) as covariate for dimensional outcomes, and χ^2 analyses for categorical outcomes. Furthermore, Pearson correlations were computed among the study variables. We calculated partial eta squared (η^2) effect sizes: an η^2 between .01 and .06 can be interpreted as a small effect, an η^2 between .06 and .14 as moderate and above .14 as a large (Cohen, 1988).

Follow recommendations by MacKinnon, Lockwood and Williams (2004), a nonparametric, resampling approach (bootstrapping procedure; see Preacher & Hayes, 2008) was used to test two mediation models in which (1) impulsivity and (2) cognitive attentional strategy is hypothesized to mediate the relation between adjusted BMI and difficulty to resist temptation. As dependent variable the subjective experience of the delay of gratification was used (“how difficult was it for you to resist the reward during the delay period?”). For these mediational analyses the R package mediation was used (Tingley, Yamamoto, Keele and Imai, 2012).

Since a high proportion of the children waited the whole 20 minutes, the variable ‘waiting time’ could not be analysed as a continuous variable.

Results

Descriptive statistics.

Descriptive statistics for all of the study variables are presented in Table 1. First, we controlled whether any of the demographic variables are related to children’s’ weight status. These analyses revealed no significant differences between the two groups for gender ($\chi^2(1) = 1.20$, p =.274) , age ($F(1,99) = .10$, $p = .752$), IQ ($F(1,80) = 2.18$, $p = .143$), and SES ($F(1,66) = 1.25$, $p = .268$).

Correlational analyses

Table 2 represents the Pearson’s correlations between the main study variables. First, the table indicates that both impulsivity (as measured with the Urgency scale) and cognitive attentional strategies were significantly correlated with adjusted BMI and with subjective experience of the delay time. These associations are positive with impulsivity and the maladaptive attentional strategies (focus on the bell and on the rewards) and negative with attention focus elsewhere. Second, results show that appetite is significantly correlated with subjective experience of the delay time.

Weight group differences in delay of gratification.

Delay task. Significant more overweight children chose to end the delay period prematurely and rang the bell as compared to the average weight children (15.7% versus 3.8%, $\chi^2(1) = 3.99$, $p = .046$). The results were only significant in the food reward condition.

Subjective experience during the delay task. The result showed no differences between the two weight groups for experiencing subjective difficulty of resisting temptation during the delay task, $F(1,88) = .124$, $p = .725$, $\eta^2 = .001$ and this was so for both reward conditions.

Attention focus strategy. During the delay, compared to the average weight group the overweight children were significantly more focussed at the bell ($F(1,91) = 14.51$, $p = .000$, $\eta^2 = .138$) and less able to distract their attention away ($F(1,91) = 4.36$, $p = .040$, $\eta^2 = .046$). Children in both weight groups were equally focussed on the rewards ($F(1,91) = .95$, $p = .331$, $\eta^2 = .010$). The Attention focus strategy appeared to be significantly different depending on the type of reward, in a way that all children are significantly more focussed at the rewards ($F(1,91) = 8.68$, $p = .004$, $\eta^2 = .087$) and less distracting their attention away ($F(1,91) = 6.31$, $p = .014$, $\eta^2 = .065$) in the non-food condition as compared to the food condition.

Impulsivity self-report measures. The results suggest that compared to the average weight children, the overweight children report higher levels of Urgency ($F(1,76) = 15.56$, $p < .001$, $\eta^2 = .170$), of Perseverance ($F(1,76) = 14.80$, $p < .001$, $\eta^2 = .163$), the same levels of Lack of Premeditation ($F(1,76) =$

.10, p = .755, η^2 = .001) and lower levels of Sensation Seeking (F(1,76) = 6.31, p = .014, η^2 = .077) .

Mediational analyses

The effect of weight status on subjective experience during the waiting time and the mediational pathways via impulsivity and attentional coping strategies were analysed.Given the relative small sample size (n = 68 for the model with Urgency as mediator; n = 88 for the model with attentional coping strategy (distraction) as mediator) and following MacKinnon et al. (2004), we used a nonparametric resampling method (bias-corrected bootstrapping, Preacher and Hayes, 2008). To derive the 95% confidence interval (CI) for each of the effect components (total, indirect and direct effect) we took 1000 bootstrap samples with replacement form the original sample. The effects are expressed in unstandardized regression weights.

(1) First, the results for Urgency as a mediator are presented. The direct effect of X on Y was not significant (estimate = -0.00817; 95% CI [-.02149 , .00540] p = .21). However, we observed a significant indirect effect of X on Y through Urgency (estimate = 0.00943, 95% CI [.00273 , .01870] p < .00). This mediating effect was opposite to the direct effect. Combined, these effects cancelled each other out leading to suppression of a total effect (estimate = .00126; 95% CI [-.01336 , .01587] p = .21).

(2) Second, the results for attentional strategy as a mediator are presented. The direct effect of X on Y was not significant (estimate = -0.003664, 95% CI [-.015551 , .009930] p = .59). However, we observed a significant indirect effect X on Y through attentional strategy (estimate = 0.004637, CI [.000858 , .009554] p = .02). This mediating effect was opposite to the direct effect.

Combined, these effects cancelled each other out leading to suppression of a total effect (estimate = .000973, 95% CI [-.012804 , .015061] p=.95)

Discussion

In general, the current findings suggest poor self-regulation in overweight children due to higher levels of impulsivity and less adaptive attentional coping strategies, inside and outside the context of eating. These results are consistent with the study hypotheses and in line with previous research, which emphasizes self-regulation failure as an important mechanism implicated in the development and/or control of food intake and overweight in children and adolescents.

In a classic DGP – compared to non-overweight children and despite similar IQ, age, and social status – **overweight children** tended here more often to stop the delay and take the immediately available smaller reward, and this was especially the case if they were waiting for food reward. Furthermore, the classic DGP allowed us to study which processes hamper children to forego temptation. Interestingly, we found that all overweight children displayed more unfavourable cognitive-attention strategies and reported higher levels of impulsivity. Furthermore, in line with previous research the meditational analyses suggest that higher levels of impulsivity are detrimental to delay gratification, whereas attention directed away from the temptations facilitates delay of gratification (Mischel & Ayduk, 2002; Mischel et al., 1996). In this way, although the majority of the overweight children were able to delay the short waiting period, both the seemingly higher levels of impulsivity and the decreased availability of cognitive-attention strategies may leave them more vulnerable to the power of the immediate rewarding environment in daily life.

Most subjects in both weight groups did manage to delay gratification. This is not an unusual result for a study with older children: maximum delay appears to have been the modal response in the studies reported by Funder and Block (1989), and Rodriguez et al. (1989) as well. This finding does not necessarily imply that delay of gratification is a simple manner in daily life where the immediately available rewards are much more powerfully attractive than those administered in a brief experimental situation (Funder & Block, 1989).

Furthermore, the current findings provide also arguments that self-regulation is more than just a cognitive competency that children master as they get more mature. We therefore must acknowledge the importance of individual differences in the availability of cognitive-attention strategies as well as the interaction of the cognitive control with a hot system. In this study, the participants in both weight groups were between 10 and 15 years old, which can developmentally be seen as mature enough to cognitively master a delay of 20 minutes.. Therefore, the observed cognitive-attention differences between the weight groups were of special relevance here. Based on the literature, we assume here an impact of individual differences in executive brain functioning which explains why the cool system seems less able to regulate and inhibit hot system processing in some children and leaves them more controlled by immediate temptations (Rodriguez et al., 1989). This suggestion is in line with previous research exploring the neuropsycholgical dificits in overweight adolescents (Verdejo-Garcia et al., 2010) and adults (Cserjési et al., 2009; Gunstad et al., 2007).

Additionally, given the higher levels of impulsivity, we assume that especially the interaction between the cool system and a powerful hot system makes it harder for the overweight children to resist temptation. Higher impulsivity levels, measured by "Urgency" and defined as "the tendency to experience strong impulses, frequently under conditions of negative affect" (Whiteside & Lynam, 2001) significantly mediated the association between body weight and difficulty to resist temptation during delay time. This facet of impulsivity is related to the inability to deliberately suppress dominant or prepotent responses, especially in conditions of intense emotions. This inability may contribute to an overweight person's problem controlling eating in situations of strong emotions, such as conflict situations (Guerrieri, Nederkoorn, & Jansen, 2008; Mobbs, Crépin, Thiéry, Golay, & Van der Linden, 2010). This is also in line with Graziano et al. (2010) who showed that except cognitive-attention control, other skills such as emotion regulation may be at work when controlling reward processes that relate to eating.

Although the focus in the current study was on the Urgency scale, we also analysed group differences on the other impulsivity scales. Compared to the average weight group, the overweight children reported higher levels of Lack of Perseverance, equal levels of Lack of Premediation. These findings are in line with previous research from Mobbs et al. (2010) in adult women . Finally, the scores for Sensation Seeking, defined as 'the tendency to enjoy and pursue activities that are exciting, and openness for new experiences' were lower in the overweight group as compared to the average weight group. This finding accords with the observation that individuals with a higher BMI are less frequent engaged in rewarding behaviour due to a diminished enjoyment from those behaviours (Pagoto, Spring, Cook, McChargue, & Schneider, 2006).

Several distinct hypotheses can call for the finding that despite the occurrence of more unfavourable underlying self-regulatory processes, many overweight children succeeded in sustaining the delay time. Firstly, the fact that the overweight children were at the beginning of therapy may have made them more sensitive to their long-term goals of food and weight control. De Ridder, Kuijer and Ouwehand (2006) observed that implicitly reminding young women about their long-term weight goals already significantly improved their self-regulatory competencies compared to the competencies of women who were not reminded of these goals. The Counteractive control theory (Trope & Fishbach, 2000) gives a possible explanation here. This theory posits that temptations may automatically trigger goal-directed behaviour by mentally activating the long-term goal. This means that food temptations would actually remind these overweight children at the beginning of therapy of their weight watching goal and thus consequently lead to successful self-control (Kroese, Evers, & De Ridder, 2009). This seems however inherent in all experiments were informed consent is required. The previous hypotheses make it advisable to replicate the current findings in a non-clinical sample of overweight children, in which we can possibly expect even more distinct results. Another hypothesis states that children may be more able to wait due to the certainty of long-term reward in the classic DGP. King and Logue (1992) demonstrated that when confronted with uncertainty in the expectancy of larger food rewards, humans tend to become less willing to wait for these bigger rewards. Therefore, future research could assess self-regulatory competencies of children using other paradigms, such as the Iowa Gambling Task (IGT, Bechara, Damasio, Damasio, & Anderson, 1994), in which future rewards are unpredictable.

To conclude, this study was able to demonstrate two possible pathways that may hamper overweight children to forego temptation and strive for long term weight control. Both cognitive deficits and higher levels of impulsivity were found in overweight children – in other words an imbalance between the cold and hot system resulting in more difficulties to cognitively cope with delay and resist temptation. Therefore, improvement of cognitive control should be integrated better in programmes for overweight children. In this manner, overweight children can learn to activate adequate cognitive coping strategies to override their impulses when confronted with temptation.

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Tables

Table 1. Means, standard deviations, F-values for the two weight-groups for characteristics and the dependent variables.

	Average weight (N = 48)	**Overweight** (N = 49)	
Gender (boys/girls)	26/22	19/30	ns
Age	12.25 (1.29)	12.34 (1.41)	ns
Adjusted BMI	98.13 (10.71)	166.20 (24.35)	***
RAVEN	46.10 (6.38)	43.91 (6.84)	ns
SES	36.28 (6.70)	41.31 (14.36)	ns
Impulsivity measures			
UPPS Urgency	2.24 (.52)	2.74 (.58)	15.56***
UPPS Perseverance	1.82 (.46)	2.26 (.54)	14.80***
UPPS Premeditation	2.15 (.36)	2.19 (.57)	.10
UPPS Sensation Seeking	3.17 (.52)	2.81 (.70)	6.31*
Attentional strategy			.95
Attention focus reward	18.35 (12.81)	21.76 (13.4)	14
Attention focus bell	2.11 (2.92)	6.00 (6.36)	.51***
Attention focus elsewhere	79.54 (13.66)	72.24 (16.86)	4.36*
Subjective experience			
Difficulty	3.08 (2.26)	3.28 (2.90)	2.82
Appetite			
Pre	2.65 (1.91)	2.49 (2.18)	.16
Post	2.94 (2.30)	2.88 (2.61)	.02

Note. IQ: intelligence Quotient; SES: socio economic status; ns: not significant †p< .1, *p<.05, **p<.01, ***p<.001.

Table 2. Pearson's correlations between the main study variables

	(2)	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
(1) adjusted BMI	*.30***	*.17*	*-.24**	*.47****	*.00*	*.07*	*.03*
(2) attention focus to bell		*.33***	*-.61****	*.32***	*.08*	*.06*	*.10*
(3) attention focus to rewards			*-.95****	*.17*	*.09*	*.06*	*.26**
(4) attention focus elsewhere				*-.24**	*-.10*	*-.07*	*-.25**
(5) Urgency					*.07*	*.16*	*.35***
(6) appetite pre						*.78****	*.30***
(7) appetite post							*.30***
(8) subjective experience							

Note. * $p < .05$; ** $p < .01$; *** $p < .001$

Chapter 5

How is reward sensitivity related to bodyweight in children?[1]

Previous research assumes that there are two seemingly opposing hypotheses for the relation between reward sensitivity (RS) and bodyweight: hyper-responsiveness model and reward deficiency syndrome (RDS), leading to the proposition of a feed forward process of weight gain. High RS may contribute to overeating and weight-gain among normal weight individuals. Over time the excessive food-intake may evolve in a down-regulation of dopamine (RDS), resulting in overeating as a form of self-medication and the progression to obesity. This process was evidenced in adults showing a curvi-linear relationship between self-reported RS and BMI. The aim of the current study was to investigate the association between self-reported RS and BMI in children (10-15y). The results confirm the non-linear relationship between RS and body weight and subscribe the suggestion of the same feed forward process in children. These findings imply that it seems crucial to reduce the intake of high palatable foods in high RS children to prevent the decrease in RS and reduce the risk for future weight gain.

[1] Verbeken, S., Braet, C., Lammertyn, J., Goossens L., & Moens, E. (2012). How is reward sensitivity related to bodyweight in children? Appetite, 58, 478-483, doi: 10.1016/j.appet.2011.11.018

Introduction

The impact of the modern food-environment on the recent boom of childhood obesity is well-established. A greater food palatability, a wide variety of foods, the high and easy availability (in the home and workplace), the stimulation by advertising, the food saliency, a larger portion size, and a higher energy density of food, all contribute to an increased reward value of foods, which overrides existing satiety signals and fosters overeating (Rolls, 2011). Consequently, in an increasing part of western society a positive energy balance is likely, which could lead to weight gain. Although not everyone in the same high rewarding food-environment becomes overweight, which points also at the role of interacting individual factors. It is reasonable to propose that individual differences in reward sensitivity (RS) or the tendency to engage in motivated approach behavior in the presence of rewarding stimuli may be one of the factors that contribute to a vulnerability to overeat and become obese (Small, 2009).

Obese individuals find palatable foods more rewarding than non-obese (McGloin et al., 2002; Nicklas, Yang, Baranowski, Zakeri, & Berenson, 2003; Rissanen et al., 2002), but it remains unclear *why* this is so (Lowe et al., 2009). According to Gray's Reinforcement Sensitivity Theory (RST, Gray, 1994; Gray & McNaughton, 2000; McNaughton & Corr, 2004), RS reflects functional outcomes of the behavioral activation system (BAS), which is organized primarily by the dopaminergic neurotransmitter system (Di Chiara, 1995; Gray & McNaughton, 2000; Pickering & Gray, 1999). Additionally, it has been postulated that dopamine (DA) deregulation contributes to development of obesity and binge eating (Davis et al., 2008; Davis et al., 2009; Geiger et al., 2009; Mathes et al., 2010).The dual vulnerability theory of dopamine deregulation presents two opposing hypotheses (Davis et al., 2008;

Stice, Spoor, Janet, & Zald, 2009). The first hypothesis, the hyper-responsiveness model, states that hypersensitivity to reward due to increased dopaminergic functioning, may motivate individuals to seek rewarding stimuli simply because the reinforcement value of the reward is so great (Davis, Strachan, & Berkson, 2004; Davis et al., 2008; Dawe & Loxton, 2004). Alternatively, Reward Deficiency Syndrome (RDS), states that individuals with relative insensitivity to reward because of low dopaminergic functioning, seek more rewarding substances to increase endogenous dopamine levels and improve mood (Blum, et al., 2000; Noble et al. 1997; Spitz et al., 2000; Wang, Volkow, & Fowler, 2002; Volkow, Wang, Fowler, & Telang, 2008).

The **hyper-responsiveness model** was supported by experimental research in healthy volunteers. Guerrieri, Nederkoorn, and Jansen (2008) identified high and low RS-children based on their performance on a behavioural task and measured their caloric intake via a Bogus Taste Test. Interestingly, when varied food was offered, the high RS children ingested significantly more calories than their low RS counterparts. When monotonous food was offered, RS did not really affect caloric intake. This finding was further supported in adults by Blundell et al. (2005). They showed that in a large group of individuals who habitually consume a high-fat diet, a strong hedonic attraction to palatable foods and to eating is an important factor to differentiate between individuals who gained weight and those who remained lean.

Similarly imaging research in adults found that RS as measured with the BIS/BAS self-report scale (Carver & White, 1994), significantly predicted activation to appetizing foods (relative to bland foods) in brain areas implicated in food reward (Beaver et al., 2006; Schienle, Schäfer, Hermann, & Vaitl, 2009). Additionally, fMRI data proved that obese children and adolescents versus their lean counterparts showed greater activation in brain reward areas in response to visual food stimuli (Bruce et al., 2010; Batterink, Yokum, & Stice, 2010) and in response to food consumption (Stice, Spoor, Bohan, & Small, 2008). Especially relevant is the fact that it was previously shown in mice that activation of these brain areas produces overeating and increases the preference for foods high in fat and sugar (Kelley, 2004).

The assumed initial vulnerability that increases risk for obesity may be a generalized hyper-responsiveness to various reward types as opposed to a specific deficit within the eating domain (Stice, Yokum, Burger, Epstein, & Small, 2011). Stice et al. (2011) found that adolescents at high-risk versus low-risk for future obesity by virtue of parental obesity not only showed greater activation in reward regions in response to palatable food, but also to monetary reward. Similarly, compared to lean individuals, obese children continue to play a rewarded computer game longer (Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006; Verbeken, Braet, Claus, Nederkoorn, & Oosterlaan, 2009) and report higher generalized RS (Davis et al., 2004; Kane, Loxton, Staiger, & Dawe, 2003; Mobbs, Crépin, Thiéry, Golay, & Van der Linden, 2010). Furthermore, substantial longitudinal research evidenced that children with higher generalized RS (measured with a self-regulation task) were more likely to be classified as overweight or obese several years later (Francis & Susman, 2009; Graziano, Calkins, Keane, 2009; Seeyave et al., 2010). However the paradigm used in these longitudinal studies provides a mixed measure of RS and inhibitory control, and therefore it is impossible to rule out the unique predictive value of RS.

The second hypothesis, here labeled as **Reward Deficiency Syndrome** (RDS) rests on the premise that palatable food can be used in the same manner as addictive drugs, and that risk for its overuse should therefore be greater among those at the anhedonic end of the RS continuum (Davis et al. 2004). Imaging data proved that compared to normal-weight children, obese children showed indeed a weaker appetitive or approach reaction in response to food cues (Davids et al., 2010) and to food receipt (Stice et al., 2008), as indicated by their significant lower activation of a part of the dopaminergic reward system. These findings imply that food may be experienced as less rewarding by obese children.To our knowledge, there is until now no evidence for this model based on behavioural measures or self-report data in children. Few studies in adults and adolescents found evidence for the relation between reduced self-reported RS and uncontrolled eating, emotional eating, binge eating, and obesity (Davis et al., 2004; Davis & Fox, 2008; Goldfield et al., 2010; Keränen, Rasinaho, Hakko, Savolainen, & Lindeman, 2010; Pagoto, Spring, Cook, McChargue, & Sneider 2006).

It is however also assumable that these seemingly opposing data might not be contradictory but reflect a **dynamic vulnerability (DV) model** for obesity that may evolve and change over time in response to overeating (Stice et al., 2011). The DV-model states that it is possible that heightened generalized RS is an initial risk factor for excessive food intake among normal weight individuals resulting in a positive energy balance and weight gain. However, the excessive food-intake can overload the DA system in such a way that it reduces the DA activity. Hence, excessive overeating is assumed in the long run to lead to an insensitive reward system which enhances further overeating to reach an acceptable level of hedonic satisfaction (Davis, et al., 2004; Lowe et al, 2009; Stice et al.,2011). This DV-model was already evidenced in adults showing a curvi-linear relationship between BMI and RS, based on self-report (Davis & Fox, 2008), but has never been examined in children. Such knowledge seems however pivotal in unraveling differential mechanisms leading to overeating but also in tailoring early intervention.

The current study aimed to investigate the DV model in children by analysing the association between self-reported RS and bodyweight in children. From the age of 10 years, it seems relevant to assess RS via self-report. Based on the findings of Davis and Fox (2008), we expect a positive association between self-reported RS and BMI, which will change to a negative association among children with obesity.

Method

Participants

Participants (10-15y) were recruited from two schools in the Dutch-speaking part of Belgium. Passive informed consent was obtained from parents. Parents received a letter explaining the purpose and method of the study two weeks prior to the data collection and they were asked to fill out a form if they did not want their child to participate in the study. Less than 2% of the parents did not allow their child to participate. Moreover, active informed consent was obtained from the children whose parents gave permission to participate in the study. All children agreed to participate. The questionnaires were administered during a class period. Children had approximately 15 minutes to complete the survey. This procedure resulted in a sample of 438 children (52.5% female) with a mean age of 12.07 years (SD = 1.51; range = 10-15 years). All participants were following a regular academic track. This study was approved by the local research ethics committee.

Measures

Body weight. Each participant reported on his or her own height and weight. The Body Mass Index (BMI) (weight/height²) was determined for each child. In order to make BMI comparisons between children of different ages, this study uses the adjusted BMI (adj 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, 2000). An adj BMI score equal to or smaller than 85% is considered as underweight, a score equal to or greater than 120% as overweight, and a score equal to or greater than 140% as obese (Van Winckel & Van Mil, 2001). In the current sample 10.5% of the children were classified as underweight, 67.1% as average weight, 9.4% as overweight and 13.0% as obese.

Data on the validity of self-reported weight and height suggest that preadolescents and adolescents provide information on their weight and height that is as valid as the information provided by adults (with correlations between self-reported and objectively measured data up to r = .98 for weight and r =.73 for height) (Field et al., 1999).

Reward Sensitivity The BIS/BAS self-report scale was administered (Carver & White, 1994; Dutch version: Putman et al., 2004). This scale measures affective responses to impending rewards (Behavioural Approach System, BAS) or punishments (Behavioural Inhibition System, BIS) and contains 20 items, scored on a 4-point Likert scale. The BAS items are divided into three subcategories: items tapping strong pursuit of appetitive goals (BAS Drive) (e.g., "I go out of my way to get things I want"), positive affect/excitability (BAS Reward Responsiveness) (e.g., "When good things happen to me, it affects me strongly"), and the inclination to seek out new rewarding situations (BAS Fun Seeking) (e.g. “I’m always willing to try something new if I think it will be fun”). In accordance to Dawe and colleagues (Dawe, Gullo, & Loxton, 2004; Dawe & Loxton, 2004), the BAS Drive scale is the main focus in the current study. These authors suppose that relative to the other BAS scales, BAS Drive is the best predictor of appetitive motivation and approach behaviour and is purported to closely reflect individual differences in the activity of brain reward circuitry (Pickering & Gray, 1999). This assumption was also underscored by imaging research (Beaver et al., 2006) examining the relationship between the BAS-drive scale and neural responses to appetizing foods (e.g. chocolate cake, pizza) using fMRI in healthy volunteers. They found that BAS-drive scores significantly predicted activation to appetizing foods (relative to bland foods) in the brain areas of reward. Relative to the other BAS scales, it has a unique predictive quality to such cues over and above that offered by the other two scales, and has the highest internal reliability (Beaver et al., 2006)

The alpha coefficients in the present study were .88 for the BAS Drive scale, .80 for the BAS Reward Responsiveness scale and .72 for the BAS Fun Seeking scale.

Statistical analyses

To investigate the predicted inverted U-relationship of reward sensitivity with BMI, we fitted a quadratic regression model of BAS Drive on adj BMI. To control for gender and age effects, we also added these variables to the model as well as second order interactions between BMI, age and gender. An orthogonal polynomial basis was used for the quadratic component in BMI. Gender was added to the model as a dummy variable, coded 1 for males and 0 for females. To follow the example of Davis and Fox (2008), we also fit a non-parametric regression model to the data to find out whether the predicted non-linear relationship is different from the one we predicted. To validate if the fitted model is indeed quadratic, we selected the equivalent degrees of freedom for the smoothing spline in adjusted BMI by means of generalized cross-validation (Wood, 2000).

Results

Descriptive statistics

Table 1 presents the means, standard deviations, quartiles and range values for adjusted BMI and the BAS Drive subscale, split up for boys (n = 208) and girls (n = 230). In terms of adjusted BMI, there were no significant differences between boys and girls (t = 0.02, df = 429, p = 0.98). For the BAS Drive subscale scores varies between 1 and 4 whereby, boys had a marginal higher average score compared to girls (t = 1.93, df = 406, p = .05).

Regression analysis

In Table 2, the analysis of variance is presented for the quadratic regression, with BAS Drive score as dependent variable. None of the second order interaction terms is significant (Sex X BMI: p = .91, Age X BMI: p = .65 and Sex X Age: p = .98). There is however an effect of BMI (p = .013). More specifically the quadratic component of BMI is significant (p = 0.011). Table 3 represents the coefficients for the additive quadratic regression of BAS Drive on BMI, sex and age. The additive model accounts for almost 3% of the variation (R^2 = 0.028).

In Figure 1a, the partial quadratic relationship between BAS Drive and BMI is displayed by means of an effect plot (Fox, 1987, Fox & Hong, 2009). Similarly, Figure 1b shows an effect plot for the additive non-parametric regression presented earlier. The equivalent degrees of freedom for the BMI spline term in the model is 2.23 which is very close to the 2 degrees of freedom used in quadratic regression. The similarity between the non-parametric and the quadratic regression model is also expressed by the high correlation of .95 between the fitted values of both models, which underscores the validity of the model.

As depicted in the Figure 1a there is a positive relationship between adj BMI and the BAS Drive score until an adj BMI score of 133% is reached. Above this change point, the direction of the relationship is negative.

Discussion

This is the first study to demonstrate the quadratic association between RS and BMI in a group of healthy children with a wide variety in bodyweight. It was shown that self-reported generalized RS shows a great level of individual differences covering the wide range of the BAS drive scale and interestingly this is significantly associated with BMI. Consistent with the findings in adults (Davis & Fox, 2008) the results show a positive association in the normal weight and overweight children, which changed to a negative association among the children with obesity, suggesting that the DV model is also feasible in children.

As predicted, the children with overweight report high levels of RS, which is consistent with previous research in adults showing that high RS is correlated with increased body weight (Davis et al., 2004; Davis, Levitan, Muglia, Bewell, & Kennedy, 2004; Franken & Muris, 2005, Mobbs et al., 2010; but Pagoto et al., 2006). This finding assorts with the premise that high RS individuals are more likely to approach and take pleasure form natural rewards like food. Consequently, these individuals will probable eat more when palatable foods are omnipresent. Evidence for this account was already found in adult studies proving a significant positive association between RS and overeating, the preference for high fat and sweet food (Davis, Patte, Tweed, & Curtis, 2007; Guerrieri et al., 2008), binge eating (Davis & Woodside, 2002; Loxton & Dawe, 2001), and food cravings (Franken & Muris, 2005).

These findings are in line with the assumption that brain reward systems also play an important role in feeding behaviour (Lutter & Nestler, 2009; Saper, Chou, & Elmquist, 2002). The rewarding effects of palatable food are a powerful motivating force and very tempting for high RS individuals in which these effects can easily override homeostatic signals resulting in caloric intake exceeding requirements (Kenny, 2011; Shomaker, et al., 2010; Zheng, Lenard, Shin, & Berthoud, 2009).

On the other hand the current finding of a turning point resulting in decreased RS in obese children accords with previous research in adults (Davis & Fox, 2008; Davis et al., 2004) and with the hypothesis that RDS is also a key factor in the etiology of obesity. Using positron emission tomography it was shown that the availability of dopamine D2 receptor was decreased in obese individuals in proportion to their BMI (Wang et al., 2001; Haltia et al., 2007). Furthermore, a decrease of activation in reward areas was found in obese versus lean children, implying that food cues may be experienced as less rewarding by obese children (Davids et al., 2010). Animal studies found the same reward dysfunction induced by drugs of abuse and hypothesized that this deficit may contribute to the transition from controlled to uncontrolled drug use by providing a new source of motivation to consume the drug in order to alleviate the persistent state of diminished reward (Ahmed & Koob, 2005; Kenny et al., 2006). Therefore, it is possible that low RS may perpetuate pathological eating as a mean of compensating for decreased activation of reward circuits as a way to alleviate the persistent state of negative reward (Kenny, 2011; Berridge & Robinson, 1998; Wang et al., 2001).

Overall, the current study suggest that already in children individual differences in RS were remarkable and not refer to a linear path. The actual observations can help us understand why seemingly conflicting findings in overweight and obese individuals can index one model. Though still speculative, the results subscribe the dynamic vulnerability (DV) model for obesity (Davis, et al;, 2004; Lowe et al., 2009; Stice et al., 2011): in a food-abundant environment, high RS leads to excessive food-intake which may trigger neurobiological adaptations resulting in anhedonia and further overeating as compensation. That this feed forward process may already be observable in children was suggested by animal studies. In mice, the exposure to high fat, high sugar diets during *early periods in life*, might induce changes in the DA brain reward circuits, resulting in subjects that are exceptionally vulnerable to environmental factors that contribute to obesity (Shalev et al., 2010).

However, since the current data are cross-sectional, it remains unclear if the responsiveness of brain reward systems is influenced by intrinsic or diet-induced alterations. Intrinsic hypo-responsiveness due to a deficit in dopamine reward circuits may also be indicated in children. To explain the comorbidity of ADHD and obesity, it was hypothesized that obesity and ADHD represent different manifestations of the same underlying dysfunction - the imbalance of dopaminergic reward system. This defect drives individuals to engage in activities of behavioral excess, which, in turn, enhance brain dopamine function (Liu, Li, Yang, & Wang, 2008). Stice (2011) suggest that RS-dysfunction may need to be coupled with a hyper-responsiveness of somatosensory regions to convey specific risk for obesity versus other behavioral problems. Future longitudinal research is needed to clarify this remarkable and promising hypothesis, as direction of effects cannot be determined from the current study.

The actual findings also underpin the importance of the clinical cut off points overweight versus obese. In research these groups are too often examined as a whole: overweight/obese versus average weight, and this way possible diversities between the groups are disguised.

Furthermore, the current study highlighted RS as one type of factor that may influence weight gain in children, but future work should consider additional factors that may influence eating behaviour, such as the ability for inhibitory control (Rolls, 2011). It was suggested by imaging data that the deregulation in reward circuitry in obese subjects contribute to overeating in part through deregulation of prefrontal regions implicated in inhibitory control (Volkow et al., 2008). Children low in inhibitory control may be less able to direct their attention away from foods that are desirable or may use different strategies to redirect their attention (Mischel, Shoda, & Rodriguez, 1989). The moderating effect of inhibitory control is also described in recent dual pathway models of overeating (and drug-use) (e.g. Appelhans, 2009; Epstein, Salvy, Carr, Dearing, & Bickel, 2010; Stice et al., 2010; Strack & Deutch, 2004); More specifically, the combination of high RS and poor inhibitory control may be the behavioural phenotype that may be associated with high energy intake.

Finally, since the adolescent behavioral profile is characterized by a heightened RS, it seems worthwhile to examine in future research the association between RS and BMI in adolescents. Reward-related processes appear to develop in a curvilinear manner with a peak during adolescence, while inhibitory processes show a protracted linear development throughout adolescence, leaving the adolescent with highly sensitive, reward-driven processes that can only be moderately regulated by gradually developing inhibitory processes (for a review, see Hardin, 2010). We performed a first analyses on a small group of 34 adolescents age 16-17 years and found that the association between RS and BMI was indeed attenuated with age. Compared to the younger children, the lower scores at the extremes disappeared among the adolescents; they all reported relative high RS, independent of the BMI.

In sum, the current study provide evidence that individual differences in RS may play a critical role in the vulnerability to overeat and becoming overweight or obese and suggest that initial high RS over time may decrease due to diet-induced alterations in the brain fostering further overeating. This means that in treatment it seems promising to focus on alteration of food reward value or the offer of reward alternatives (Volkow et al., 2003; Volkow et al., 2008). Additionally, since mainly high RS children with poor inhibitory capacity are unable to delay gratification for food, it may be worthwhile to consider including standard approaches to reducing impulsivity and improving executive functioning as components of obesity treatment programs (Epstein & Wrotniak, 2010). Furthermore, the DV model implies that prevention programs should strive to reduce intake of high-fat and high-sugar foods during development to avoid the decrease in RS and reduce the risk for future weight gain in vulnerable populations (Stice et al., 2011)

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Tables

Table 1. Distribution of adjusted BMI and Reward Sensitivity scores (BAS Drive).

	Mean	SD	Minimum	Q1	Median	Q3	Maximum
Adjusted BMI							
Males	109.48	28.25	76.05	91.13	99.41	118.72	216.98
Females	109.43	27.46	67.21	91.20	102.53	118.11	222.92
BAS Drive							
Males	2.53	0.86	1.00	2.00	2.50	3.25	4.00
Females	2.38	0.72	1.00	2.00	2.25	2.75	4.00

Table 2. Analysis-of-variance for the regression model fit to BAS Drive

Source	*Sum of squares*	Df	*F*	*p*
Sex	2.37	1	3.77	0.053
Age	0.00	1	0.00	0.977
BMI	5.54	2	4.41	0.013
Linear	0.02	1	0.04	0.849
Quadratic	4.10	1	6.53	0.011
Sex x BMI	0.12	2	0.09	0.912
Linear	0.02	1	0.04	0.842
Quadratic	0.09	1	0.15	0.702
Age X BMI	0.54	2	0.43	0.651
Linear	0.01	1	0.01	0.923
Quadratic	0.52	1	0.84	0.361
Sex X age	0.00	1	0.00	0.984
Error	268.73	428		
Total	??	437		

Table 3. Coefficients and standard errors for the additive quadratic regression BAS Drive on BMI, Sex and Age

	Coefficient	Standard Error
Intercept	2.54	0.31
BMI		
Lineair	0.45	0.80
Quadratic	-2.32	0.79
Sex (Female = 1)	-0.15	0.08
Age	-0.00	0.03
R squared = 0.028		

Figures

Figure 1a

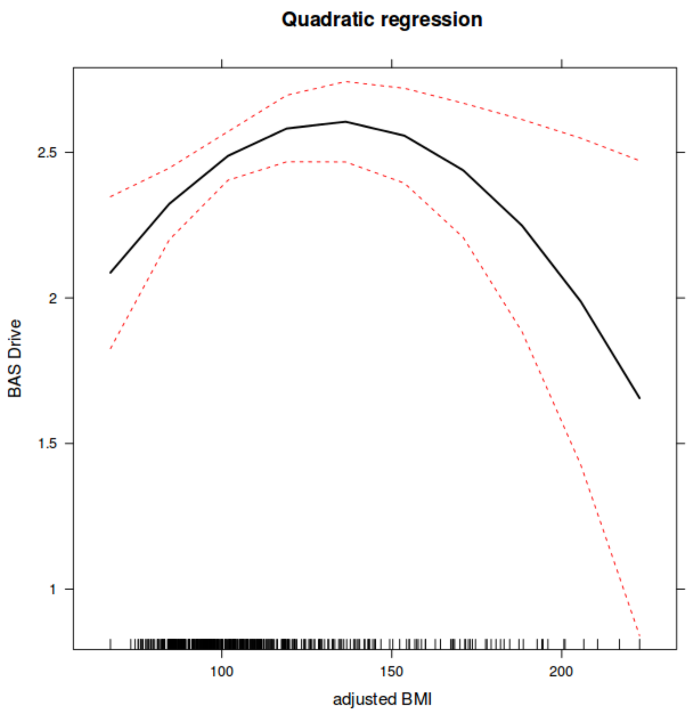
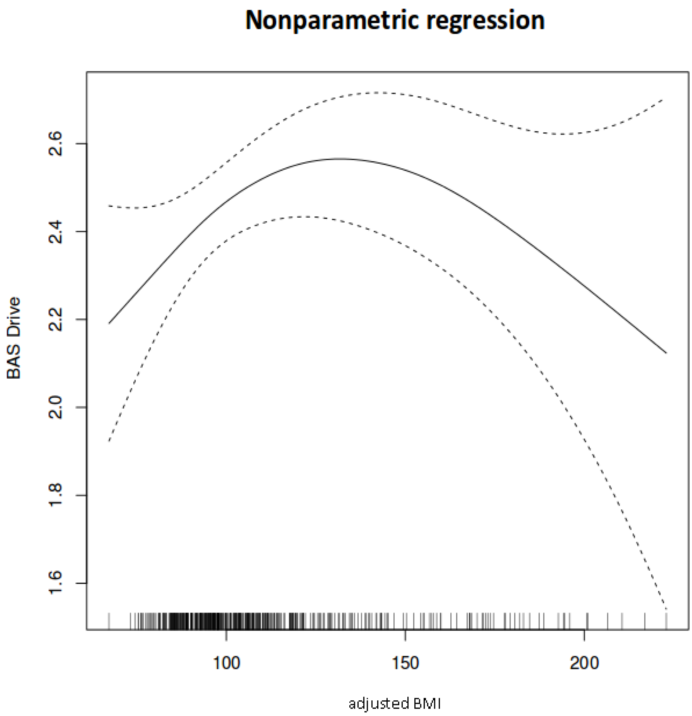


Figure 1b


Nonparametric regression
BAS Drive
1.6
1.8
2.0
2.2
2.4
2.6
100
150
200
adjusted BMI

Chapter 6

Executive function training with game elements for obese children: A novel treatment to enhance self-regulatory abilities for weight-control[1]

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 (8-14 years) who were in the final months of a 10-months inpatient treatment program 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.

[1] Verbeken, S., Braet, C., Goossens, L., & Van der Oord, S. Executive function training with game elements for obese children: A novel treatment to enhance self-regulatory abilities for weight-control. Manuscript in revision.

Introduction

The dramatic rise in childhood obesity in the last decades is well established (Ogden, Carrol, Curtin, Lamb, & Flegal, 2010). The major associated health problems and psychosocial consequences make the development of an effective treatment for obese children imperative. Multidimensional treatment programs, including diet, exercise and behavior change have demonstrated their efficacy, showing positive outcomes in the short term as well as some evidence for long term maintenance of treatment effect (Luttikhuis, 2008). However, for the severely obese children these interventions suffer from high drop-out 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 of 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 disability to resist temptations and inhibit automatic responses, which refers to poor functioning of controlling one’s impulses (Smith, Hay, Campbell, & Trollor, 2011). Impressive longitudinal research showed that children between two and five years old with limited impulse control were more likely to be above average weight at the age of 5, 11 or 12 years (Francis, & Susman, 2009; Graziano, Calkins, & Keane, 2010; Seeyave et al., 2009). Cross-sectional studies found that overweight children act more on impulse than normal weight children, and one prospective study shows that impulsivity hinders weight loss in therapy (Braet, Claus, Verbeken, & Van Vlierberghe, 2007; Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006; Nederkoorn, Jansen, Mulkens, & Jansen, 2007).

Executive function deficits have often been proposed as underlying core deficits to poor impulse control (Barkley, 1997). Executive Functions (EF) allow individuals to regulate their behavior, thoughts and emotions, and thereby enable self-control. Weight-loss and weight-loss maintenance clearly require executive functioning. First, cognitive control such as inhibition of automatic responses and approach behavior is highly indicated when for example a child has 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. Moreover, both EF-functions are related since the cognitive capacity to inhibit automatic responses and forego temptations is limited and depends upon the disposal 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 may facilitate overeating (Wang, Volkow, Thanos, & Fowler, 2009) and result in a higher body mass index (BMI) (Volkow et al., 2009; Batterink, Yokum, & Stice, 2010). Conversely, higher prefrontal cortex (PFC) activation was shown to be associated with dietary restraint (DelParigi et al., 2007) and lower BMI (Batterink et al., 2010). Similarly, behavioral studies in obese children suggest that children with obesity have problems with behavioural inhibition, as assessed with a well-validated computerized measure to assess behavioural inhibition (Stop-signal Task; e.g. Nederkoorn et al., 2006; Verbeken, Braet, Claus, Nederkoorn, & Oosterlaan, 2009). Additionally, the association between weight control and working memory was 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 average weight children, obese children performed significantly poorly on a visual spatial working memory test.

Today, treatment programs for severely obese children already focus on improving impulse control by means of learning self-regulation skills such as self-observation, self-instructions, self-evaluations 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. Probably, as long as children do not strengthen their EF, the acquired impulse self-control skills remain of limited capacity. 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 was to evaluate in obese children an intensive cognitive training developed specifically to strengthen children's 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 and samples of children with low working memory (but no ADHD) (Holmes, Gahercole, & Dunning, 2009; Klingberg, Forssberg, & Westerberg, 2002; Klingberg et al., 2005; Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009; Van der Oord, Ponsioen, Geurts, Ten Brink, & Prins, submitted). For example, Klingberg and colleagues (2005) showed that in a sample of children with ADHD, an individually adaptable computerized working memory training not only improved the trained working memory, but training effects also generalized to other non-trained executive functions such as response inhibition and complex reasoning. Further, not only the core executive functions improved, but also objective behavior improved; there was a significant reduction of parent-rated inattention and hyperactivity/impulsivity symptoms and positive effects were maintained at three months follow-up. In low working memory samples, not only working memory performance improved, but also relevant and objective school results; math performance at 6 month's follow-up was improved (Holmes et al., 2009), suggesting again generalisability of results to objective behavior.

Fewer studies have been conducted on the trainability of inhibition through cognitive training (Thorell et al., 2009; White & Shah, 2006). 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. This may be due to the training task used, since within the training task the level of inhibition was not adapted to the level of the child. An individually adaptable task is deemed crucial in improving executive functioning through training (Klingberg, 2010). Recently, Dovis and colleagues (2008b) 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.

Next to impulse control deficits, motivational deficits may be related to obesity. Research suggests that compared to control children of 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 reward (Verbeken, Braet, & Lammertyn, in prep). Adding external incentives to a potentially boring task may help children optimize their motivational state and their cognitive performance (Dovis, Van der Oord, Wiers, & Prins, 2011). A feature that may increase children's motivation is adding computer game-elements to tasks. This was already confirmed 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). Also, studies show enhanced cognitive performance on EF-tasks due to adding gaming elements to these tasks (Dovis et al., 2011; Prins, Dovis, Ponsioen, Ten Brink & Van der Oord, 2011). In the current study, we use an executive functioning training, in which game-elements are added, in order to optimize children's motivational state and potentially optimalize their cognitive performance on the training.

In sum, current treatments for childhood obesity are not always even effective, and do not target possible core deficits of executive functioning. In other samples, characterized by executive functioning deficits, EF-training has shown to be effective. Therefore, the purpose of this treatment study was to evaluate the effectiveness and acceptability of a 6 week intensive cognitive EF-training embedded in a game-world for obese children above the effects of an intensive 10-months inpatient treatment program. Obese children in the last months of the inpatient treatment program were randomized to either the EF-training condition or the care as usual only (CAU) condition. The training aims to improve working memory capacity and response inhibition by directly training both core cognitive processes. Outcomes are 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 that were randomized to the CAU-only control condition. After ending the inpatient treatment program, the confrontation with the daily food environment at home enables the study of long-term effects of treatment in the natural environment characterized by high risk for relapse. We expected better weight loss maintenance at 8 and 12 weeks after leaving the clinic in those randomized to the EF-training condition as compared to the children in the care as usual only condition.

Method

Participants

All overweight children in the final months of a one year 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, 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: 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. 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. 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 the delay between the go and the stop signal. The longer this delay, the harder it is to inhibit the response.

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. By using the tracking mechanism, success rate on inhibition trials is .5. This means that SSRT can be calculated by subtracting the mean delay from the mean go signal reaction time (Scheres et al., 2003).

*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 from *boring/not funny to very funny)* and if they tried hard enough to score well (1 = *a little*, 5 = *very much*).

Procedure

At the start of the 'returning home phase' after 6 months of inpatient treatment and after pretest, participants 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.

Before the beginning of the EF- training, the pre-test was conducted. The children 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 and 12 weeks after the cognitive EF training, children returned to the clinic for testing and BMI determination. The assessors for the post-test and follow-up measures 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, differences between treatment conditions were tested with ANOVAs for repeated measures analyses 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 (χ^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 interaction 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. Between group 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% (*n*=19) tried hard to very hard to score well during the training tasks and 44.4% liked the training sessions well to very well.

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 a cognitive EF-training with game elements to a 10-month inpatient treatment program 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 both 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 care as usual only condition, the children who completed the EF-training appeared to be more capable to maintain their weight-loss until 8 weeks post-training. These results are remarkable, especially since to date evidence shows that the treatment for obesity is typically followed by weight regain. Therefore, strengthening the patient's skills that enables better long-term weight control may be the main challenge in the treatment of obesity (Latner et al., 2000). Our data suggest that the EF-training could be effective at least as a short term weight stabilization intervention after an intensive healthy lifestyle program for obese children.

We can speculate as to why the EF-training may have a surplus value to improve weight-loss maintenance. After leaving the clinic, the children are assumed to maintain the learned healthy life style behaviors over their lifespan to keep a healthy weight. Research has provided some evidence that neurocognitive factors may be implicated in these patterns of healthy behavior 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 notable in better weight maintenance when returning home, until 8 weeks follow-up.

Because of the absence of evidence of trainability of EF in obese children, we chose an EF-training of *both* working memory and response inhibition. The reason was twofold: (1) in other samples (for example ADHD), more evidence is reported for trainability of working memory (Klingberg 2010) and to lesser extent of inhibition (Thorell et al., 2009) and (2) the limited evidence of EF-deficits in obese samples show mainly inhibition deficits. Other studies in ADHD samples did show generalization of 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 is not sensitive enough to measure subtle advances in inhibition abilities or that inhibition is not trainable with this program. However, within analyses of the individual inhibition scores of the training task indicated improvement in all participants from the first to the last session suggesting promising potential for the training of inhibition (data available from first author). Therefore it seems reasonable to assume that the present 25 sessions-intervention may have trained both executive functions to some degree, but not enough for observing significant changes on the Stop Task. The conclusion is further qualified by observed significant improvement of the children on their ability of cognitive control as reported on the BRIEF total score and the BRIEF meta-cognition index.

Remarkably, weight maintenance effects were no longer visible at the 12 weeks follow-up. This is in line with other training studies in children and adults showing that training related gains were stable for some weeks but ceased afterwards (Holmes et al., 2010; Buschkuehl et al., 2008). Probably the EF functions need permanent training and therefore, it is worthwhile testing if a schedule of “maintenance” EF-training could further help the children controlling their weight.

The study revealed 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 posttest a significant reduction in executive functioning was observed in the care as usual only 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 inherent of the third phase of the inpatient program. In the last weeks of the inpatient treatment, gradually the firm structure is attenuated en more frequent home visits are implemented, which included more food temptations to overcome. Furthermore anticipating the admission of the clinic and the upcoming summer holiday may cause more arousal and emotions thereby limiting the capacity for inhibited behavior. This in turn is reflected by the reduction of observed EF functioning in the care as usual only group. The maintenance of a good level of executive functioning may therefore already be interpreted as a good progression in the children due to the EF training.

There are a number of strengths and weaknesses that need to be considered in interpreting the results of this study. First of all, the strengths of this study include the use of a novel intervention, based on a theoretical model of causal and maintenance mechanism of overweight and obesity in children. Additionally, we used both cognitive tasks and ratings to assess EF-functioning. Moreover, eestimates of efficacy are often only based 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 (ES). 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, future research should try to unraffle 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, the inhibition training or the combination of the two training elements. We also wonder for example whether the trained capacity in working memory is related with weight loss through self-controlled food-intake.

The study is somewhat limited in power. Larger randomized controlled trials are worthy to considerate. This way it will be possible to identify potential moderators to determine which obese children might respond best to this intervention. Nevertheless, even with only 44 inpatient and severely clinical disturbed patients and with an active 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 it was 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 let to organisational problems, mitigation and more drop-out. Therefore, non-specific treatment effects in the EF-training condition (such as attention of the childcare workers) were not controlled for. However, our significant long-term effects on weight-loss maintenance in the EF-training condition do in fact provide indications towards true unbiased effects of the training.

In sum, the intervention tested in this study may serve as the basis for future research examining interventions that target overweight and obesity in children. Although treatment programs already attests 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 for the efficacy of an EF-training in obese children. Future studies should further 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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Tables

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	181.88	32.65	185.67	25.06	*F*=.186
Pre-test adjusted BMI	131.58	21.70	132.91	15.98	*F*=.054

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

	EF-training (*n*=22)		Care-as-usual (*n*=22)		*F*
BRIEF childcare worker (*Mean/SD*)					
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.

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

	Pretest				Posttest				Time	η^2	Time by Group	η^2
	EF-Training		Care-as-usual		EF-Training		Care-as-usual					
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*				
CW-Outcome*s*												
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: Childcare worker outcomes, B-Inhib= Inhibition scale of the Behavior Rating Inventory of Executive Functioning, B-WM= Working Memory scale of theBehavior Rating Inventory of Executive Functioning, B-MC= Meta-cognition index of theBehavior Rating Inventory of Executive Functioning Child= Child outcomes; 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.

,*$p \leq .05$, **$p \leq .01$, ***$p \leq .001$; [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**	
	EF-training	Care-as-usual	EF-training	Care-as-usual	EF-training	Care-as-usual	EF-training	Care-as-usual
	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)

	Time F(1.38)	**ŋ²**	**Time by condition** F(1.38)	**ŋ²**	**Time by condition contrasts** F(1,40)					
					Pre-post	ŋ²	Post-FU1	ŋ²	Post-FU2	ŋ²
Adjusted BMI	30.13***	.70	3.56*	.22	.00	.00	7.75**	.16	.54	.01

Note: FU1= 8-weeks follow up, FU2= 12-weeks follow up. *p≤.05, ** p≤.01, ***p≤.001

Figures

Figure 1. Flow of participants through the trial.

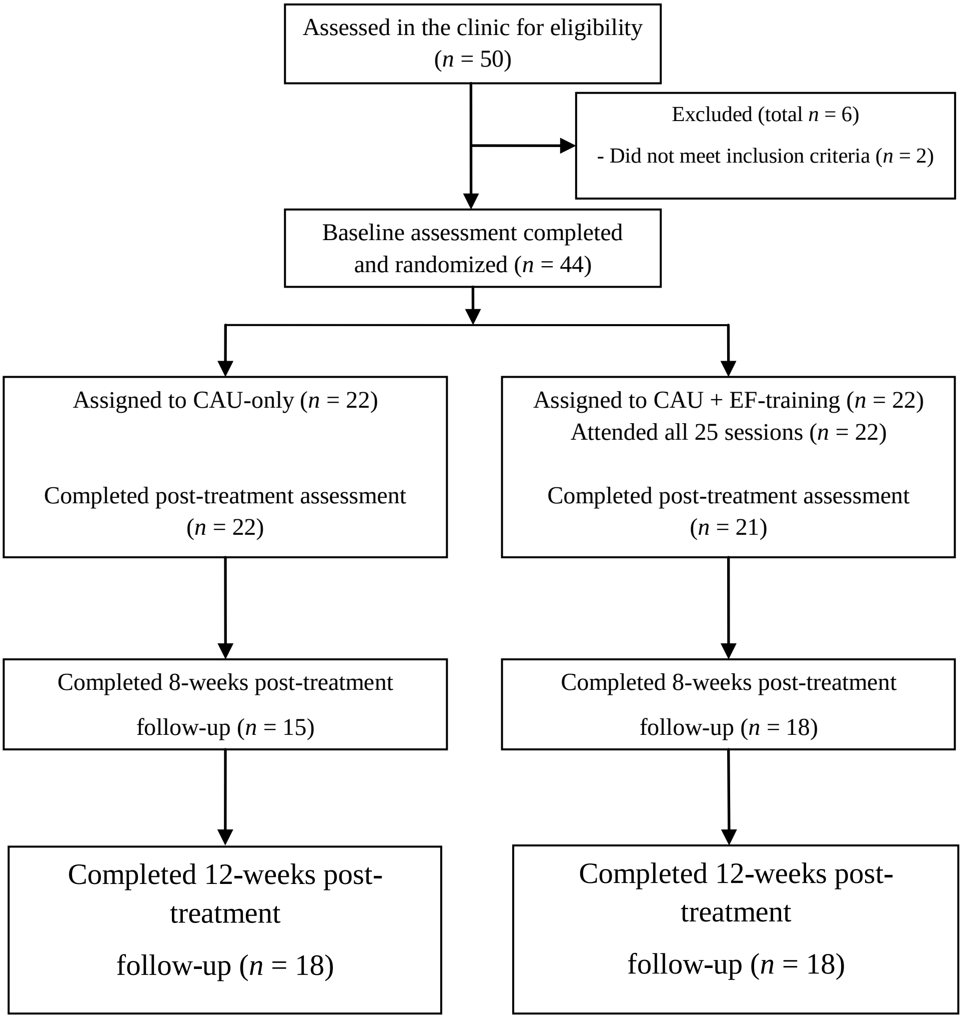
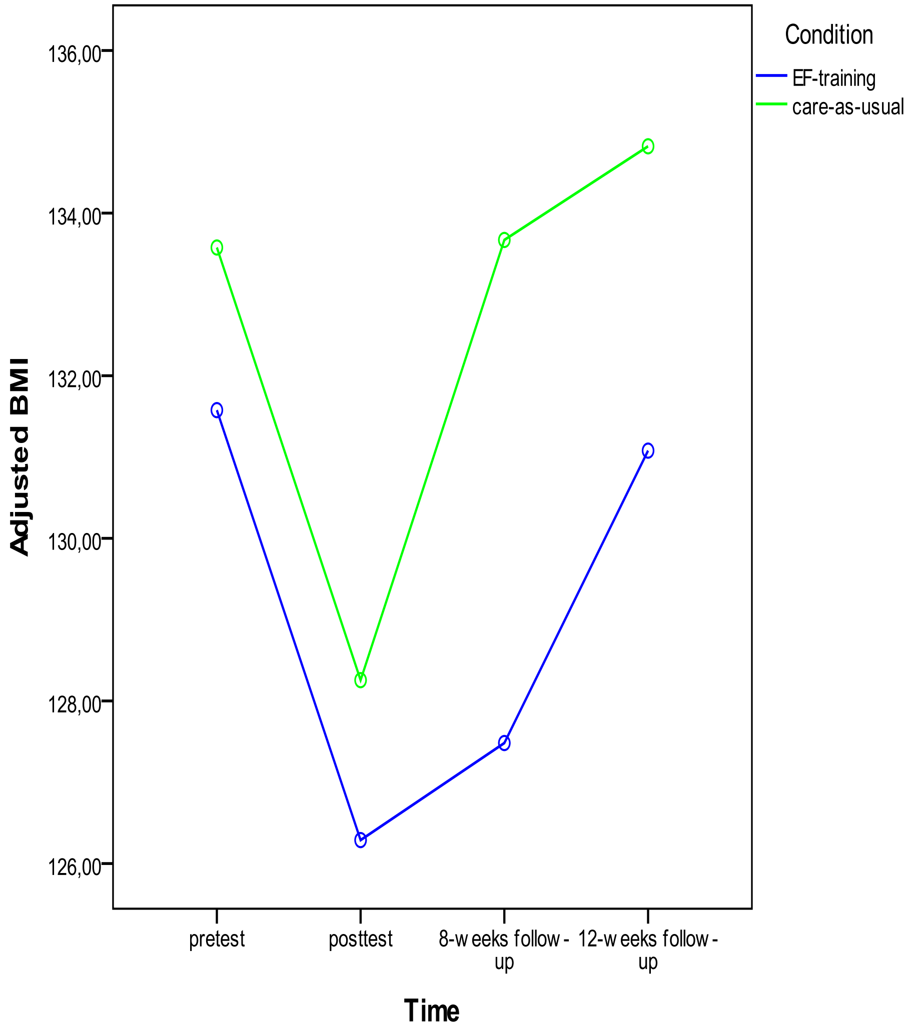


Figure 2. Weight control effects for overweight children during an after and intensive treatment with or without adding an EF-training



Chapter 7

General discussion

In this section the main findings of the different studies in this dissertation are presented and discussed. Strengths, limitations, clinical implications and suggestions for future research are described.

Overview of the research findings

Childhood obesity is associated with considerable adverse physical, psychosocial and economical outcomes, both in the short and long-term (Freedman, Khan, Dietz, Srinivasan, & Berenson, 2001). The most prominent consequence of childhood obesity seems to be the significant increased risk of remaining obese into adulthood. In children between 10 and 15 years old, 80% of the obese children were obese by age 25 (Whitaker, Wright, Pepe, Seidel, & Dietz, 1997) and similar evidence emerged in 25 longitudinal studies from around the world, as reviewed by Singh, Mulder, Twisk, van Mechelen, and Chinapaw (2008). The finding that childhood obesity is not a transient developmental phenomenon is alarming given the association between adult obesity and several morbidities and given the fact that extremely obese children may suffer cumulative effects of their “pound-years” (Xanthakos & Inge, 2007). Unfortunately, most obesity treatment and prevention programs only result in moderate positive outcomes in the short term and do not reduce risk for future weight gain (Braet, Tanghe, Decaluwé, Moens, & Rosseel, 2004; Luttikhuis, 2008; Stice, Shaw, & Marti, 2006). The previous findings underscore the need to map the factors that promote excessive weight in childhood.

Living under conditions of abundance means living with the continuous temptation of the immediately rewarding value of palatable, high-caloric foods. Resisting temptation requires self-regulatory resources which are challenged by emotions, thoughts and psychological processes like impulsivity. Therefore, it was the general purpose of this dissertation to explore the influence of impulsivity on childhood obesity. However, the study of impulsivity is complicated, since it is not a unidimensional construct. Consequently, chapter 2 aimed to distinguish between the different processes of impulsivity which might be related to overweight in children with the use of performance based measures. The findings suggest that different processes seem to underlie the impulsive behavior in overweight children. Compared to non-overweight children, the overweight children showed poor inhibitory control, hypersensitivity to reward and poor decision making, suggesting problems in the two main aspects of impulsivity: more active bottom up reward processes (hot system) and less active top down inhibitory control processes (cold system). However the findings were different depending on the measure used.

To further enhance our understanding of how these self-regulatory processes may hamper overweight children to forego temptation the following chapters (chapter 3 and 4) were based on paradigms assessing self-regulation in a conflict situation in the presence of rewards. Chapter 3 compared performance patterns of decision-making in children with and without overweight on a developmentally appropriate variant of the IGT, the Hungry Donkey Task (HD task). The findings revealed differences between the two weight groups in their decision-making performance. The overweight children showed more impaired decision-making compared to the average weight group and the decision making failure of the overweight children seemed to be more the result of insensitivity to future consequences then it is affected by hypersensitivity to reward.

Chapter 4 explored the mediating role of top down attentional strategies and bottom up impulsive processes on the link between bodyweight and self-regulation in a classic delay of gratification paradigm (Mischel, 1974) in and outside a food context. The findings showed that compared to average weight children, overweight children tended more often to stop the delay and take the immediately available smaller reward, and this was especially the case if they were waiting for a food reward. Furthermore, independent of the reward condition children with a higher BMI reported to experience more difficulties to delay gratification due to higher levels of impulsivity and to poor cognitive attentional strategies.

The association between reward processes and bodyweight was further explored in chapter 5. The findings revealed a quadratic association between reward sensitivity and BMI in a group of healthy children with a wide variety in bodyweight. It was shown that self-reported generalized reward sensitivity shows a great level of individual differences covering the wide range of the BAS drive scale and interestingly this was significantly associated with BMI. The results showed a positive association in the normal weight and overweight children, which changed to a negative association among the children with obesity.

Finally, chapter 6 evaluated the effectiveness of adding a cognitive executive functioning (EF) training with game-elements to a 10- month inpatient treatment program for obese children in the 'returning home phase'. The cognitive executive training improved the children's executive functioning skills, mainly working memory, but also compared to the children in the care as usual only condition, the children who completed the EF-training appeared to be more capable to maintain their weight-loss until 8 weeks post-training.

In what follows these principal findings from the five empirical studies will be integrated and critically evaluated.

Self-regulation failure

The fact that not everyone in the same high rewarding food-environment becomes overweight points at the role of individual interacting variables. Recently, there has been increased interest in the role of self-regulation in the development of overweight in children. In general, the current findings (chapter 3 and 4) confirm poor self-regulation in overweight children. In both studies – compared to non-overweight children and despite similar IQ, age, and social status – overweight children tended more often to forego long term goals and take the immediately available smaller reward. These results are in line with considerable previous research, which emphasizes self-regulation failure as an important mechanism implicated in the development and/or control of food intake and overweight in children. (e.g. Seeyave et al., 2009).

A dual process model presented by Appelhans (2009) posits that self-regulation or the decision to go for the immediate reward and eat palatable food or to strain for the larger future benefit of weight loss and improved health is the product of the balance between bottom up reward processes and active top down inhibitory control.

Hot system: Reward processes

(For a summary of the findings see table 1)

Besides the recognized genetic predisposition of childhood obesity, the impact of the modern food-environment is well established. An increased reward value of foods overrides existing satiety signals and fosters overeating (Rolls, 2011). It is reasonable to propose that individual differences in reward sensitivity (RS) may be one of the factors that contribute to a vulnerability to overeat and become obese (Small, 2009). Chapter 2 showed that within the reward-directed paradigm “the Door Opening Task” reveals differences between children with and without overweight. The overweight children kept gambling longer despite increasing losses, suggesting greater reward sensitivity and response perseveration. Unexpectedly, delay aversion as measured with the

Maudsley Index of Childhood Delay Aversion did not differ between the groups. Possible explanations were suggested in chapter 2.

Furthermore, findings from chapter 4 proved that a powerful hot system may be a burden for self-regulation in overweight children. Higher impulsivity levels, measured by "Urgency" and defined as "the tendency to experience strong impulses, frequently under conditions of negative affect" (Whiteside & Lynam, 2001) significantly mediated the association between body weight and difficulty to resist temptation during delay time. This facet of impulsivity is related to the inability to deliberately suppress dominant or prepotent responses, especially in conditions of intense emotions. This inability may contribute to an overweight person's problem controlling eating in situations of strong emotions, such as conflict situations (Guerrieri, Nederkoorn, & Jansen, 2008; Mobbs, Crépin, Thiéry, Golay, & Van der Linden, 2010). This way, although the majority of the overweight children were able to delay the short waiting period of the experiment, the higher levels of impulsivity may leave them more vulnerable to the power of the immediate rewarding environment in daily life.

Previous studies showed that overweight individuals have a strong hot system, the following research (chapter 3 and 5) aimed to explore *why* this is so. Literature suggest that at least two distinct reward processes may underlie self-regulatory failure: (1) overweight children may be so/too sensitive to reward that they ignore the punishment that goes along with it, or (2) overweight children may be insensitive to future outcomes, and therefore they choose options that are appetitive on a short-term basis. To examine these possibilities, the participants completed both the standard and the reversed version of the HD task (chapter 3). Analyses revealed that the decision making behaviour of overweight children seemed to be more the result of insensitivity to future consequences then it is affected by hypersensitivity to reward. This finding was somewhat surprising and in contrast with previous research linking relative body weight and high sensitivity to reward (Davis et al., 2007; Davis et al., 2004; Davis & Woodside, 2002; Guerrieri et al., 2008; Loxton & Dawe, 2001; Franken & Muris, 2005). However, since poor decision-making abilities on the IGT, characterised by future insensitivity is linked to a reduced dopaminergic activity (Sevy et al., 2006) the findings suggests that already in children the reward deficiency syndrome (RDS) hypothesis or the anhedonic route to obesity is supported. The fact that a greater part of the children in the above average weight group were obese (*n* = 66.60%) may account for these observations. These findings are in line with the findings in chapter 5, using self report data on reward sensitivity (RS). The data demonstrated a quadratic association between RS and BMI in a group of healthy children with a wide variety in bodyweight. It was shown that self-reported generalized RS shows a great level of individual differences covering the wide range of the BAS drive scale and interestingly this is significantly associated with BMI. Consistent with the findings in adults (Davis & Fox, 2008) the results showed a positive association in the normal weight and overweight children, which changed to a negative association among the children with obesity.

As predicted in chapter 5, the children with overweight reported high levels of RS, which is consistent with previous research in adults showing that high RS is correlated with increased body weight (Davis et al., 2004; Davis, Levitan, Muglia, Bewell, & Kennedy, 2004; Franken & Muris, 2005, Mobbs et al., 2010; but Pagoto et al., 2006). This finding assorts with the premise that high RS individuals are more likely to approach and take pleasure from natural rewards like food. Consequently, these individuals will probable eat more when palatable foods are omnipresent. Evidence for this account was already found in adult studies proving a significant positive association between RS and overeating, the preference for high fat and sweet food (Davis, Patte, Tweed, & Curtis, 2007; Guerrieri et al., 2008), binge eating (Davis & Woodside, 2002; Loxton & Dawe, 2001), and food cravings (Franken & Muris, 2005).

On the other hand the current finding of a turning point resulting in decreased RS in obese children accords with previous research in adults (Davis & Fox, 2008; Davis et al., 2004) and with the hypothesis that RDS is also a key factor in the etiology of obesity. Using positron emission tomography it was shown that the availability of dopamine D2 receptor was decreased in obese individuals in proportion to their BMI (Wang et al., 2001; Haltia et al., 2007). Furthermore, a decrease of activation in reward areas was found in obese versus lean children, implying that food cues may be experienced as less rewarding by obese children (Davids et al., 2010). Animal studies found the same reward dysfunction induced by drugs of abuse and hypothesized that this deficit may contribute to the transition from controlled to uncontrolled drug use by providing a new source of motivation to consume the drug in order to alleviate the persistent state of diminished reward (Ahmed & Koob, 2005; Kenny et al., 2006). Therefore, it is possible that low RS may perpetuate pathological eating as a mean of compensating for decreased activation of reward circuits as a way to alleviate the persistent state of negative reward (Kenny, 2011; Berridge & Robinson, 1998; Wang et al., 2001).

Overall, the findings from both studies (chapter 3 and 5) suggest that already in children individual differences in RS were remarkable and not refer to a linear path. The actual observations can help us understand why seemingly conflicting findings in overweight and obese individuals can index one model. Though still speculative, the results subscribe the dynamic vulnerability (DV) model for obesity (Davis, et al;, 2004; Lowe et al., 2009; Stice et al., 2011): in a food-abundant environment, high RS leads to excessive food-intake which may trigger neurobiological adaptations resulting in anhedonia and further overeating as compensation. This feed forward process may already be observable in children and suggest that the exposure to high fat, high sugar diets during early periods in life, might induce changes in the DA brain reward circuits, resulting in RDS that makes them exceptionally vulnerable to environmental factors that contribute to obesity.

Cold system: executive functioning processes

(For a summary of the findings see table 1)

Executive functions are cognitive processes mediating top down control of behaviour. This may ensure that behaviour complies with long-term goals, also when being challenged by immediately available rewards.

The first study (chapter 2) explored possible deficits in inhibitory control. The Stop Task seems to provide a remarkable differentiation between children who are or are not overweight. The overweight children showed longer SSRTs indicating less efficient executive inhibitory control. Unlike our expectations, the overweight children performed equally well on the inhibition of a verbal response, an indication of interference control (Opposite Worlds Task), and contrary to our hypotheses, the overweight children performed better on the inhibition of an ongoing, continuous motor response (Circle Drawing Task) than the children with normal weight. Possible explanations were provided in chapter 2.

How can the cool system help to delay gratification? In other words, which cognitive processes may help children to forego temptation? A series of early experiments revealed that redirection of the attentional focus can be an effective strategy to reduce the frustration of continuing to wait (Mischel & Ayduk, 2002; Mischel et al., 1996). Using the classic delay of gratification paradigm (chapter 4) we found that compared to average weight children, overweight children displayed less self-distraction by looking away from the temptation. Furthermore, a mediational analysis showed that children with a higher BMI experienced the delay as more difficult due to less favourable cognitive attentional strategies. In this way, although the majority of the overweight children were able to delay the short waiting period, the decreased availability of cognitive-attention strategies may leave them more vulnerable to the power of the immediate rewarding environment in daily life.

We must acknowledge the importance of individual differences in the availability of cognitive-attention strategies. In chapter 4, the participants in both the average and above average weight groups were between 10 and 15 years old, which can developmentally be seen as mature enough to cognitively master a delay of 20 minutes. Therefore, the observed cognitive-attention differences between the weight groups were of special relevance here. Based on the literature, we assume an impact of individual differences in executive brain functioning which explains why the cool system seems less able to regulate and inhibit hot system processing in some children and leaves them more controlled by immediate temptations (Rodriguez et al., 1989). This suggestion is in line with previous research exploring the neuropsycholgical deficits in overweight adolescents (Verdejo-Garcia et al., 2010) and adults (Cserjési et al., 2009; Gunstad et al., 2007).

Treatment

Previous chapters showed poor self-regulation in overweight children and provided evidence for alterations in both the bottom up reward processes and in the top down executive functioning processes. As such, treatment of overweight children should focus on the underlying processes to enhance their ability for self-regulation. In succession of these results, an intervention study was included. Chapter 6 provided a first evaluation of the acceptability and effectiveness of adding a cognitive EF-training with game elements to a 10-month inpatient treatment program 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 both 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, but also, compared to the children in the care as usual only condition, the children who completed the EF-training appeared to be more capable to maintain their weight-loss until 8 weeks post-training. These results are remarkable, especially since to date evidence shows that the treatment for obesity is typically followed by weight regain. Therefore, strengthening the patient's skills that enables better long-term weight control may be the main challenge in the treatment of obesity (Latner et al., 2000). Our data suggest that the EF-training could be effective at least as a short term weight stabilization intervention after an intensive healthy lifestyle program for obese children.

We can speculate as to why the EF-training may have a surplus value to improve weight-loss maintenance. After leaving the clinic, the children are assumed to maintain the learned healthy life style behaviors to keep a healthy weight. Research has provided some evidence that neurocognitive factors may be implicated in these patterns of healthy behavior 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 notable in better weight maintenance when returning home, until 8 weeks follow-up.

Because of the absence of evidence of trainability of EF in obese children, we chose an EF-training of *both* working memory and response inhibition. The reason was twofold: (1) in other samples (for example ADHD), more evidence is reported for trainability of working memory (Klingberg 2010) and to lesser extent of inhibition (Thorell et al., 2009) and (2) the limited evidence of EF-deficits in obese samples show mainly inhibition deficits. Other studies in ADHD samples did show generalization of 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 in this study. It may be that our task is not sensitive enough to measure subtle advances in inhibition abilities or that inhibition is not trainable with this program. However, within analyses of the individual inhibition scores of the training task indicated improvement in all participants from the first to the last session suggesting promising potential for the training of inhibition (data available from first author). Therefore it seems reasonable to assume that the present 25 sessions-intervention may have trained both executive functions to some degree, but not enough for observing significant changes on the Stop Task. The conclusion is further qualified by observed significant improvement of the children on their ability of cognitive control as reported on the BRIEF total score and the BRIEF meta-cognition index.

Remarkably, weight maintenance effects were no longer visible at the 12 weeks follow-up. This is in line with other training studies in children and adults showing that training related gains were stable for some weeks but ceased afterwards (Holmes et al., 2010; Buschkuehl et al., 2008). Probably the EF functions need permanent training and therefore, it is worthwhile testing if a schedule of “maintenance” EF-training could further help the children controlling their weight.

The study revealed also 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 posttest a significant reduction in executive functioning was observed in the care as usual only 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 inherent of the third phase of the inpatient program. In the last weeks of the inpatient treatment, gradually the firm structure is attenuated en more frequent home visits are implemented, which included more food temptations to overcome. Furthermore anticipating the admission of the clinic and the upcoming summer holiday may cause more arousal and emotions thereby limiting the capacity for inhibited behavior. This in turn is reflected by the reduction of observed EF functioning in the care as usual only group. The maintenance of a good level of executive functioning in the training group may therefore already be interpreted as a good progression in the children due to the EF training.

In sum, the intervention tested in this study may serve as the basis for future research examining interventions that target overweight and obesity in children. Although treatment programs already attests 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 for the efficacy of an EF-training in obese children.

Methodological strengths and limitations

Conceptualization of self-regulation/impulsivity

The concept of impulsivity covers a wide range of “actions that are poorly conceived, prematurely expressed, unduly risky, or inappropriate to the situation and that often result in undesirable consequences” (Daruna & Barnes, 1993, p.23). There may be many ways to conceptualize impulsive behavior; however, there is often little discussion of the processes that contribute to these behaviors Each observation of impulsivity is constituted of a balance between top down control processes (PFC) and bottom up reward processes (mesolimbic dopamine regions). In impulsivity this balance favors the behavioural output of the reward regions (Bickel, Jarmolowicz, Mueller, Gatchalian, & McClure, 2012). Through the empirical chapters we have tried to capture both sides of the balance in overweight children which we see as a strength.

The bottom up hot processes were measured in chapter 2, 3, 4 and 5. They were conceptualized as poor decision making processes in chapter 2 and 3 and measured using gambling tasks (Door opening task and Hungry donkey task). Results on both tasks showed poor decision making in overweight children. In chapter 4 and 5 overactive bottom up processes were measured as higher scores on a trait impulsivity questionnaire. Results showed higher levels of impulsive responding and dysfunctional Reward Sensitivity (higher levels in overweight children, and lower levels in obese children) compared to average weight children. The impulsivity questionnaires have been validated in neuroimaging research (Beaver et al., 2006; Diekhof & Gruber, 2010).

The top down control processes were measured in chapter 2, 4 and 6. In chapter 2 and 6 inhibitory control was assessed using the Stop Task. Further in chapter 6 different aspects of executive functioning were measured using the BRIEF and working memory performance was assessed using the Corsi Block Tapping Task forwards and backwards. In chapter 5 attentional control processes were assessed via observation. Overall lower levels of top down control were found in overweight children.

A limitation of is this study is that we could not simultaneously measure both processes and their interaction; neither cross-sectional nor longitudinal.

Measurement issues

Questionnaire-based measures or performance-based measures? As indicated before, through the empirical chapters we have tried to capture both sides of the balance in overweight children and also with different measures; which we see as a second strength.

Self-report questionnaires focus on trait impulsivity, but there is no single personality trait that underlies the disposition to impulsive action (Whiteside & Lynam, 2001; Smith et al., 2007). Whiteside and Lynam (2001) describe four dispositions to impulsive behaviour (see UPPS impulsivity scale, chapter 4: Urgency, Lack of premeditation, Lack of perseverance, and Sensation Seeking) which leads to more homogeneous measures of personality risk for impulsive action (Dick et al., 2011). The different dispositions may have different external correlates. We found in overweight children that higher levels of “Urgency” predict more difficulties in delaying gratification. Compared to the average weight group, the overweight children also reported higher levels of Lack of Perseverance and equal levels of Lack of Premeditation. These findings are in line with previous research from Mobbs et al. (2010) in adult women. Finally, the scores for Sensation Seeking, defined as 'the tendency to enjoy and pursue activities that are exciting, and openness for new experiences' were lower in the overweight group as compared to the average weight group. This finding accord with the observation that individuals with a higher BMI are less frequent engaged in rewarding behaviour due to a diminished enjoyment from those behaviours (Pagoto, Spring, Cook, McChargue, & Schneider, 2006).

Performance-based measures are thought to measure cognitive processes underlying impulsive behaviour. Similar to the questionnaire based literature; different performance-based tasks grasp different aspects of impulsivity and have been related to different external criteria (Dick et al., 2011). Chapter 2 aimed to assess impulsivity using five different types of cognitive tasks as suggested by Dougherty and colleagues (Dougherty, Mathias, Marsh, & Jagar, 2005): Stop Task, Circle Drawing Task, Opposite Worlds Task, Maudsley Index of Childhood Delay Aversion, and Door Opening Task (see also table 1). Overall, overweight individuals showed failure to inhibit prepotent responses in a Stop Task (Chapter 2), failure to make advantageous decisions (chapter 2 and 3) and failure to resist temptation during a delay task (chapter 4). The types of failure found in overweight children may reflect urgent responding and therefore it is possible that overweight children act based on high levels of urgency, suggesting multiple associations between impulsivity and obesity (Dick et al., 2011).

The performance based task used in chapter 4, a delay of gratification task, was usually used in experiments with pre-school children. In the current study, the participants were older children aged 10 – 15 years old. As a consequence, most children in both weight groups did manage to delay gratification during 20 minutes. This is not an unusual result for a study with older children: maximum delay appears to have been the modal response in the studies reported by Funder and Block (1989), and Rodriguez et al. (1989) as well. This finding does not necessarily imply that delay of gratification is a simple manner in daily life where the immediately available rewards are much more powerfully attractive than those administered in a brief experimental situation (Funder & Block, 1989). Several distinct hypotheses were formulated for the finding that despite the occurrence of more unfavourable underlying self-regulatory processes, many overweight children succeeded in sustaining the delay time in chapter 4.

As a limitation, we must recognize that the different measures used in this dissertation have all been referred to as measures of impulsivity but, they are not highly correlated and do not load on a single factor; this is true for both questionnaire-based and performance-based measures (Dick et al., 2011). Reynolds et al., (2004) also showed that overall self-report measures of impulsivity did not correlate highly with the behavioural measures of impulsive behaviour. To optimize the validity of the results drawn from future studies, it is crucial to clearly specify process of interest.

Finally a next limitation is that, the current studies measured overweight as a construct closely related to eating behaviour, rather than eating behaviour in a laboratory or naturalistic setting. These studies were of great importance to identify the psychological processes associated with impulsivity in overweight children, but future research should further explore how the eating behaviour of overweight children is related to impulsivity or lack of self control.

Sampling issues

Clinical-based sample. The current findings may not be easily generalized due to the potential risk of selection bias of a clinic-based sample of overweight children which is certainly a limitation of our studies (except for chapter 5). However because the consequences of obesity are so substantial in Flanders, thanks to the school guidance centres, almost all overweight children were referred for therapy. Additionally, recruiting clinical samples makes it more feasible to obtain sufficient power to analyse group differences on performance-based measures.

Cognitive maturation – intelligence. In child research, it is generally accepted that children of different ages can react differently. It is reasonable to assume that cognitive maturation can be of importance here. Since all children attended regular schools, we assumed that none of them had severe intellectual deficits. However, since executive function measures are strongly related to IQ, in general performance improves with higher IQ (Mahone et al., 2002). Therefore, we recommend that future research should specifically control for IQ. We tried to meet this stringent criterion by controlling for IQ in the chapters 2, 3, 4 and 6 but we could not collect IQ in all children due to time constraints which can be seen a shortcoming. However, we analysed IQ data we collected in these different studies and found no correlation between IQ and performance on the Stop Task, Door Opening Task, Hungry Donkey Task and subjective experience in the delay of gratification task. We however found a significant association between IQ and maladaptive attentional control strategies (r = -.261*) and the performance on the Corsi Block Tapping Task backwards (r = .379*). The link between IQ and attentional control strategies during a delay of gratification paradigm is in line with previous research linking ability to delay gratification to success across a variety of academic measures (Mischel et al., 1988; Duckworth, Peterson, Mathews, & Kelly, 2007). Nisbett and collegues (2012) suggest three possible explanations for the relationship between self-regulation and IQ: (a) the ability to self-regulate could be a manifestation of intelligence, (b) the constructs are both affected by a third variable or (3) self-regulation is a process that facilitates the development of intelligence. Also the relationship between working memory and intelligence has been noted by many researchers and is on average .72 (Kane, Hambrick, & Conway, 2005). It was also recently shown that IQ can be enhanced by training people in their working memory capacity (e.g. Klingberg, Forssberg, & Westerberg; 2002), which we see as first evidence for the third hypothesis.

Furthermore, since the adolescent behavioral profile is characterized by a heightened RS, it seems worthwhile to examine the association between RS and BMI in adolescents. Reward-related processes appear to develop in a curvilinear manner with a peak during adolescence, while inhibitory processes show a protracted linear development throughout adolescence, leaving the adolescent with highly sensitive, reward-driven processes that can only be moderately regulated by gradually developing inhibitory processes (for a review, see Hardin, 2010). We performed first analyses on a small group of 34 adolescents aged 16-17 years and found that the association between RS and BMI was indeed attenuated with age. Compared to the younger children, the lower scores at the extremes disappeared among the adolescents; they all reported relative high RS, independent of the BMI.

Finally, given the known association between pubertal status and BMI, we made a good attempt to control for this variable via the use of the adjusted BMI controlling for age and gender.

Cut off points. The actual findings also underpin the importance of the clinical cut off points between overweight and obesity in children and to study if both groups are affected by different pathological routes. In research these groups are too often examined as a whole: overweight/obese versus average weight, and this way possible diversities between the groups are disguised.

Treatment related issues

There are a number of strengths and weaknesses that need to be considered in interpreting the results of the treatment study. First of all, the strengths of this study include the use of a novel intervention, based on a theoretical model of causal and maintenance mechanism of overweight and obesity in children. Additionally, we used both cognitive tasks and ratings to assess EF-functioning. Moreover, estimates of efficacy are often only based 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 (ES). 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, future research should try to unraffle 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, the inhibition training or the combination of the two training elements. It would also be interesting to know if enhanced working memory capacity is related with enhanced attention control skills which are seen as important in self regulation. We also wonder for example whether the trained capacity in working memory is related with weight loss through self-controlled food-intake.

The treatment study is also somewhat limited in power. Larger randomized controlled trials are worthy to considerate. This way it will be possible to identify potential moderators to determine which obese children might respond best to this intervention. Nevertheless, even with only 44 inpatient and severely clinical disturbed patients and with an active 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 it was 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 lead to organisational problems, mitigation and more drop-out. Therefore, non-specific treatment effects in the EF-training condition (such as attention of the childcare workers) were not controlled for. However, our significant long-term effects on weight-loss maintenance in the EF-training condition do in fact provide indications towards true unbiased effects of the training.

Clinical implications

The findings of the present dissertation suggest that obesity treatment programs can develop specific techniques for helping overweight children to master effective and specific inhibitory skills as well as to strengthen their ability to resist temptation and delay gratification. Chapter 2 and 4 and 6 showed that improvement of cognitive control should be integrated better in programmes for overweight children. In this manner, overweight children can learn to activate adequate cognitive coping strategies to override their impulses when confronted with temptation.

Furthermore, the current findings of chapter 3 and 5 provide evidence that individual differences in RS may play a critical role in the vulnerability to overeat and becoming overweight or obese and suggest that initial high RS over time may decrease due to diet-induced alterations in the brain fostering further overeating. This means that in treatment it seems promising to focus on alteration of food reward value or reward alternatives (Volkow et al., 2003; Volkow et al., 2008). Furthermore, the DV model implies that prevention programs should strive to reduce intake of high-fat and high-sugar foods during development to avoid the decrease in RS and reduce the risk for future weight gain in vulnerable populations (Stice et al., 2011). Concretely, preventive interventions in childhood should focus more on creating a less tempting obesogenic environment, an essential step to reduce energy intake. In this way, some guarantees will be provided for preventing activation of the brain's reward circuitry that generates the motivation to eat (Appelhans, Whited, Schneider, & Pagoto, 2011). Parents should remove tempting high energy foods from their home. Therefore, it can be helpful to shop from a grocery list or to use online grocers (Appelhans et al., 2011). Also in public places, and particularly in schools, there should be little exposure, if any, to foods which are high in calories. Schools could remove junk foods form dispending machines where they seduce children into obesity and the food industry could make healthy foods more attractive, palatable, and less expensive (Volkow & Wise, 2005).

Future research

This dissertation has attempted to answer four important questions about self-regulation in overweight children (see also general introduction). Many additional questions remain:

Interaction of both hot and cool factors that may influence eating behaviour.

The current research highlighted RS as one type of factor or cognitive control as one type of that may influence weight gain in children. However, it was suggested by imaging data that the deregulation in reward circuit in obese subjects contributes to overeating in part through deregulation of prefrontal regions implicated in inhibitory control (Volkow et al., 2008). Children low in inhibitory control may be less able to direct their attention away from foods that are desirable or may use different strategies to redirect their attention (Mischel, Shoda, & Rodriguez, 1989). The moderating effect of inhibitory control is also described in recent dual pathway models of overeating (and drug-use) (e.g. Appelhans, 2009; Epstein, Salvy, Carr, Dearing, & Bickel, 2010; Stice et al., 2010; Strack & Deutch, 2004). The dual process model posits however that the decision to go for the immediate reward and eat palatable food or to strain for the larger future benefit of weight loss and improved health is the product of the balance between bottom up reward processes and active top down inhibitory control mediated by the prefrontal cortex. More specifically, the combination of high RS and poor inhibitory control may be the behavioural phenotype that may be associated with high energy intake. Recent neuroimaging data support the idea that the capacity for inhibitory control to forego immediate reward depend on the functional interaction between the PFC and subcortical regions of the reward system (Diekhof & Gruber, 2010). Therefore, future work should consider the interaction of both hot and cool factors that may influence eating behaviour.

The role of genetic factors.

Which genetic factors influence the balance between appetitive motivation and inhibitory control? Obesity is caused by multiple factors, and specifically genetic factors play an important role by regulating the energy balance (Bouchard, 2009). Besides this, the study of biological differences in brain functioning is still in its infancy. Future research in this domain exploring for individual differences in cognitive control and self-regulation skills, is indicated and more specifically, the existence of a specific group of children characterised by a developmental VM brain dysfunction. Although this dysfunction alone does not lead to obesegenic eating habits, it may present a phenotypic characteristic of certain subjects that may succumb to excessive overeating. This is consistent with clinical experiences that some children, despite great motivation to lose weight, report objective episodes of overeating not related to hunger or tasty food and consequently will not succeed in maintaining their weight loss. In this way, if future research can replicate the existence of decision-making deficits in obese children and create more homogeneous sub-groups, more specific treatment targets can be implemented.

The need for longitudinal studies.

The cross-sectional nature of the current research prevents a causal interpretation of the relationships. It remains unclear if low inhibitory control prospectively predicts overweight or if the responsiveness of brain rewards systems is influenced by intrinsic or diet-induced alterations. Intrinsic hypo-responsiveness due to a deficit in dopamine reward circuits may also be indicated in children. To explain the comorbidity of ADHD and obesity, it was hypothesized that obesity and ADHD represent different manifestations of the same underlying dysfunction - the imbalance of dopaminergic reward system. This defect drives individuals to engage in activities of behavioral excess, which, in turn, enhance brain dopamine function (Liu, Li, Yang, & Wang, 2008). Stice (2011) suggest that RS-dysfunction may need to be coupled with a hyper-responsiveness of somatosensory regions to convey specific risk for obesity versus other behavioral problems. Future longitudinal research is needed to clarify this remarkable and promising hypothesis, as direction of effects cannot be determined from the current research.

Disentangle the role of effective treatment techniques.

Finally, future studies should further replicate and disentangle the positive treatment effects from chapter 6 in overweight children. It is however indicated to explore more specific the differential effects for each EF-task, besides the role of a gaming environment. Ultimately, when taken into account all top down and bottom up processes that may be at play, we should unrafle which EF-training component would be most effective for each specific child that suffers from overweight

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Tables

Table 1. *Overview of the samples and instruments used, and the evidence found in the different empirical chapters*

	Sample	Age range	Instruments	Evidence for strong hot system	Evidence for poor cool system
Chapter 2 (N =82)	Overweight Treatment seekers (n=41) Average weight (n=41)	10 - 14	Stop Task OW-TEA-Ch Circle Drawing task Door Opening Task Maudsley Index of Childhood Delay Aversion	Impulsive decision making	Poor inhibitory control
Chapter 3 (N = 132)	Overweight treatment seekers (n=64) Average weight (n=66)	11 - 16	Hungry Donkey Task Standard version Reversed version	Impulsive decision making Future insensitivity	
Chapter 4 (N = 97)	Overweight treatment seekers (n=49) Average weight (n=48)	10 - 15	Delay of gratification task Subjective experience Attention focus strategy UPPS	Delay aversion Higher Urgency, Lack of Perseverance	Poor attentional control
Chapter 5 (N = 438)	Community sample	10 - 15	BIS/BAS scale	High Reward Sensitivity in overweight Low Reward Sensitivity in obese	
Chapter 6 (N = 44)	Overweight treatment seekers	9 - 14	BRIEF Corsi Block Tapping Task Stop Task		Trainability of working memory and inhibitory control

Nederlandse samenvatting

Weerstaan aan voedselverleiding: Invloed van context, impulsiviteit en copingsgedrag

Hoofdstuk 1: Algemene inleiding

Wereldwijd is er de laatste decennia een sterke toename in de prevalentie van overgewicht en obesitas bij kinderen én van de bijhorende negatieve gevolgen op zowel medisch, pychosociaal als economisch vlak (Ogden, Carrol, Curtin, Lamb, & Flegal, 2010). Obesitas of vetzucht wordt gedefinieerd als een overmatige opstapeling van lichaamsvet. Overgewicht daarentegen verwijst naar een te hoog lichaamsgewicht in relatie tot de lengte onafhankelijk van de samenstelling ervan (Field, Barnoya, & Colditz, 2002). Voor de diagnosestelling wordt meestal de Body Mass Index (BMI, gewicht in kg/ lengte in m²) gehanteerd met als cutoff punten: BMI>25 is overgewicht en BMI>30 is obesitas. Bij kinderen is het echter ook van belang om de leeftijd en het geslacht in rekening te brengen (Troiano & Flegal, 1998). Daarom wordt aanbevolen om gebruik te maken van de BMI met eigen percentiel curven als maatstaf. Een percentiel boven de 85 betekent overgewicht en een percentiel boven de 95 wordt gedefinieerd als obesitas (CDC, 2000). Een alternatieve methode om overgewicht bij kinderen te definiëren is de adjusted BMI ((huidig BMI/ percentiel 50 van het BMI voor een bepaalde leeftijd en geslacht) X 100). Een percentage groter dan 120% wordt gezien als overgewicht, een percentage groter dan 140% wordt beschouwd als obesitas (Van Winckel & Van Mil, 2001).

Overgewicht ontstaat door een verstoorde energiebalans: te hoge energie-inname in relatie tot het energieverbruik (Maffeis, 1999). Deze verstoorde energiebalans wordt beïnvloed door een interactie van genetische, omgeving- en kind karakteristieken (Harrison, et al., 2011). Overgewicht wordt zelden veroorzaakt door één enkel gen, maar wordt meestal toegeschreven aan multiple genen. Deze 'kwetsbaarheids genen' in een sterk obesogene omgeving zorgen ervoor dat sommige mensen meer gevoelig zijn voor de omgevingsfactoren en daardoor meer vatbaar voor de ontwikkeling van overgewicht (Orsi et al., 2011). Er zijn heel wat omgevingsfactoren die van invloed zijn het ontstaan van overgewicht bij kinderen: gezin, school, buurt, maatschappij. Al hoewel niet elk kind in dezelfde rijke voedsel omgeving ontwikkelt overgewicht wat het belang van kindfactoren onderstreept. In het kader van dit doctoraat zal vooral de rol van de kindfactoren worden geëxploreerd.

Waarom kunnen sommige kinderen weerstaan aan de constante voedselverleiding terwijl anderen bezwijken en overgewicht ontwikkelen? De basis van dit doctoraat is de vraag in welke mate kinderen met overgewicht in staat zijn om hun voedselinname zelf te reguleren. In hoofdstuk 2, 3, 4 en 5 worden belangrijke processen van zelfregulatie bestudeerd bij kinderen met en zonder overgewicht en in hoofdstuk 6 wordt een behandelprogramma voor kinderen met overgewicht geëvalueerd.

Hoofdstuk 2: Kinderobesitas en impulsiviteit: een onderzoek met gedragsmaten.

Onze rijke westerse omgeving met een constante verleiding van onmiddellijk belonend calorierijk smakelijk voedsel vergt heel wat impulscontrole of zelfregulatie vermogen. Er is inderdaad een duidelijke gelijkenis tussen impulsief gedrag en obesogene eetgewoontes zoals het onvermogen om regelmatig te eten, tussendoortjes te mijden, of te weerstaan

aan de drang om snacks te eten (Lyke & Spynella, 2004). Bij volwassenen is er al aanzienlijk onderzoek gebeurd wat wijst op de relatie tussen impulsiviteit en overeten en overgewicht (o.a. Nederkoorn, Smulder, Havermans, Roefs, & Jansen, 2006; Guerrieri et al., 2007). De link tussen impulsiviteit en overgewicht werd veel minder onderzocht bij kinderen. Er werd gevonden dat in vergelijking met kinderen met gemiddeld gewicht kinderen met overgewicht meer impulsief gedrag vertonen en dat impulsiviteit gewichtsverlies belemmert tijdens therapie (Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006; Nederkoorn, Jansen, Mulkens, & Jansen, 2007).

Aangezien impulsiviteit een multidimensioneel concept is, dienen de verschillende processen ervan die gerelateerd zijn aan overeten te worden onderscheiden. Twee paradigmata lijken de verschillende processen gerelateerd aan het construct impulsiviteit te vatten: (1) het ‘rapid-decision’ paradigma evalueert de executieve inhibitie effecten, en (2) het ‘reward-directed’ paradigma evalueert de motivationele inhibitie effecten (Dougherty et al., 2003). In het eerste paradigma worden executieve inhibitie effecten gedefinieerd als processen voor intentionele controle gericht op hogere orde of lange termijn doelen. Ten tweede, de studie van inhibitie processen in verschillende beloningscontexten is op meerdere manieren gebeurd. Het ‘delay aversion model’ (Sonuga-Barke, 1994) definieert impulsief gedrag als de keuze voor een kleine onmiddellijke beloning boven een grotere uitgestelde beloning omdat het kind het uitstel nodig om de grote beloning te krijgen niet verdraagt (Dougherty et al., 2003). Een ander manier om motivationele inhibitie te bestuderen is door het meten van gokgedrag. Gokgedrag is gestuurd door sterke korte termijn effecten van onmiddellijke beloning waarbij de negatieve lange termijn effecten van het gedrag genegeerd worden.

Tot op heden was er geen omvattende studie van impulsiviteit bij kinderen met overgewicht. Hoofdstuk 2 had als doel aan deze tekortkoming tegemoet te komen. Een uitgebreide batterij van impulsiviteit gedragsmaten die de belangrijkste inhibitie processen evalueren werd opgenomen met als doel te onderzoeken welke specifieke inhibitieprocessen de zelfregulatie verstoren bij kinderen met overgewicht. Op basis van vorig onderzoek werd de hypothese gesteld dat in vergelijking met kinderen met een gemiddeld gewicht, kinderen met overgewicht meer impulsief zullen reageren op alle taken. Ze zullen minder executieve inhibitie controle vertonen, minder verkiezen om te wachten, meer gevoelig zijn aan beloningen, en langer doorgaan met gokken.

De overgewichtgroep bestond uit 41 kinderen tussen 10 en 14 jaar die op de wachtlijst stonden voor een residentieel gewichtscontrole programma. Hun adjusted BMI was tussen 125.42% en 273.92%. De controlegroep bestond uit 41 kinderen tussen 10 en 14 jaar uit scholen in Vlaanderen. Ze werden zo geselecteerd dat ze overeenkwamen in leeftijd en geslacht met de kinderen uit de overgewichtgroep. Hun adjusted BMI was tussen 73.05% en 115.40%.

De kinderen deden de 5 gedragstaken passend binnen de twee paradigmata gedurende individuele sessie van ongeveer 2u (voor een uitgebreide beschrijving van de taken en de procedure: zie hoofdstuk 2).

De resultaten toonden dat kinderen met overgewicht minder executieve inhibitiecontrole vertonen en meer gevoelig zijn aan beloningen, hoewel dit niet consistent is voor alle taken.

Hoofdstuk 3: Keuze gedrag en de regulatie van eetgedrag bij kinderen.

De moderne omgeving vereist een voortdurende keuze tussen onmiddellijke belonende smakelijk calorierijk voedsel en het lange termijn doel van gezondheid en slankheid, vooral van mensen die bezorgd zijn om hun gewicht. Twee oudere studies tonen dan kinderen met overgewicht minder goed zijn in uitstel van behoeftebevrediging (Bonato & Boland, 1983; Johnson, Parry, & Drabman, 1978). Deze bevindingen werden recent bevestigd in longitudinaal onderzoek wat toont dat kinderen met beperkt vermogen tot uitstel van behoefte bevrediging op de leeftijd van 3 en 5 jaar vaker overgewicht vertonen op de leeftijd van 11 en 12 jaar (Francis & Susman, 2009; Seeyave et al., 2009). Verder werd in de literatuur een duidelijke link aangetoond tussen impulsiviteit en overgewicht bij kinderen (o.a. Braet, Claus, Verbeken, & Van Vlierberghe, 2007; Nederkoorn, Braet, Van Eijs, Tanghe, Jansen, 2006). Al deze resultaten suggereren dat kinderen met overgewicht meer gedreven zijn door onmiddellijke nood aan voedsel en minder in staat zijn deze nood te controleren en de juiste keuze te maken, ook al weten ze dat hun gedrag kan resulteren in negatieve gevolgen op lange termijn.

De literatuur toont dat er twee verschillende processen deze ‘myopia’ voor de toekomst kunnen verklaren: (1) kinderen kunnen zo overgevoelig zijn voor beloningen dat ze de straf/het verlies die erbij komt op lange termijn negeren of (2) kinderen kunnen zo ongevoelig zijn voor toekomstige resultaten dat ze steeds de meeste voordelige opties kiezen op korte termijn (Bechara et al., 1994). Deze processen kunnen onderzocht worden aan de hand van de Iowa Gambling Taak (IGT). Volwassenen met overgewicht presteren minder goed op de taak dan leeftijdsgenoten met een gemiddeld gewicht (Davis, Levitan, Muglia, Bewell, & Kennedy, 2004; Pignatti et al., 2006), maar er werd niet onderzocht wat het onderliggende proces was. Bij kinderen werd overgewicht werd de IGT nog niet gebruikt. Hoofdstuk 3 heeft dan ook als doel te onderzoeken of kinderen met overgewicht minder voordelige keuzes maken in de IGT dan kinderen met gemiddeld gewicht én of dit het gevolg is van een overgevoeligheid aan beloningen of van een ongevoeligheid voor de toekomst.

Overgevoeligheid voor beloningen lijkt de voor de hand liggende hypothese bij kinderen met overgewicht aangezien deze eigenschap het moeilijk maakt voor een individu om te weerstaan aan sterk belonend smakelijk voedsel. Onderzoek toont inderdaad een positieve relatie tussen een hoge beloningsgevoeligheid en overeten, voorkeur voor vetrijke en suikerrijk voedsel, en lichaamsgewicht (Davis, Patte, Tweed, & Curtis, 2007; Davis, Strachan, & Berkson, 2004).

Anderzijds werd aangetoond dat een relatieve ongevoeligheid voor beloningen (reward deficiency syndrome, RDS) ook een factor is in de etiologie van obesitas (Wang et al., 2001). RDS wordt veroorzaakt door een verminderde dopamine activiteit in de beloningscircuits in de hersenen en dit werd gelinkt aan onvoordelig keuze gedrag in de IGT als gevolg van ongevoeligheid voor de toekomst (Sevy et al., 2006).

In totaal namen 132 kinderen tussen 11 en 16 jaar deel aan de studie. De overgewicht groep (n = 64) had een gemiddeld adjusted BMI van 145.37% (SD = 16.27%) en de gemiddeld gewicht groep (n = 66) had gemiddeld adjusted BMI van 102.56% (SD = .8.99). Er werd een kindversie gebruikt van de IGT, namelijk de 'Hungry Donkey Task' (Crone, & Van der Molen, 2004). Om de onderliggende processen van het keuze gedrag te onderzoeken deed elk kind de standaard versie en de omgekeerde versie van de taak. De volledige taak duurde ongeveer 30' en erna werden lengte en gewichtsgegevens verzameld door onderzoekers die geen kennis hadden van de studie hypotheses (voor een volledige beschrijving van de taak: zie hoofdstuk 3).

De resultaten toonden dat de kinderen in de overgewicht groep minder voordelig keuzegedrag vertoonden in de IGT in vergelijking met de kinderen in de gemiddeld gewicht groep en dat dit voornamelijk het gevolg lijkt te zijn van een ongevoeligheid voor de toekomstige gevolgen van dit gedrag en niet zozeer door een hoge beloningsgevoeligheid. Deze bevinding lijkt te suggereren dat RDS hypothese reeds bij kinderen mogelijk is. Het feit dat de meerderheid van de kinderen in de overgewicht groep obese waren (66.6%) kan deze resultaten mogelijk verklaren. Het "dynamic vulnerability model" voor obesitas (Davis et al., 2004; Lowe et al., 2009; Stice et al., 2011) stelt dat het mogelijk is dat een overgevoeligheid voor beloningen de initiële risicofactor is voor overeten wat resulteert in een positieve energiebalans en gewichtstoename. Deze overmatige prikkeling van de beloningcircuits kan het dopamine systeem overbelasten en leiden tot een verminderde dopamine activiteit. Wat dan betekent dat deze kinderen met ernstig overgewicht een ongevoelig beloningssysteem hebben wat hen aanzet tot compensatoir overeten en verdere gewichtstoename.

Hoofdstuk 4: Uitstel van behoefte bevrediging bij kinderen en adolescenten met overgewicht.

De voornaamste bevindingen over zelfregulatie processen komen voort uit onderzoek aan de hand van 'het delay of gratification paradigm' (DGP) of 'de marshmallow taak' (Mischel, 1974; Mischel & Ebensen, 1970). Dit is een specifieke gestandaardiseerde wachttaak ontwikkeld om te gebruiken bij jonge kinderen. Gedurende deze procedure worden de kinderen geconfronteerd met een dilemma: één snoepje onmiddellijk of twee snoepjes na enkele minuten wachten. De situatie creëert een conflict tussen de verleiding om het uitstel te beëindigen en de onmiddellijk beschikbare- hoewel kleinere – beloning te nemen of te blijven wachten voor de grotere meer geprefereerde beloning.

Onderzoek toont dat kinderen die hun aandacht weg richten van de beloning gemakkelijker kunnen wachten dan kinderen die hun aandacht op de beloning richten (o.a. Mischel, Shoda, & Rodriguez, 1989). Deze essentiële cognitieve aandacht strategieën zijn afhankelijk van de balans tussen een cognitief traag 'cool' systeem en een emotioneel, impulsief 'hot' systeem (Mischel & Ayduk, 2004).

Ook al weten we uit vorig onderzoek dat kinderen met overgewicht minder goed presteren in het DGP (o.a. Bonato & Boland, 1983), het blijft onduidelijk of dat het gevolg is van onvoldoende cognitieve aandachtscontrole of van een overactief impulsief systeem. Onderzoek toont enerzijds dat kinderen met overgewicht meer impulsief zijn (o.a. Braet, claus, Verbeken, & Van Vlierberghe, 2007), en anderzijds minder cognitieve controle vertonen (o.a. Cserjesi, Luminet, Poncelet, & Lenard, 2009). Hoofdstuk 4 had dan ook als doel om het vermogen tot uitstel van behoeftebevrediging te onderzoeken bij kinderen met overgewicht tijdens een DGP wat ons toeliet de specifieke onderliggende processen te onderzoeken. Op basis van vorig onderzoek stelden we als hypothese dat kinderen met overgewicht minder goed presteren in het DGP omwille van hogere niveaus van impulsiviteit en minder goede cognitieve aandachtstrategieën.

Onderzoek naar uitstel van behoeftebevrediging bij adolescenten met overgewicht is eerder schaars of gebeurde enkel aan de hand van vragenlijsten waardoor de onderliggende processen niet kunnen worden bestudeerd (Duckworth, Tsukayama, & Geier, 2010). De studie van zelfregulatie processen tijdens de transitie naar de adolescentie is zeker zinvol gezien het een kritische periode vormt voor de ontwikkeling van overgewicht (Dietz, 1994). Daarom werd in hoofdstuk 4 de leeftijdsrange opgetrokken tot de vroege adolescentie.

Verder had hoofdstuk 4 ook tot doel na te gaan of de verwachte moeilijkheden tot uitstel van behoefte bevrediging bij de kinderen met overgewicht voedselspecifiek zijn of niet. De bevindingen uit vorig onderzoek hierover zijn wisselend.

Er namen 55 meisjes en 48 jongens tussen 10 en 15 jaar deel aan de studie. De overgewichtgroep bestond uit 49 kinderen die op de wachtlijst stonden voor een residentieel gewichtscontrole programma. Het gemiddeld adjusted BMI was 166.20% (SD = 24.35). De controlegroep bestond uit 48 kinderen gerekruteerd in Vlaamse scholen. Ze werden zo geselecteerd dat ze overeenkwamen in leeftijd en geslacht met de kinderen uit de overgewichtgroep. Het gemiddeld adjusted BMI was 98.13% (SD = 10.71).

Uitstel van behoeftebevrediging werd gemeten aan de hand van het klassieke DGP (Mischel, 1974; Mischel, Shoda, & Rodriguez) in de obesitas kliniek voor de overgewicht groep en op de universiteit voor de gemiddeld gewicht groep. De wachttaak werd opgenomen op video om de aandachtstrategieën te onderzoeken (gedetailleerde beschrijving zie hoofdstuk 4).

De resultaten suggereren een zwakker vermogen tot uitstel van behoeftebevrediging bij kinderen met overgewicht in vergelijking met kinderen met een gemiddeld gewicht als gevolg van hogere niveaus van impulsiviteit en minder adaptieve aandachtstrategieën. Deze resultaten zijn in lijn met vorig onderzoek en beklemtonen dat het vermogen tot zelfregulatie een belangrijk mechanisme kan zijn in de ontwikkeling van overgewicht bij kinderen en adolescenten.

Hoofdstuk 5: Hoe is beloningsgevoeligheid gerelateerd aan lichaamsgewicht bij kinderen?

Individuen met overgewicht vinden smakelijk voedsel meer belonend dan individuen met gemiddeld gewicht (McGloin et al., 2002; Rissanen et al., 2002), maar het blijft onduidelijk waarom dit zo is (Lowe et al., 2009). Volgens de 'Reinforcement Sensitivity Theory' (RST, Gray, 1994) van Gray weerspiegelt beloningsgevoeligheid de activiteit van het 'behavioural activation system' (BAS) wat voornamelijk gestuurd wordt door de neurotransmitter dopamine. Daarenboven heeft onderzoek aangetoond dat een verstoring van de dopamine functie bijdraagt aan de ontwikkeling van overgewicht (Davis et al., 2008; Mathes et al., 2010). De duale kwetsbaarheids theorie stelt twee tegengestelde hypotheses voor in verband met dopamine. De eerste hypothese, het hyper-gevoeligheids model, stelt dat een overgevoeligheid aan beloningen als gevolg van een toegenomen dopamine activiteit zorgt voor een verhoogde motivatie om belonende stimuli te zoeken omdat de bekrachtigende waarde van de beloning zo groot is (Davis et al., 2008; Dawe & Loxton, 2004). De tweede hypothese, het 'reward deficiency syndrome' (RDS) stelt dat individuen met een relatieve ongevoeligheid voor beloningen als gevolg van een verminderde dopamine activiteit meer belonende stimuli zoeken om de interne dopamine niveaus te laten toenemen en zich beter te voelen (Blum et al., 2000; Wang, Volkow, & Fowler, 2002).

Beide hypothesen vinden ondersteuning in de literatuur in verband met overgewicht. Stice en collega's (2011) stellen dat deze blijkbaar tegengestelde bevindingen mogelijks een dynamisch kwetsbaarheidsmodel van obesitas weerspiegelen. Dit model stelt dat een verhoogde beloningsgevoeligheid een initiële risicofactor kan zijn voor overeten bij personen met een normaal gewicht met als resultaat gewichtstoename. Deze overmatige voedselinname kan een overbelasting vormen voor het dopamine systeem en leiden tot een vermindering van de activiteit. Op deze manier zal overmatige voedselinname op lange termijn aanleiding geven tot een ongevoelig beloningsysteem wat verder overeten cultiveert om een aanvaardbaar niveau van goed-voelen te bereiken (Davis et al., 2004; Lowe et al., 2009; Stice et al., 2011). Dit dynamisch kwetsbaarheidmodel werd reeds aangetoond bij volwassenen door Davis en Fox (2008). Deze onderzoekers vonden een curvi-lineare relatie tussen BMI en beloningsgevoeligheid op basis van zelfrapportage, maar dit werd nog nooit onderzocht bij kinderen. Hoofdstuk 5 had dan ook als doel de relatie tussen zelfgerapporteerde beloningsgevoeligheid en lichaamsgewicht bij kinderen te analyseren en zo na te gaan of het dynamische kwetsbaarheidmodel ook al van toepassing kan zijn op jonge leeftijd.

Kinderen tussen 10 en 15 jaar werden gerekruteerd in Vlaamse scholen, wat resulteerde in 438 deelnemers (52.5% meisjes). Ze vulden allen de BIS/BAS zelf rapportage vragenlijst in. Op basis van vorig onderzoek werd de BAS Drive schaal de primaire focus van deze studie (Dawe, Gullo, Loxton, 2004; Beaver et al., 2006).

De resultaten tonen een duidelijke interindividuele variabiliteit in beloningsgevoeligheid en een significant associatie met lichaamsgewicht. Net als bij volwassenen (Davis & Fox, 2008) tonen de resultaten een positieve associatie bij de kinderen met gemiddeld gewicht en overgewicht, wat verandert in een negatieve associatie bij de kinderen met obesitas. Deze resultaten suggereren dat het dynamische kwetsbaarheidmodel ook waarschijnlijk is bij kinderen.

Hoofdstuk 6: Executieve functie training met game elementen voor kinderen met obesitas: Een nieuwe behandeling voor het versterken van het zelfregulatie vermogen voor gewichtscontrole.

Recent onderzoek toont dat gewichtstoename deels het resultaat is van de onmogelijkheid om te weerstaan aan verleidingen en automatische responsen te inhiberen, wat verwijst naar zwakke impulscontrole (Smith, Hay, Campbell, & Trollor, 2011).

Zwakke impulscontrole verwijst naar tekorten in de executieve functies (EF). EFs staan in voor de regulatie van gedrag, gedachten en emoties en zorgen dus voor zelfcontrole (Barkley, 1997). Gewichtsverlies en behoud van gewichtsverlies vereisen duidelijk EFs, meerbepaald inhibitie controle om te weerstaan aan smakelijke snacks en werkgeheugen capaciteit om te onthouden wat men ging doen of wat men moet doen om een bepaald doel te bereiken.

Onderzoek toont dat verstoring van inhibitie controle en werkgeheugen gerelateerd is aan overeten en hogere BMI (Batterink, Yokum, & Stice, 2010; Li, Dai, Jackson, & Zhang, 2008).

Hoewel de huidige behandelprogramma's voor kinderen met obesitas al gericht zijn op het verbeteren van de impulscontrole door het aanleren van zelfcontrole vaardigheden (Braet et al., 2004), lijkt het voor heel wat kinderen met obesitas moeilijk om deze noodzakelijke vaardigheden te implementeren in het dagelijkse leven en blijken ze niet effectief op lange termijn aangezien ze heel vaak terugvallen. Het is mogelijk dat een versterken van de EFs nodig is om te voorzien in voldoende vermogen.

De literatuur biedt evidentie voor de trainbaarheid van zowel inhibitie- als werkgeheugen vermogen (Klingberg et al., 2005; Thorell et al., 2009). Verder toont onderzoek dat het toevoegen van game-elementen zorgt voor een toegenomen motivatie en een groter trainingseffect (Dovis, Van der Oord, Wiers, & Prins, 2011). Daarom was het doel van hoofdstuk 7 om de effectiviteit en aanvaardbaarheid van een intensieve EF-training ingebed in een gamewereld te evalueren bij kinderen met obesitas boven de effecten van een residentieel behandelprogramma.

Er werden 44 kinderen (9-14jaar) opgenomen in de studie en random verdeeld in een EF-training conditie en een controle conditie. De kinderen zaten allen in de laatste maanden van de 10 maand durende residentiële behandeling. Er werd een pre meting uitgevoerd bij de kinderen aan de hand van de Stop taak en de Corsi Block Tapping taak; en bij de opvoeders aan de hand van de BRIEF. Na de training was er een post meting met dezelfde maten. Er werd een follow-up meting gedaan van de BMI 8 en 12 weken na afloop van de training. (Voor een gedetailleerde beschrijving van de EF training zie hoofdstuk 6).

De resultaten tonen een significante verbetering van het werkgeheugen vermogen als gevolg van de training. Ook lijken de kinderen die de training volgden beter in staat om hun gewicht onder controle te houden tot 8 weken follow-up. Deze resultaten suggereren dat een EF training effectief kan zijn als een gewichtstabilisatie interventie, ten minste op korte termijn.

Hoofdstuk 7: Algemene discussie

Weerstaan aan verleidingen veronderstelt vermogen tot zelfregulatie wat uitgedaagd wordt door emoties, gedachten en psychologische processen zoals impulsiviteit. Daarom was het centrale doel van dit doctoraat het onderzoeken van de invloed van impulsiviteit bij kinderen met obesitas. Gezien de multidimensionaliteit van het impulsiviteit construct is het belangrijk om een onderscheid te maken tussen de verschillende processen van impulsiviteit die mogelijk gerelateerd zijn aan overgewicht bij kinderen. Deze impulsiviteit processen werden gemeten aan de hand van gedragsmaten. De resultaten toonden aan dat in vergelijking met kinderen met een gemiddeld gewicht kinderen met overgewicht een zwakke inhibitie controle hebben, hypergevoelig zijn voor beloningen en minder goed keuzegedrag vertonen. Deze bevindingen suggereren dat er bij kinderen met overgewicht mogelijk problemen zijn in de twee hoofdaspecten van impulsiviteit: meer actieve bottom up beloningsprocessen (hot syteem) en minder actieve top down inhibitie controle processen (cold systeem).

Om beter te begrijpen hoe deze zelfregulatie processen kinderen met overgewicht verhinderen om aan verleidingen te weerstaan kunnen paradigmata gebruikt worden die zelfregulatie meten in een conflictsituatie in de aanwezigheid van beloningen. Ten eerste, de resultaten op de Iowa Gambling Task tonen dat kinderen met overgewicht minder voordelige keuzes maken en dat dit voornamelijk het resultaat is van een ongevoeligheid voor toekomstige gevolgen en minder door een overgevoeligheid aan beloningen. Ten tweede werd het klassiek ‘delay of gratification paradigma’ (Mischel, 1974) gebruikt om de mediërende rol van top down aandachtstrategieën en bottom up impulsieve processen te onderzoeken in de link tussen lichaamsgewicht en zelfregulatie. De resultaten tonen dat in vergelijking met kinderen met een gemiddeld gewicht, kinderen met overgewicht vaker het wachten onderbreken en de onmiddellijke kleine beloning nemen, en dit was voornamelijk zo bij het wachten op een voedsel beloning. Bovendien, rapporteerden de kinderen met een hoger BMI meer moeilijkheden te ervaren bij het wachten in de aanwezigheid van een beloning door hogere niveaus van impulsiviteit en zwakkere aandachtstrategieën.

In een verder onderzoek naar het verband tussen beloningsprocessen en lichaamsgewicht werd evidentie gevonden voor een kwadratische associatie tussen zelfgerapporteerde beloningsgevoeligheid en lichaamsgewicht: een positieve associatie bij de kinderen met gemiddeld gewicht en overgewicht, en een negatieve associatie bij de kinderen met obesitas.

Tot slot werd de effectiviteit geëvalueerd van het toevoegen een cognitieve executieve functie training met game elementen bij een 10-maanden durend residentieel behandelprogramma voor kinderen met obesitas. De training verbeterde de executieve vaardigheden van de kinderen, voornamelijk werkgeheugen, en deze kinderen die de training volgden bleken ook meer in staat hun gewichtsverlies te behouden in de thuissituatie tot 8 weken post training.

Algemeen bevestigen de resultaten van dit doctoraat de rol van zelfregulatie in de ontwikkeling van overgewicht bij kinderen en zijn in lijn met het duaal proces model van Appelhans (2009). Dit model stelt dat zelfregulatie of de keuze tussen het eten van onmiddellijk belonend smakelijk voedsel of te streven naar het lange termijn voordeel van gewichtsverlies en betere gezondheid het resultaat is van de balans tussen bottom up beloningsprocessen en actieve top down inhibitie controle.

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