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Children's reward motivation, dietary habits and body composition changes

Annelies De Decker

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Promotor: Prof. dr. Stefaan De Henauw
Co-promotor: dr. ir. Isabelle Sioen

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Annelies De Decker
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The choices you make,
not the chances you take,
determine your destiny

MEMBERS OF THE GUIDANCE COMMITTEE

Promotor: Prof. dr. Stefaan De Henauw
Department of Public Health, Ghent University, Belgium

Co-promotor: Dr. ir. Isabelle Sioen
Department of Public Health, Ghent University, Belgium

Prof. dr. Caroline Braet
Department of Developmental, Personality and Social Psychology, Ghent University, Belgium

Dr. Sandra Verbeken
Department of Developmental, Personality and Social Psychology, Ghent University, Belgium

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Prof. dr. Myriam Van Winckel
Department of Pediatrics and Genetics, Ghent University, Belgium

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Summary

Background

The current dietary pattern of the vast majority of Belgian children does not meet the recommendations: besides a too low daily intake of vegetables, fruit and water, the consumption of energy-rich but micronutrient-poor foods is too high. Further, the prevalence of overweight and obesity in children is high. Overweight and obesity generally occurs when an individual's energy intake through food consumption exceeds his/her energy expenditure over an extended period of time.

This excessive energy intake on an individual level can partly be explained by the operation of the reward system. When hungry, the reward system increases the motivation to eat. This reward motivation can be compared with a strong feeling of attraction aiming to initiate behavior to approach and consume foods. As such, the reward system plays a role in energy homeostasis. However, the reward system reacts similarly in sated states when perceiving cues that are learned to be associated with consumption of energy-rich, sweet and salt foods, further on called 'palatable foods'. The current food environment with an increased availability of palatable foods and associated signals such as advertisements causes a more frequent activation of reward motivation to consume these foods.

Nevertheless, not everyone that is exposed to palatable foods and food cues overconsumes. Research in adults suggests that inter-individual variation in reward motivation partly explains the differences in vulnerability to overconsumption and weight gain. However, in school children, research on this topic is sparse. Further, weight gain includes both lean and adipose tissue accretion, while mainly adipose tissue accretion is problematic. Since an inadequate diet as well as the presence of overweight including obesity are risk factors for the development of diverse physical and psychosocial problems, and since changing dietary habits and losing weight is difficult, primary prevention of both risk factors starting in childhood is crucial. Moreover, it is important to identify vulnerable groups as it is known that preventive interventions tailored to characteristics of vulnerable groups may have a higher effectiveness. Based on all these arguments and information, a longitudinal study was conducted to investigate if children high in reward motivation traits have an increased risk for palatable but unhealthy food choices and/or adiposity gain.

Method

For this doctoral study, a cohort of children from the region of Aalter was followed over a period of four years (at the start in 2011: n=446, 50% boys, 5.5 to 12 years). The majority of the participants were initially recruited for the IDEFICS study in 2008; in 2013, also extra children were recruited. The children, mostly accompanied by their parents, came to the survey center where their body composition was measured and questionnaires were filled in by the children and their parents. Besides the body height and weight, the fat- and lean mass of the children was determined based on volume-measurements using a BOD POD device. In the statistical analyses, age, sex and height adjusted values for body mass as well as fat and lean masses were used. Two reward motivation traits were considered: (a) food cue responsiveness, which is the strength of reward motivation activation by food-reward cues; (b) reward sensitivity, which is the strength of reward motivation activation by cues of rewards in general, i.e. not only to food-reward but to all kinds of rewards. Food cue responsiveness was measured using the 'external eating' (child report) and 'food responsiveness' (parent report) scales; reward sensitivity was measured using the short 'drive' scale (child or parent report). Further, information was collected on the home availability of fat- and sugar-rich snacks and the usual weekly consumption frequency of multiple food items (/groups) (parent report). For data-analyses, the consumption frequency of rewarding food was grouped into three food indices: (1) fast food, (2) sweet food, (3) sweet drinks. Furthermore, the parents were asked how many hours the participating children spend weekly doing sports in sports clubs and in front of a screen (TV, computer, tablet, …).

Results

First, a methodological study aimed to compare the scores of parents and children on the drive questionnaire (n=217), and to evaluate if the parent scores remained stable over two years (n=207). The study results suggested that the questionnaire to measure reward sensitivity is consistently scored and repeatable over time. Although parents and children seemed to interpret the questionnaire similarly, reward sensitivity of a child was differently scored by the child versus the parent. In younger children, child ratings tended to be higher than parent ratings, whereas in older children, child ratings tended to be lower than parent ratings. Additionally, the discrepancy between ratings of fathers and children was higher than the discrepancy between ratings of mothers and children. Further, the parent score on average did not change over two years.

Second, a cross-sectional study investigated the relation of children's reward sensitivity with the body mass index and weight-related behaviors (i.e. palatable food consumption frequency, screen time and physical activity at sports clubs; n=443). Children high in reward sensitivity consumed on average more frequently fast food and sweet drinks, but not sweet food. Further, reward sensitivity was not significantly related to the weekly hours of doing sports in a sports club and screen time. Next, a positive cross-sectional association was found between reward sensitivity and the Body Mass Index (BMI).

Third, a cross-sectional study investigated if food cue responsiveness mediated the relation between reward sensitivity and the consumption frequency of fast food, and if this relation was moderated by the home availability of fat- and sugar-rich foods (n=174). A moderated mediation was confirmed using 'external eating' (but not 'food responsiveness') as food cue responsiveness measure, suggesting that children high in reward motivation traits only had a higher consumption frequency of fast food through external eating when a lot of fat- and sugar-rich foods were available at home.

Fourth, the relation between reward sensitivity and adiposity gain over four years was investigated in boys and in girls (n=446 at baseline). Girls high in reward sensitivity had on average a higher fat mass increase over four years than was expected based on their age and height (compared to reference data). Moreover, the increase in lean mass was lower than expected based on their age and height. Conversely, relations between reward sensitivity and fat and lean mass accretion over time were not found in boys.

Fifth, the interplay between scores on the 'food responsiveness' measure, sex and the home availability of fat- and sugar-rich foods on adiposity gain over two years was investigated (n=129). The scores on the 'food responsiveness' questionnaire were positively associated with a higher relative increase in fat mass over two years in girls, but not in boys. This relation in girls was not amplified by a high home availability of fat- and sugar-rich foods, possibly because other factors as well play a role in excessive energy intake, such as portion sizes and the food environment outside home.

Discussion

The results of this epidemiological study suggest that reward motivation traits play indeed a role in unhealthy food choices in school children. The home food environment of children high in reward motivation traits seems an important influencing factor, since the study indicated that these children consumed more unhealthy food only when they were confronted with unhealthy food. Further, girls high in reward motivation traits may have a higher risk for

an unfavorable development of their body composition. Nonetheless, further longitudinal studies are warranted to confirm these results in other study populations, and to investigate why this relation was only found in girls. Additionally, future research is needed to confirm the presumption that not only the home environment, but also other environments in which children are confronted with unhealthy but palatable foods, influence unhealthy food consumption in children high in reward motivation traits.

The current findings suggest that primary prevention efforts are needed in children high in reward motivation traits to prevent an unfavorable body composition development and the acquirement of unhealthy food habits, which both may last further in their life. Some possibilities are proposed for interventions in children and their parents, for instance the strengthening of inhibitory control skills in order to increase the ability of inhibiting approach behavior to palatable food, and the limiting of rewarding but unhealthy foods at home. However, it is the drastically changed food environment, with the omnipresence of rewarding food cues, that makes it so difficult to limit palatable food consumption for children high in reward motivation traits. Therefore, policies are proposed to downsize the amount of food cues in the environment, such as a ban on food advertisement targeting children.

Samenvatting

Achtergrond

Het huidige voedingspatroon van de overgrote meerderheid Belgische kinderen voldoet niet aan de voedingsrichtlijnen: naast een te lage dagelijkse inname van groenten, fruit en water is de consumptie van energierijke maar nutriënt-arme voedingsmiddelen te hoog. Daarnaast is er ook bij kinderen een hoge prevalentie van overgewicht en obesitas. Overgewicht en obesitas ontstaan voornamelijk als gevolg van een aanhoudende periode waarin de energie inname van een individu via voeding groter is dan zijn/haar energie verbruik.

Deze excessieve energie inname op individueel niveau kan deels verklaard worden door de werking van het beloningssysteem. Het beloningssysteem zorgt ervoor dat de motivatie om te eten vergroot bij honger. Deze beloningsmotivatie is te vergelijken met een sterke aantrekkingskracht, die aanzet tot acties om de voedingsmiddelen toe te naderen en te consumeren. Op deze manier speelt het beloningssysteem een rol in energiehomeostase. Maar het beloningssysteem doet dit ook wanneer er geen honger is, bij het waarnemen van signalen waarvan geleerd werd dat ze geassocieerd zijn met de consumptie van energierijke, zoete en zoute voedingsmiddelen. Deze voedingsmiddelen worden verder 'belonende voedingsmiddelen' genoemd. De huidige voedingsomgeving met een verhoogde aanwezigheid van belonende voedingsmiddelen en geassocieerde signalen zoals reclame leidt tot een frequentere activatie van beloningsmotivatie om deze voedingsmiddelen te eten.

Echter, niet iedereen die blootgesteld wordt aan belonende voedingsmiddelen en -signalen consumeert teveel. Onderzoek bij volwassenen suggereert dat interindividuele variatie in beloningsmotivatie deels de verschillen verklaart in de kwetsbaarheid voor overconsumptie en gewichtstoename. Bij lagereschoolkinderen is er over deze relatie slechts weinig onderzoek uitgevoerd. Daarenboven verwijst gewichtstoename naar toename in zowel vet- als vetvrije massa, terwijl vooral de vetmassa-toename problematisch is. Aangezien een ontoereikend voedingspatroon alsook overgewicht/obesitas risicofactoren zijn voor het ontwikkelen van talrijke lichamelijke en psychosociale problemen, en het veranderen van eetgewoonten en gewichtsverlies bovendien moeilijk is, is primaire preventie van beide risicofactoren vanaf de kindertijd cruciaal. Daarenboven is identificatie van kwetsbare groepen nodig vermits preventieve interventies op maat van de karakteristieken van kwetsbare groepen effectiever blijken te zijn. Op basis van al deze argumenten en informatie werd een longitudinale studie uitgevoerd om te onderzoeken of kinderen met sterke beloningsmotivatie karakteristieken een hoger risico hebben op belonende maar ongezonde voedselkeuzes en/of vetmassa-toename.

Methode

Voor deze studie werd een cohort van kinderen uit de regio Aalter opgevolgd over een periode van vier jaar (bij de start in 2011: n=446, 50% jongens, 5.5 tot 12 jaar). De meeste deelnemers werden initieel gerekruteerd voor de IDEFICS studie in 2008; in 2013 werden ook extra kinderen gerekruteerd. De kinderen kwamen, meestal met hun ouders, naar het studiecentrum waar hun lichaamssamenstelling werd bepaald en vragenlijsten werden ingevuld door zowel kinderen als ouders. Naast de lichaamslengte en het lichaamsgewicht werd de vet- en vetvrije massa van de kinderen bepaald op basis van een volumemeting door een BOD POD-toestel. Waarden voor het gewicht, de vet- en de vetvrije massa gecorrigeerd voor leeftijd, geslacht en lengte werden gebruikt in de statistische analyses. Twee beloningsmotivatie karakteristieken werden onderzocht: (a) voedselsignaal responsiviteit; dit is de mate van activatie van beloningsmotivatie door voedselbeloningssignalen; (b) beloningsgevoeligheid, dit is de mate van activatie van beloningsmotivatie door signalen van beloningen in het algemeen, namelijk niet alleen voedselbeloning maar alle soorten beloningen. Voedselsignaal responsiviteit werd gemeten aan de hand van de ‘extern-eten’ schaal (kinderrapportage) alsook de ‘voedsel-responsiviteit’ schaal (ouderrapportage); beloningsgevoeligheid werd gemeten aan de hand van de korte ‘drive’ schaal (ouder- of kinderrapportage). Verder werd er informatie verzameld over de beschikbaarheid van vet- en suikerrijke snacks thuis en de gebruikelijke wekelijkse consumptiefrequentie van een hele reeks voedingsmiddelen(-groepen) (ouderrapportage). Voor data-analyse werd de consumptiefrequentie van belonende voedingsmiddelen in drie groepen gegroepeerd: (1) fast food, (2) zoete voedingsmiddelen, (3) zoete dranken. Voorts werd aan de ouders gevraagd hoeveel uren de deelnemende kinderen spenderen aan sporten in een sportclub en hoeveel uren per week ze doorbrengen voor een scherm (TV, computer, tablet, …).

Resultaten

Ten eerste werd een methodologische studie uitgevoerd met als doel de scores van ouders en kinderen op de drive vragenlijst te vergelijken (n=217), en te evalueren of de ouderscores stabiel bleven over twee jaar (n=207). De studie wees uit dat de beloningsgevoeligheid vragenlijst consistent gescoord wordt en herhaalbaar is over de tijd. Ook al leken ouders en kinderen de vragen gelijkaardig te interpreteren, de beloningsgevoeligheid van een kind werd verschillend gescoord door het kind versus de ouder. De scores van jongere kinderen waren gemiddeld gezien hoger dan de scores van hun ouders, terwijl de scores van oudere kinderen gemiddeld gezien lager waren dan de scores van hun ouders. Verder werd gezien dat de discrepantie tussen de scores van vaders en kinderen groter was dan de discrepantie tussen de scores van moeders en kinderen. Daarnaast veranderde de ouderscore gemiddeld gezien niet over het verloop van twee jaar.

Ten tweede onderzocht een cross-sectionele studie de relatie tussen enerzijds beloningsgevoeligheid en anderzijds de Quetelet Index (BMI) en gewichts-gerelateerde gedragingen (consumptie frequentie van belonende voedingsmiddelen, schermtijd en fysieke activiteit in sportclubs; n=443). Kinderen met een sterke mate van beloningsgevoeligheid grepen gemiddeld gezien frequenter naar fast food en zoete dranken, maar niet frequenter naar zoete voedingsmiddelen. Er werden geen significante verbanden gevonden tussen beloningsgevoeligheid en het aantal uren sport in een sportclub of het aantal uren voor een scherm. Vervolgens werd er een positief cross-sectioneel verband gevonden tussen beloningsgevoeligheid en de Quetelet Index (BMI).

Ten derde onderzocht een cross-sectionele studie of voedselsignaal responsiviteit de relatie verklaarde tussen beloningsgevoeligheid en de consumptie frequentie van fast food, en of deze relatie afhankelijk was van de beschikbaarheid van vet- en suikerrijke voedingsmiddelen thuis (n=174). Een gemodereerde mediatie werd bevestigd bij gebruik van de ‘extern-eten’ schaal als maat voor voedselsignaal responsiviteit (maar niet bij gebruik van de ‘voedsel-responsiviteit’ schaal), waarbij het positieve verband tussen beloningsgevoeligheid en fast food consumptie enkel aanwezig bleek te zijn bij kinderen bij wie thuis veel vet- en suikerrijke voedingsmiddelen aanwezig waren.

Ten vierde werd de relatie tussen beloningsgevoeligheid en toename in vetmassa over vier jaar in jongens en meisjes onderzocht (n=446 bij de start van de studie). Meisjes met een sterke mate van beloningsgevoeligheid hadden gemiddeld gezien een toename in hun vetmassa die hoger was dan werd verwacht op basis van hun toename in leeftijd en lengte (ten opzichte van referentiedata). Daarnaast was de toename van de vetvrije massa van meisjes net beperkter dan verwacht op basis van hun toename in leeftijd en lengte. Daartegenover werden bij jongens geen significante verbanden gevonden tussen beloningsgevoeligheid en vet-/vetvrije massa stijging over de tijd.

Ten vijfde onderzocht een longitudinale studie het samenspel tussen scores op de ‘voedsel-responsiviteit’ schaal, het geslacht en de beschikbaarheid van vet- en suikerrijke voedingsmiddelen thuis (n=129). De scores op de ‘voedsel-responsiviteit’ schaal waren positief geassocieerd met een groter dan verwachtte vetmassa stijging in meisjes over twee jaar van het onderzoek, maar niet in jongens. De gevonden associatie in meisjes werd echter niet versterkt door een grote mate van aanwezigheid van veel vet- en suikerrijke voedingsmiddelen thuis, mogelijks omdat ook andere factoren een rol spelen in excessieve energie inname, zoals portie groottes en de voedingsomgeving op school.

Discussie

De resultaten van deze epidemiologische studie suggereren dat beloningsmotivatie karakteristeken inderdaad een rol spelen in het maken van ongezonde voedselkeuzes bij schoolkinderen. De thuisomgeving van kinderen met sterke beloningsmotivatie karakteristieken lijkt een belangrijke beïnvloedende factor te zijn, want deze studie geeft aan dat deze kinderen enkel frequenter ongezonde voedingsmiddelen consumeerden wanneer ze met ongezonde voedingsmiddelen geconfronteerd werden thuis. Verder lijken meisjes met sterke beloningsmotivatie karakteristieken een verhoogde kans te hebben op een ongunstige evolutie van hun lichaamssamenstelling. Echter, verdere longitudinale studies zijn nodig om na te gaan of onze resultaten ook in andere studiepopulaties bevestigd kunnen worden, en om uit te zoeken waarom we dit verband enkel zien bij meisjes. Daarnaast dient verder onderzocht te worden of het vermoeden klopt dat niet alleen de thuisomgeving maar ook andere contexten waarin kinderen geconfronteerd worden met ongezonde maar belonende voedingsmiddelen gerelateerd zijn aan ongezonde voedselkeuzes bij kinderen met sterke beloningsmotivatie karakteristieken.

De huidige bevindingen suggereren dat primaire preventie nodig is voor kinderen met sterke beloningsmotivatie karakteristieken om een ongunstige evolutie in lichaamssamenstelling en het ontwikkelen van ongezonde eetgewoonten te verhinderen, die ze - eens ontwikkeld - vermoedelijk meedragen voor de rest van hun leven. Een aantal mogelijkheden voor interventies bij kinderen en hun ouders worden voorgesteld, zoals het versterken van de vaardigheid om impulsen te inhiberen (zodat kinderen toenaderingsgedrag naar belonende voedingsmiddelen beter kunnen onderdrukken) en het beperken van de aanwezigheid van ongezonde voeding thuis. Echter, het is de sterk veranderde voedingsomgeving, met een alomtegenwoordigheid van signalen van belonende voeding, die het zo moeilijk maakt om de consumptie van ongezonde voedingsmiddelen te beperken voor kinderen met sterke beloningsmotivatie karakteristieken. Daarom worden ook beleidsmaatregelen voorgesteld om de hoeveelheid voedingsprikkels in de omgeving te verminderen, zoals het verbieden van voedingsreclame voor kinderen.

Abbreviations

AIC	Akaike’s Information Criterion.
BAS	Behavioral Activation System
BASD	BAS drive
BASRR	BAS reward responsiveness
BASFS	BAS fun seeking
BIS	Behavioral Inhibition System
BMI	Body Mass Index
CEBQ	Child Eating Behavior Questionnaire
CF	Weekly consumption frequency
CFI	Comparative fit index
CR	Child report/child reported
DRD4	Dopamine D4 receptor
Etc.	Etcetera
FMI	Fat Mass Index
FR	Food responsiveness
FTO	Fat- and obesity-associated transcript
HAS	Home availability of fat- and sugar-rich snacks
HBSC	Health Behavior in School-Aged Children
IOTF	International Obesity Task Force
ISCED	International Standard Classification of Education
kg	Kilogram
LMI	Lean Mass Index
m	Meter
N	Number
PAclub	Physical activity in sports clubs.
PEL	Highest parental education level of both parents
PR	Parent report/parent reported
RMSEA	Root mean squared error of approximation
RS	Reward sensitivity
sd	Standard deviation
STANDIF	Standardized difference score
WHO	World Health Organization

WLSMV	Weighted Least Squares Means and Variances adjusted
zBMI	Age- and sex-independent z-score/standard deviation score of BMI, based on Flemish reference curves
zFMI	Age- and sex-independent z-score/standard deviation score of FMI, based on British reference curves
zLMI	Age- and sex-independent z-score/standard deviation score of LMI, based on British reference curves

Foreword on terminology

In view of a correct understanding, this foreword addresses the terminology used in this thesis to describe reward processes and traits.

Three brain reward processes are discerned. One process is the elicitation of a state of pleasure in an individual by a stimulus, which is also called 'hedonic reaction' or 'liking'. Thereby, the term '**hedonic**' refers to pleasure, delight. The stimulus that elicit the hedonic reaction is further on called '**a reward**'. Another process is reward learning, which is learning about the association between a neutral stimulus in the environment and the obtainment of a reward. As states of pleasure intrinsically motivate individuals to obtain the pleasure state again, a third process is the evocation of a **state of reward motivation**. Reward motivation is the motivational drive or property that can initiate behavior in order to pursue a reward. This state is sometimes compared to a magnetic force: an individual may be attracted towards a reward like a magnet to a magnetic board. Reward motivation is typically elicited in the brain by the experience of pleasure during an encounter with a reward or by reward-associated cues. Other terms used in the scientific literature to describe the state 'reward motivation' are 'wanting' and 'reward drive'. However, the term reward motivation is used in the title and throughout this thesis as this term is immediately understandable to readers that are not familiar with the research field on reward processes.

The activation level of reward motivation by a reward (or associated cue) differs between individuals; hence, it is a **trait** of an individual. **Reward motivation traits** and their relation with food consumption and body composition are the main focus of the original research of this thesis. Two traits are considered. One is called **food cue responsiveness**, which is the strength of reward motivation activation by **food-reward**(-associated cues). The other one is called **reward sensitivity**, which is the strength of reward motivation activation by reward(-associated cues) in **general**, i.e. to all kinds of rewards such as food, sex, addictive drugs, loved ones. In publications of other researchers, the term 'reward sensitivity' may refer to a broader construct, namely to inter-individual differences in the strength of the hedonic reaction and in the inclination to seek out new rewarding situations besides individual differences in the strength of reward motivation (Carver & White, 1994). Since reward sensitivity is a well-known term in the literature, the term 'reward sensitivity' was used, but the term refers in the current thesis only to individual differences in the strength of reward motivation.

GENERAL INTRODUCTION

1. The importance of a healthy diet

Compliance with dietary guidelines is important since they are made to support healthy growth and prevent diseases (Chopra, Galbraith, & Darnton-Hill, 2002). This section starts with a short exploration of the current dietary pattern of children in Belgium and the compliance with dietary guidelines. Then, it proceeds with the consequences of an inadequate dietary pattern, of which one of the consequences is explained in more detail, namely overweight and obesity. At the end of the section, the need for innovative approaches to improve the dietary pattern and prevent the development of overweight and obesity is highlighted.

This section aims to provide the reader with a brief introduction to the above described topics, but a complete review of prevalence numbers for all food groups, a complete review of all databases providing prevalence numbers on the dietary pattern, overweight, and obesity in children as well as a complete review of the consequences, including the level of evidence, is beyond the scope of this thesis.

1.1 The current dietary pattern of Belgian children

Table 1 displays the recommended daily intake of fruit, vegetables, water and not-sugared beverages for children and adolescents, as well as the maximum recommended amount of daily kilocalories derived from foods "to be consumed sparingly" according to the food guide pyramid. The food guide pyramid is a method to visualize the dietary guidelines. The top of the Flemish food guide pyramid represents the foods "to be consumed sparingly": these foods are not necessary for a balanced diet and should be avoided or strongly moderated because they are energy- and/or salt-rich but micronutrient-poor, such as sugared beverages, sauces, fat- and/or sugar-rich snacks, pastry, fried potatoes and potato croquettes (De Ridder et al., 2016; VIGeZ, 2016). These are products that are on average perceived as highly palatable.

Further, Table 1 displays some important results of the Belgian Food Consumption Survey 2014: almost all the Belgian children and adolescents consume too little fruit, vegetables, water and not-sugared beverages, all necessary for a healthy growth and life; furthermore, almost all the Belgian children and adolescents also consume more than the maximum recommended amount of daily kilocalories derived from foods from the top of the food guide pyramid (De Ridder et al., 2016). Hence, it can be concluded that the majority of children do not meet the recommendations for a healthy diet.

Table 1 Daily recommendation and consumption of four food groups in Belgian children and adolescents

Age range		6-9 years	10-13 years	14-17 years
Fruit	**Recommendation**	250g or 2 p/d	250-375g or 2-3 p/d	375g or 3 p/d
	Did not meet recommendation	94%	98%	100%
	Average amount consumed	120 g/d	99 g/d	85 g/d
Vegetables	**Recommendation**	250-300 g/d	250-300 g/d	300 g/d
	Did not meet recommendation	99%	99%	99%
	Average amount consumed	96 g/d	103 g/d	110 g/d
Water and not-sugared beverages	**Recommendation**	1500 ml	1500 ml	1500 ml
	Did not meet recommendation	98%	95%	92%
	Average amount consumed	613 g/d	739 g/d	848 g/d
Foods of top of food guide pyramid	**No more than … recommended**	145 kcal/d	145-230 kcal/d	230 kcal/d
	Consumed more than recommended	99%	98%	97%
	Average amount consumed	623 kcal/d	688 kcal/d	705 kcal/d

Note. g, gram. p, pieces. /d, per day. kcal, kilocalories. Results derived from De Ridder et al. (2016).

Fortunately, 85% and 74% of the Belgian children aged 6-9 and 10-13 years follow the recommendation of consuming a **breakfast** daily. The consumption of breakfast is positive since it can help to reduce consumption of energy-rich micronutrient-poor foods during the day, and hence, help the establishment of a healthier eating pattern. However, only 55% of the adolescents aged 14-17 years consumes a breakfast daily, 11% consumes a breakfast on 5 or 6 days a week, and the other 44% consumes a breakfast on only 4 days a week or less (Bel, 2015).

Data of the 'Health Behavior in School-Aged Children' study (HBSC) are used for **comparison** of the Belgian data with those of other countries. HBSC is a World Health Organization (WHO) collaborative that collected data in countries and regions across Europe and North America in children aged 11, 13 and 15 years, including the Flemish and French part of Belgium. Based on the survey in 2013/2014, the proportion of children who consumed a breakfast every weekday in the Flemish part of Belgium was among the highest of the 42 countries and regions participating in HBSC, while that in the French part was among the midst. However, the proportion of children who consumed fruit daily was among the highest in the French part and among the lowest in the Dutch part. Further, the proportion of children who consumed vegetables daily in the Flemish and the French part of Belgium was among the highest of the 42 countries and regions included in HBSC. Unfortunately, the proportion of children who consumed sugar-sweetened beverages daily in the Flemish and French part was also among the highest. The consumption of foods derived from the top of the food guide pyramid was not reported (Inchley & al., 2016).

The frequency of consuming **out-of-home prepared food** was not assessed in the HBSC study, the Belgian Health Survey of 2013 or the Food Consumption Survey of 2014. However, these numbers may be important since the dietary quality of out-of-home prepared food is less optimal (Lachat et al., 2012). To illustrate the importance of out-of-home prepared food, prevalence numbers of a neighboring country are given: based on data of the national Diet and Nutrition Survey of the United Kingdom, 19% of children eat meals out once a week or more, and 21% of the children eat take-away meals at home once a week or more (Adams et al., 2015).

1.2 Consequences of inadequate food consumption

An inadequate diet is a **risk factor for infectious diseases as well as non-communicable diseases** (WHO, 2016c). It is beyond the scope of this thesis to give a full overview of all reported associations between dietary patterns and diseases. However, some main topics are listed.

First, it is well established that the consumption of fruits and/or vegetables is inversely associated with the occurrence of diseases causing morbidity and mortality, such as stroke, coronary heart disease and cancer. Hence, adequate consumption of the recommended amount of fruit and vegetables may protect for these diseases later in life (Dauchet, Amouyel, Hercberg, & Dallongeville, 2006; Hu, Huang, Wang, Zhang, & Qu, 2014; Scarborough, Nnoaham, Clarke, Capewell, & Rayner, 2012; Vieira et al., 2016; Zhao et al., 2016). Further, a high sugar consumption is related to dental caries (Freeman, 2014), while salt consumption is positively associated with blood pressure (Aburto et al., 2013).

The following suggestions have to be further confirmed by future research.

(a) Sugar-sweetened beverage consumption may predict the occurrence of type II diabetes mellitus independent of weight status (O'Connor et al., 2015).

(b) Deficiency of nutrients as well as abundancy of certain nutrients such as refined sugars, salt and saturated fatty acids may affect the immune system. This may lead to increased inflammation, reduced control of infections, increased rates of cancer and

increased risk for allergic and auto-inflammatory disease. Amongst others, the gut microbiome may play a mediating role therein (Myles, 2014).
(c) A current research interest is the impact of food consumption on cognition, since in rodents, some indications exist that consumption of an energy dense, 'western' diet has consequences on brain functions such as learning, memory, and behavior (Cordner & Tamashiro, 2015; Hargrave, Davidson, Lee, & Kinzig, 2015; Kaczmarczyk et al., 2013; Kanoski & Davidson, 2011).

Other important consequences of an inadequate diet are undernutrition and weight gain. U**ndernutrition** is defined as the outcome of insufficient food intake and repeated infectious diseases. Undernutrition includes being **underweight** for one's age, too short for one's age (stunted), dangerously thin, and deficient in vitamins and minerals ("Unicef, a report card on nutrition, No 4," 2006). W**eight gain** occurs when energy intake exceeds energy expenditure resulting in storage of the excess energy into body fat and lean tissue (Hall et al., 2011). In turn, weight gain over an extended period of time may result in **overweight and obesity**, which are defined as abnormal or excessive fat accumulation that may impair health (WHO, 2016c). Only a **small daily excess energy intake relative to energy expenditure** is needed to develop obesity on the long term: a recent approach based on mathematical modeling attributed the United States' **obesity epidemic** to a positive **energy imbalance** of only ~30 kilojoules/day (Hall et al., 2011). Hence, a **healthy diet and physical activity pattern** are both important to maintain a normal weight. However, on top of an inadequate diet, the majority of children and adolescents do not meet the recommendations for physical activity and sedentary behavior. Only 7% and 2% of Belgian children and adolescents aged 6-9 years and 10-17 years respectively meet the recommendation of doing at least 60 minutes a day moderate to vigorous physical activity. Furthermore, 11% and 55% of the children and adolescents aged 6-9 years and 10-17 years respectively had more screen time on a normal weekday and 53.7% and 84% respectively had more screen time on a normal weekend day than maximally recommended, i.e. more than 2 hours a day (Bel, De Ridder, Lebacq, Ost, & Teppers, 2016).

Besides on an unhealthy dietary pattern, the focus of this thesis is on **overweight and obesity**. Therefore, the section below elaborates on the classification, prevalence, trends, and consequences of overweight and obesity.

1.2.1 Classification, prevalence, trends and consequences of overweight/obesity

To **classify** overweight and obesity, the **Body Mass Index** (BMI), i.e. weight in kilograms (kg) divided by height in square meters (m), is often used. In adults, a BMI equal to or greater than 25 kg/m^2 is called overweight, while a BMI equal to or greater than 30 kg/m^2 is called obesity (WHO, 2016c). In children, the cut-offs for adults are not applicable because children's BMI depends on their age and sex. Different cut-offs exist to classify children into BMI categories such as overweight and obesity. The below mentioned prevalence numbers in Belgian children are based on **cut-offs of the International Obesity Task Force** (IOTF) (T. J. Cole, Bellizzi, Flegal, & Dietz, 2000; T. J. Cole, Flegal, Nicholls, & Jackson, 2007).

Based on the fact sheet of the WHO, the **worldwide prevalence of obesity more than doubled between 1980 and 2014**. Currently, there are **more people who are obese than underweight** (WHO, 2016c). Overweight and obesity were once considered as a problem of high-income countries, but they are now on the rise in low- and middle-income countries too, particularly in urban settings. These countries are now facing a **'double burden'** of disease, since it is not uncommon that undernutrition and obesity co-exist within the same country, the same community and the same household (WHO, 2016c). Even in the same individual, obesity and undernutrition can co-exist due to deficiency of one or various vitamins or minerals; this may be explained by diets based on energy-dense foods that lack micronutrients (WHO, 2016a).

Based on the **Belgian** Food Consumption Survey 2014, 45% of the Belgian population between 3 and 64 years had overweight including obesity in 2014. Overweight including obesity was found in 16.6%, 19.2%, and 17.2% of the Belgian children and adolescents aged 6-9 years, 10-13 years, and 14-17 years respectively (Lebacq, 2015). Still, the situation in Belgium is better than in a lot of other countries, such as Canada, the United Kingdom or the United States (Inchley & al., 2016; Lebacq, 2015). Further, the Belgium Health Survey 2013 reported that the prevalence of overweight and obesity in Belgian children (a) is significantly higher in children from lower educated parents compared to higher educated parents, (b) is significantly higher in children living in urban versus rural regions, and (c) has significantly increased between 1997 and 2013, but not between shorter time intervals such as between 2001 and 2013, between 2004 and 2013, and between 2008 and 2013 (Drieskens, 2014). The HBSC study also concluded that the prevalence in childhood overweight and obesity in

Belgium did not significantly change between 2002 and 2010. The rise in overweight and obesity prevalence seems to be stabilized between 2002 and 2010 in most countries participating in the HBSC study, except in Eastern European countries (Ahluwalia et al., 2015).

Although the rise in childhood overweight and obesity tends to stabilize and the prevalence is lower in Belgium than in other countries, every child with obesity is one child too much since these problems are **associated with several adverse health consequences**. These consequences can occur in the short-term, already during childhood or adolescence, and in the long-term, during adulthood (S. R. Daniels, 2009).
Obesity-related physical health conditions **already reported in childhood** are presented in Table 2. Besides these **physical** disorders, children with a higher BMI also experience **psychosocial** problems, such as increased stress, depression, anxiety, body dissatisfaction, and bullying, and decreased quality of life (Bell et al., 2011; Michels et al., 2015; Shunk & Birch, 2004; Ul-Haq, Mackay, Fenwick, & Pell, 2013).

Table 2 Disorders related to childhood obesity, presented by organ system.

Physical disorders related to childhood obesity	
System	**Disorder**
Cardiovascular	Hypertension Left ventricular hypertrophy Atherosclerosis
Metabolic	Insulin resistance Dyslipidemia Metabolic syndrome Type 2 diabetes mellitus
Pulmonary	Asthma Obstructive sleep apnea
Gastrointestinal	Nonalcoholic fatty liver diease Gastroesophageal reflux
Skeletal	Tibia vara (Blount disease) Slipped capital-femoral epiphysis
Other	Polycystic ovary syndrome Pseudotumor cerebri

Note. Adapted based on S. R. Daniels (2009).

In the long-term, high childhood BMI has been associated with an increased incidence of adult diabetes, coronary heart disease and a range of cancers. Further, obese youth are more likely to remain obese during childhood and adulthood, which is called '**tracking'**, and which in turn leads to obesity-related complications in adulthood as well. Furthermore, weight loss and maintenance of **weight loss over the long term is difficult** for a large portion of people. Therefore, some have postulated that the **life expectancy will decrease** in large part because of obesity and its related comorbidities (R. E. Brown & Kuk, 2015; S. R. Daniels, 2009; A. Llewellyn, Simmonds, Owen, & Woolacott, 2016; McGuire, Wing, & Hill, 1999; Singh, Mulder, Twisk, van, & Chinapaw, 2008; Wright, Emmett, Ness, Reilly, & Sherriff, 2010).

In addition to health consequences on the individual level, inadequate diets as well as the burden of obesity and its related morbidities result in a **high societal burden** due to direct and indirect economic consequences like increased health care expenditure, increased absenteeism etc. (Verhaeghe, De Greve, & Annemans, 2016; Watkins, Olson, Verguet, Nugent, & Jamison, 2016). For Belgium, it is estimated that a one unit decrease in BMI in the overweight and obese population would result in a total economic benefit of 15.9 billion euros for the society over a 20 year time period (Verhaeghe et al., 2016).

1.3 Conclusion: need for innovative prevention approaches

Based on the information in section 1.1 and 1.2, it can be concluded that the current dietary pattern of many children does not comply with the dietary guidelines. This has individual physical and psychosocial consequences as well as societal consequences. A major concern is the high prevalence of overweight and obesity. When the risk factors 'inadequate diet' and 'overweight including obesity' already develop in childhood, they may track into adulthood because changing dietary habits and losing weight is difficult (Craigie, Lake, Kelly, Adamson, & Mathers, 2011; Singh et al., 2008). Although weight loss interventions can be effective, the success rates are generally low, certainly when evaluating the maintenance of weight loss on the long term (Fildes et al., 2015; McGuire et al., 1999; Reinehr, 2013; Snethen, Broome, Treisman, Castro, & Kelber, 2016). Hence, **primary prevention of** the risk factors **'inadequate diet' and 'overweight including obesity' is critical**, and this already **during childhood.**

Although evidence supports the effectiveness of particular interventions for preventing childhood obesity, the effect size of these interventions is generally small (Y. Wang et al., 2015). A lot of existing interventions focus on changing conscious processes through (psycho)education in the total population. However, dietary behaviors are suggested to be in large part the consequence of automatic responses to environmental food cues, which are omnipresent in our current environment (D. A. Cohen & Babey, 2012). Hence, innovative **prevention approaches that take into account these automatic processes** may be more effective in preventing childhood obesity. To develop such interventions, these automatic processes should be thoroughly understood. Moreover, it is important to identify vulnerable groups of children (e.g. children with stronger automatic responses to environmental food cues): as not every intervention strategy works for everyone, interventions that target vulnerable groups and thereby use strategies tailored on specific characteristics of the vulnerable groups have been recommended (Belsky & van Ijzendoorn, 2015; Silveira et al., 2016).

The next section therefore elaborates on the brain reward system, which is found to be involved in these automatic responses to environmental food cues. Possibly, individual differences between children in the functioning of the brain reward system may be able to partly explain a higher vulnerability to adopt inadequate dietary behavior and develop overweight or obesity. This hypothesis is further explored in the current thesis.

2. The role of reward motivation in food consumption

This chapter starts with a general description of human biological mechanisms behind the consumption of food. Second, one of these biological mechanisms, namely the reward system, is described in more detail. This is followed by an elaboration on the drastic changes in the current food environment that lead to more frequent and intense activations of the reward system in all individuals exposed to it, and that may direct detrimental food consumption patterns. Further, a transactional model is described that explains individual differences in food consumption when exposed to the current food environment. This model includes individual characteristics. Then, one individual characteristic is highlighted, namely the strength of the functioning of one reward process. This trait may be able to explain an enhanced vulnerability to overconsumption of energy- and/or salt-rich, micronutrient-poor food when exposed to the current food environment.

2.1 Biological mechanisms underlying food consumption

This thesis focusses on the role of the reward system in food consumption. Nonetheless, when considering the regulation of food consumption, the important role of homeostatic systems needs to be mentioned, since food consumption primarily serves to meet energy and nutrient needs of the body.

An important homeostatic system in the regulation of food consumption is the **energy homeostatic system,** which can detect and signal a deviation in the energy balance. In states of a positive energy balance, i.e. satiation, the signals sent by the energy homeostatic system aim to decrease appetite and increase energy expenditure, whereas in states of a negative energy balance, i.e. homeostatic hunger, they aim to increase appetite and decrease energy expenditure. The system consists of central as well as peripheral structures, hormones and neurotransmitters, and of elements that regulate the energy balance on the short as well as on the long term. The **hypothalamus** has been identified as the most important central structure, receiving food consumption controlling signals from and sending those signals to **different central and peripheral structures** (Figure 1) (Farr, Li, & Mantzoros, 2016).

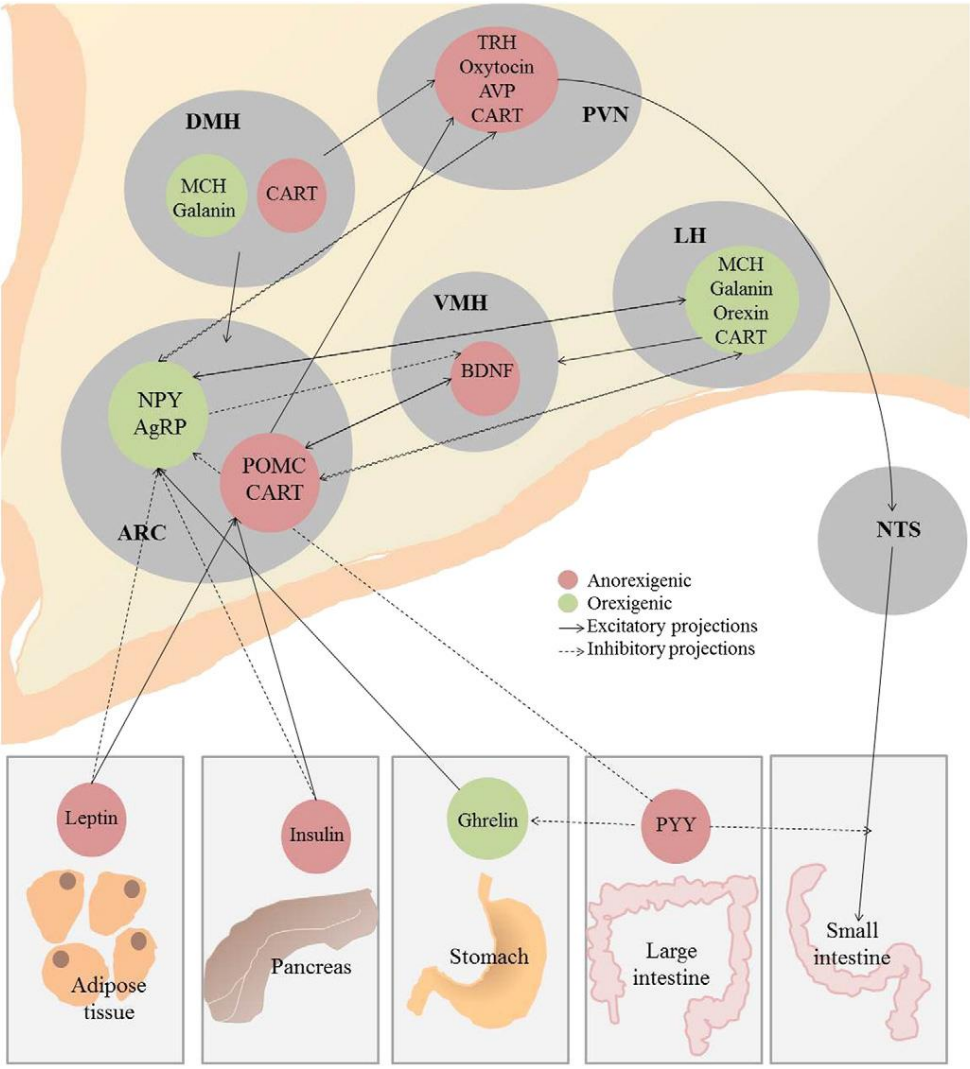

Figure 1 Schematic representation of nuclei in the hypothalamus, peripheral organs, hormones, and neurotransmittors, important in the homeostatic control over eating (Farr et al., 2016).
Note. AgRP, agouti-related peptide; ARC, arcuate nucleus; AVP, arginine-vasopressin; BDNF, brain-derived neurotrophic factor; CART, cocaine- and amphetamine-regulated transcript; DMH, dorsomedial hypothalamus; LH, lateral hypothalamus; MCH, melanin-concentrating hormone; NPY, neuropeptide Y; NTS, nucleus of the solitary tract; POMC, proopiomelanocortin; PVN, paraventricular nucleus; PYY, peptide YY; TRH, thyroid-releasing hormone; VMH, ventromedial nucleus.

The hypothalamus is also in cross-talk with central systems outside of the homeostatic system. One of these central systems is the **reward system** (Finlayson, King, & Blundell, 2007). The reward system reacts to signals of a negative energy balance by increasing the motivation to consume food and increasing the hedonic reaction to food intake; further, the reward system reacts to signals of a positive energy balance by dampening the motivation and hedonic reaction (see section 2.2.1 for an explanation of the term hedonic reaction) (Berridge, Ho, Richard, & DiFeliceantonio, 2010; Cameron, Goldfield, Finlayson, Blundell, & Doucet, 2014; Epstein, Leddy, Temple, & Faith, 2007; J. Zhang, Berridge, Tindell, Smith, &

Aldridge, 2009). Research suggests that modulation of motivation and hedonic reaction by energy states can happen through direct neural pathways from the hypothalamus to the reward system, as well as indirectly, through endocrine signals (e.g. insulin, leptin, and ghrelin) or nutrient components (e.g. triglyceride-rich particles) (Cansell et al., 2014; Figlewicz, 2015; Stice, Figlewicz, Gosnell, Levine, & Pratt, 2013).

Importantly, the **reward system can also underlie food consumption independently of the homeostatic system** (Lowe & Butryn, 2007). Satiety may dampen food motivation and hedonic reactions to food, but may not completely eliminate them or reverse them into a food aversion (Berridge et al., 2010). Additionally, satiety caused by consumption of one food may dampen the food motivation for that specific food, but exposure to other preferred foods may still evoke motivation to consume them (Epstein et al., 2007; Rolls, 2011). The next section addresses the brain reward system processes and their role in food consumption.

2.2 The brain reward system

In this section, the reward system processes generated to all kinds of rewards are first sketched in broad outlines, followed by a focus on food reward. A main literature source was the synthesis of original research literature by Berridge and colleagues, which are prominent researchers in this field. They have proposed a model that parses reward processes into three components, which is explained below. When valuable for the topic of this thesis, elements of the synthesis or research of other authors are used.

2.2.1 Reward system processes: liking, learning and motivation

Three reward processes are discerned: (a) the hedonic reaction to a stimulus, also called liking (b) learning about relationships among stimuli and about the consequences of actions, and (c) reward motivation (Berridge et al., 2010; Berridge & Robinson, 2003b). Thereby, the term '**hedonic**' refers to pleasure. Based on the observations that (a) stimuli that are necessary for survival and reproduction can evoke pleasure in individuals (e.g. food, sex, social bonds with important others) and (b) pleasure-triggering stimuli intrinsically motivate individuals to pursue them, it is postulated that these reward system processes may have evolved during **evolution** for reasons of **survival** of the species (Berridge, 1996). In Figure 2, an overview of the three processes is given.

The evocation of pleasure by a stimulus in an individual, i.e. the **hedonic reaction**, is called **liking** by Berridge (1996). He and his colleagues postulated that liking can be a consciously experienced process as well as an unconscious process (Berridge & Kringelbach, 2015). The stimulus that elicit the hedonic reaction is further on called '**a reward**'.

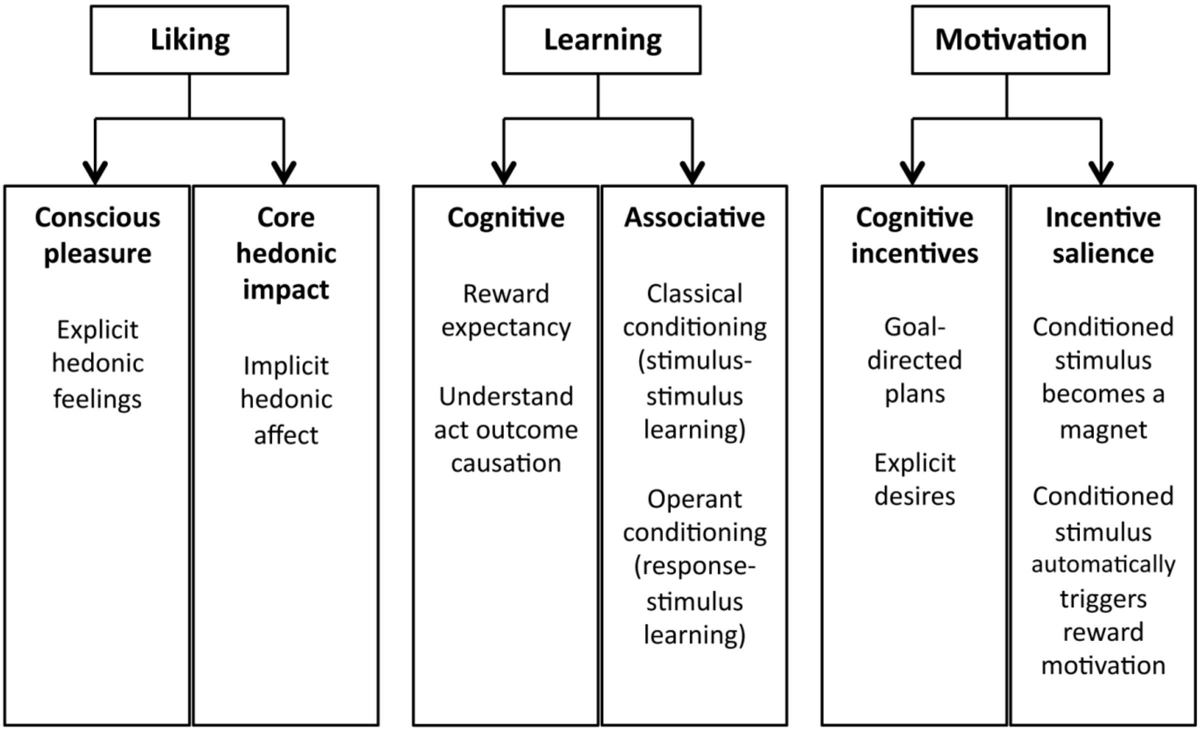

Figure 2 Reward components. Based on Berridge and Robinson (2003a).

Learning encompasses the **acquisition of knowledge** about the relationships among stimuli and the consequences of actions (Berridge & Robinson, 2003b). Learning about reward includes (a) learning to predict the strength of the hedonic reaction, (b) learning where to find it, and (c) how to behave to get it. Reward learning processes can be cognitively-driven or automatic, i.e. 'associative learning'. **Associative learning** usually refers to either operant or classical conditioning, which are described here shortly; for more details on the different mechanisms of reward learning, see the review of Dayan and Berridge (2014).

In **operant conditioning** (also called **instrumental** conditioning), a reward-stimulus follows the conductance of a behavior. The hedonic reaction to the reward-stimulus potentiates learning of the association between the behavior and the reward-stimulus. When re-obtainment of the hedonic reaction is wanted, the behavior will be conducted again (i.e. instrumental response). For example, when pressing on a lever is followed by getting a gift, the individual will press again on the lever to obtain a new gift.

In **classical conditioning** (also called **Pavlovian** conditioning), a meaningful biologically relevant stimulus that automatically provokes a response (also called 'unconditioned stimulus' and 'unconditioned response' respectively) is paired with a neutral stimulus or cue, i.e. a cue that initially provokes no reaction. The cue can be a sensory perception (e.g. visual, olfactory, auditive), an imaginary representation, an object or a situation. After pairing the two stimuli, the individual learns that the neutral cue is associated with the unconditioned response. Through this learning, the cue can elicit a response similar to that of the unconditioned stimulus, which can be an anticipatory response, behavioral habits or even the emotions appropriate to the unconditioned stimulus itself. The cue is than called the conditioned stimulus, and the response it evokes is called the conditioned response (Berridge & Robinson, 2003b). For example, a palatable food is a biologically relevant stimulus (unconditioned stimulus) that elicits salivary production (unconditioned response). If eating a palatable food is paired with a sound, hearing the sound later on (conditioned stimulus) can already elicit salivary production (conditioned response). This conditioned response to the sound anticipates obtainment of the palatable food.

Also variations of the two learning mechanisms exist. For example, in Pavlovian-instrumental transfer, a Pavlovian conditioned stimulus can influence instrumental responding.

However, mere knowledge about reward-stimuli is not sufficient to **actually induce and control behavior**. Therefore, a motivational drive is needed that makes an individual **pursue reward** (Berridge, 2012). This motivational drive is generated by the brain reward system and is called **wanting** by Berridge (1996). Also wanting can be (a) directed by cognition, generating goal-directed plans and explicit desire (e.g. I want to lose 5 kilograms; note that this form of reward motivation involves additional cortical brain mechanisms beyond the reward system) or (b) an **automatic** motivational process, which is eventually perceived by the individual as a feeling of '**desire**' for the reward (Berridge et al., 2010). The term **reward motivation** is further used to refer to the automatic component of wanting in this thesis. Reward motivation is typically **triggered by reward-associated cues**[1] or **by the encounter with the reward-stimulus itself** (Berridge, 2012). A stimulus that generates a strong liking typically also generates a strong reward motivation; hence, liking mostly precedes reward

[1] Berridge & Robinson have argued that some cue has to be present to elicit reward motivation and that learned instrumental behavior to obtain a reward belongs to learning and not to reward motivation (Berridge & Robinson, 2003b), while Salamone & Correa have argued that instrumental behavior ('how hard is worked for the reward') itself a part of reward motivation (Salamone & Correa, 2002).

motivation.[2] Further, learning about the association of a cue with a stimulus is a prerequisite for cue-triggered reward motivation. Reward motivation involves that **incentive salience is attributed to a cue**, and makes the cue and its reward more attractive, sought after and attention grabbing. In other words, it makes an individual attracted by the cue and the subsequent expected reward like a magnet to a magnetic board. It is important to note that recent (sufficient) experience with a reward can reduce reward motivation for the reward immediately afterwards, also called reinforcer satiation (Epstein et al., 2007). However, reward motivation for the reward can reoccur at later instances.

According to Berridge and Kringelbach (2015), the three processes can occur together at any time during the reward-behavior cycle, but the **anticipatory phase of reward is mainly dominated by reward motivation**. Further, although reward motivation typically coheres with liking, **reward motivation can dissociate from liking.** One example of this is that in some cases, reward motivation may become much stronger than liking for the same stimulus after repeated exposure to a reward, which is called ‘incentive sensitization’ (Berridge et al., 2010).

The three components seems to have discriminable **neural substrates**: for liking, learning and reward motivation, brain manipulations that only turn off or enhance that specific component and not the others have been found. However, the underlying neural substrates of the three components are not yet identified completely (Berridge & Kringelbach, 2015). Intensive research in multiple scientific domains is ongoing and may increase knowledge as well as change current hypothesis. Based on research up to now, liking seems to be generated by a small set of ‘hedonic hot spots’, which are little regions within limbic brain circuitry. This regions may generate liking to all kinds of pleasures, such as food, sex, addictive drugs and loved ones (Berridge & Kringelbach, 2015). Thereby, neurotransmission by opioids, endocannabinoids and orexin is assumed to be important. Reward motivation is thought to be generated by a large and distributed brain system, and may include mesolimbic dopamine systems, opioid networks outside the hedonic hotspots and corticolimbic glutamate signals (Berridge et al., 2010). Neural substrates for learning seem to be distributed relatively widely

[2] Liking not always precedes motivation, e.g. a primarily not liked, intense salty taste can become wanted during moments of sodium depletion. In this example, only exposure, and not liking was a prerequisite of motivation (Robinson & Berridge, 2013).

across both subcortical and cortical brain structures (Berridge & Robinson, 2003b). Although a role of dopamine neurotransmission in reward processing is acknowledged, it is still uncertain if dopamine mediates reward motivation or learning (Berridge & Kringelbach, 2015; Sclafani, Touzani, & Bodnar, 2011).

2.2.2 Reward processes for food reward

In section 2.2.1, a model of the reward system processes in general, i.e. to all kinds of rewards, was described. As already mentioned in section 2.1, activity of the brain reward system is also involved in food consumption. Applying what is explained in section 2.2.1 to food, consumption of a food can elicit **liking** in the brain. Liking in turn potentiates **learning**, e.g. a child can learn how to behave to receive a cookie from his grandparents (e.g. smile sweet, hug, …), and which cues are associated with a certain food (e.g. packaging of a brand of cookies predicts the specific cookie and the strength of the expected hedonic reaction when the cookie is consumed). Cues as well as consumption of a food that evokes liking can trigger **reward motivation** in order to pursue and obtain the food again. Berridge (2010) described the process of reward motivation with a - for most people recognizable - example: “the sight of a cookie or the smell of a favorite food may evoke a sudden urge to eat, and a few bites of a tasty morsel can spur and urge to eat more”. Further, food cues can also elicit anticipatory responses, such as salivary production. Furthermore, reward motivation makes the cue and the associated food consumption attractive, and focusses attentional processes on the food cue or food (Berridge et al., 2010). As mentioned in section 2.2.1, it is **reward motivation** that **actually aims to generate behavior, directing the individual to food consumption.** Hence, reward motivation is the **focus of this thesis** since this reward process seems important for actual food choices, initiation and persistence of food consumption. Of course, besides the reward motivation process, also the energy homeostatic system is important for food consumption (section 2.1).

Importantly, reward motivation is typically stronger when liking is higher (section 2.2.1). Applying this to food, **reward motivation for food is typically stronger when food is more palatable**. Therefore, the first section below describes the determinants of palatability of food, and thus, which foods have typically more potential to evoke reward motivation in humans. Thereafter, the assumed evolutionary etiology of the innate, biological process of food reward is described.

a. Palatability

Palatability is defined as the strength of the hedonic reaction to sensory factors of a food under standardized conditions (i.e. when not sated) (Yeomans, 1998). Palatable food is capable to **trigger reward motivation**, and consequently, food intake. T**he more palatable** a food is, **the more reward motivation** is elicited in the early stages of an eating episode, and **the greater the food intake** is over the whole eating episode in conditions of freely-available food (Drewnowski, 1998; Yeomans, 1998).
However, in the literature, there is discussion on which food-related factors codetermine palatability and subsequent reward motivation, and which of these factors are preponderant. Some studies have suggested that the palatability of food increases for most individuals as a function of the **energy-density** (Beeler et al., 2012; Drewnowski, 1998), while other studies have suggested a role for the availability of certain **nutrients** in food (Ackroff, 2008; Berthoud, Munzberg, Richards, & Morrison, 2012). Still others have suggested that palatability of food depends on the **flavor** (Yeomans, Gray, Mitchell, & True, 1997; Yeomans et al., 2005), the **texture** (e.g. fat texture) and the **temperature** of food (Rolls, 2011). Thereby, flavor is defined by Yeomans as the combination of gustatory (**taste**) and olfactory (**smell**) components of food into a single percept (Yeomans, 1998); Rolls added also **visual** components to this definition (Rolls, 2011). Possibly, all these factors may have a role in the induction of reward motivation by food cues or food consumption (Spetter, Mars, Viergever, de Graaf, & Smeets, 2014). The effects of these factors on reward processes may be mediated through oral or post-oral detection of taste, smell, temperature, texture, nutrients and energy-density, but as mentioned also through detection of food cues before food intake, i.e. by visual or olfactory perception (Berthoud et al., 2012; Stice & Yokum, 2016).

A systematic description of the literature on specific food components that **on average** contribute more to palatability is beyond the scope of this thesis. Some major points are mentioned, important for the topic of this thesis.
Considering **energy density**, it has been shown that foods with high energy density, which are in general high in **fat** and sometimes high in sugar, are more preferred and rated as more palatable than foods with low energy density (Birch, 1999; Blechert, Klackl, Miedl, & Wilhelm, 2016; Drewnowski, 1998; Ventura & Worobey, 2013).
Considering taste, it is established that **sweet and salt tastes are innately preferred** (Bartoshuk & Beauchamp, 1994). The innate preference for (moderate levels of) salt develops

from the age of 4 months (Bartoshuk & Beauchamp, 1994), and sweet and salt preferences are stronger in children than in adults (Mennella, Finkbeiner, Lipchock, Hwang, & Reed, 2014). In contrast to innate preferences, **aversive reactions** are seen in newborns **to bitter and sour tastes** (Figure 3) (Steiner, Glaser, Hawilo, & Berridge, 2001).
Considering flavor, it seems important that the **flavor** is in the right **balance** (not too less or too strong) (Yeomans, 1996), and that the taste and smell are **consonant** (e.g. glutamate presented as a taste stimulus may not be palatable alone or in combination with sweet, sour, bitter or salt tastes, but may be palatable when combined with a consonant savory odor of vegetables (Rolls, 2009)).

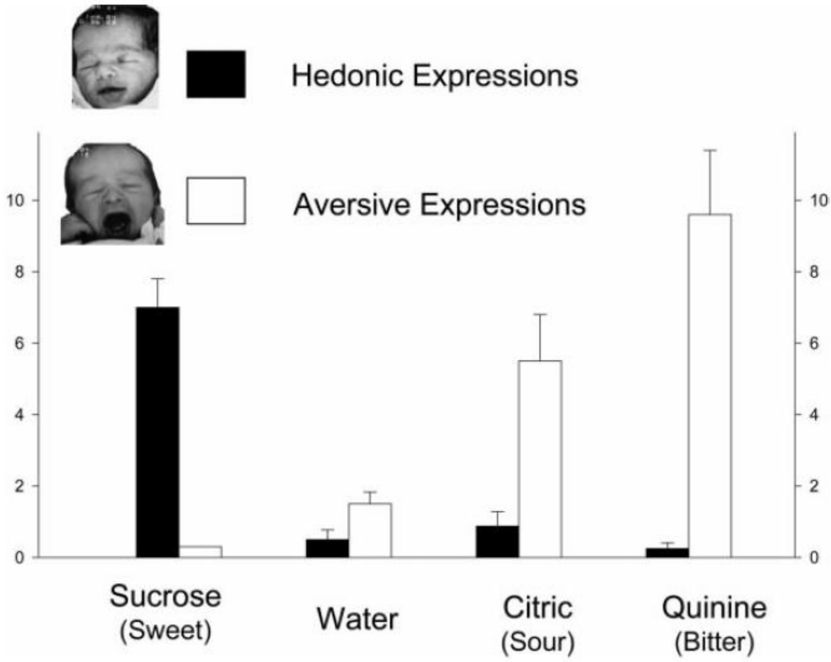

Figure 3 Averaged hedonic and aversive category scores of hedonic and aversive facial reactions elicited from human newborn infants by sweet, water, sour and bitter substances (Steiner et al., 2001)

Nevertheless, food preferences are not only determined by innate responses, but can also be acquired during life. Similar to the increase in acceptance and preference due to repeated exposure to all kind of stimuli, repeated exposure to a particular flavor can increase acceptance and preference for the flavor. For example, children can learn to tolerate and even prefer foods that have bitter components (as is for instance the case in some vegetables) after repeated exposure to the foods (S. L. Johnson, 2016).

b. Evolutionary perspective on food reward

In accordance to the evolutionary function of reward processes mentioned in section 2.2.1, liking of food may have evolved for reasons of **survival**, i.e. to evoke reward motivation that drives behavior to seek the food again or eat more of it.

As noted above, reward motivation for food may not be completely eliminated by satiety (section 2.1). This may have evolved to support overconsumption in times of food abundancy, leading to the storage of excess energy as fat, which helps to survive potential later episodes of food shortage. The alternation between periods with oversupply of food and with undersupply is also called the feast and famine cycle. Due to this cycle, a panhuman genotype that is thrifty may have evolved, which include a propensity to overeat (Bouchard, 2007; Wells, 2012a). Further, the reduction in reward motivation for a certain food after eating a lot of the food without reduction in reward motivation for not-abundantly eaten foods (i.e. food-specific satiety, section 2.1) may have evolved to encourage eating a variety of foods, and as such, to obtain a range of nutrients (Rolls, 2011). Moreover, the above mentioned age differences in preference to specific foods may reflect a mechanism of adaptation to age-dependent physiological needs (Mennella & Bobowski, 2015).

Regarding specific components that contribute to food palatability, reward motivation for energy-dense foods may have evolved because a strong motivation may be needed for the huge effort of hunting on animals. Further, the innate sweet preference may be developed as a consequence of natural selection, favoring animals that prefer to consume products rich in calories as well as essential nutrients (e.g. ripe fruits) (Bartoshuk & Beauchamp, 1994; Birch & Anzman-Frasca, 2011). Next, the innate aversion to bitter and sour may have served to eliminate toxic products from the mouth, since many bitter compounds are toxic (Bartoshuk & Beauchamp, 1994; Steiner et al., 2001). Additionally, the innate preference and motivation for salt may have developed because physiological concentrations of sodium in the body are critical to preserve life (salt preference is therefore only a preference for moderate levels of salt; high salt concentrations are generally not experienced as palatable, e.g. sea water). Although sodium motivation is dampened when concentrations are higher than normal, sodium motivation can be present without a sodium need. This need-free sodium motivation may have evolved to motivate the sodium-dependent human to seek and learn about sources of sodium in its surrounding. Certainly in individuals that have previously experienced a sodium shortage (e.g. excessive salt loss through diarrhea or sweat, shortage of salt in available food), an enhanced need-free sodium motivation is seen, which may be an expression of biological preparedness, working as a hedge against salt deficit in an environment of ‘proven’ scarcity (Fu & Vallon, 2014; Yeomans, Blundell, & Leshem, 2004).

In for example the times of the **hunter-gatherers**, diets were plant or animal based. Access to energy-dense and sweet and salt tasting foods was limited and required a high expenditure of calories. In those times, the above described responses of the brain reward system were **adaptive** to the food environment. In the following section, we will describe why these responses have currently turned into maladaptive mechanisms.

2.3 Drastic changes in the food environment challenge the reward system

The current food environment is totally different from that in the times of the hunter-gatherers. Because of **industrialization**, the food environment drastically changed in industrialized countries, and currently also in developing countries undergoing an economic transition to capitalism (Wells, 2012b).

This **nutritional transition** includes that large amounts of today’s consumed foods do not originate directly from nature anymore. Food industry uses food components from natural resources (e.g. fruit, seeds, vegetables, nuts, animals,…). These components are mixed to create processed food products, e.g. a whole grain bread which is still rich in fibers. However, the food components are often also refined, e.g. **refined** sugar, flour, fat, oil, salt, … A part of the processed food products mainly contains refined products, and therefore, are relatively **poor in fibers and/or micronutrients** and relatively **rich in sugar, fat and/or salt** than foods originating directly from nature (I. J. Brown, Tzoulaki, Candeias, & Elliott, 2009; Cribb, Emmett, & Northstone, 2013). On top, taste and odor substances are added, the texture is optimized, and the appearance of the food is made appealing. Therefore, the end product of food processing can be a food that is **highly palatable**. Next, the exposure to the changed food environment can occur **already early in life**, e.g. in newborns, industrialization has led to the possibility of formula feeding instead of breastfeeding (Chopra et al., 2002; Wells, 2012b; WHO, 2003). Further, even **on very short time spans**, the food environment can drastically change. An example is the strong increase of the use of high-fructose corn syrup in processed foods and beverages over a couple of decades (Bray, Nielsen, & Popkin, 2004). Furthermore, with modern food processing techniques, it is also easy to create an enormous **variety** of foods. Additionally, there is an **oversupply** of food. Because very few people currently produce the majority of their own food (i.e. through farming, ranching or hunting), most people depend on commercial food sources such as supermarkets, grocery stores and restaurants. Currently, these contemporary settings are **widely available**, and therefore, food is nowadays mostly **obtained without much energy expenditure**. To sell their products and maximize profit, these settings use many different **food cues**, which are omnipresent (for a review on environmental cues in away-from-home food settings, the interested reader is referred to Cohen and Babey (2012)). Further, these settings frequently offer **larger than optimal portion sizes** of food (Berridge et al., 2010; D. A. Cohen & Babey, 2012; Rolls, 2011).

This **drastically changed food environment can have an impact on energy intake** of individuals exposed to it. First, as mentioned before, the high palatability of these contemporary foods increases reward motivation and food intake (see section 2.2.2). However, the presence of preferred tastes in processed foods no longer predicts the supply of scarce or less abundant nutrients. Second, the omnipresent food cues may frequently trigger reward motivation, and the individual may not be conscious of these automatic responses to food cues (see section 2.2.1 and 2.2.2). Third, the serving of large portion sizes have also been consistently related to higher amounts of food intake (D. A. Cohen & Babey, 2012). Fourth, the increased food variety may result in higher energy intake due to the phenomenon of food-specific satiety (i.e. although a person is satiated for one kind of food after abundant consumption of it, cues of other not-abundantly eaten foods still can trigger motivation to consume the other foods) (Epstein et al., 2003; Temple, Giacomelli, Roemmich, & Epstein, 2008). Even very subtle forms of variety, such as differently shaped pasta, has been associated with higher energy consumption (Epstein et al., 2007; Epstein, Robinson, Roemmich, Marusewski, & Roba, 2010). Fifth, excess calories are not expended anymore in periods of food scarcity (see section 2.2.2).

Hence, one of the ways in which the food environment exerts its effects on individual’s nutrient and energy intake is through the once adaptive process of reward motivation for food. Reward motivation may be frequently evoked by the current food environment while the individual is not in a negative energy balance. Thereby, the individual can experience a **subjective feeling of hunger, which solely serves for the pursue of pleasure and not to fulfill energy requirements**. This is called ‘**hedonic hunger**’ by Lowe and colleagues, based on previous work of Berridge, Blundell, Finlayson, Smith, Yeomans and others (Berridge, 1996; Blundell & Finlayson, 2004; Lowe & Butryn, 2007; Lowe & Levine, 2005; Yeomans et al., 2004). In accordance with the term of hedonic hunger, **actual food consumption** beyond energy requirements because of reward motivation is called '**hedonic eating'** by Lowe and colleagues.

It is important to mention that on top of the changes in the food environment leading to nutritional inadequate diets and over-intake of energy, the environment also changed physically causing decreases in energy expenditure. The current **built environment** makes physical activity less needed and paves the way to sedentary behavior due to advances in technology (e.g. electronic devices increasing screen time) and transportation (e.g. motorized transport) (J. O. Hill & Peters, 1998). The food and physical environmental changes **coincidence with the rise in overweight and obesity prevalence** (Popkin, 2001). The composite of the current food and physical environment is referred to as '**obesogenic environmen**t'.

As noted before, this thesis focusses on the role of reward motivation in children's food consumption and body composition. This section described that **current inadequate diets and overconsumption of calories may be explained by an interaction between panhuman reward mechanisms and the drastically changed food environment**.
Nonetheless, **not all individuals exposed** to the same food environment have an inadequate diet or become overweight or obese. Therefore, the following section describes how **inter-individual differences** in food consumption when exposed to the current food environment can be explained.

2.4 Transactional model of individual differences in food consumption

Story, Neumark-Sztainer, & French (2002) proposed a transactional model to explain individual differences in food consumption, which will be described for children in this section. The model conceptualizes food consumption as being a function of **multiple levels of influence**. Additionally, the authors propose **reciprocal interactions** between food consumption itself and the multiple levels of influence, besides interactions within and across levels of influence.

On the most distal level, influences of the **macrosystem** are situated, such as mass media, cultural norms, policies and laws. For example, changing policies on advertising have been found to influence food consumption (Dhar & Baylis, 2011).

At a more proximal level, a child's food consumption is also influenced by the **physical environment,** such as the accessibility and availability of foods (e.g. K. J. Campbell et al. (2007)). Further proximally, **social environmental factors** influence food consumption, such as family, peers and schools that codetermine what, how and at which times of a day a child eats. For example, parental feeding practices have been related to children's food consumption (K. Campbell et al., 2010).

At the most proximal level, **individual factors** influence food consumption. This may be psychosocial factors, such as attitudes (Melbye, Overby, & Ogaard, 2012), or biological factors, such as reward motivation. The levels of both factors can considerably vary across individuals.

This thesis focusses on inter-individual differences in reward motivation, which is further addressed in the next section.

2.5 Individual differences in reward motivation

As mentioned in section 2.2.1, reward motivation is an **activation** of specific components of the **brain reward system** by reward-associated cues in the environment, and this activation **leads to approach behavior**. Although reward motivation is triggered by reward-related cues in all individuals with an adequate functioning reward system, the strength of cue-triggered reward motivation can differ between individuals on a continuum. Hence, it is a **trait** of an individual. The existence of individual differences in reward motivation in children can be noticed by observing behavior of children, which is illustrated below with two examples:

> (a) when a family with two children sees the first signs of a playground, one child may run over the green to the playground and the other child may quietly keep on walking over the path next to his/her parents;
>
> (b) when a plate with potato chips is put on a table, one child quits his play, runs to the table, stays next to the plate and continues to eat at a high pace until the plate is empty, while another child keeps on playing, takes just now and then some potato chips and eats them slowly.

As reward motivation is a response to cues in the environment, the strength of reward motivation is a factor on the individual level of the transactional model that directly interacts with factors on the social environmental level (e.g. talking about food with peers), the physical environmental level (e.g. the sight of available food), and the macrosystem level (e.g. attention to food advertisement) (see section 2.4). Therefore, **individual differences in reward motivation may be able to partly[3] explain why in our current food environment, some individuals are more vulnerable to palatable food overconsumption, which in turn may result in adiposity gain.** This is the major hypothesis that will be investigated in children in the current thesis. Thereby, food-specific as well as general **reward motivation traits** are considered. Section 2.5.1 elaborates on the differentiation between food-specific and general reward motivation traits, and on the origins of the terms that are used further in the thesis to describe both traits. Further, section 2.5.2 and 2.5.3 inform the reader about the hypothesized etiology of these individual differences in reward motivation and about the role of inhibitory control capacities in the expression of the individual differences, respectively.

2.5.1 Reward motivation traits 'food cue responsiveness' and 'reward sensitivity'

As the outcome of this doctoral research is food consumption and adiposity gain, individual differences in the strength of reward motivation activation by food-reward cues are relevant. However, also measurement approaches exist for the strength of activation of reward motivation by reward-associated cues in general, i.e. to all kinds of rewards such as food, sex, addictive drugs and loved ones. Considering individual differences in general reward motivation is also relevant as these differences might explain food consumption as well as other behaviors associated with adiposity gain (e.g. it was reported that behaviors such as screen time and physical activity also may have rewarding potential (Buckley, Cohen, Kramer, McAuley, & Mullen, 2014; Garland et al., 2011; Herrera et al., 2016; Katsyri, Hari, Ravaja, & Nummenmaa, 2013)).

In the following, **individual differences in food-specific reward motivation** are referred to as **'food cue responsiveness'**, whereas **individual differences in general reward**

3 Since the causes of obesity are heterogeneous, individual differences in reward motivation are not involved in all cases of eating anomalies or obesity. Further, in some cases, reward motivation may be only secondary disrupted (Berridge et al., 2010).

motivation are referred to as **'reward sensitivity'**. The terms 'food cue responsiveness' and 'reward sensitivity' originate from two different theories postulated before the above described model of Berridge and Robinson (2003b) (section 2.2.1). The term 'food cue responsiveness' originates from the **Externality Theory** of Schachter (1968), which mentioned the existence of individual differences in responsiveness to environmental food-related cues. The term 'reward sensitivity' originates from Gray's **Reinforcement Sensitivity Theory**. This theory postulated three decades ago that the reactivity in at least two major brain systems underlies motivated behavior and affect: the Behavioral Inhibition System (BIS), responding to cues of punishment and non-reward, and the Behavioral Approach System (BAS), responding to cues of reward and non-punishment (J. A. Gray, 1987). When BIS is activated, avoidance motivation will be triggered aiming to induce avoidance behavior (e.g. avoidance of negative or painful outcomes), as well as feelings of anxiety. Activation of BAS causes the experience of positive feelings as well as approach motivation, which aims to induce approach behavior towards known rewards or new possibly rewarding situations. Hence, the process 'activation in the BAS to reward cues causing approach motivation' has similarities with the description of reward motivation states (described in section 2.2.1 based on the model of Berridge and Robinson (2003b)); however, BAS includes also other components, such as the component 'experience of positive feelings' which has similarities with the liking component of the model of Berridge and Robinson (2003b). Other similarities between activation in the BAS and reward motivation states are the assumed underlying neural substrates, namely the mesolimbic dopamine systems. Stable individual differences in the BAS are referred to as reward sensitivity (Carver & White, 1994); as noted in the foreword, the term reward sensitivity is used in this thesis to refer only to the strength of reward motivation activation by reward cues and not to the broader BAS construct.

Both 'food cue responsiveness' and 'reward sensitivity' are suggested to **emerge early in life** Further, both constructs have been proposed to be **traits that display relative stability over time**, i.e. individuals retain their position on the trait continuum relative to others over time (Ashcroft, Semmler, Carnell, van Jaarsveld, & Wardle, 2008; Carver & White, 1994; Caspi & Silva, 1995; C. H. Llewellyn, van Jaarsveld, Johnson, Carnell, & Wardle, 2010; Pedlow, Sanson, Prior, & Oberklaid, 1993). Furthermore, both reward motivation traits are assumed to be **strongly related to each other**, whereby food cue responsiveness is a **sub-trait** of the broader reward sensitivity trait. It has been suggested that individuals high in food cue responsiveness are high in reward sensitivity and on top, have a hyper-responsivity of oral somatosensory regions (Stice, Yokum, Burger, Epstein, & Small, 2011).

2.5.2 Role of nature and nurture in reward motivation traits

Although this thesis does not address the etiology of reward motivation traits, this section elaborates on the topic to inform the reader. The reward motivation traits ‘reward sensitivity’ and ‘food cue responsiveness’ are suggested to result from nature and nurture influences, as well as from the interaction between both (i.e. **gene-environment interactions**, means that genetic influences may be amplified or suppressed depending on environmental factors) (Faith, Carnell, & Kral, 2013).

Considering **nature** influences, the interested reader is referred to a review by Hess et al. that summarizes studies of **genetic polymorphisms** underlying reward motivation traits (Hess, Kawaguchi, Wagner, Faraone, & Glatt, 2016).

Considering **nurture** influences, literature reviews are sparse since it is a very recent research topic. It is beyond the scope of this thesis to fully review literature on nurture influences. As an example, some results of animal studies are given that suggest an influence of a **high-fat diet** on reward processes: (a) animal research indicates that prenatal exposure to a high-fat diet through the maternal diet affects the brain reward function; this influence is assumed to be mediated through epigenetic mechanisms (Grissom, Bowman, & Reyes, 2014); (b) animals consuming a high-fat diet for at least one week exhibit changes in dopamine metabolism, and these changes are independent of the development of obesity (J. F. Davis et al., 2008; Kaczmarczyk et al., 2013; York, Teng, & Park-York, 2010); (c) in animals vulnerable to develop obesity, the infusion of small amounts of triglyceride-rich particles in the carotid artery decreased reward motivation for a palatable food (probably driven by homeostasis), but prolonged intra-carotid infusion leaded to a return of reward motivation, which cannot be explained by homeostasis (Cansell et al., 2014); (d) insulin and leptin reduce reward motivation in animals on a normal diet, but were ineffective in reducing reward motivation in animals fed a high-fat diet (Figlewicz, Bennett, Naleid, Davis, & Grimm, 2006) (however, the latter two examples may also be due to acquired resistance to signals of fat abundancy, e.g. leptin resistance).

Considering possible **gene-environment interactions,** one example is given: when maternal warmth was high, children and young adults with a particular gene polymorphism were found to have higher reward motivation levels than those without this polymorphism; conversely, when maternal warmth was low, the children and young adults with the gene polymorphism were found to have lower reward motivation levels than those without this polymorphism (J. S. Richards et al., 2016).

To conclude, reward motivation traits may be determined by nature, nurture and the interaction between nature and nurture. Nevertheless, more longitudinal or experimental studies in humans are needed to elucidate which factors (e.g. high-fat diet, maternal warmth, …) influence the strength of reward motivation traits in a human individual.

2.5.3 Role of inhibitory control in the expression of reward motivation traits

Besides a powerful brain reward system, it is important to acknowledge that the brain also contains more recently evolved **prefrontal cortical structures,** underlying **inhibitory control**.

As stated in section 2.2.1 and 2.2.2, the automatic elicitation of reward motivation in response to a reward-associated cue by the brain reward system aims to generate behavior. These automatically induced behavioral tendencies can be counteracted by an **effortful** inhibitory control reaction. This reaction enables individuals to inhibit their automatic behavioral tendencies, such as the tendency to eat when food-cues have triggered reward motivation. As such, inhibitory control helps to guide behavior in order to achieve or maintain long-term goals and personal standards, e.g. maintain a normal weight status, or - considering an evolutionary perspective - be able to conserve food for periods of scarcity and to ensure future exchange of food by adapting to the social feeding norms of the group (Appelhans, 2009; Ziauddeen, Alonso-Alonso, Hill, Kelley, & Khan, 2015).

The average capacity to inhibit automatic tendencies of an individual can considerably vary across individuals. Hence, the ‘inhibitory control capacity’ is also a factor on the individual level of the transactional model (section 2.4) that may partly explain individual’s food consumption. Indeed, a systematic review in children and adolescents concluded that poorer inhibitory control capacity was associated with increased (high-fat/high-sugar) snack intake, decreased fruit and vegetable intake, increased tendency to overeat in response to environmental cues, and higher weight (Liang, Matheson, Kaye, & Boutelle, 2014). Further, strong inhibitory control capacities were found to protect individuals from future weight gain (see Ziauddeen et al. (2015) for a recent review).

As reward motivation and inhibitory control can counteract each other, the expression of reward motivation traits may be less clear in children high in inhibitory control capacities (i.e. they may more frequently inhibit their automatic behavioral tendencies to approach rewards). On the other hand, children high in reward motivation traits may be even more vulnerable to palatable food overconsumption if their inhibitory control capacities are poor (Vainik, Dagher, Dube, & Fellows, 2013). Although this implies that inhibitory control may moderate the main hypothesized relation investigated in children in this thesis, the moderation by inhibitory control capacities is not investigated here and constitutes an important direction for future research (see section 12). However, as mentioned by Ziauddeen et al. (2015), it is unlikely that an effortful, goal-directed inhibitory control reaction intervenes on every encounter with palatable food cues, certainly not in children. Results of a meta-analysis of van Meer, van der Laan, Adan, Viergever, and Smeets (2015) suggested that inhibitory control regions are less activated in response to food cues in children and adolescents compared to adults. This is explained by the still developing prefrontal cortical structures underlying inhibitory control capacities during childhood, which are only fully matured in early adulthood (van Meer et al., 2015).

RESEARCH OBJECTIVE

3. Problem analysis, objectives and research questions

Considering the content of section 1, it is clear that efficient strategies to prevent overconsumption of energy-dense and micronutrient-poor foods are highly needed, and this already in childhood. Section 2 highlighted the role of the reward system, and more specifically, of reward motivation in the consumption of these palatable foods when exposed to a food environment replete with palatable food cues. The section ended with the hypothesis that individual differences in reward motivation may be able to partly explain why in our current food environment, some individuals are more vulnerable to palatable food overconsumption, which in turn may result in adiposity gain.

This hypothesis is supported by a recent review on the association of individual differences in reward processes with overeating and weight gain (Stice & Yokum, 2016). Based on the reviewed studies, the authors have proposed a new etiologic model of reward-driven overeating and weight gain, namely the refined dynamic vulnerability model, shown in Figure 4. Thereby, strong evidence exists for the relation of food cue responsiveness with overeating and weight gain.

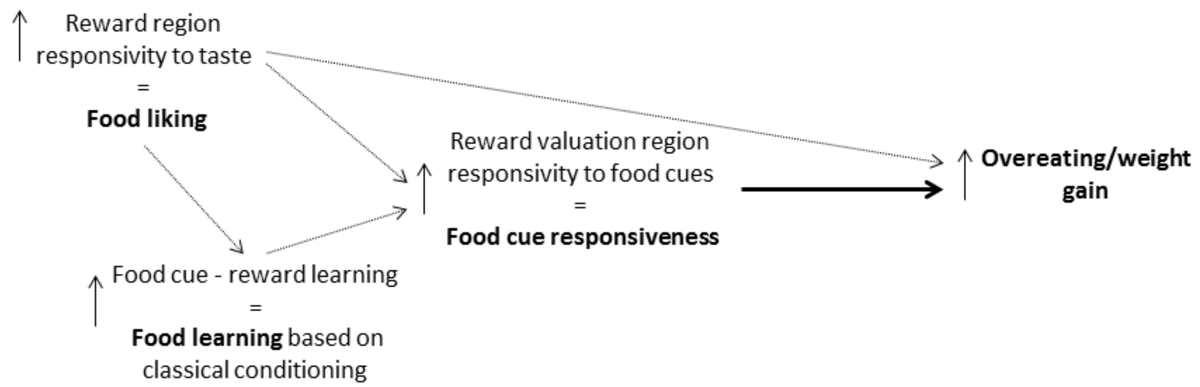

Figure 4 Presentation of a part of the 'refined version of the dynamic vulnerability model'.
Note. Thick black arrows represent relations for which strong evidence exists; and thinner black arrows represent relations with a more provisional degree of empirical support (adapted from Stice and Yokum (2016)).

However, the conclusion of strong evidence is based on research in adolescents and adults. In **children**, research on this topic is sparse; the available research is listed in section 3.1 and 3.2. Nonetheless, it cannot be assumed that the strong evidence found in adolescents and adults can also be found in children. Although individual differences in reward motivation levels are suggested to display longitudinal relative stability (see section 2.5.1 and section

7.1.2b), recent research hypothesized that reward motivation levels do not display longitudinal absolute stability during development, i.e. that absolute reward motivation levels remain not stable over time. A U-shaped inverted relation with age has been suggested, with reward motivation levels peaking in adolescence (Cauffman et al., 2010; Figner, Mackinlay, Wilkening, & Weber, 2009; J. D. Gray, Hanna, Gillen, & Rushe, 2016; Urosevic, Collins, Muetzel, Lim, & Luciana, 2012). Hence, absolute levels of reward motivation may be lower in childhood compared to adolescence. Further, it is suggested that the expression of genetic constitutions may be greater as children grow (Faith et al., 2013; Wardle & Carnell, 2009). Moreover, children's food consumption more strongly depends on others (i.e. caregivers) compared to adolescents' or adults' food consumption. Because of these three factors, the above mentioned strong evidence for an association of food cue responsiveness with overeating/weight gain in adolescents and adults may be not present or too weak to detect in children. However, additional research to investigate if the relations are also present in children may **provide information for intervention development to prevent** palatable food overconsumption and obesity in children.

To address this, **the current thesis investigates the epidemiologic relations of reward sensitivity and food cue responsiveness with palatable food consumption and body composition development in primary and first grade secondary school children**. Thereby, the theoretical model shown in Figure 5 is followed.

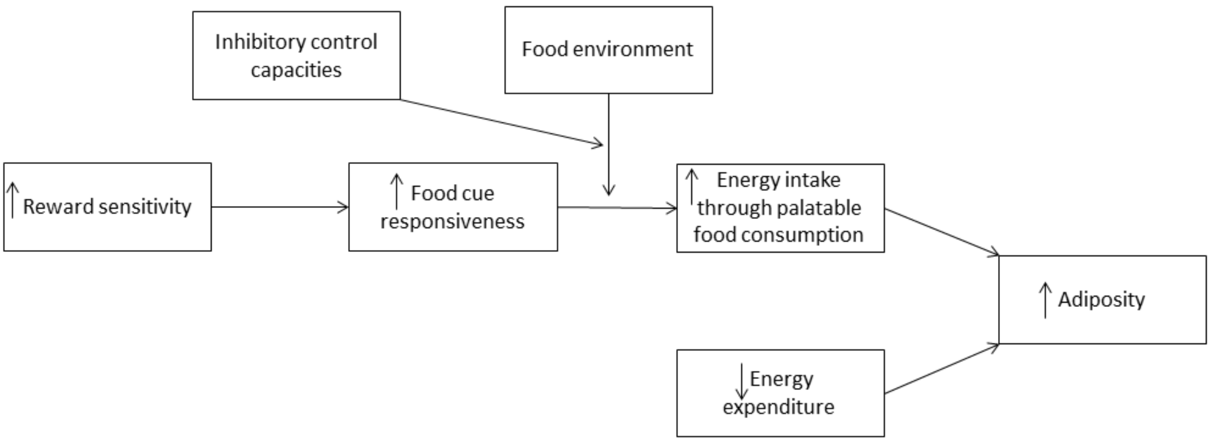

Figure 5 Theoretical model displaying the hypothesized influence of reward sensitivity and food cue responsiveness on the energy balance. Thereby, it is assumed that an individual's food cue responsiveness has a stronger positive effect on energy intake when more food cues are present in the environment.

Different measurement techniques exist to measure reward sensitivity and food cue responsiveness: neuroimaging, behavioral tasks, and questionnaires. For the epidemiological research design of this thesis, for which a large community sample of children is used, questionnaires are more suited since they are easily assessable and inexpensive. Therefore, **questionnaires measuring reward sensitivity and food cue responsiveness** will be used in the original research of this thesis.

The thesis starts with a **methodological study on the assessed questionnaires of reward sensitivity**, i.e. a comparison of a parent report (PR) and child report (CR) version of the used questionnaire as well as the investigation of the longitudinal stability of one of these questionnaires (section 7.1). The methodological study is followed by **studies with palatable food consumption and body composition as outcome**.

The section below (a) describes the existing research **in primary and first grade secondary school children,** further on referred to as 'school children', on the relation of reward sensitivity and food cue responsiveness with palatable food consumption (section 3.1) and with body composition (section 3.2), (b) highlights the research gaps and (c) describes the concrete research aims of this thesis. In section 3.3, the specific research questions are listed.

3.1 Reward motivation traits and palatable food consumption

Regarding the relation between reward motivation traits and palatable food consumption, one **neuroimaging** study reported correlations between activity in a reward region to sucrose taste, reflecting **food cue responsiveness**, and palatable food consumption, but these were only trend significant (Boutelle et al., 2015).

Concerning studies using **behavioral tasks,** one study reported a positive association between **reward sensitivity**, measured with the door-opening-task, and total calorie intake. However, this association was only present when palatable food that was varied in color, form, taste and texture was served, and not when only one kind of palatable food was served (Guerrieri, Nederkoorn, & Jansen, 2008). Another study however did not find an association between reward sensitivity, also measured with the door-opening-task, and palatable food consumption (Scholten, Schrijvers, Nederkoorn, Kremers, & Rodenburg, 2014). Furthermore, one study found a significant positive association between **food cue responsiveness,** measured using an attentional bias task**,** and total energy intake in an ad libitum situation (Folkvord, Anschutz, Wiers, & Buijzen, 2015).

Using **questionnaires** of **reward sensitivity**, one recent study has reported a positive association with palatable food consumption (using the behavioral activation scale; Lu, Xiong, Arora, and Dube (2015)). Using questionnaires of **food cue responsiveness**, (a) one study did not find a significant association with the servings of snacks and sugar sweetened beverages (using the food responsiveness subscale of the Child Eating Behavior Questionnaire; Rodenburg, Kremers, Oenema, and van de Mheen (2012)), (b) two have reported a significant positive association with total energy intake (using the external eating subscale of the Dutch Eating Behavior Questionnaire; Braet and VanStrien (1997)) and also total fat and protein intake (using the reinforcing value of food questionnaire; Epstein et al. (2015)), (c) one reported a significant positive association with children’s intake of sweets (using the external eating subscale; Elfhag, Tholin, and Rasmussen (2008)), and (d) one reported a significant positive association with total energy intake only when large portion sizes were served (using the food responsiveness subscale; Mooreville et al. (2015)).

Recently, Lu et al. (2015) have reported on the positive relation between reward sensitivity ratings and daily energy, fat and carbohydrate intake. However, this information was not yet available at the start of this thesis project in 2012. Therefore, the original research of this thesis investigated the relation between ratings of reward sensitivity with the frequency of palatable food consumption (section 8.1).
Further, it was uncertain if the interaction between reward motivation traits and the food environment, reported by a laboratory study (Guerrieri et al., 2008), is also present in real life. Hence, there was a need for an observational study measuring the natural, common food environment and palatable food consumption of children, being conducted for this thesis. The interaction between food cue responsiveness and the home food environment on common palatable food consumption frequency was examined (section 8.2).
Moreover, it is assumed that reward sensitivity and food cue responsiveness are interrelated (see section 2.5), but this had not been investigated in children. Therefore, it was investigated in this thesis if food cue responsiveness mediates a possible association between reward sensitivity and palatable food consumption frequency (section 8.2).

3.2 Reward motivation traits and body composition

Relative adiposity gain and relative weight gain are defined as a relative increase in fat mass and in total body mass, respectively ('relative' means that the measures are adjusted for age, sex and height). Hence, weight gain includes both lean and fat tissue accretion, while mainly fat tissue accretion is problematic in the development of overweight and obesity (section 1.2).

To our knowledge, no **neuroimaging** studies have reported on the association of reward sensitivity or food cue responsiveness with adiposity or weight gain in children. The limited amount of cross-sectional studies showed that brain activity to food pictures, to food receipt or in resting state differed between healthy weight and overweight or obese subjects, but these differences were not always found in the same brain reward regions as in adults (Black et al., 2014; Boutelle et al., 2015; Bruce et al., 2010; Bruce et al., 2013).

Using **behavioral tasks**, only cross-sectional studies investigating the relation between reward sensitivity and relative weight were found. These studies all used the door-opening-task to assess reward sensitivity. Overweight children were not more reward sensitive than lean children in the study of Guerrieri et al. (2008). Similarly, Scholten et al. (2014) did not find a significant association between **reward sensitivity** and relative weight (Scholten et al., 2014), while another study found a higher reward sensitivity in overweight compared to lean children (Verbeken, Braet, Claus, Nederkoorn, & Oosterlaan, 2009).

To our knowledge, a **prospective** association between **reward sensitivity ratings** and adiposity gain or weight gain has not been reported yet in children. Two studies reported a positive **cross-sectional** association between scores on the reward responsivity subscale of the 'Sensitivity to Punishment and Sensitivity to Reward Questionnaire' and weight (van den Berg et al., 2011) and between scores on the drive subscale of the 'Behavioral Activation Scale' and weight (Verbeken, Braet, Lammertyn, Goossens, & Moens, 2012). Nevertheless, one study did report on the **prospective** association between **food cue responsiveness ratings** (using the relative reinforcing value of food questionnaire) and relative adiposity gain after one year of follow-up, and found a significant positive association (C. Hill, Saxton, Webber, Blundell, & Wardle, 2009). Between weight gain and food cue responsiveness assessed by the food responsiveness subscale of the Child Eating Behavior Questionnaire, a significant positive association was found in children aged 6 years at baseline and 8 years at follow-up (Steinsbekk & Wichstrom, 2015), but not in children aged 7-10 years at baseline and 8-11 years at follow-up (Rodenburg, Kremers, Oenema, & van de Mheen, 2012). Evidence on the

cross-sectional association between food cue responsiveness ratings and relative adiposity or weight is also mixed, with most studies finding a significant positive (food responsiveness subscale: Carnell and Wardle (2008), Eloranta et al. (2012), Groppe and Elsner (2014), Santos et al. (2011), Sleddens, Kremers, and Thijs (2008), Viana, Sinde, and Saxton (2008), Webber, Hill, Saxton, Van Jaarsveld, and Wardle (2009); external eating subscale of Dutch Eating Behavior Subscale: Braet and VanStrien (1997), Groppe and Elsner (2014)) and others a negative relation (external eating subscale, in multi-ethnic youth and Chilean children, respectively: Ledoux, Watson, Baranowski, Tepper, and Baranowski (2011), Silva, Capurro, Paz Saumann, and Slachevsky (2013)). Inconsistencies may be due to the use of different questionnaire measures, sample characteristics, statistical methodologies or duration of follow-up in the prospective studies.

In sum, results of studies investigating the relation between food cue responsiveness ratings and weight or adiposity gain in school children were inconsistent. Further, the relation with adiposity gain has not been investigated yet using a questionnaire of reward sensitivity. However, the latter may have advantages over questionnaires of food cue responsiveness in the framework of intervention development, since children high in reward sensitivity may not only be reactive to food cues, but to all kinds of reward cues. As it was reported that other weight-related behaviors such as screen time (e.g. computer games) and physical activity (e.g. endurance running) also have rewarding potential (Buckley et al., 2014; Garland et al., 2011), it is useful to investigate the relations using a questionnaire of reward sensitivity.

Therefore, this thesis investigated the cross-sectional relation between reward sensitivity and weight (section 8.1). Additionally, using a longitudinal design, it was examined if reward sensitivity (section 8.3) and food cue responsiveness (section 8.4) predict adiposity gain in children. Since a study in adults suggested that the association between reward sensitivity and weight is stronger in females compared to males (Dietrich, Federbusch, Grellmann, Villringer, & Horstmann, 2014), the associations were investigated separately in boys and girls (section 8.3 and 8.4). Further, the association between reward sensitivity and lean mass accretion over time was also investigated in boys and girls (section 8.3), as this has to our knowledge not been investigated yet in school children and as reward sensitivity may be related to physical activity or sedentary behaviors.

Furthermore, and in accordance to palatable food consumption, also adiposity gain may be higher in children with high food cue responsiveness that are highly exposed to palatable foods in their daily living environment. As the interaction between food cue responsiveness and the home food environment on adiposity gain has to our knowledge not been reported yet, this interaction was also investigated (section 8.4).

3.3 Research questions

3.3.1 Methodological research questions on the used reward sensitivity questionnaire

- Are the factor structures of the PR and CR measurement invariant? If measurement invariant, do the scores on both versions agree? If parent-child disagreement is found, are primary child and parent characteristics influencing factors of the discrepancies? (see section 7.1)
- Is the factor structure of the PR version measurement invariant when assessed at two different time points? If measurement invariant, does the PR demonstrate absolute and rank order stability over two-years in children? (see section 7.1)

3.3.2 Major research questions on association between reward motivation traits and palatable food consumption

- Is reward sensitivity positively associated with the consumption of palatable food (fast food, sweet food, and sugared and artificially sweetened beverages)? (see section 8.1, Figure 6 number 1)
- Can a stronger positive association be found of reward sensitivity via food cue responsiveness on children's fast food consumption frequency when the availability of energy-dense, palatable snacks at home is high? (see section 8.2, Figure 6 number 2)

3.3.3 Major research questions on association between reward motivation traits and body composition

- Is reward sensitivity positively associated with children's relative weight? (see section 8.1, Figure 6 number 3)

- Do inter-individual differences in reward sensitivity explain differences in relative fat and lean tissue accretion between children over time? Can differences in this relation be found between boys and girls? (see section 8.3, Figure 6 number 4)
- Do inter-individual differences in food cue responsiveness explain differences in relative fat tissue accretion between children over time? Is the effect of food cue responsiveness on fat tissue accretion stronger when living in a home with a high availability of energy-dense, palatable snacks? Can differences in this relation be found between boys and girls? (see section 8.4, Figure 6 number 5)

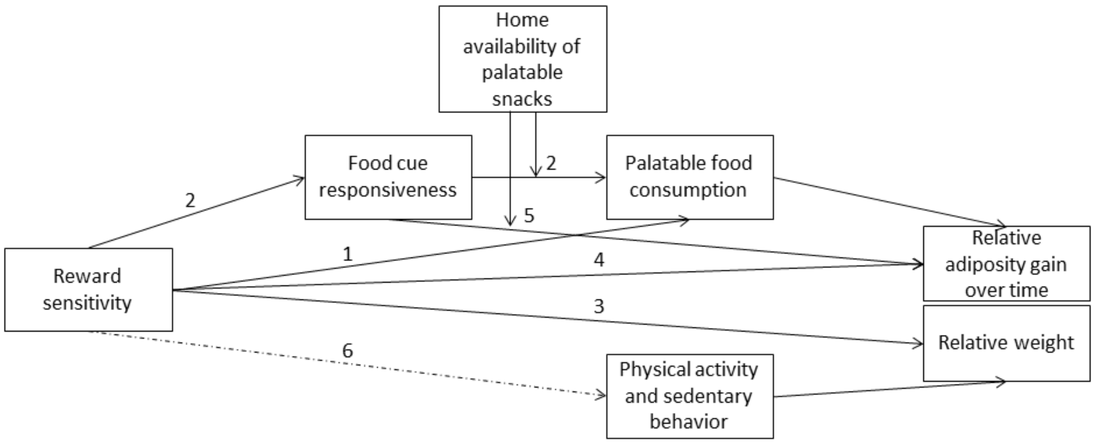

Figure 6 Relationships investigated in the current thesis.

3.3.4 Minor explorative research question

- Is reward sensitivity significantly associated with screen time and physical activity? (see section 8.1, Figure 6 number 6)

GENERAL METHODOLOGY

4. Recruitment of study participants

This thesis is based on data of a longitudinal study, of which the measurement campaigns were financed by alternating follow-up projects. Therefore, the study name differs depending on the measurement wave (Figure 7).

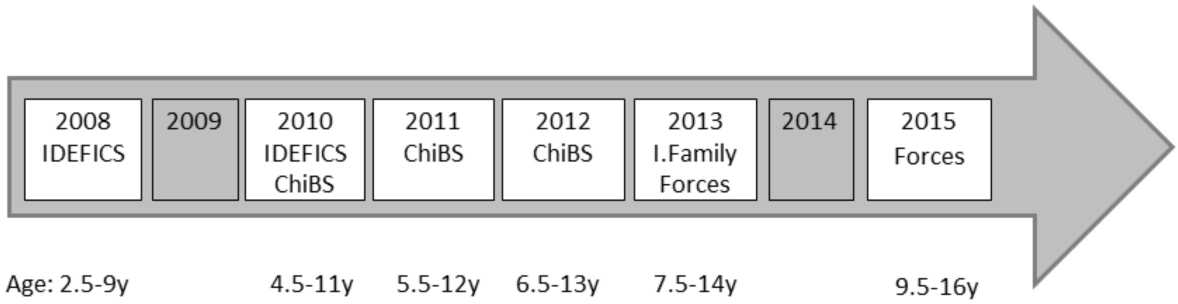

Figure 7 Names of the study in the different measurement waves

The first (2008, T0) and second (2010, T1) study waves were organized in the framework of the 'Identification and Prevention of Dietary- and Lifestyle-Induced Health Effects in Children and Infants' project (**IDEFICS**), financed by the European Community. The study was conducted in eight European countries, and in each country, a control and intervention cohort was constituted. However, for the original research of the current thesis, **only the participants of the control region of Belgium**, namely Aalter, are relevant. These children were recruited by random cluster design (all children of twelve primary schools of Aalter were contacted; for more details, see Ahrens et al. (2011)).

The second study wave (2010, T1) was co-financed by Ghent University in the framework of a BOF project called 'Children's Body Composition and Stress' (**ChiBS**), which also supported the organization of the third (2011, T2) and fourth (2012, T3) study waves (Michels et al., 2012).

The fifth study wave (2013, T4) was organized in the framework of two projects:

(a) 'Investigating the determinants of food choice, lifestyle and health in European children, adolescents and their parents' project (**I.Family**), financed by the European Community; in accordance to IDEFICS, I.Family was conducted in the original eight

European countries, and in the control as well as intervention regions; as mentioned above, only the data of the control region of Belgium were relevant in this thesis.

(b) ‘Rewarding-FOod ChoicES’ project (**Forces**), which is one of the work packages of the REWARD study (www.rewardstudy.be), financed by Flanders Innovation & Entrepreneurship. The current thesis is embedded in the REWARD study.

For the I.Family-Forces project, all IDEFICS participants of the **cohort of Aalter** were invited to participate via mail, email and, if no response, telephone calls. On top, children outside of the IDEFICS-cohort of the same region Aalter, with an age similar to that of the existing cohort, were invited to join the Forces project in 2013 via an advert on one Flemish television channel and in local newspapers.

Finally, the sixth (2015, T5) study wave was organized within the Forces project.

The cohort consisted of **Dutch-speaking Belgian children**. The original research of this thesis was conducted on data of the waves from 2011 to 2015 because one reward motivation trait questionnaire was already assessed in the wave in 2011. In Table 3, an overview of the number of participants in each study wave and the flow of participants over the study waves can be found. Table 3 also indicates which data are included in the original research studies of this thesis.

Further, Table 4 provides an overview of the sociodemographic characteristics of the study sample. As mentioned above, the sample originates from the region of Aalter. Aalter is a municipality in Flanders with 19860 inhabitants in 2012 on a surface area of 81.9 km2. The median net income is average-to-high compared to the average in Belgium (18434€/year compared to 17085€/year). Further, the proportion of immigrants is lower in Aalter compared to Belgium (2.4% versus 11.2%) (Statbel).

Table 3 Number of participants per wave and per relevant parameter

Study wave	2011	2012	2013	2015
Total number of participants[a]	455	330	300	237
N of new participants	1	0	21	0
N not included in the previous wave but was included in one of the earlier waves	0	3	52	21
N definitively dropped out	302	74	89	84
N dropped out for this wave	5	54	14	0
N Child-gender	455[c,d,f]	330	300[c,e,f,g]	237[g]
N Child-age	455[c,d,f]	330	300[c,e,g]	237
N Gender of parent that completed PR BIS/BAS scale			271[c]	230
N Parental Education Level	428[b,d,f]	318[b]	296[e,g,i]	233[i]
N PR BIS/BAS scale	446[c,d,f]		271[c]	233
N CR BIS/BAS scale			238[c,e]	235
N Food responsiveness			233[e,g]	229
N External Eating	438	325	201[e]	235
N Unhealthy home environment			232[e,g]	229
N Consumption frequency of food indices	445[d]	312	250[e]	229
N Physical activity questionnaire	397[d]	309	251	230
N Screen time questionnaire	391[d]	324	198	230
N zBMI	455[d,f]	330[f]	293[e,f,g]	237[f,g]
N zFMI	451[f]	326[f]	245[f,g]	196[f,g]
N zLMI	451[f]	326[f]	245[f,g]	196[f,g]
N Household net income	392[b]		130	
N Number of children in household	428[b]		279	
N Family situation	435[b]		274	
N Occupation of parents	432[b]		268	
N Migrant status child	446[b]			
N Migrant status father	440[b]			
N Migrant status mother	444[b]			

Note. N, number. PR, parent report. BIS/BAS, Behavioral Inhibition System/Behavioral Activation System. CR, child report. zBMI, age- and sex-independent z-score of the body mass index. zFMI, age- and sex-independent z-score of the fat mass index. zLMI, age- and sex-independent z-score of the lean mass index. [a]173 children participated in all four waves. [b]Data based on data of 2010. [c]Parameters included in section 7.1. [d]Parameters included in section 8.1. [e]Parameters included in section 8.2. [f]Parameters included in section 8.3. [g] Parameters included in section 8.4. [i] Data based on data of 2010 or 2013.

Table 4 Socio-demographic data of the study sample

Study wave		**2011**	**2012**	**2013**	**2015**
% boys		49.7%	49.1%	50.3%	51.1%
Age (years)		5.5-12	6.5-13	7.5-14	9.5-16
Parental education level:					
% of children with no tertiary educated parent:		23.3%[a]	20.9%[a]	22.0%[b]	19.0%[b]
% of children with minimum one tertiary educated parent:		70.8%[a]	75.5%[a]	76.7%[b]	79.3%[b]
% missing data:		5.9%[a]	3.6%[a]	1.3%[b]	1.7%[b]
Monthly household net income:					
-2010: <1800€	- 2013: <2250€	1.6%[a]		2.3%	
-2010: 1800-2250€	-2013: 2250-2750€	6.0%[a]		1.7%	
-2010: 2250-2750€	-2013: 2750-3250€	10.0%[a]		5.7%	
-2010: 2750-3500€	-2013: 3250-4150€=median	18.0%[a]		14.7%	
-2010: 3500-4250€=median	-2013: 4150-5050€	19.0%[a]		6.3%	
-2010: 4250-5000€	-2013: 5050-6000€	13.3%[a]		8.7%	
-2010: >5000€	-2013: >6000€	11.0%[a]		4.0%	
-% missing data		21.1%[a]		56.6%	
Number of children in household:					
-Median (range)		2 (1-6)[a]		2 (1-5)	
-% missing data		27.0%[a]		7.0%	
Family situation:					
-Child lives with both parents		81.1%[a]		75.7%	
-Child lives mostly with one of the parents		10.6%[a]		9.0%	
-Child lives ½ of the time with each parent		3.5%[a]		6.3%	
-Other family situation		0.4%[a]		0.3%	
-% missing data		4.4%[a]		8.7%	
Migrant status:					
-Child not born in Belgium		1.5%[a]			
Child born in Belgium		96.5%[a]			
% missing		2.0%[a]			
-Father not born in Belgium		0.9%[a]			
Father born in Belgium		95.8% [a]			
% missing		3.3% [a]			
-Mother not born in Belgium		3.3%[a]			
Mother born in Belgium		94.3% [a]			
% missing		2.4% [a]			
-Both parents not born in Belgium		<0.1%[a]			

Note. [a]*Data based on data of 2010.*[b]*Data based on data of 2010 or 2013.*

5. Study protocol

For the study waves from 2011 to 2015, children (in most cases accompanied by minimum one parent) attended the survey center at a prefixed appointment. During this appointment, measurements (i.e. anthropometric measurements including bio-impedance and body volume measurements, obtainment of blood and hair sample, computer tasks, …) of the child were conducted and questionnaires were filled in by the child and the parent. If the parent could not accompany the child, the parents were asked to fill in the questionnaires at home.

A **special note** has to be made **on the data collection of the I.Family-Forces campaign in 2013**. For both I.Family and Forces, a large battery of measurements had to be conducted. To improve the participation rate, different options were given to the participants:

- Option A: only the parameters needed for the Forces study were assessed
- Option B: the parameters for the Forces as well as the I.Family study were assessed
- Option C: since the participant rate was still too low with option A and B, a third option was provided after the data collection of A and B. For this option, the children of the IDEFICS-cohort that did not participate in option A and B due to time constraints of children or parents were contacted again by telephone. The parents were asked to complete only the questionnaire of the Forces project at home, and the children were asked to be measured at school before the lunch break (weight, height and bio-impedance) or at the study center (weight, height, body volume and bio-impedance). Further, the children were asked to complete only one part of the questionnaire (on reward sensitivity). Therefore, the data obtained by option C were less extended than by option A and B.
- Option D: I.Family recruited also siblings of the original IDEFICS cohort. If the siblings or their parents filled in one of the questionnaires of the Forces study, they were seen as 'newly recruited children of the cohort in Aalter' (see above), and were also included in the original research of the current study.

As a consequence of the provision of different options and the possibility for children to withdraw from any measurement, the participation rates differ for each parameter (Table 3).

All study waves were conducted according to the guidelines laid down in the Declaration of Helsinki and approved by the Ethics Committee of Ghent University Hospital. Written informed consent was obtained from all parents and from all children older than twelve years. Younger children gave verbal assent.

6. Measures of the considered reward motivation traits

This section lists the four measures used to assess the two main predictors, namely reward sensitivity and food cue responsiveness. Measures of other parameters, i.e. the home food environment, physical activity and screen time, and of the outcomes, i.e. palatable food consumption and body composition, are described in the methodology of the original research chapters.

6.1 Measures of reward sensitivity

The subscale **'drive'** of the **Behavioral Activation/Behavioral Inhibition Scale (BIS/BAS scale)** was used as a measure of **reward sensitivity**. The BIS/BAS scale was developed by Carver and White (1994) based on the Reinforcement Sensitivity Theory of J. A. Gray (1982); see section 2.5.1 and 7.1 for more details. The BIS scale contains seven items and includes statements of sensitivity to punishments (e.g., I am very fearful compared to my friends). The BAS scale is an aggregate scale of three subscales: drive, reward responsiveness and fun seeking. The drive subscale contains four items tapping strong pursuit of appetitive goals (e.g., I go out of my way to get things I want). The reward responsiveness subscale is measured by five items of positive affect/excitability (e.g., When good things happen to me, it affects me strongly). The fun seeking subscale inquires four items that represents the inclination to seek out new rewarding situations (e.g., I'm always willing to try something new if I think it will be fun). Hence, drive is the subscale that aims to measure the construct 'reward sensitivity' as defined in section 2.5.1. Scores on the drive subscale, but not on the reward responsiveness and fun seeking subscales, have been significantly positively associated with neural responsiveness in the brain reward system to food reward cues relative to bland food cues in young adults (Beaver et al., 2006). In children, an association with responsiveness to food reward has to our knowledge not been investigated yet, but a positive association between drive-scores, but not reward responsiveness or fun seeking scores, and neural responsiveness to monetary reward has been reported in participants aged 8-27 years (Braams, van Duijvenvoorde, Peper, & Crone, 2015).

For assessment in Dutch children, a PR as well as a CR version of the BIS/BAS scale exist (Muris, Meesters, de Kanter, & Timmerman, 2005; Vervoort et al., 2015).

The drive subscale of the **CR** version has a satisfactory internal reliability, with Cronbach's α's ranging between 0.67 and 0.81 (Bjornebekk, 2009; De Cock, Van Lippevelde, Vervoort, et al., 2016; Kingsbury, Coplan, Weeks, & Rose-Krasnor, 2013), and external validity (small positive relations of the drive score with extraversion and neuroticism scores of the 'Junior Eysenck Personality Questionnaire Revised-Abbreviated') (Bjornebekk, 2009).

The drive subscale of the PR-version also has a satisfactory internal reliability, with Cronbach's α's ranging between 0.83 and 0.85 (Vandeweghe, Verbeken, Moens, Vervoort, & Braet, 2016; Vervoort et al., 2015), and a satisfactory external validity (moderate positive correlation with Sensitivity to Reward score and small negative relation with Sensitivity to Punishment score of the 'Sensitivity to Punishment and Sensitivity to Reward Questionnaire'; small positive relation with negative affectivity and moderate positive relation with approach/positive anticipation and surgency/extraversion scores of the 'Child Behavior Questionnaire-short'; small positive relation with externalizing problems score of the 'Child Behavior Checklist') (Vervoort et al., 2015).

6.2 Measures of food cue responsiveness

To measure individual differences in **food cue responsiveness**, two frequently used questionnaire measures were used in this thesis (Carnell, Benson, Pryor, & Driggin, 2013; Faith et al., 2013). Both are based on the externality theory of Schachter (1968), and are developed to measure the tendency to approach and consume food in response to external food cues, without regard to internal hunger or satiety.

One is the subscale '**food responsiveness**' of the Child Eating Behavior Questionnaire (CEBQ), which consists of 5 items (e.g. 'even if my child is full up s/he finds room to eat his/her favorite food') (Wardle, Guthrie, Sanderson, & Rapoport, 2001). Cronbach's α's for the food responsiveness subscale ranging between 0.72-0.80 were reported. Further, food responsiveness scores have been positively related to BMI z-scores, eating rate and total energy intake (Carnell & Wardle, 2007; Sleddens et al., 2008).

The other is the subscale '**external eating**' of the Dutch Eating Behavior Questionnaire (DEBQ), which consists of 10 items (e.g. 'If you see or smell something delicious, do you have a desire to eat?') (Van Strien, Frijters, Bergers, & Defares, 1986). For assessment in Dutch children, a parent-report as well as a child-report version exist (Braet & VanStrien, 1997; Van Strien & Oosterveld, 2008). Because in the waves of the preceding ChiBS project, the Dutch self-report version originally developed for adolescents and adults was assessed, the adolescent/adult version was also assessed during the waves of the Forces project. In a study in adults using this subscale, the Cronbach's α was 0.81 and the external eating score was significantly related to BMI (Barrada, van Strien, & Cebolla, 2016). A Cronbach's α of 0.82 and a positive relation with unhealthy snack and sugar sweetened beverage intake was found in a sample of adolescents aged 14-16 year (De Cock, Van Lippevelde, Goossens, et al., 2016).

ORIGINAL RESEARCH RESULTS

7. Methodological results

7.1 BIS/BAS scale in school children: Parent-child agreement and longitudinal stability[4]

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[4] This section is based on De Decker, A., Verbeken, S., Sioen, I., Michels, N., Vervoort, L., Braet, C., De Henauw, S. BIS/BAS scale in school children: Parent-child agreement and longitudinal stability. In review in Behaviour Change.

7.1.1 Abstract

The current study provided psychometric information on the parent and child version of the Behavioral Inhibition System (BIS)/Behavioral Approach System (BAS) scale. Parent-child agreement was evaluated (N=217, 7.5 to 14 years, 50% boys). Moreover, absolute and rank order stability of mother-reported BIS/BAS scores over a two-year period were assessed (N=207, 5.5 to 11 years at baseline, 49% boys). Only full measurement invariant (sub-)scales were considered in the parent-child agreement and longitudinal stability assessment. Parent and child ratings were found to be measurement invariant but discrepant on BAS drive and BAS reward responsiveness. In younger children, child ratings on BAS drive tended to be higher than parent ratings, whereas in older children, child ratings tended to be lower than parent ratings. Further, the discrepancy between the BAS drive ratings of fathers and children was higher than the discrepancy between the BAS drive ratings of mothers and children. Finally, the study results suggested two-year absolute and rank order stability of the measurement-invariant mother-reported BIS and BAS drive scores in children aged 5.5 to 11 years at baseline.

7.1.2 Introduction

Gray's Reinforcement Sensitivity Theory of personality (RST) postulated that the reactivity in at least two major brain systems underlies motivated behavior and affect: the Behavioral Inhibition System (BIS), responding to signals of punishment and non-reward, and the Behavioral Approach System (BAS), responding to signals of reward and non-punishment (J. A. Gray, 1987). When BIS is activated, inhibition of movement toward goals or avoidance of negative or painful outcomes will be triggered. Activation of BAS causes behavioral activation and a tendency to approach goals. The septohippocampal system and the dopaminergic system were identified as the underlying neurobiological circuits of respectively BIS and BAS (Carver & White, 1994; Davey, Yucel, & Allen, 2008). Stable individual differences in the reactivity of the BIS and BAS are referred to as punishment and reward sensitivity, respectively.

For the purpose of assessing individual differences in reactivity of BIS and BAS, three kinds of measurement methods are used: neuroimaging, behavioral tasks and questionnaires. Questionnaires are the most practical in use in clinical and large-scale epidemiological settings. A widely used questionnaire is the BIS/BAS scale of Carver and White, containing only 20 items. The BIS scale contains seven items; the BAS scale (BAS) contains thirteen items and is the aggregate of three BAS subscales, namely BAS drive (BASD), BAS reward responsiveness (BASRR) and BAS fun seeking (BASFS). The BIS/BAS scale has been used in research as a two-factor (BIS, BAS) and four-factor (BIS, BASD, BASRR, BASFS) scale.

The original BIS/BAS scale was developed as a self-report measure for adults (Carver & White, 1994). However, examining individual differences in the reactivity in BIS and BAS is also important in childhood developmental and public health research, since they can explain the variation in the occurrence of multiple mental and physical health outcomes (Bijttebier, Beck, Claes, & Vandereycken, 2009; De Decker et al., 2016; Kingsbury et al., 2013; Verbeken et al., 2012). To measure BIS and BAS reactivity in children, parent report (PR) (Blair, 2003; Vervoort et al., 2015) and child report (CR) (Muris et al., 2005) versions of the BIS/BAS scale have been developed. The aim of the present study was to evaluate two methodological concerns when using the PR and/or CR BIS/BAS scale to study individual differences between children in developmental and public health research: (1) whether parents and children agree in their reporting on the BIS/BAS scale, and (2) whether BIS/BAS scores are stable during child development. The rationale and specific research questions to these two main study aims are explained in more detail below.

a. Main study aim 1 - Parent-child agreement on BIS/BAS scores

Because various informants may be complementary in providing crucial data concerning a child's psychosocial functioning, the use of multiple informants in clinical psychosocial assessment is broadly accepted and recommended in literature (Offord et al., 1996). Nevertheless, it is a consistent finding that multiple informants provide discrepant information about a child (Achenbach, McConaughy, & Howell, 1987; De Los Reyes et al., 2015), with Pearson correlation coefficients around 0.25 (weak relationship) between parent and child ratings. Discrepant information can bias research and clinical practice. Hence, it is important to know whether or not parents and children agree on the BIS/BAS scale. Since no research has addressed this issue yet, the first main study aim is to investigate if parents and children agree or provide discrepant information. Additionally, this study also includes an examination on how possible discrepancies can be explained by examining factor structural differences as well as influencing factors like child or parent characteristics.

Although testing the agreement is the first main aim, tests of factor structural differences between the CR and PR have to be conducted before testing agreement between CR and PR: when both versions do not have the same factor structure, i.e. are not measurement invariant, they may not have a similar meaning to parents and children, and therefore, parents' and children's ratings cannot be compared (D. A. Cole, Hoffman, Tram, & Maxwell, 2000). Thus, it is a prerequisite that the factor structure is similar, before testing agreement of the ratings on the CR and PR.

Next, in case the factor structures are similar but ratings do not agree, it is relevant to look at influencing factors of the parent-child discrepancy. Different techniques exist to evaluate parent-child discrepancies. One technique is comparing the parent-child correspondence (i.e. correlation coefficients between child and parent ratings) across different subpopulations. Using this technique, (a) a recent meta-analysis of De Los Reyes et al. (2015) concluded that parent-child correspondence was not different in younger versus older children, and (b) an earlier review of De Los Reyes and Kazdin (2005) concluded that child-gender is probably not associated with parent-child discrepancies. The technique 'difference scores' can provide other information about informant discrepancies, namely information on patterns of under and over reporting of one informant relative to another informant that may vary with e.g. primary child and parent characteristics. Research using difference scores is to our knowledge sparse compared to research using correspondence in subpopulations.

Hence, the current study investigated parent-child discrepancies using standardized difference scores (STANDIF), following the recommendation of De Los Reyes and Kazdin (2004). Using STANDIF, a study addressing another questionnaire on children's psychosocial functioning than the BIS/BAS scale found that child-age but not child-gender was significantly associated with parent-child discrepancies (Weems, Taylor, Marks, & Varela, 2010). Further, as it is known that mothers and fathers provide discrepant information about their child's psychosocial functioning (Achenbach, 2006; Duhig, Renk, Epstein, & Phares, 2000), mother-child discrepancies might differ from father-child discrepancies. Therefore, the current study investigated if child-age, child-gender and parent-gender were influencing factors of parent-child discrepancies on the BIS/BAS scale.

In summary, this study examined the following research questions within main study aim 1: (1.1) are the factor structures of the PR (Vervoort et al., 2015) and CR (Muris et al., 2005) versions of the BIS/BAS scale measurement invariant; (1.2) do the PR and the CR agree; and (1.3) in case parent-child discrepancies are present, are they influenced by primary parent and child characteristics, i.e. child-age, child-gender and parent-gender? Thereby, it was hypothesized that (1.1) the factor structures in both PR and CR were equivalent, (1.2) parent-child ratings exhibit weak agreement on all scales, (1.3) and child-age and parent-gender but not child-gender are significant predictors of parent-child discrepancies; since mothers are on average still the primary caregivers (VUB, 2015), it was hypothesized that the mean difference between PR and CR was more close to zero in mothers compared to fathers.

b. Main study aim 2 - Two-year stability of PR BIS/BAS scores

Longitudinal personality research has argued that the reflection of the neurobiological systems BIS and BAS on behavior and affect in individuals should be relatively stable over time. Thereby, two aspects of stability over time can be considered: absolute stability, i.e. the extent to which absolute scores on a scale remain similar over time, and rank order stability, i.e. the extent to which the rank ordering of individuals on a scale are related over time. In support of this statement, Caspi and Silva (1995) found that the rank ordering of individual's on behavioral style continua remains similar between early childhood (age 3) and young adulthood (age 18). Gest (1997) also reported moderate absolute stability of a construct similar to BIS reactivity between childhood (age 8 to 12) and early adulthood (age 17 to 24). Regarding constructs with similarity to BAS reactivity, one study based on parental reports found that the dimension of approach exhibited substantial absolute and rank order stability from infancy to 8 years (Pedlow et al., 1993).

In contrast with the above mentioned personality research, recent research suggested less absolute stability in BIS and BAS reactivity during development, specifically during adolescence. Using a cross-sectional design, some researchers reported a linear increase from age 10 to 30 in BIS reactivity (Cauffman et al., 2010) while others reported a peak in middle and late adolescence compared to early adolescence and young adulthood (J. D. Gray et al., 2016). Further, BAS reactivity was reported to display a U-shaped inverted relation with age, peaking in adolescence (Cauffman et al., 2010; Figner et al., 2009; J. D. Gray et al., 2016; Urosevic et al., 2012). However, longitudinal designs are a necessity to investigate stability over time. When using a longitudinal design and the BIS/BAS scale, results on absolute stability are inconsistent: Urosevic et al. (2012) found an increase of the BASRR scores of individuals aged 9-23 years at baseline and 11-25 years at follow-up over two years, while Braams et al. (2015) did not find any change on the scores on the subscales from 8 to 27 years. Possibly, this inconsistency is due to a lack of measurement invariance of the BIS/BAS scale over time, which has not been investigated yet. Comparable to what is mentioned for the PR and CR version in the previous section, it is a prerequisite to test measurement invariance, i.e. that the factor structure of the BIS/BAS scale does not differ between two time points, before investigating absolute and rank order stability on the BIS/BAS scale.

Besides measurement invariance, also absolute and rank order stability on the PR BIS/BAS scale have to our knowledge not been investigated yet in children. Using other questionnaires to measure BIS and BAS reactivity, literature reporting on stability over time of the reactivity in the BIS and BAS during childhood is sparse. To elucidate if reactivity in BIS and BAS actually predicts health outcomes in children, longitudinal research is recommended, and therefore, information on absolute and rank order stability over time of scores on the BIS/BAS scale during childhood is needed.

To address these issues, this study examined the following research questions within main study aim 2: whether the PR BIS/BAS scale (2.1) is measurement invariant over time, (2.2) displays absolute stability over time, and (2.3) displays rank order stability over time? Thereby, factor structural (2.1), absolute (2.2) and rank order stability (2.3) were hypothesized.

7.1.3 Methods

a. Study design

Participants were Flemish Dutch-speaking children and their parents initially recruited for the European identification and prevention of Dietary- and lifestyle-induced health EFfects In Children and infantS study (IDEFICS) carried out between 2007 and 2010 (Ahrens et al., 2011). Part of the children of the Belgian IDEFICS cohort of the region Aalter also participated in the follow-up study called ChiBS, that took place between 2010-2012 (Michels et al., 2012). In Spring 2013, these children (7.5-14 years old) were invited to participate in a new follow-up study called Forces. The Forces study, which is part of the REWARD-project (Rewarding Healthy Food Choices; www.rewardstudy.be), aims to investigate the role of sensitivity to reward in the development of eating habits and in changes in body composition in children and adolescents. Besides children of the ongoing IDEFICS-ChiBS cohort, also new children of the same age range could join the Forces study in 2013.

The projects were conducted according to the guidelines laid down in the Declaration of Helsinki and were approved by the Ethics Committee of the Ghent University Hospital. All parents and children older than 12 years signed an informed consent. Younger children gave verbal assent.

b. Participant characteristics of subsamples used in the analyses

In the surveys of 2011 and 2013, the BIS/BAS PR version was completed. In the survey of 2013, also the BIS/BAS CR version was completed. Hence, data of these surveys are used to investigate the research questions.

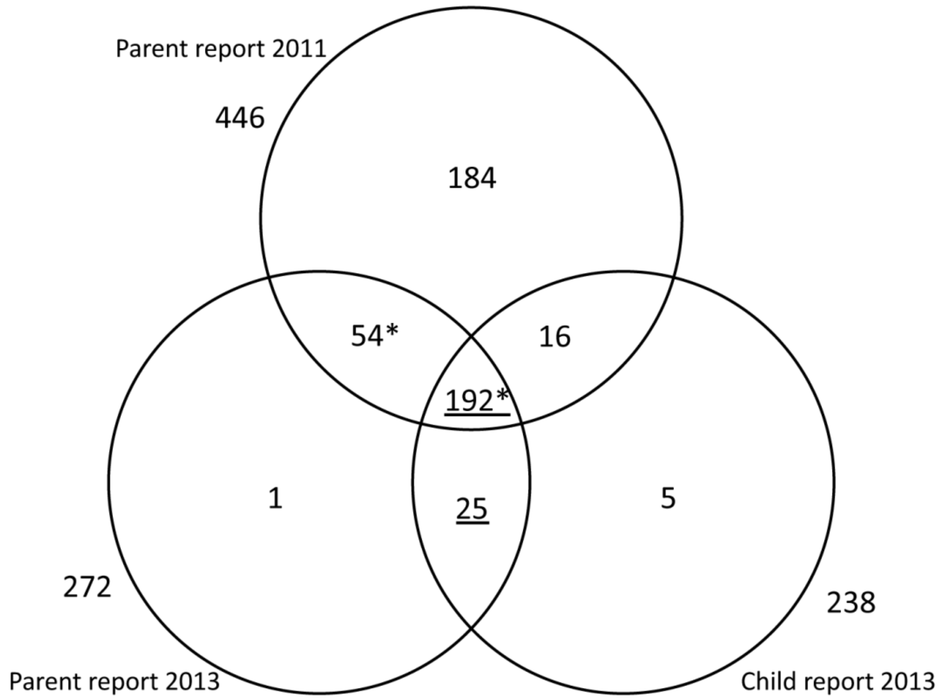


Figure 8 Venndiagram displaying numbers of participating children for which the parent reported BIS/BAS scale was completed in the survey of 2011 and/or 2013, and for which the child reported BIS/BAS scale was completed in the survey of 2013.
*Note. _, population used to investigate main study aim 1. *, population used to investigate main study aim 2.*

The Venn diagram shown in Figure 8 displays (1) the number of parents that completed the PR in 2011 (n=446; subsample *PR2011*), (2) the number of parents that completed the PR in 2013 (n=272, 14.3% fathers; subsample *PR2013*), (3) the number of children who completed the CR in 2013 (n=238; subsample *CR2013*), (4) the number of new participants in 2013 (n=5+25+1=31), (5) the number of participants (n=446-184=262) and non-participants (n=184) at follow-up, (6) the number of parent-child dyads that completed both the PR (13.8% fathers) and CR in 2013 (underlined numbers; n=192+25=217; subsample *PR2013-CR2013*), and (6) the number of parents that completed the PR in 2011 as well as in 2013 (numbers with *; n=192+54=246). Of the latter 246 parents, 207 were biological mothers in the survey in 2013. The identity of the parent that completed the PR2011 was not registered, but field workers reported that it was mostly done by mothers accompanying their children to the study centre. Therefore, we assumed that if the biological mother had filled out the PR2013, she also had filled out the PR2011. These 207 PR2011-PR2013 data formed the subsample *mother-report 2011-2013*. Children's characteristics of the five subsamples mentioned above are displayed in Table 5.

Table 5 Participant Characteristics of Five Study-Subsamples Used in Five Groups of Analyses

Subsample name (= requirement for subsample-inclusion)	**Analyses conducted on subsample**	**N(%boys)**	**Child-age (y)**				
			Min.	**P25**	**P50**	**P75**	**Max**
Parent report 2011 (PR2011)*	Reliability and CFA PR2011	446 (50.0%)	5.65	7.8	8.97	10.1	11.95
Parent report 2013 (PR2013)**	Reliability and CFA PR2013	272 (50.0%)	7.58	9.66	10.79	12	13.93
Child report 2013 (CR2013)**	Reliability and CFA CR	238 (50.4%)	7.59	9.54	10.82	11.9	13.93
Parent and child report 2013 (PR2013-CR2013)**	Main study aim 1	217 (50.2%)	7.59	9.57	10.78	11.9	13.93
Mother-report 2011-2013*	Main study aim 2	207 (49.3%)	5.65	7.61	8.73	9.79	11.19

*Note. * Child-age in 2011 is reported. ** Child-age in 2013 is reported. N, number. y, year. Min., minimum. P25, percentile 25. P50, median. P75, percentile 75. Max., maximum. CFA, confirmatory factor analysis. PR, parent report. CR, child report.*

Drop-out analyses compared the 262 participants and 184 non-participants at follow-up. Using unpaired t-tests, (1) the mean PR2011 BIS/BAS scores did not significantly differ between both groups (BIS: t=0.974, p=0.331, $r_{effect\ size}$ =0.05; BAS: t=0.556, p=0.578, $r_{effect\ size}$=0.03; BASD: t=0.950, p=0.343, $r_{effect\ size}$ =0.07; BASRR: t=0.772, p=0.441, $r_{effect\ size}$ =0.06; BASFS: t=-0.531, p=0.595, $r_{effect\ size}$ =0.05), and (2) the mean child-age of participants at follow-up was significantly lower (mean age=8.66, SE=0.09) than the child-age of non-participants at follow-up (mean age=9.12, SE=0.11; t=3.276, p=0.001, $r_{effect\ size}$=0.15). Although child-age differences were significant, the age was equally distributed across the age range of 5.5 to 11 years in the participants of follow-up (median age=8.82). Therefore, it was concluded that the higher drop-out of older children had no implications for the analyses of two-year stability and parent-child agreement. Finally, a Pearson's Chi-Square test revealed no gender differences between both groups; χ^2=0.148, p=0.773, $r_{effect\ size}$=0.027.

c. Measures: PR and CR BIS/BAS scale

Children's BIS/BAS reactivity was measured by the BIS/BAS scale of Carver and White (1994), using a PR and CR. In both PR and CR, twenty items need to be scored on a four-point Likert scale (1=not true; 2=somewhat true; 3=true; 4=very true). The BIS scale contains seven items and includes statements of sensitivity to punishments (e.g., I am very fearful compared to my friends). The BAS scale is an aggregate scale of three subscales: BASD, BASRR and BASFS. BASD contains four items tapping strong pursuit of appetitive goals (e.g., I go out of my way to get things I want). BASRR is measured by five items of positive affect/excitability (e.g., When good things happen to me, it affects me strongly). BASFS inquires four items that represents the inclination to seek out new rewarding situations (e.g., I'm always willing to try something new if I think it will be fun).

The CR was completed by the children in 2013 under surveillance of the field workers. This CR-version was developed and externally validated for Dutch children by Muris et al. (2005). It has a satisfactory internal reliability, with Cronbach's α's ranging between 0.70 and 0.80 for BIS, and 0.79-0.85 for BAS (Muris et al., 2005; Vervoort et al., 2010); Cronbach's α's of 0.67 for BASD, 0.71 for BASRR and 0.69 for BASFS were reported for an English version of the Dutch CR (Kingsbury et al., 2013). A principal component factor analysis demonstrated the existence of four factors, but because the BASFS items did not load together on one of the four factors, the authors concluded that a two factor structure was more appropriate (Muris et al., 2005). However, a confirmatory factor analysis (CFA) conducted by Kingsbury et al. (2013) was more in support for the four factor structure.

The PR was completed by parents during the survey in 2011 and 2013. This Dutch PR-version was developed by Braet and Verbeken and was externally validated by Vervoort et al. (Vervoort et al., 2015). A satisfactory external validity, and Cronbach's α's of 0.76 for BIS, 0.86 for BAS, 0.85 for BASD, 0.74 for BASRR, and 0.57 for BASFS were reported. A principal component analysis supported the original four factor structure (Vervoort et al., in review).

d. Data Analyses

Analyses were performed using PASW Statistical Program version 20.0 (SPSS, IBM, IL, USA), unless otherwise specified. All analyses in SPSS were conducted on sum scores.

Outliers and missing data. When a Likert-category on an item was chosen in ≤ 1% of cases in the three largest subsamples (PR2011, PR2013, and CR2013), the choice for that answer was seen as outlier. This was the case for category one (not true) for two PR and CR BASRR items; the scores of one were recoded to a missing value. The 18 other items exhibited no outliers. Further, when the value on one item of a (sub-)scale was missing, the participant's data were excluded from the analyses concerning that specific (sub-)scale. In total, two CR2013's missed an item on the BIS scale; six CR2013's missed an item on the BASD-subscale; six CR2013's, four PR2011's and two PR2013's missed an item on the BASRR-subscale; and one CR2013 missed an item on the BASFS-subscale. The distribution of missing values across the subsamples PR2013-CR2013 and mother-report 2011-2013 can be inferred from the participant numbers in Table 7.

Reliability and CFA of the PR and CR. These psychometric properties were tested before proceeding to the main research aims to support comparison with previous research and to define which factor model should be used. To check reliability, Cronbach α's were computed for all subscales on data of the subsamples PR2011, PR2013 and CR2013. Further, CFA's were conducted to test the two-factor (BIS, BAS) as well as the four-factor structure (BIS, BASD, BASRR, BASFS) of the CR, and to confirm the four-factor structure of the PR using Mplus version 7.2. As data were categorical, the robust estimator Weighted Least Squares Means and Variances adjusted (WLSMV) was used. As recommended, model fit was assessed by a combination of three goodness-of-fit indices of three different categories, namely chi-square, comparative fit index (CFI), and root mean squared error of approximation (*RMSEA*). However, the chi-square statistic is sensitive to the sample size and may reject a model even when the model is acceptable. Therefore, a model was also seen as adequate when the CFI was above 0.90 and the RMSEA below 0.08, and a model was seen as good when the CFI was above 0.95 and the RMSEA below 0.06 (Bentler, 1990; Bentler & Bonett, 1980; Browne & Cudeck, 1992; Chen, Curran, Bollen, Kirby, & Paxton, 2008).

Main study aim 1 - Parent-child agreement on BIS/BAS scores. The research questions of main study aim 1, namely 1.1, 1.2, and 1.3 (see introduction), were investigated on subsample PR2013-CR2013.

For research question 1.1, full measurement invariance analysis between PR and CR were conducted in Mplus version 7.2. Thereby, each (sub-)scale was considered separately with a single-group approach (T. A. Brown, 2006), a method taking into account the paired data-structure. As data were categorical, estimator WLSMV and the default delta parameterization were used. The fit indices of a configural model and of a model constraining both thresholds and factor loadings in tandem were examined (Muthén & Muthén, 1998-2012). In both models, correlated errors were specified between similar items of the PR and CR (e.g. item one of the PR with item one of the CR) (T. A. Brown, 2006). The more constrained model is nested in the configural model, and thus both models can be compared using the nested chi-square difference test option of Mplus (Muthén & Muthén, 1998-2012). When this nested chi-square difference test was not significant, full measurement invariance between PR and CR on the tested subscale was concluded. Only the subscales with full measurement invariance were included in the analyses described below. Partial measurement invariance was not tested, because this allows only to compare factor scores and not sum scores, whereas in clinical and public health research, only the sum scores of BIS, BAS, BASD, BASRR and BASFS are used.

To answer research question 1.2, a technique described by Bland-Altman and frequently conducted in biomedical sciences was used, and Pearson correlations between PR and CR (sub-)scales were calculated to assess correspondence, i.e. extent to which the PR and CR scores are related. The Bland-Altman technique constitutes of the descriptive statistics (1) mean of raw differences, i.e. mean of absolute PR minus absolute CR scores, and (2) the 95%-range of raw differences, i.e. |Mean of raw differences+1.96 standard deviations, mean of raw differences -1.96 standard deviations|. Thereby, the 95%-range of raw differences on each (sub-)scale were evaluated on clinical acceptability against the total range of that subscale, e.g. BIS scale containing seven items has a total range of (7*4)-(7*1)=28-7=21. Further, on plots with on the X-axis the mean of PR and CR scores and on the Y-axis the raw differences between PR and CR scores, the distribution of data has to be visually evaluated: if a heteroscedasticity or dispersion trend across the range of mean scores of the two measurements is present, agreement between two measurement methods is different according to the size of the measured values (technique of Bland and Altman (1986)).

For research question 1.3, multiple linear regressions with child-age, child-gender and parent-gender as independent variables and the STANDIF on the BIS and BAS (sub-)scales as dependent variable were conducted. The STANDIF of the (sub-)scales are calculated by subtracting the child standardized rating from parent standardized rating (De Los Reyes & Kazdin, 2004). When interpreting the results of the regression analyses, it is import to keep in mind that the sign of STANDIF can be positive (i.e. children rate lower than parents) as well as negative (i.e. children rate higher than parents).

Main study aim 2 - Two-year stability of PR BIS/BAS scores. The research questions of main study aim 2, namely 2.1, 2.2, and 2.3 (see introduction), were investigated on the subsample mother-report 2011-2013 (Table 5).

For research question 2.1, full measurement invariance over time was tested, using the same analysis technique as described above for main study aim 1, research question 1.1. Only the (sub-)scales with full measurement invariance were included in the analyses described below.

To answer research question 2.2, the descriptive statistics mean of raw differences, i.e. PR2013 minus PR2011 mother reported scores on each (sub-)scale, and 95%-range of raw differences were reported (cf. research question 1.2). Further, full-factorial repeated measures ANCOVA's were conducted. Therefore, the PR2011 and PR2013 BIS/BAS scores were included in different repeated measures ANCOVA's as within-subjects factors (*time*). Child-gender was included as between-subjects factor and child-age as covariate in each repeated measures ANCOVA, and the default interaction terms of time with child-age and child-gender were allowed. As such, possible average change over time of scores in boys and/or girls (time*gender), possible average change over time with the age-continuum (more change in older or younger children; time*age), and possible average change over time of scores in boys and/or girls with the age-continuum (time*gender*age). The sphericity assumption was not violated as the within-subject factor time contained only two levels. Generalized eta squared values were computed, which are recommended effect sizes for repeated measures ANCOVA's (Bakeman, 2005).

To answer research question 2.3, Spearman correlations between PR2011 and PR2013 BIS/BAS scores were calculated.

7.1.4 Results

a. Reliability and CFA of the PR and CR.

Cronbach's α's, reported first for BIS (7 items), followed by BAS (13 items), BASD (4 items), BASRR (5 items) and BASFS (4 items), were equal to 0.78, 0.85, 0.85, 0.71 and 0.55 for the PR2011, to 0.76, 0.88, 0.89, 0.70, and 0.61 for the PR2013, and to 0.70, 0.80, 0.78, 0.70, and 0.45 for the CR2013.

CFA on the PR2013 displayed an adequate fit for the four-factor model (BIS, BASD, BASRR, BASFS). On the PR2011, the four-factor structure did not fit adequately. On the CR, the fit of the four-factor structure was adequate, the fit of the two-factor structure was not. Goodness-of- fit indices are shown in Table 6.

Table 6 Confirmatory factor analyses goodness-of-fit indices for two- and four-factor models

Measure	Number of Factors	Chi-square	*df*	CFI	RMSEA
PR2011	4	723.598*	164	0.902	0.088
PR2013	4	400.157*	164	0.948	0.073
CR2013	4	316.071*	164	0.912	0.064
CR2013	2	394.653*	169	0.870	0.077

*Note. df, degrees of freedom. CFI, Comparative Fit Index. RMSEA, Root Mean Square Error of Approximation. PR, parent report. CR, child report. *p<0.001.*

b. Main study aim 1 - Parent-child agreement on BIS/BAS scores

Table 7 shows the descriptive statistics on the BIS/BAS scores for subsample PR2013-CR2013.

Table 8 shows goodness-of-fit indices of the measurement invariance analysis (research question 1.1). The configural model was adequate for BAS, BASFS and BASRR, and good for BIS and BASD. The constrained model was adequate for BIS, BAS, BASFS and BASRR, and good for BASD. However, the chi-square difference test was significant for BIS, BAS and BASFS, which means that the null-hypothesis of measurement invariance between these PR and CR (sub-)scales had to be rejected. The chi-square difference test was non-significant for BASD and BASRR. Hence, only for BASD and BASRR, full measurement invariance was concluded and further analyses were conducted.

Table 7 Descriptive statistics of the BIS/BAS Scores

		BIS		BAS		BASD		BASRR		BASFS	
		Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
Main study aim 1 (subsample PR2013-CR2013)											
Mother-reported PR2013	N	96	91	96	91	96	91	96	91	96	91
	Mean	16.21	17.46	32.96	31.11	9.32	8.77	14.34	14.13	9.29	8.21
	sd	3.36	3.83	7.40	6.60	3.26	3.18	2.92	2.25	2.46	2.25
	Mi-Ma	8-26	10-28	17-49	19-45	4-16	4-16	8-20	8-19	5-16	4-14
Father-reported PR2013	N	13	17	13	17	13	17	13	17	13	17
	Mean	16.46	16.65	36.69	32.82	10.69	9.65	15.77	14.24	10.23	8.94
	sd	3.26	2.62	7.11	5.24	2.87	2.40	2.46	2.41	2.68	1.89
	Mi-Ma	12-24	10-22	26-51	21-44	6-16	5-14	13-20	8-20	7-15	6-13
CR2013	N	109	106	102	104	106	105	105	107	109	108
	Mean	14.61	16.52	32.26	32.81	8.89	8.78	14.29	14.87	9.03	9.27
	sd	3.37	3.74	6.05	5.94	2.75	2.75	2.67	2.81	2.10	2.10
	Mi-Ma	9-24	7-25	20-51	21-47	4-15	4-15	9-20	9-20	4-16	5-14
Main study aim 2, (subsample mother-report 2011-2013)											
PR2011	N	102	105	100	104	102	105	100	104	102	105
	Mean	16.48	17.26	32.09	29.71	8.86	8.11	14.39	13.74	8.72	7.79
	sd	3.71	3.56	7.01	5.68	3.18	2.66	2.61	2.44	2.53	1.82
	Mi-Ma	9-25	9-25	19-47	16-46	4-16	4-16	9-19	8-20	4-15	4-13
PR2013	N	102	105	101	104	102	105	101	104	102	105
	Mean	16.06	17.56	31.94	30.48	9.05	8.51	14.05	13.92	8.84	8.04
	sd	3.40	3.80	7.48	6.91	3.29	3.24	2.90	2.46	2.47	2.30
	Mi-Ma	8-27	8-28	17-49	17-45	4-16	4-16	8-20	8-19	5-16	4-14

Note. N, number. sd, Standard deviation. Mi-Ma, Minimum – Maximum. BIS, Behavioral Inhibition System. BAS, Behavioral Activation System. BASD, drive subscale of the BAS scale. BASRR, reward responsiveness subscale of the BAS scale. BASFS, fun seeking subscale of the BAS scale. PR, parent report. CR, child report.

For research question 1.2, the means, standard deviations and 95%-range of raw differences were respectively 0.29, 3.44, and [-6.45, 7.03] on BASD, and -0.26, 3.41, and [-6.94, 6.42] on BASRR. The total range on BASD and on BASRR was 12 and 15, respectively. Although the means of raw differences between PR and CR on BASD and BASRR were close to zero, good agreement could not be confirmed: the 95%-ranges of raw differences were not clinical acceptable when compared to the total ranges (e.g. BASD: parent rating could be 6.45 points lower or 7.03 points higher than child rating in 95% of cases, while maximum 12 points of difference are possible on this scale). The Bland-Altman plots for BASD (Figure 9) and BASRR (Figure 10), revealed no trends across the range of scores, i.e. no increasing nor decreasing trend of the difference in scores between PR and CR when the values of the BASD or BASRR scores increased. Further, the Pearson correlation coefficients between PR and CR on BASD and BASRR were weak, i.e. 0.33 ($p<0.001$) and 0.19 ($p=0.005$) respectively.

Table 8 Measurement invariance analyses: goodness-of-fit indices for the configural and the constrained model; nested chi-square difference test between the configural and constrained model

	Model	Chi-square	*df*	CFI	RMSEA	ΔChi-square	Δ*df*
Main study aim 1 research question 1.1 (PR 2013 – CR 2013)							
BIS	Configural	87.748	69	0.984	0.036		
	Constrained	150.54**	88	0.947	0.057	61.311**	19
BAS	Configural	513.238**	285	0.939	0.062		
	Constrained	564.702**	320	0.935	0.061	68.37**	35
BASD	Configural	13.647	15	1.000	<0.001		
	Constrained	30.081	25	0.998	0.031	16.259	10
BASRR	Configural	56.984**	29	0.954	0.067		
	Constrained	74.781**	40	0.943	0.064	18.998	11
BASFS	Configural	26.563*	15	0.947	0.060		
	Constrained	46.222**	25	0.902	0.063	20.355*	10
Main study aim 2 research question 2.1 (PR 2011 – PR 2013)							
BIS	Configural	136.348**	69	0.951	0.069		
	Constrained	147.694**	88	0.957	0.057	16.412	19
BAS	Configural	752.224**	285	0.917	0.090		
	Constrained	779.329**	320	0.918	0.084	53.66*	35
BASD	Configural	15.359	15	1.000	0.011		
	Constrained	25.618	25	1.000	0.011	10.592	10
BASRR	Configural	94.73*	29	0.922	0.106		
	Constrained	138.795**	40	0.884	0.110	46.407**	11
BASFS	Configural	37.498**	15	0.964	0.085		
	Constrained	47.188**	25	0.964	0.065	13.301	10

*Note. *p<0.05, **p<0.01. df, degrees of freedom. CFI, Comparative Fit Index. RMSEA, Root Mean Square Error of Approximation. Δ, change. PR, parent report. CR, child report. BIS, Behavioral Inhibition System. BAS, Behavioral Activation System. BASD, drive subscale of the BAS scale. BASRR, reward responsiveness subscale of the BAS scale. BASFS, fun seeking subscale of the BAS scale. Configural, model with factor loadings and thresholds free to vary across rater (research question 1.1) or across time (research question 2.1). Constrained, model with factor loadings and thresholds constrained to be invariant across rater (research question 1.1) or across time (research question 2.1).*

The results of the multiple linear regressions conducted for research question 1.3 are shown in Table 9. Child-age significantly and positively influenced BASD STANDIF, indicating a tendency of higher rating by younger children and lower rating by older children compared to their parents. There was a positive but not-significant association between child-age and BASRR STANDIF. Regarding child-gender, the regression coefficients were not significant, although a non-significant trend of a child-gender relation (higher rating of boys compared to PR than girls) with BASRR STANDIF was present. Parent-gender significantly influenced BASD STANDIF scores, indicating that fathers have more tendency to rate higher on BASD compared to the self-rating of children than mothers (estimated means and 95% confidence intervals on BASD STANDIF were 0.50 [0.07, 0.92] for fathers and -0.03 [-0.20, 0.14] for mothers).

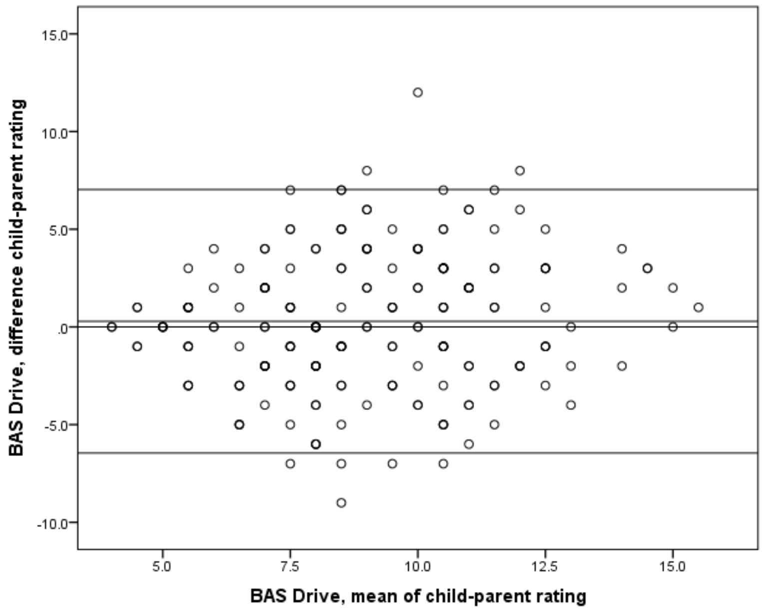


Figure 9 Bland-Altman plot for BAS drive

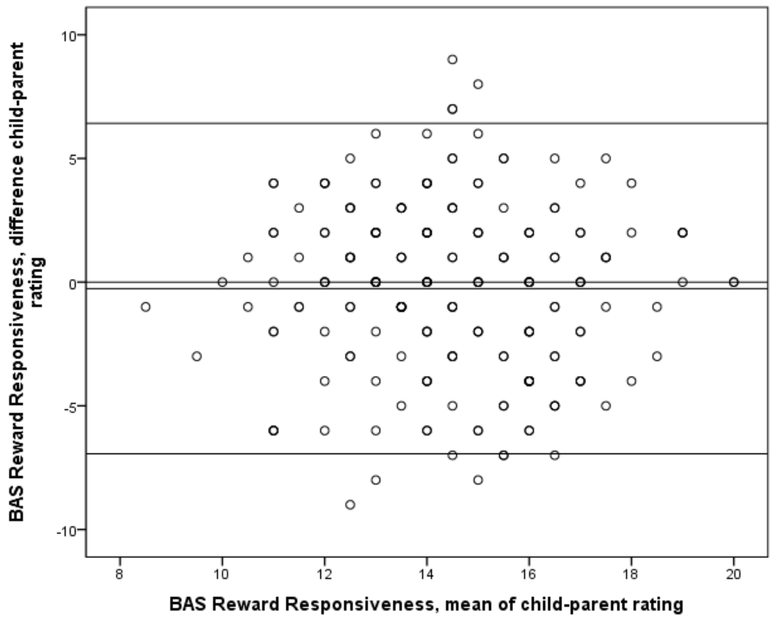


Figure 10 Bland-Altman plot for BAS reward responsiveness

Table 9 Research question 1.3 – Multiple Linear Regression To Identify Influencing Factors of Parent-Child Discrepancies

Outcome [a]		Child-age	Child-gender[b]	Parent-gender [b]
	Adjusted R^2	β (t)	β (t)	β (t)
STANDIF BASD	0.041	0.155 (2.277)*	-0.062 (-0.910)	-0.153 (-2.261)*
STANDIF BASRR	0.017	0.109 (1.598)	-0.133 (-1.936)	<0.001 (0.005)

*Note. *p<0.05. β= standardized regression coefficient. t=value of t-test statistic, between brackets. STANDIF, the standardized parent score minus standardized child score. BASD, drive subscale of the BAS scale. BASRR, reward responsiveness subscale of the BAS scale. [b]Male=0; female=1.*

c. Main study aim 2 - Two-year stability of PR BIS/BAS scores

Table 7 shows the descriptive statistics on the BIS/BAS scores for subsample PR2011 and PR2013.

Table 8 displays goodness-of-fit indices of the measurement invariance analysis (research question 2.1). The configural model was adequate for BIS and good for BASD, but not for BAS, BASFS and BASRR. The constrained model was good for both BIS and BASD, and also the chi-square difference test was not significant for BIS and BASD. Hence, full measurement invariance was concluded for the BIS and BASD (sub-)scale.

Considering research question 2.2, the means, standard deviations and 95%-range of raw differences, i.e. mother-report 2013 minus mother-report 2011, were -0.05, 3.72, and [-7.34, 7.24] on BIS, and 0.29, 2.78, and [-5.16, 5.74] on BASD, respectively. The total range on BIS and on BASD was 21 and 12, respectively. Both means of raw differences were close to zero (|<0.3|). Concerning BIS, 95% of the raw difference scores were up to one third of the total range higher or lower at 2013 compared to 2011. Concerning BASD, raw difference scores varied between one third and half of the total range. Further, the repeated measures ANCOVA's, shown in Table 10, revealed no significant within-subject effects (factor time, time*age, time*gender, time*age*gender). This absence of significant time-effects indicated that on average, the mother-reported BIS and BASD scores did not change over a time period of two years in children aged 5.5-11 years at baseline and 7.5-13 at follow-up.

Spearman correlation coefficients between mother-reported PR2011 and PR2013 BIS and BASD scores were moderate, i.e. 0.47 (p<0.001) and 0.59 (p<0.001), respectively (research question 2.3).

Table 10 Research question 2.2 – Tests of Within-Subjects Effects of Repeated Measures ANCOVA's on BIS and BASD

N=207		BIS		BASD	
Within-Subject Factors	**df**	**F**	**n^2_G**	**F**	**n^2_G**
Time	1	0.02	<0.001	0.80	<0.001
Time*Child-age	1	0.04	<0.001	1.33	0.001
Time*Child-gender	1	0.44	<0.001	0.48	<0.001
Time*Child-gender*Child-age	1	0.82	0.001	0.62	<0.001
Error	203				

*Note. *p<0.05, **p<0.01. N, number. BIS, Behavioral Inhibition System Scale. BASD, drive subscale of the BAS scale. df, Degrees of freedom (df are the same for both ANCOVA's). F, F-test of repeated measures ANCOVA. n^2_G, effect size generalized eta squared as a measure (abP-design, see Bakeman (2005)).*

7.1.5 Discussion

The present study evaluates two methodological concerns about the use of a PR and CR version of the BIS/BAS scale for children. First, agreement of parent and child ratings was investigated. Second, stability of the PR scores over time was examined. These main aims are discussed below.

Before investigating the main research aims, the internal validity of the scales was checked. The Cronbach α's of the PR- and CR-version were comparable or better than in previous studies (Kingsbury et al., 2013; Muris et al., 2005; Vervoort et al., 2015; Vervoort et al., 2010). Similar to previous studies, the BASFS subscale was less reliable in the current study. Further, the four-factor structure of the PR reported by Vervoort et al. (in review) was confirmed for the PR2013. Remarkably, the fit was not adequate in 2011. This might be due to the measurement process: in 2011, parents may filled out the PR after filling out other questionnaires, while in 2013, parents first filled out the PR. Since every subscale was tested separately for measurement invariance over time, and since the Cronbach α's of the PR2011 (sub-)scales were similar to the α's of the PR2013 (sub-)scales, the PR2011 could be used for the aims of the present study. Considering the CR, the finding in favour of the four-factor model is in line with results of a CFA conducted by Kingsbury et al. (2013).

In sum, the BIS, BASD and BASRR subscales of the PR and CR may be validly applied in children. Caution is indicated regarding the internal reliability of the BASFS subscale. Adaptations of the BASFS subscale were beyond the scope of this study, but future research might explore how to improve the BASFS reliability.

a. Main study aim 1 - Parent-child agreement on BIS/BAS scores

Before testing parent-child agreement, measurement invariance between parents' and children's rating on the scale scores was tested. The criteria for full measurement invariance between PR and CR were not reached for the BIS and BAS scales and for the BASFS subscale, and therefore, their sum scores could not be compared between PR and CR. The items might not have a similar meaning to parents than to children (T. A. Brown, 2006).

On the measurement invariant BASD and BASRR subscales, correspondence and agreement between parent and child were evaluated. The current results depicted that parent-child correspondence on BASD and BASRR approach typical levels of parent-child agreement, i.e. weak correlation, such as often observed for most symptom measures of psychopathology and child/adolescent behavioral and emotional questionnaires (Achenbach et al., 1987; De Los Reyes et al., 2015). Based on this weak correlation results and the wide 95%-ranges of raw differences on BASD and BASRR, discrepancy between PR and CR BASD and BASRR ratings may be concluded.

The conclusion of measurement non-invariance on BIS, BAS and BASFS, and discrepancy on BASD and BASRR is important for future research. It is often recommended to use multiple informants to assess a child's psychosocial functioning (Offord et al., 1996), and to combine the multiple informants' ratings into a single variable (De Los Reyes, Thomas, Goodman, & Kundey, 2013). However, it might be better to collect both reports but treat them independently since the current study found that parent and child ratings may not have a similar meaning.

Further, it was evaluated if primary parent and child characteristics were influencing factors of parent-child discrepancies on the measurement invariant BASD and BASRR subscales. Concerning child-age, the results suggested that, compared to the parent rating, the child rating on BASD tends to be higher in younger and lower in older children. On BASRR, similar but non-significant tendencies were found. This tendency of higher CR in younger children compared to PR, and lower CR in older children compared to PR, was also found in a study of Weems et al. (2010). This finding might be explained by improvement of cognitive skills and/or rising of social desirability in children with age, or by parental response bias (e.g. cultural ideas on how approach behavior has to appear in different age groups), but these explanations remain speculative. Future research has to explore the above mentioned hypotheses. Concerning child-gender, no significant influence on parent-child discrepancies was found for BASD and BASRR. This finding is also in line with the study of Weems et al.

(2010) in which child-gender was also not significantly associated with the STANDIF scores. Concerning parent-gender, a significant parent-gender relation with BASD parent-child discrepancies was found, but not on BASRR. As hypothesized, the average STANDIF on BASD was more close to zero in mothers compared to fathers. This finding might be explained by mothers being on average still the primary caregivers (VUB, 2015). Possibly, mothers are somewhat more accurate reporters on their child's behavior than fathers. Future research has to confirm this hypothesis. However, this finding suggests the importance of considering parent-gender when investigating the influencing factors on parent-child discrepancies. Until now, mainly but not exclusively mothers are included in studies of parent-child discrepancies, probably because mothers are often more consistently available (De Los Reyes & Kazdin, 2005; Duhig et al., 2000). Nevertheless, not considering parent-gender may lead to biased conclusions and to inconsistencies in literature.

Although not investigated in this study, the remaining unexplained parent-child discrepancy may be due to other influencing factors, e.g. different attributions and perspectives of parent and child, different perceptions on the strength of avoidance or approach behavior, differences in memory recall, and response bias (De Los Reyes & Kazdin, 2005).

b. Main study aim 2 - Two-year stability of PR BIS/BAS scores

Before testing the stability of the PR BIS/BAS scores over two years, measurement invariance was considered. The criteria for full measurement invariance between the mother-report 2011 and 2013 were not met for the BAS scale, and the BASRR and BASFS subscales. Consequently, sum scores of these (sub-)scales could not be compared over time. Future research is needed to repeat these findings.

For the measurement-invariant BIS scale and the BASD subscale, the current study was the first to demonstrate that on average, absolute mother-reported BIS and BASD scores in children aged 5.5-11 years at baseline may not change over a two-year period. However, the scores of an individual child could increase or decrease up to one third of the total range of the BIS scale, and up to half of the total range of the BASD subscale, reflecting changes in BIS and BASD scores when looking at an individual level instead of an average level of change. Besides this, the rank order of children remained moderately stable over two years on BIS and BASD.

In sum, these results suggest that on average, mother-reported punishment sensitivity and motivated behavior to pursuit rewarding goals is not changing substantially over two years in this study sample with participants between 5.5 and 13 years using the PR BIS/BAS scale. The findings are in line with results of previously mentioned personality research (Caspi & Silva, 1995) and of findings by Braams et al. (2015), but in contrast with the recently emerging hypothesis of age-related absolute changes in BIS and BAS reactivity during development (e.g. Cauffman et al. (2010) and Urosevic et al. (2012)). One explanation for the contrasting finding might be the use of different measures to assess BIS and BAS reactivity, i.e. PR BIS/BAS scale in the present study versus original adult self-report BIS/BAS scale in the study of Urosevic et al. (2012) versus behavioral measures in the study of Cauffman et al. (2010). The BAS subscales might be individual difference measures that are not related to age because the respondent answers the questionnaire age-adequately, i.e. compares the level of general reward motivation to other children of the same age. If so, an explanation for the results of Urosevic et al. (2012) might be that the BASRR subscale was not measurement invariant over time, which was not tested. An alternative explanation might be the different age ranges of the study samples. For example, Urosevic et al. (2012) found a significant time-effect on the BASRR subscale of the adult Carver and White BIS/BAS scale over a two-year period in a study sample with ages 9-18 years at baseline. These results suggested a rise in BASRR from 9 years on. However, when only analysing the early adolescent group (age 9-12 at baseline), no significant time-effect was found (Urosevic et al., 2012). Possibly, the increase in reactivity in the underlying neurobiological systems is not emerging before onset of puberty.

7.1.6 Strengths, limitations, and directions for future research

The presented study was conducted on a large study sample, that was followed over a period of two years. The sample consisted of primary and first grade secondary school children, an understudied age group. Further, the internal validity of the used measures was checked.

The present findings also have some limitations. First, in the survey in 2011, the identity of the parent who completed the PR was not registered, but we assumed PR2011 completion by the mother in all cases in which the PR2013 was completed by the mother. Anyhow, no significant average PR change over time in BIS and BASD scores was found. Second, some authors question the BIS scale, which is based on the original RST, and proposed a revised version of the RST (J. A. Gray & McNaughton, 2000). However, for the current study, it was decided to use the BIS scale as developed based on the original RST (Carver & White, 1994) since in literature, the original BIS scale and BAS subscales have been found to be suitable for clinical practice and epidemiological research to determine risk factors of divers health outcomes (e.g. Bijttebier et al. (2009) and Verbeken et al. (2012)). Further limitations are the limited number of influencing factors of parent-child discrepancies, and the preponderance of mothers compared to fathers in our study.

For future research, it is recommended to include other influencing factors of parent-child discrepancies in BIS/BAS scores such as psychosocial problems in the child or parent, and problems in parent-child communication (De Los Reyes & Kazdin, 2006; Guion, Mrug, & Windle, 2009). Next, we recommend that in the future, both mother- and father-reports, or - if impossible - only mother- or only father-reports, are included in studies. The present study was designed to investigate the main study aims during childhood. However, adolescence is suggested to be an important developmental phase of reward-related processes, and therefore, future longitudinal research is recommended to examine measurement invariance, and absolute and relative stability on the PR and CR BIS/BAS scores between the transition from pre-puberty to puberty. Because onset of puberty can be a better cut-off than age when analysing the relation between developmental phases and BIS or BAS reactivity, the inclusion of methods to measure the onset of puberty is strongly recommended.

7.1.7 Conclusion

The PR and CR version of the BIS/BAS scale were found to be measurement invariant but discrepant on BASD and BASRR. As hypothesized, child-age and parent-gender were significant influencing factors of the discrepancies on BASD, and child-gender was not. However, no significant influence of child-age and parent-gender were found on parent-child discrepancies on BASRR. In younger children, child ratings on BASD tended to be higher than parent ratings, whereas in older children, child ratings tended to be lower than parent ratings. Further, fathers' rating on BAS drive tended to be higher compared to the self-rating of children than mothers' rating. Finally, the current study found that the mother-reported BAS scale and the BASRR and BASFS subscale were not measurement invariant over time, and therefore, PR-data on BAS, BASRR and BASFS of 2011 and 2013 were not comparable. However, mother-reported BIS and BASD scores could be compared. The results suggested that mother-reported BIS and BASD scores may be used as stable parameters in longitudinal analyses to predict health outcomes in primary and first grade secondary school children over a period of two years.

8. Results on palatable food consumption and body composition

8.1 Associations of Reward Sensitivity with Food Consumption, Activity Pattern, and BMI in Children[5]

[5] This section is based on De Decker, A., Sioen, I., Verbeken, S., Braet, C., Michels, N., & De Henauw, S. (2016). Associations of reward sensitivity with food consumption, activity pattern, and BMI in children. *Appetite*, *100*, 189-196.

8.1.1 Abstract

In the current study, the associations of reward sensitivity with weight related behaviors and body mass index were investigated in a general population sample of 443 Flemish children (50.3% boys) aged 5.5-12 years. Cross-sectional data on palatable food consumption frequency, screen time, physical activity, parental education level and measured length and weight were collected. The drive subscale of the 'Behavioral Inhibition Scale/Behavioral Activation Scale' was used as a short method to measure reward sensitivity. A significant positive association of reward sensitivity with the fast food and sweet drink consumption frequency was found. Furthermore, a significant positive association of reward sensitivity with the z-score of body mass index was demonstrated, which explained additional variance to the variance explained by palatable food consumption frequency, screen time, physical activity and parental education level. Hence, the assessment of reward sensitivity may have an added value to the assessment of weight-related behavior indicators when evaluating the determinants of overweight in a child. In sum, children high in reward sensitivity might be more attracted to fast food and sweet drinks, and hence, might be more vulnerable to develop unfavorable food habits and overweight. These findings suggest that considering inter-individual differences in reward sensitivity is of importance in future childhood obesity prevention campaigns.

8.1.2 Introduction

The prevalence of childhood overweight and obesity has increased dramatically since 1990 (Y. Wang & Lim, 2012). Since childhood overweight and obesity is associated with multiple adverse health outcomes, the current prevalence is identified as a global public health problem (Baker, Olsen, & Sorensen, 2007; Deckelbaum & Williams, 2001; Shrivastava, Shrivastava, & Ramasamy, 2014). Moreover, overweight and obese youth have an increased risk of maintaining their unfavorable weight status into adulthood (Singh et al., 2008). Therefore, it is of the highest importance to prevent childhood overweight and obesity. Unfortunately, current overweight prevention approaches have no or only small effects (Kamath et al., 2008). A better understanding of the determinants of childhood overweight is needed to improve future prevention approaches.

Research has demonstrated positive associations between Body Mass Index (BMI) and the consumption of highly palatable, mostly energy dense foods in children, e.g. fast food (Fraser, Clarke, Cade, & Edwards, 2012), sugar sweetened beverages (Malik, Pan, Willett, & Hu, 2013), and artificially sweetened beverages (Sylvetsky, Rother, & Brown, 2011). For the consumption of sweet food, a significant positive association with BMI was reported in adults, but this association was not demonstrated in children (Te Morenga, Mann, & Mallard, 2013). Furthermore, positive associations between BMI and screen time (Falbe et al., 2013), and negative associations between BMI and physical activity (PA) have been found in children (Chaput et al., 2014). The current western environment facilitates these unfavorable weight-related behaviors, i.e. a high consumption of widely available palatable foods, prolonged engagement in screen time activities, and sedentary lifestyle combined with low levels of PA (Lowe & Butryn, 2007). However, not all children exposed to this obesogenic environment display these unfavorable weight-related behaviors and become overweight (Blundell et al., 2005). It has been shown that some individuals are more reactive to the palatable food environment (Paquet et al., 2010), and noteworthy, Forman et al. reported that this reactivity codetermined the effect of the obesity prevention approaches used in their study (Forman et al., 2007). Furthermore, this reactivity to the food environment depends upon individual differences in reward sensitivity (RS) (Paquet et al., 2010).

RS is the tendency to engage in motivated approach behavior in the presence of environmental cues associated with reward, such as the sight of palatable foods (Carver & White, 1994). Heightened RS has recently been associated with higher intakes of sugar-sweetened beverages and unhealthy snacks in adolescents (De Cock et al., 2015), and with higher fat intake in adults (Tapper, Baker, Jiga-Boy, Haddock, & Maio, 2015). Moreover, in normal to overweight adolescents and adults, a positive association was reported between RS and BMI (C. Davis & Fox, 2008; C. Davis et al., 2007; Verbeken et al., 2012). Unfortunately, in children, findings are less consistent. One study did not find associations of RS with unhealthy snack consumption and BMI in children (Scholten et al., 2014), while another study reported a positive association between RS and BMI in children, which was mediated by overeating (van den Berg et al., 2011). These inconsistencies might be due to the use of a different RS measure.

Besides consumption of palatable foods, also screen time (e.g. computer games) and PA (e.g. endurance running) were reported to have rewarding potential (Buckley et al., 2014; Garland et al., 2011). This might implicate that RS also plays a role in those weight-related behaviors (Buckley et al., 2014). Nevertheless, literature on the association of RS with PA and screen time is to our knowledge absent in children and adolescents. In adults, one study reported no relation between RS and PA (Finlayson, Cecil, Higgs, Hill, & Hetherington, 2012), whereas another study reported more PA in individuals with higher RS (Voigt et al., 2009).

Since previous research suggested that knowledge on the association of RS with weight-related behaviors and BMI is imperative for the development of effective prevention strategies, the current study aimed to investigate these associations in a large general population sample of children aged 5.5-12 years. Therefore, consumption frequencies of different types of palatable food, screen time, PA, and BMI calculated upon measured weight and height were used. In accordance to the studies in adolescents (De Cock et al., 2015; Verbeken et al., 2012), the current study used the drive subscale of the 'Behavioral Inhibition/ Behavioral Activation Scales' (BIS/BAS) as a measure of RS, which is conceptualized as the motivation to approach potentially pleasurable activities (Carver & White, 1994). Important advantages of the drive subscale are that (a) it was validated in neuro-imaging research (Beaver et al., 2006), (b) it is a short 4-item scale, easily and practically applicable in epidemiological research, obesity prevention interventions and clinical practice, and (c) it does not only measure reactivity to food, but to all kinds of reward, such that it has the potential to be associated with food consumption as well as screen time and PA.

A positive association between RS and the consumption of high-fat fast food, sweet food, and sugared and artificially sweetened beverages was hypothesized. Additionally, the relation of RS with screen time and PA was explored. Further, it was hypothesized that RS was positively associated with BMI and explained additional variance of BMI to the assessment of known predictors of BMI (i.e. palatable food consumption, screen time, PA and parental education level).

8.1.3 Method

a. Study participants

Participants were Dutch-speaking Belgian children aged 5.5 -12 years, recruited by random cluster design for the longitudinal Children's Body Composition and Stress (ChiBS) study (Michels et al., 2012) that took place between 2010 and 2012. Children (in most cases accompanied by minimum one parent) attended the survey centre at a prefixed appointment, during which the anthropometric measurements of the child were conducted and questionnaires were filled in by the parent. If the parent could not accompany the child, the parents were asked to fill in the questionnaires at home.

The 455 children who participated in the ChiBS study wave of 2011 were included in the current study. Of the 455 children, twelve children were excluded from the analyses (nine had missing RS-data; three children reached the criteria for obesity, see discussion for argumentation on exclusion of children with obesity). As such, the total study sample consisted of 443 children. A post hoc power calculation was performed based on a sample size of 443 children and the mean of the two squared correlation coefficients (i.e. 0.02) reported in the study of van den Berg et al. that demonstrated a significant relation between scores on two RS measures and BMI in children (van den Berg et al., 2011). This revealed a power of 0.79 to detect a true association between RS and BMI in the current study.

The ChiBS study was conducted according to the guidelines laid down in the Declaration of Helsinki and was approved by the Ethics Committee of Ghent University Hospital. Written informed consent was obtained from all parents and the children gave verbal assent.

b. Measures

RS. The BAS scale of the BIS/BAS scale consists of three subscales, namely the drive, reward responsiveness, and fun seeking subscale (Carver & White, 1994). However, the validity of the fun seeking subscale is questioned (see section 7.1 and De Cock, Van Lippevelde, Vervoort, et al. (2016)). The drive subscale was designed to reflect strong pursuit of appetitive goals and consists of four items which all need to be scored on a 4-point Likert scale (1=not true, 2=somewhat true, 3=true, 4=very true; items are (a) when your child wants something, he/she usually goes all the way to get it, (b) your child does everything to get the things that he/she wants, (c) when your child sees an opportunity to get something that he/she wants, he/she goes for it right away, (d) nobody can stop your child when he/she wants something). Further, the drive subscale is more strongly related to palatable food intake in adolescents than the reward responsiveness subscale, and is not related to the intake of healthy snacks, which was the case for the reward responsiveness subscale (De Cock, Van Lippevelde, Vervoort, et al., 2016; Vervoort et al., 2015). Furthermore, the drive subscale, but not the reward responsiveness subscale, is strongly associated with neural responses to food-reward cues relative to bland food cues in the brain reward circuitry (Beaver et al., 2006). Therefore, the term RS refers to the sum of the four items of the drive subscale. Because the youngest children of the cohort were too young to answer the questionnaire themselves, parents answered a Dutch parent version of the BIS/BAS scale (Vervoort et al., 2015). The Cronbach alpha coefficient of RS (4 items) in the current study (0.85) was comparable to the alpha reported by Vervoort et al. (i.e. 0.85) in children and adolescents aged 2-18 years (Vervoort et al., 2015).

Food indices. Parents completed the Children's Eating Habits Questionnaire - Food Frequency Questionnaire to report the child's usual weekly consumption frequency (CF), thereby considering the preceding 4 weeks. The questionnaire consists of 43 food items/categories and was developed and validated within the EU FP6 IDEFICS project (I. Huybrechts et al., 2011; Lanfer et al., 2011).

Table 11 Food indices based on the food categories included in the Children's Eating Habits Questionnaire – Food Frequency Questionnaire

Fast food consumption frequency=Weekly consumption frequency of the following food categories
Fried potatoes, potato croquettes
Pizza as main dish
Chips, tortillas, popcorn
Sausage roll, cheese roll, pizza-snack
Hamburger, hotdog, kebab, wrap, pita, durum
Ketchup
Mayonnaise, mayonnaise based products
Sweet food consumption frequency
Candies, marshmallow
Chocolate, candy bars
Biscuits, cakes, pastries
Ice cream
Sweet drink consumption frequency
Fruit juice
Sweet and soft drinks
Light and zero soft drinks
Sugared milk

For each item, the following response options were used (the assigned score is indicated in brackets): 'never/less than once a week' (value 0), 'one to three times a week' (value 2), 'four to six times a week' (value 5), 'one time a day' (value 7), 'two times a day' (value 14), 'three times a day' (value 21), 'four or more times a day' (value 30), or 'I have no idea' (missing). Based on this questionnaire, three food indices were calculated by summing up the weekly CF's of related food items/categories: (a) Fast food CF, contains all fast food and combined sauces categories; (b) Sweet food CF, contains all sweet food categories; (c) Sweet drink CF, contains all sweet tasting drink categories (Table 11).

Screen time and PA. Parents reported on the number of hours of TV/DVD/video viewing and computer/games-console use both for typical weekdays and weekend days. Response categories included: 'not at all' (value zero), '<0.5 hours a day' (value 0.25), '<1 hours a day' (value 0.75), 'between 1 and <2 hours a day' (value 1.5), 'between 2 and <3 hours a day' (value 2.5), '>3 hours a day' (value 4). Children's weekly TV/DVD/video viewing (5 times week and 2 times weekend viewing) and computer/games-console use (5 times week and 2 times weekend use) were summed to obtain the hours of screen time per week (Olafsdottir et al., 2014).

Parental report on *"How much hours and minutes does he/she spend doing sport in a sports club per week"* (no response categories) was used as a proxy measure for moderate to vigorous PA, further referred to as PA at sports clubs (PAclub).

BMI. Height (m) and body mass (kg) were measured. Children were not allowed to eat or drink during 2 hours preceding the weighing. Upon weight and length data, BMI (kg/m^2) was calculated, and the standard deviation score of BMI (zBMI) was computed to adjust for age- and sex using xILMS (i.e. an excel add-in for using growth reference data in the LMS format; abbreviation LMS refers to smooth curve-L, mean-M and coefficient of variation-S) with Flemish growth reference data of 2004 (T. J. Cole, Freeman, & Preece, 1998; Roelants, Hauspie, & Hoppenbrouwers, 2009). According to the cut-offs of the International Obesity Task Force (T. J. Cole & Lobstein, 2012), children with BMI z-scores of ≥ 2.29 for boys and ≥ 2.19 for girls (equivalent of BMI 30 at age 18) were classified as obese, and excluded from further analyses (see discussion section 8.1.5 for argumentation on exclusion of children with obesity).

Parental education level. The highest parental education level of both parents (PEL) was categorized according to the International Standard Classification of Education (ISCED) (UNESCO, 1997). Because of low numbers of participants in category zero to four, the ISCED-categories were aggregated into two levels (ISCED level 0 – 4 = low PEL, value zero; ISCED level 5-6 = high PEL, value one).

c. Statistical analyses

Analyses were performed using PASW Statistical Program version 20.0 (SPSS, IBM, IL, USA). The two-sided level of significance was set at $p<0.05$. Missing values were not estimated since most missing values were the consequence of questionnaires that were not filled in due to time constraints. Histograms and boxplots were drawn to identify outliers and non-normal distributions. Based on visual inspection, it was decided to exclude five extreme outliers of the sweet drink CF (ranging from 44 to 83 times a week) and two of the sweet food CF (35 and 40 times a week) from further analyses. The fast food, sweet food, and sweet drink CF, and PAclub were found to be non-normally distributed. To use the food indices as dependent variables in regressions, correlations, and t-tests, value one was added to the scores on the single food items of the fast food, sweet food, and sweet drink CF, resulting in a food frequency range of [1;31] instead of [0;30]. Then, the fast food CF, sweet food CF and sweet drink CF sum scores were calculated again, and the natural logarithms (ln) of all food indices were computed, which approached the normal distribution. For PAclub, transformations did not change the distribution towards normality. To use PAclub as dependent variable in regressions, it was dichotomized using a median-split (Table 12; zero to two hours per week = low PAclub, value zero; more than two hours per week= high PAclub, value one).

Explorative unadjusted Pearson correlations (exception: Spearman correlation for PAclub) and unpaired t-tests (exception: Mann-Whitney U test for PAclub) were conducted to find out if age, sex and PEL had to be included as covariates when regressing weight-related behaviors on RS. They were only included as covariates in regression models if (trend) significant associations were present between age, sex or PEL and (a) the predictor, and (b) the dependent variable.

To investigate the research hypothesis that RS was positively associated with the three food indices, three linear regression models were conducted with RS as predictor and fast food CF, sweet food CF and sweet drink CF as dependent variables. To explore if RS was associated with screen time and PAclub, a linear and a logistic regression were conducted respectively with RS as predictor and screen time and PA club as dependent variables.

To investigate if RS was positively associated with zBMI and if it explained additional variance to the assessment of known predictors, a hierarchical linear regression model with zBMI as dependent variable was conducted. This analysis was conducted on a subsample of the total study sample, for which all predictors included in the model were reported. In step 1 of the hierarchical linear regression model, the three food indices, screen time, PAclub and

PEL were added as predictors. In step 2, also RS was added as predictor to the regression model. Since zBMI scores are adjusted for age and sex, and inclusion of age and sex as covariate did not change the results, age and sex were not included in the regression model.
For the linear regression models, semi-partial correlations were computed to measure the effect size of RS (Aloe, 2014). Effects of 0.10 were interpreted as small, of 0.30 as medium and of 0.50 as large (J. Cohen, 1992).

8.1.4 Results

a. Descriptive statistics and comparisons between the total sample and subsample

Table 12 shows the descriptive statistics on age, RS, zBMI, and weight-related behaviors. Of the total study sample of 443 children (50.3% boys), 22.6% had low PEL, 70.7% high PEL, and 6.8% missing PEL-data. Further, 46.7% children were categorized as low and 40.6% as high PAclub; 12.7% had missing PAclub data.
The subsample of children for which all variables included in this study were reported consisted of 344 children (50.6% boys; 21.8% low PEL; 51.7% low PAclub). Using unpaired t-tests, the mean RS and zBMI score did not significantly differ between the 344 participants with all data and the 99 participants with missing data on one or more variables (RS: t(441)=0.52, p=0.60; zBMI: t(441)=-0.11, p=0.91).

Table 12 Descriptive data of the key variables

	N	Min	P25	P50	P75	Max	M	sd
Age (years)	443	5.65	7.80	8.98	10.07	11.95	8.86	1.48
RS (range 4-16)	443	4.00	6.00	8.00	11.00	16.00	8.66	2.84
Fast food CF (times per week)	427	0.00	2.00	6.00	8.00	20.00	6.09	4.26
Sweet food CF (times per week)	431	0.00	5.00	9.00	13.00	30.00	9.25	5.63
Sweet drink CF (times per week)	427	0.00	4.00	8.00	14.00	37.00	9.32	6.94
Screen time (hours per week)	383	0.50	6.75	9.50	15.25	33.00	11.06	6.07
PAclub (hours per week)	387	0.00	1.00	2.00	3.50	8.00	2.29	1.68
zBMI	443	-2.89	-0.83	-0.22	0.34	2.19	-0.22	0.91

Note. N, number. Min, minimum. P25, percentile 25. P50, median. P75, percentile 75. Max, maximum. M, mean. sd, standard deviation. RS, reward sensitivity. CF, weekly consumption frequency. PAclub, physical activity in sports clubs. zBMI, age- and sex-independent z-score of Body Mass Index.

b. Association of RS with food indices, screen time and PAclub

Explorative analyses. Correlations and comparisons were performed to find out which variables should be included as covariates in the regression models with RS as predictor and weight-related behaviors as dependent variables (Table 13). Based on these results, age was included as covariate in all five regression models with RS as predictor and the weight-related behaviors as dependent variables because (a) a trend significant correlation between RS and age was present, and (b) age was significantly related to screen time and PAclub, and trend significant to the fast food and sweet food CF. Sex was only included as covariate in the regression model with screen time as dependent variable, since trend significant sex differences were only present on RS and screen time. PEL was not included as covariate in the regression models: although the CF of fast food and sweet drink were significantly higher in low PEL (mean fast food CF low PEL=7.61, high PEL=5.57 times a week; mean sweet drink CF low PEL=11.39, high PEL=8.69 times a week), no association was found between PEL and RS.

Regression analyses adjusted for covariates. Table 14 shows the results of the five regressions. RS was significantly and positively related to the fast food CF and sweet drink CF, but not to the sweet food CF, screen time, and PAclub. The models predict that children aged 8.86 years (i.e. mean age) at percentile 10 versus 90 of RS consume fast food on average 4.89 versus 5.85 times a week respectively, and consume sweet drinks on average 6.95 versus 8.42 times a week, respectively.

Table 13 Pearson correlations between reward sensitivity, age and weight-related behaviors and comparisons of these variables across sex and parental education level

	RS		Age		Fast food CF[a]		Sweet food CF[a]		Sweet drink CF[a]		Screen time		PAclub		zBMI	
	r	*P*	r	*P*	r	*P*	r	*P*	r	*P*	r	*P*	r[b]	*P*	*r*	*P*
Age	-0.09	0.06														
Fast food CF[a]	0.09	0.06	0.08	0.10												
Sweet food CF[a]	-0.03	0.51	-0.09	0.07	0.10*	0.05										
Sweet drink CF[a]	0.09	0.06	0.03	0.57	0.26**	<0.01	0.15**	<0.01								
Screen time	0.03	0.62	0.23**	<0.01	0.29**	<0.01	0.11*	0.04	0.14**	0.01						
PAclub[b]	0.02	0.67	0.16**	<0.01	<-0.01	0.96	<-0.01	0.87	-0.03	0.55	0.03	0.63				
zBMI	0.13**	<0.01	-0.08	0.12	0.11*	0.02	-0.13**	<0.01	0.01	0.81	0.04	0.40	-0.08	0.13		
	t (df)	*P*	t (df)	*P*	t (df)	*P*	t (df)	*P*	t (df)	*P*	t (df)	*P*	U (Z)	*P*	t(df)	*P*
Sex	1.82 (441)	0.07	-0.35 (441)	0.73	0.59 (425)	0.56	0.54 (429)	0.59	0.82 (425)	0.41	1.76 (359.44)	0.08	16604.00 (-1.61)	0.11	-0.76 (441)	0.450
PEL	0.47 (411)	0.64	1.66 (411)	0.10	3.99 (396)**	<0.01	-1.24 (400)	0.22	3.60 (395)**	<0.01	3.15 (367)**	<0.01	11294.00 (-1.07)	0.29	4.47 (411)**	<0.01

*Note. RS, reward sensitivity. CF, weekly consumption frequency. PAclub, physical activity in sports clubs.zBMI, age- and sex-independent z-score of Body Mass Index. r, correlation coefficient. t(df), t-value and degrees of freedom of unpaired t-test. U(Z), Mann-Whitney U and Z test statistic. PEL, parental education level. [a]The natural logarithm of the food indices was used. [b] Spearman instead of Pearson correlation was conducted. *P<0.05, **P<0.01.*

Table 14 Linear and logistic regressions with reward sensitivity as predictor and weight-related behaviors as dependent variables

Dependent variable		Intercept		RS			Age[b]			Sex[c]				
	N	b (SE)	*P*	b (SE)	β	*P*	b (SE)	β	*P*	b (SE)	β	*P*	r_{sp} (RS)	R^2
Fast food CF[a]	427	2.42 (0.05)	<0.01	0.01 (0.01)	0.10	0.04	0.02 (0.01)	0.09	0.07				0.10	0.02
Sweet food CF[a]	431	2.55 (0.07)	<0.01	-0.01 (0.01)	-0.04	0.42	-0.03 (0.01)	-0.09	0.06				-0.04	0.01
Sweet drink CF[a]	427	2.30 (0.08)	<0.01	0.02 (0.01)	0.10	0.05	0.01 (0.02)	0.04	0.46				0.10	0.01
Screen time	383	10.92 (1.04)	<0.01	0.08 (0.11)	0.04	0.44	0.96 (0.20)	0.24	<0.01	-1.13 (0.61)	-0.09	0.10	0.04	0.06
	N	b_{log} (SE)	*P*	b_{log} (SE)	OR	*P*	b_{log} (SE)	OR	*P*	Nagelkerke R2				
PAclub	389	-0.57 (0.33)	0.09	0.05 (0.04)	1.05	0.18	0.27 (0.07)	1.32	<0.01	0.05				

Note. RS, reward sensitivity. r_{sp}, semipartial correlation. b, unstandardized regression coefficient. SE, standard error of b. β, standardized regression coefficient. CF, weekly consumption frequency. b_{log}, logistic regression coefficient. OR, odds ratio. PAclub, dichotomized physical activity in sports clubs with value zero for low and value one for high PAclub. [a]The natural logarithm of the food indices was used. [b]Centralized child-age. [c]Value zero for boys, value one for girls.

c. Association of RS with zBMI

RS was significantly and positively associated with zBMI (Table 15). RS significantly explained an extra 2% of the variance in zBMI to the variance explained by the weight-related behaviors and PEL. Tolerance values to check multicollinearity were all above 0.8 in both steps of the model. The model predicts that children at percentile 90 of RS have on average a 0.34 units higher zBMI than children at percentile 10 of RS.

Table 15 Linear regression with Body Mass Index as dependent variable. Weight-related behaviors and parental education level were included as predictors in step 1, reward sensitivity was added as predictor in step 2.

Dependent variable: zBMI					
	Predictor	b	SE	β	*P*
Step 1 R^2=0.08	Intercept	0.35	0.19		0.06
	Fast food CF	0.02	0.01	0.11	0.06
	Sweet food CF	-0.03	0.01	-0.15	<0.01
	Sweet drink CF	<0.01	0.01	-0.03	0.53
	Screen time	<0.01	0.01	-0.02	0.73
	PAclub	-0.04	0.03	-0.07	0.19
	PEL	-0.39	0.12	-0.18	<0.01
Step 2 R^2=0.10 $P(\Delta R^2)<0.01$	Intercept	-0.04	0.23		0.85
	Fast food CF	0.02	0.01	0.09	0.09
	Sweet food CF	-0.02	0.01	-0.15	0.01
	Sweet drink CF	-0.01	0.01	-0.05	0.4
	Screen time	<0.01	0.01	-0.02	0.74
	PAclub	-0.04	0.03	-0.07	0.15
	PEL	-0.39	0.12	-0.18	<0.01
	RS[a]	0.05	0.02	0.15	<0.01

Note. zBMI, age- and sex-independent z-score of Body Mass Index. b, unstandardized regression coefficient. SE, standard error of b. β, standardized regression coefficient. CF, weekly consumption frequency. PAclub, physical activity in sports clubs. PEL, parental education level, value zero for low and value one for high PEL. $P(\Delta R^2)$, P value of the R^2 change between step 1 and step 2. RS, reward sensitivity. [a]Semi-partial correlation of RS is 0.15.

8.1.5 Discussion

The present study investigated the associations of the scores on a short RS questionnaire, namely the drive subscale of the BIS/BAS scale (Carver & White, 1994), with weight related behaviors and zBMI in a general population sample of children aged 5.5-12 years.

The results confirmed that children with higher RS may consume more frequently fast food and sweet drinks. Similar findings were recently found in adolescents aged 14-16 years (De Cock et al., 2015). The current study findings suggest that even in children, whose access to food is strongly determined by others (e.g. parents, teachers), the individual characteristic RS may play a role in palatable food consumption. Children high in RS might be more easily tempted by palatable fast food and sweet drink cues, and more motivated to consume them. This might shape unfavorable food habits that continue during life.

The research hypothesis that RS was positively associated with the sweet food CF could not be confirmed. Nevertheless, in line with other studies, the sweet food CF was not related to PEL, whereas the fast food and sweet drink CF were related to PEL (Elinder, Heinemans, Zeebari, & Patterson, 2014). Possibly, the fast food and sweet drink CF might be determined by different parameters (PEL, RS) than the sweet food CF, which might be determined by habits in Flemish primary schools (eating biscuits and/or chocolate bars as snacks during school breaks is common).

The present study found no associations between RS and the potentially rewarding behaviors “screen time” and “physical activity in sports clubs”. Previous research on this associations in primary school children is to our knowledge absent. Possibly, RS is not associated with these weight-related behaviors. Nonetheless, the lack of a relation between RS and screen time might also be due to high parental control or restriction over screen time in this age group. Additionally, screen time was measured in the current study by the sum of ‘hours of television viewing’ and ‘hours in front of a computer/game console’, but only the hours of engagement in rewarding computer games might be related to RS. Future research is therefore needed to replicate these findings with refined measures of screen time, thereby differentiating between television and gaming. The lack of a relation between RS and PAclub was in line with results of a systematic review on children and adolescents, which concluded that PAclub was more consistently related to environmental characteristics than to interpersonal factors (de Vet, de Ridder, & de Wit, 2011). Indeed, whether children like sporting in a sports club or not, the hours of PAclub of primary school children is dependent on the permission and logistic support of their parents and on nearby sports club facilities. Further, future research in children might explore the relationship between RS and objectively measured physical activity (e.g. with accelerometers), assessing the overall level of PA during daytime.

In the current study, only a trend significant positive association between the fast food CF and zBMI was present. No associations of the sweet drink CF, screen time, and PAclub with zBMI were found. Recent reviews indicated that only some studies reported significant relations between these parameters and BMI (Malik et al., 2013; Must, Barish, & Bandini, 2009). Probably, differences in methodology can explain the different findings. Further, a negative relation between sweet food CF and zBMI was found, which is in conflict with a meta-analysis that reported no significant relationship between sweet food and BMI in children (Te Morenga et al., 2013). This negative association might be due to the assessment of consumption frequencies without inquiring portion sizes. Portion sizes of sweet food CF might vary substantially across children (e.g. one versus three cookies per consumption). Hence, future research should include more detailed assessment of dietary habits, identifying not only frequency but also portion size.

Finally, the current study demonstrated a positive association between RS, measured by the drive subscale of the BIS/BAS scale, and zBMI in normal to overweight children. This finding was already reported in children and young adolescents aged 10 to 15 years with the same RS questionnaire (Verbeken et al., 2012) and in children aged 6-13 years with a different RS questionnaire (van den Berg et al., 2011). Another study in children who used a behavioral task as RS measure did not find this association (Scholten et al., 2014). Moreover, RS assessment explained additional variance of zBMI to the variance explained by food consumption, activity pattern, and PEL. Therefore, the assessment of RS with this very short questionnaire might have an added value in public health and pediatrics.

The positive association between RS and zBMI was found in a population of children without obesity. Children with obesity were excluded from the analyses because (a) the focus of this study is on obesity prevention, (b) the obesity rate in the current sample was too low to accurately investigate the relation between RS and zBMI in obese children, and (c) most importantly, RS was only positively associated with BMI in adolescents (Verbeken et al., 2012) and adults (C. Davis & Fox, 2008) without obesity, but negatively associated with BMI in the obese population in both studies. This inverted relation is probably due to changes in brain reward processes over the course of obesity development (Kessler, Zald, Ansari, Li, & Cowan, 2014).

The positive associations of RS with fast food CF, sweet drink CF and zBMI reported in this paper are relevant for future prevention strategies, certainly if future longitudinal studies can confirm an increased obesity risk in high RS children. Such associations can offer an explanatory framework for parents and health care workers on why some children are more tempted by palatable food compared to other children. Further, specifically targeting children high in RS, which are assumed to be more vulnerable to the obesogenic environment, may improve the effectiveness of obesity prevention interventions. In fact, there is already some evidence in adults as to which elements to include in prevention interventions tailored to this RS feature. Three such elements are worth briefly describing in the context of this paper. First, messages that are framed in terms of the benefits of adopting the recommendation (i.e. gain-frame) rather than the disadvantages and costs of not adopting a recommendation are more effective in high RS individuals (Covey, 2014). Second, the study of Forman et al. (2007) compared two methods designed to help individuals manage palatable food cravings such that they do not lead to palatable food consumption: (a) 'control-based strategies', e.g. removing palatable foods from the direct home or work environment, restructuring thoughts that permit eating palatable food, and refocusing strategies designed to turn attention away from food related stimuli towards non-food related stimuli; (b) acceptance-based strategies, e.g. awareness and acceptance of the feelings of food cravings without trying to suppress or eliminate them and without taking actions in order to consume the desired food. The method with acceptance-based strategies decreased the consumption of palatable foods in participants with high RS specific to food, but increased food cravings in participants with low RS specific to food. Hence, interventions using these acceptance-based strategies are useful only in high RS individuals. Third, self-regulatory skills were found to moderate the relation between RS and BMI in adults (Lawrence, Hinton, Parkinson, & Lawrence, 2012). Therefore, the training of self-regulatory skills (Verbeken, Braet, Goossens, & van der Oord, 2013) might be effective to reduce palatable food consumption in high RS individuals. Future research should clarify if also in children, these three intervention techniques can be successfully applied.

8.1.6 Strengths, limitations, and directions for future research

The limitations of the current study include its cross-sectional design. Future longitudinal research to confirm causality is needed. Further, although BMI is a frequently used measure of adiposity, better measures exist (e.g. densitometry). Next, children with overweight and obesity, as well as families with lower levels of parental education were relatively underrepresented in the current study. Therefore, future research in a more representative sample is recommended. Additionally, RS and all weight-related behaviors were based on subjective questionnaires. The construct of RS could be confounded by parenting style, and the relation of RS and palatable food consumption in children could be confounded by food provision patterns of parents, which were not taken into account in the current study. Further, the PAclub measure did not include PA of the child outside of sports clubs. The number of missing values on weight-related variables was high due to time constraints of parents. However, no differences were found in RS and zBMI between the total sample and the subsample. Because inclusion of portion size assessment in a cohort study is a high burden for participants and would result in a reduced sample size, the food indices were only based on consumption frequency assessments. Therefore, associations between the three food indices and zBMI should be interpreted with caution. Unless the mentioned limitations, relationships between the weight-related parameters screen time, the fast food CF, sweet food CF, sweet drink CF, and PEL were as expected based on the literature (Fernandez-Alvira et al., 2015; Pearson & Biddle, 2011; Tandon et al., 2012). Further, the strengths of the current study include the large general community sample of primary school children, the use of a simple and short RS questionnaire, the consideration of multiple weight-related behaviors, and the objective measurement of weight and length.

8.1.7 Conclusion

Overall, the results of the current study suggest that children high in RS are more easily tempted by palatable fast food and sweet drink cues, which might lead to unhealthy food habits. Further, children high in RS might be more prone to develop overweight. These findings suggest that considering inter-individual differences in RS can be of importance in future childhood obesity prevention campaigns. Future longitudinal research is warranted to verify that RS is a risk factor of unfavorable food habits and overweight in children.

8.2 Palatable food consumption in children: interplay between (food) reward motivation and the home food environment[6]

[6] This section is based on De Decker, A., Verbeken, S., Sioen, I., Van Lippevelde, W., Braet, C., Eiben, G., Pala, V., Reisch, L., De Henauw, S., Consortia, I.F. Palatable food consumption in children: interplay between (food) reward motivation and the home food environment. European Journal of Pediatrics, (), 1-10.

8.2.1 Abstract

To understand the importance of the home food environment on unhealthy food consumption in children high in reward sensitivity, this study tested the hypothesis that the home availability of unhealthy food moderates the relation between reward sensitivity and children's fast food consumption frequency, exerted via food cue responsiveness. Children between 7.5 and 14 years (n=174, 50.6% boys) reported on reward sensitivity and food cue responsiveness (by means of the subscale 'external eating'). Their height and weight was measured. Parents reported on their children's fast food consumption frequency, food cue responsiveness (by means of the subscale 'food responsiveness'), and on the home availability of unhealthy foods. Two moderated mediation models were conducted, one with the parent- and one with the child-reported food cue responsiveness as mediator. Findings suggested that with a high home availability of unhealthy foods, (a) a higher fast food consumption frequency was found in children high in reward sensitivity, and (b) the relation between reward sensitivity and the fast food consumption frequency was mediated by external eating. *Conclusions:* The findings point at the importance of the home food environment in children high in reward sensitivity. They suggest to limit the home availability of unhealthy foods.

8.2.2 Introduction

Dietary guidelines are made to support healthy growth and prevent chronic diseases (Chopra et al., 2002). However, the current dietary pattern of many children in Europe does not comply with these guidelines (Diethelm et al., 2012; Mejia et al., 2013). An overconsumption of saturated fatty acids and salt has been reported (Diethelm et al., 2014; Inge Huybrechts & De Henauw, 2007). Fatty acids and salt are mainly originating from palatable, energy-dense and nutrient-poor processed foods (I. J. Brown et al., 2009; Cribb et al., 2013). Exposure to cues of palatable foods, such as the smell or a picture on a billboard, can evoke automatic approach responses leading to palatable food consumption (D. A. Cohen & Babey, 2012). These cues are omnipresent in the current daily living environment of most children (Chopra et al., 2002). However, not all children respond to them equally with (over-) consumption (Fisher & Birch, 2002). These inter-individual response differences can result from individual characteristics that interact with the food environment (Blundell et al., 2005).

The personality trait 'reward sensitivity' (RS) and the appetitive trait 'food cue responsiveness' have been proposed as two such characteristics (C. Davis et al., 2007;

Schachter, 1968). RS explains inter-individual differences in reward motivation, i.e. in motivated approach-behavior towards rewards in response to reward-predicting-cues (Carver & White, 1994). Cues can be objects, pictures, smells etcetera for which individuals learned that they were associated with the obtainment of rewards. Since also palatable foods have rewarding properties (Rolls, 2011), individuals high in RS are assumed to be more vulnerable to palatable food cues in the environment. A characteristic that is related to but distinct from RS is food cue responsiveness. Food cue responsiveness specifically explains differences in food reward motivation, i.e. the strength of the behavioral tendency to approach and consume food when food cues are perceived (Schachter, 1968).

In children and adolescents, RS has been positively associated with palatable food consumption (De Cock, Van Lippevelde, Vervoort, et al., 2016; De Decker et al., 2016). Moreover, food cue responsiveness has been identified as a mediator of the relation between RS and palatable food consumption in adolescents (De Cock, Van Lippevelde, Goossens, et al., 2016). However, in a laboratory study with children, it was found that RS was only related to palatable food consumption when multiple palatable foods were available (Guerrieri et al., 2008). An observational study in adults demonstrated a similar interaction effect between RS and the food environment on palatable food consumption (Paquet et al., 2010). To our knowledge, the interplay between RS, food cue responsiveness and the everyday food environment on palatable food consumption has not been investigated yet in primary and first grade secondary school children. However, testing the hypothesis that children high in RS are more vulnerable to palatable food cues using an observational study can be very informative with respect to parents in order to prevent overconsumption of energy-dense foods in their children.

Therefore, the current study tested the hypothesis that when unhealthy, palatable snacks are highly available at home (‘unhealthy home environment’), a positive relation between RS and children’s fast food consumption frequency via food cue responsiveness will be more likely to occur (Figure 11). In this context, fast food is seen as a relevant category of palatable, energy-dense, nutrient-poor food; its consumption frequency has already been related to RS in a previous study (De Decker et al., 2016). In addition, it is assumed that the moderation effect of the parameter ‘unhealthy home environment’ is exerted on the relation between food cue responsiveness and the fast food consumption frequency based on theory (i.e. high food cue responsiveness refers to being strongly triggered by environmental food cues).

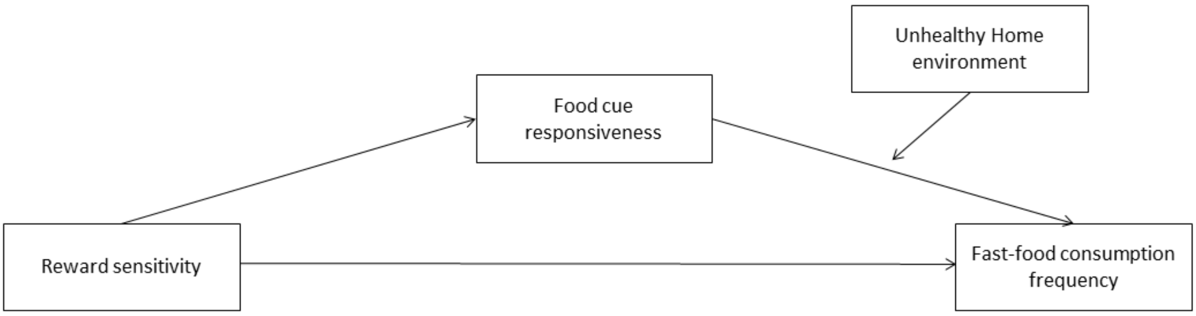


Figure 11 Conceptual diagram of the moderated mediation model.

8.2.3 Methods

a. Study participants and protocol

Subjects were Dutch-speaking Belgian children between 7.5 and 14 years, living in the region of Aalter. The subjects were recruited in the framework of the population-based ‘I.Family-Forces’ study in 2013, which was organized in the framework of two simultaneous research projects:

-the ‘Investigating the determinants of food choice, lifestyle and health in European children, adolescents and their parents’ project (I.Family; www.ifamilystudy.eu), which is a European follow-up study on the original cohort of the ‘Identification and Prevention of Dietary- and Lifestyle-Induced Health Effects in Children and Infants’ study (IDEFICS) (Ahrens et al., 2011);

-the project ‘Forces’, which is a Belgian study embedded in the REWARD study (www.rewardstudy.be).

The participants of the I.Family-Forces study were:

-children who participated earlier in the IDEFICS study and belong to the Belgian control region (the inclusion criteria to participate in the IDEFICS study were (1) the child’s age and (2) being a pupil of one of the twelve schools located in the region Aalter). In 2013, these children were re-invited to participate in the ‘I.Family-Forces study’ via mail, email and/or telephone;

-new children living in the same region (Aalter), which were invited to join the study via an advert on one Flemish television channel and in local newspapers (the only inclusion criterion was an age between 7.5 and 14 years, similar to that of the existing cohort).

Aalter is a municipality in Flanders, a region in Belgium. Aalter had 19860 inhabitants in 2012 on a surface area of 81.9 km^2, with an average-to-high median net income (18434 euro/year compared to 17085 euro/year in Belgium). The proportion of immigrants is lower in Aalter compared to Belgium (2.4% versus 11.2%) (Statbel).

In the current study, only children with complete parent-reported data on the unhealthy home environment (77.3% of the total sample) and fast food consumption (86.7% of the total sample), child-reported RS (79.3% of the total sample), and measured weight and height (97.7% of the total sample) were included, resulting in a study sample of 176 children (58.7% of the total sample; due to the large survey battery, participants with time constraints did not complete every measurement/questionnaire and therefore, the percentages on the different variables vary). The included participants did not significantly differ from the excluded participants on sex, parental education level, body mass index (BMI), RS, fast food consumption frequency, external eating, food responsiveness and the unhealthy home environment, but did significantly differ on age (mean age: included participants=10.44y, excluded participants=11.18y, t=4.16, degrees of freedom=298, $p<0.001$).

At a prefixed appointment, the children attended the survey center (in most cases accompanied by at least one parent), height and weight were measured, and the child questionnaires were completed. Some children of the IDEFICS-cohort could not come to the study center due to time constraints of children or parents; to improve the study participation rate, data collection in these children was done at school before lunch breaks. Parental questionnaires were completed at the survey center or at home.

The I.Family-Forces study was conducted according to the guidelines laid down in the Declaration of Helsinki and was approved by the Ethics Committee of Ghent University Hospital. Written informed consent was obtained from all parents and the children gave verbal assent.

b. Measures

RS. The drive subscale of the Behavioral Activation Scale measures the strength of motivated approach-behavior towards rewards in response to reward-predicting-cues (e.g. 'our child does everything to get the things that he/she wants') (Carver & White, 1994). The mean score of the four items of the Dutch drive subscale, which all have to be scored on a 4-point Likert scale from 'not true' (value "1") to 'very true' (value "4"), was used as a measure of RS

(Muris et al., 2005). The internal consistency of RS (4 items), measured by means of the Cronbach alpha coefficient, in the current study (0.79) was comparable to the alpha reported in a study in children aged 11 to 12 years (Bjornebekk, 2009).

Food cue responsiveness. Two well-validated questionnaires exist to measure the appetitive trait 'food cue responsiveness': the subscale 'external eating' of the Dutch Eating Behavior Questionnaire (Van Strien et al., 1986) and the subscale 'food responsiveness' of the Child Eating Behavior Questionnaire (Wardle et al., 2001). Both are designed to measure eating behavior in response to external food cues. The study hypothesis was tested with the mean scores of both subscales. Children reported on the 10 items of the Dutch external eating subscale (e.g. 'If you see or smell something delicious, do you have a desire to eat?'), which have to be scored on a 5 point Likert-scale from 'never' (value "1") to 'very often' (value "5") (Van Strien et al., 1986). The Cronbach's alpha in this study (i.e. 0.81) was comparable to the alpha reported in a study in children aged 13-15 years (Snoek, Engels, van Strien, & Otten, 2013) and in children aged 5-12 years (Michels et al., 2015). Parents reported on the 5 items of the Dutch food responsiveness subscale (e.g. 'even if my child is full up s/he finds room to eat his/her favorite food'), which have to be scored on a 5 point Likert-scale from 'never' (value "1") to 'always' (value "5") (Sleddens et al., 2008). The Cronbach's alpha in this study (i.e. 0.85) was comparable to the alpha reported in a study in children aged 6 to 12 years (Santos et al., 2011).

Unhealthy home environment. Parents reported on the 4 items of the subscale 'environment' of the 'Comprehensive Feeding Practices Questionnaire', which has to be scored on a 5 point Likert-scale from 'disagree' (value "1") to 'agree' (value "5"). This subscale assesses how much effort parents invest in order to create a healthy home food environment for children (Musher-Eizenman & Holub, 2007). In 10 to 12 year old children, Melbye et al. demonstrated that the four items of the environment subscale load onto two different factors: one reflecting the availability at home of healthy foods and one of unhealthy, palatable snacks (Melbye, Ogaard, & Overby, 2011). A preliminary principal component analysis on the current study data confirmed this. The two items reflecting availability of unhealthy, palatable snacks are 'I keep a lot of snack food (potato chips, Doritos, cheese puffs) in my house' and 'I keep a lot of sweets (candy, ice cream, cake, pies, pastries) in my house'. Since the current study focuses on palatable food consumption, the mean score of these two items with a Cronbach's alpha of 0.62 was used. This score was conceived as a measure of an unhealthy home environment.

Fast food consumption frequency. Parents reported on the 59 food and beverage items/categories of the 'Children's Eating Habits Questionnaire - Food Frequency Questionnaire', which measures the child's usual weekly consumption frequency in the presence of the parent, thereby considering the preceding 4 weeks (I. Huybrechts et al., 2011; Lanfer et al., 2011). For each item/category, response options (assigned values in brackets) were 'never/less than once a week' ("0"), 'one to three times a week' ("2"), 'four to six times a week' ("5"), 'one time a day' ("7"), 'two times a day' ("14"), 'three times a day' ("21"), and 'four or more times a day' ("30"). The fast food consumption frequency was calculated by summing up the weekly consumption frequencies of all items/categories referring to fast food and combined sauces, namely 'fried potatoes, potato croquettes', 'pizza as main dish', 'snacks like crisps, corn crisps, popcorn', 'snacks like savory pastries and fritters', 'not homemade hamburger, hot dog, kebab, wrap, falafel, sandwiches', 'ketchup', and 'mayonnaise and mayonnaise based products' (De Decker et al., 2016).

Anthropometry. Height (to the nearest 0.001 m) was measured with a SECA 213® and body mass (kg) with the BOD POD® balance (at the study center; software version 4.2.4, Life Measurement, Inc., Concord, California, USA) or Tanita BC418® (at school). Children were not allowed to eat or drink during 2 hours preceding the anthropometric measurements, and were measured barefooted wearing only a bathing suit. Upon weight and length data, age and sex-specific body mass index z-scores (zBMI) were calculated using Flemish 2004 growth reference data (Roelants et al., 2009).

Parental education level. The highest parental education level of both parents was first categorized according to the International Standard Classification of Education of 1997 (UNESCO, 1997), and because of low numbers in some categories, further categorized in two groups: children with no tertiary educated parents (value "0") and children with minimum one tertiary educated parent (value "1").

c. Statistical analyses

Analyses were performed using PASW Statistical Program version 20.0 (SPSS, IBM, IL, USA), and the process-macro of Hayes (Hayes, 2013). The two-sided level of significance was $p<0.05$. When only one item on the subscales RS, food responsiveness and external eating was missing, mean scores were still calculated, which was the case for 5, 0, and 5 children respectively. The mean score on these measures was not calculated for children with more than one item missing, which was the case for 16 children on external eating and for 1 child on food responsiveness (i.e. all items were missing, mostly due to time constraints of the children). Spearman correlations between the scores on the RS measure and on the two food cue responsiveness measures were computed to explore if children had the same position on the trait continua.

To investigate the research hypothesis, two hierarchical moderated mediation models (one for each food cue responsiveness measure) were tested using ordinary least square regression procedures (Figure 12 and Figure 13) (Hayes, 2013). In all steps of both models, (a) sex (value “0” for boys, value “1” for girls), zBMI and parental education level were included as covariates, and (b) centered values of RS (minus 2.5), external eating (minus 3.0), food responsiveness (minus 2.0), unhealthy home environment (minus 2.5), and age (minus 10.0 years) were used. In a first step, the main effects of RS, food cue responsiveness and unhealthy home environment on fast food consumption frequency were examined. In a second step, the interaction term of the unhealthy home environment with food cue responsiveness was added. To interpret a significant interaction effect, the region of significance of the interaction was derived with the Johnson-Neyman technique (Bauer & Curran, 2005). In a third step, the relation between RS and food cue responsiveness, and the (conditional) indirect effect of RS on the fast food consumption frequency via food cue responsiveness was tested with a moderated mediation model. If no moderated mediation was found, also a fourth step was conducted in which a simple mediation model was tested to repeat the findings of mediation by food cue responsiveness from previous studies. Significance of the index of moderated mediation and the indirect effects conditional on all integer values of the parameter ‘unhealthy home environment’ (in case of a moderated mediation model) or significance of the unconditional indirect effect (in case of a simple mediation model) was evaluated based on bias-corrected bootstrap 95% confidence intervals (CI) with 10000 bootstrap samples.

8.2.4 Results

a. Study population and descriptive statistics

Of the 176 children included in the current study, one was excluded from further analysis because of an extreme value of the fast food consumption frequency (i.e. 130 times a week) and one because data on food responsiveness as well as external eating was lacking. The remaining study sample (N=174) consisted of 50.6% boys, 21.3% children of parents with low parental education level, and 4% children with overweight including obesity (according to the International Obesity Task Force definition) (T. J. Cole & Lobstein, 2012). Table 16 shows the descriptive statistics. A trend significant small positive relation was found between the rank ordering of children on ‘food responsiveness’ and ‘external eating’ (Spearman r=0.154, p=0.052). RS was not significantly related to food responsiveness (Spearman r=0.098, p=0.200) but was significantly related to external eating (Spearman r=0.292, p<0.001).

Table 16 Descriptive statistics of continuous study variables

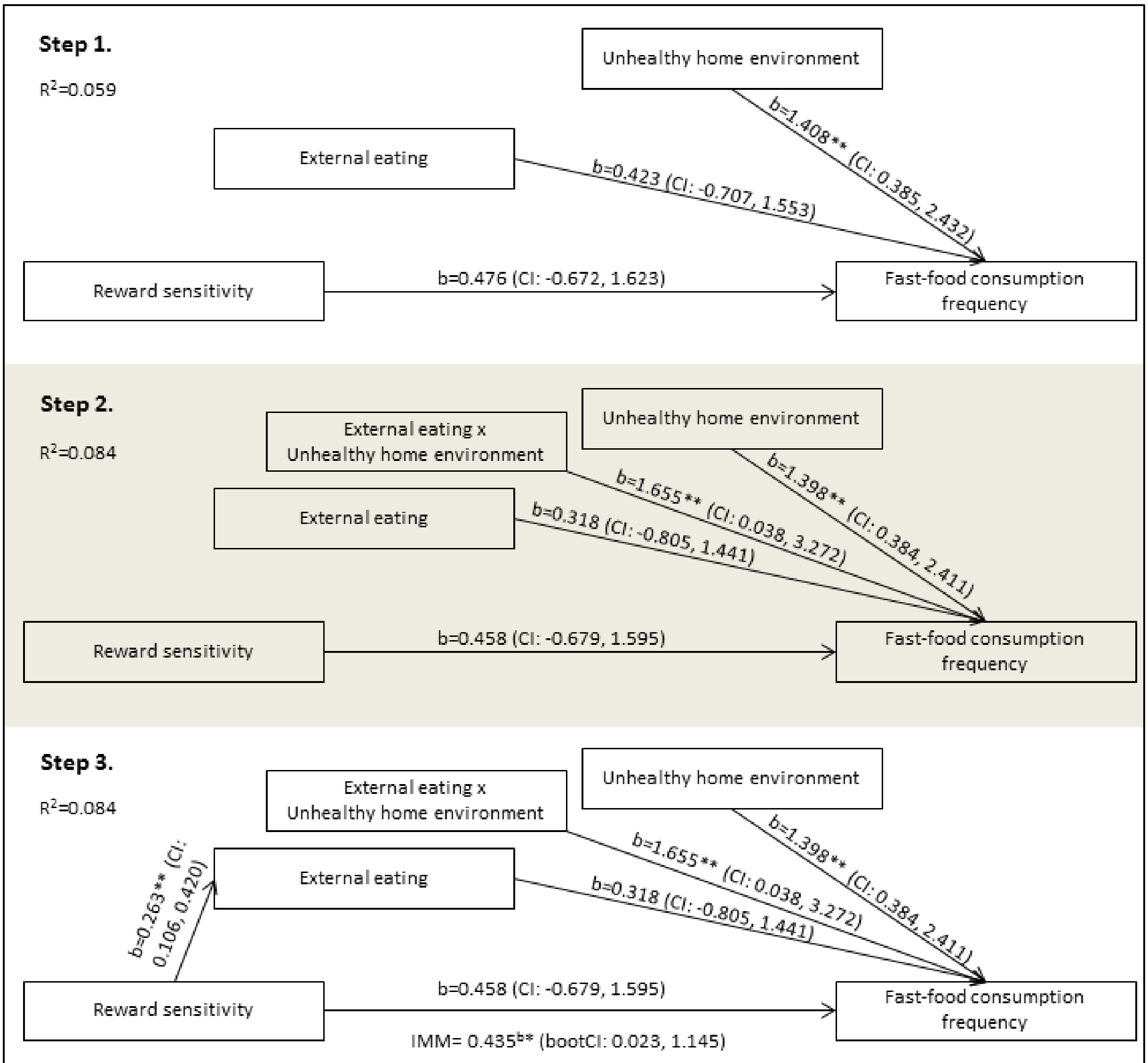
	N	M	sd	Minimum	Maximum
RS (range 1-4)	174	2.21	0.69	1.00	3.75
Food responsiveness (range 1-5)	174	2.16	0.88	1.00	4.80
External eating (range 1-5)	159	2.94	0.69	1.10	4.80
Unhealthy home environment (range 1-5)	174	2.58	0.74	1.00	5.00
Fast food consumption frequency (times a week)	174	7.43	4.89	0.00	21.00
Age (years)	174	10.47	1.50	7.59	13.66
zBMI	174	-0.38	0.91	-2.89	2.29

Note. N, number. M, mean. sd, standard deviation. RS, reward sensitivity. zBMI, age- and sex-independent z-score of Body Mass Index.

b. Model with external eating as food cue responsiveness measure

In step 1, a significant positive main effect of the unhealthy home environment on the fast food consumption frequency was found, but not of external eating or RS (Figure 12).

In step 2, a significant interaction was found between external eating and the unhealthy home environment on the fast food consumption frequency (Figure 12, step 2). The Johnson-Neyman technique indicated that the estimated regression slopes in the association between external eating and the fast food consumption frequency were not significantly different



Value of 'unhealthy home environment'	Estimate (bootCI) of indirect effect of RS on the weekly fast food consumption frequency
1	-0.569 (-1.498, 0.052)
2	-0.134 (-0.539, 0.177)
3	0.301 (-0.081, 0.928)
4	0.736b* (0.033, 2.081)
5	1.170b* (0.069, 3.243)

Figure 12 Results of multiple hierarchical regression models with external eating as mediator.
Note. Unidirectional arrows point from a predictor to a dependent variable of the model; all models are controlled for centered age (age minus 10 years), sex, age- and sex-independent z-score of the body mass index and parental education level. b indicates unstandardized regression coefficient. CI indicates 95% confidence interval. IMM indicates estimate of index of moderated mediation. bootCI indicates bias-corrected bootstrapping 95% confidence interval. x indicates an interaction term between the two specified variables. b indicates that the bias-corrected bootstrapping 95% confidence interval does not contain zero. *, p<0.05, ** , p<0.01.*

from zero for values in the range“1” to “3” of the unhealthy home environment score. Hence, when parents responded neutral or disagreed on the statements that a lot of unhealthy snacks were available at home, the relation between external eating and the fast food consumption frequency was not-significant. However, the relation between external eating and the fast food consumption frequency was significantly positive for values of the unhealthy home environment parameter between “3.5” to “5”. These values were found in 16.4% of the children in the current study. Thus, children with higher levels of external eating had a higher fast food consumption frequency if their parents agreed that a lot of unhealthy snacks were available at home. Based on the unstandardized regression coefficients (Figure 12, step 2) and assuming an unhealthy home environment score of 4 (i.e. high availability), a child with an external eating level on percentile 75 (value “3.4”) is predicted to have a 2.8 times higher fast food consumption frequency per week than a child with an external eating level on percentile 25 (value “2.4”). Additionally, no significant direct effect of RS on the fast food consumption frequency was found (Figure 12 step 2, non-significant coefficient for RS).

In step 3, it was found that RS was significantly and positively related to external eating(Figure 12, step 3). The index of moderated mediation was significant, which demonstrates that RS indirectly effected the fast food consumption frequency via external eating, but that this indirect effect was conditional on the parameter ‘unhealthy home environment’. The value of the index indicates that with an increase of one unit of the unhealthy home environment score, the indirect effect of RS on the fast food consumption frequency via external eating is predicted to increase with 0.435. For values in the range “1” to “3” of the unhealthy home environment score, no significant indirect effect was found of RS on the fast food consumption frequency via external eating. At values “4”, “4.5” and“5” of the parameter unhealthy home environment, RS had a significant positive relation with the fast food consumption frequency via external eating. The model predicts that with a value of the parameter unhealthy home environment of “4”, a child with a RS level on percentile 75 (value “2.75”) is predicted to have a 0.7 times a week higher fast food consumption frequency compared to a child with an RS level on percentile 25 (value “1.75”) as a result of the relation between RS and external eating which, in turn, is related to the fast food consumption frequency (Figure 12, step3). Step 4 was not conducted since a significant moderated mediation was found.

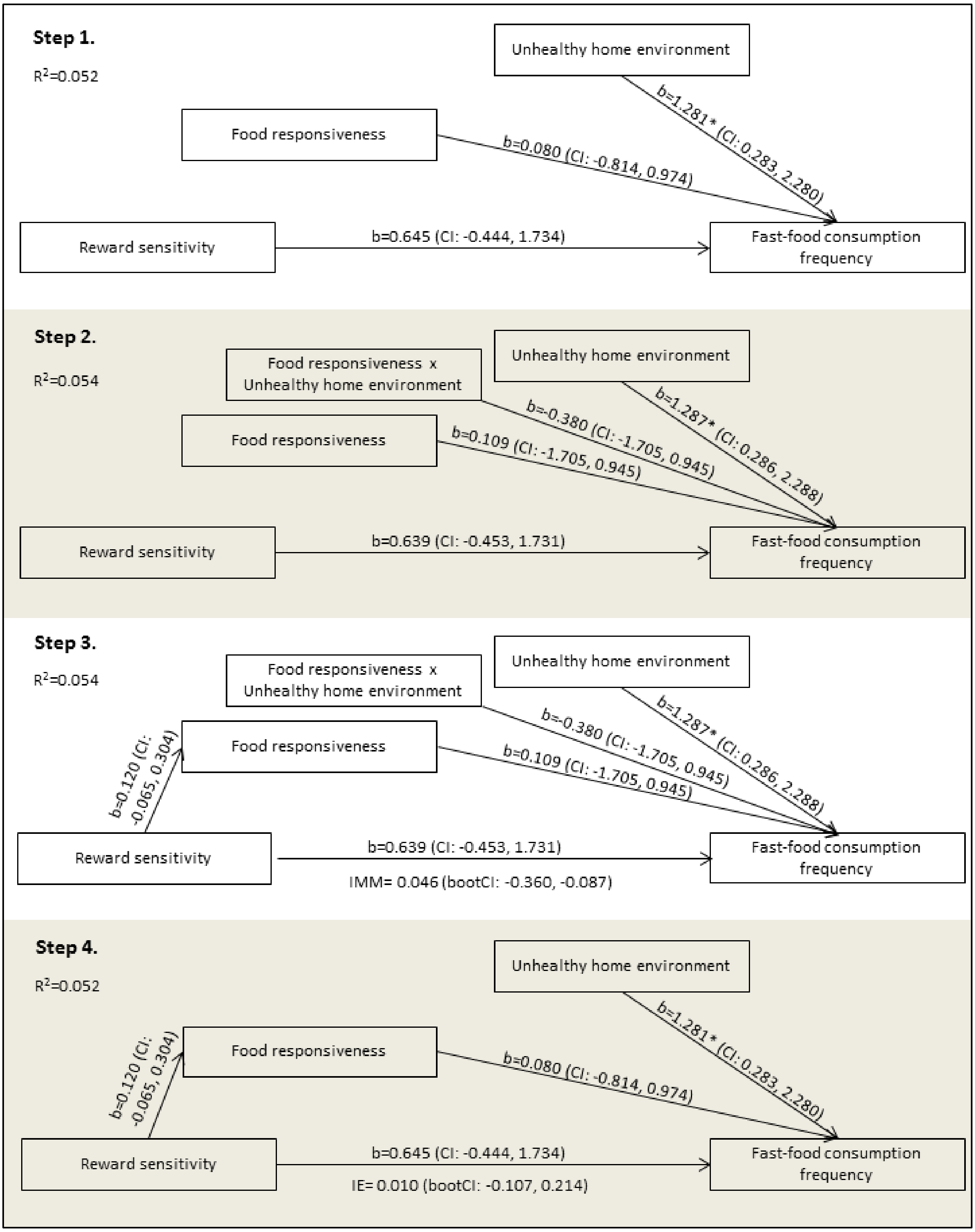


Figure 13 Results of multiple hierarchical regression models with food responsiveness as mediator.

Note. Unidirectional arrows point from a predictor to a dependent variable of the model; all models are controlled for centered age (age minus 10 years), sex, age- and sex-independent z-score of the body mass index and parental education level. b indicates unstandardized regression coefficient. CI indicates 95% confidence interval. IMM indicates estimate of index of moderated mediation. IE indicates estimate of indirect effect. bootCI indicates bias-corrected bootstrapping 95% confidence interval. x indicates an interaction term between the two specified variables. b indicates that the bias-corrected bootstrapping 95% confidence interval does not contain zero. *, p<0.05, **, p<0.01*

c. Model with food responsiveness as food cue responsiveness measure

In step 1, a significant positive main effect of the parameter unhealthy home environment on the fast food consumption frequency was found, but not of food responsiveness or RS (Figure 13). In step 2, no significant interaction was found between food responsiveness and the unhealthy home environment on the fast food consumption frequency. Additionally, no significant direct effect of RS on the fast food consumption frequency was found (Figure 13, step 1 and 2, non-significant coefficients for RS). In step 3, no significant relation between RS and food responsiveness was found. Further, the index of moderated mediation was non-significant, indicating that no significant indirect effect of RS via food responsiveness on the fast food consumption frequency conditional on the unhealthy home environment parameter was found (Figure 13, step 3). In step 4, no significant indirect effect of RS on the fast food consumption frequency was demonstrated (Figure 13, step 4).

8.2.5 Discussion

The present cross-sectional study tested the hypothesis that when the availability of palatable foods at home is high, children's RS levels are positively related to palatable food consumption via the tendency to respond to food cues with approach behavior (Figure 11). The proposed hypothesis was tested twice using two different well-validated food cue responsiveness measures: the external eating subscale of the Dutch Eating Behavior Questionnaire rated by children and the food responsiveness subscale of the Child Eating Behavior Questionnaire rated by parents.

The results confirmed the proposed hypothesis, but only when food cue responsiveness was measured with the external eating subscale. Importantly, only in a high unhealthy home environment, (a) higher levels of external eating were significantly related to higher levels of the fast food consumption frequency, and (b) in accordance, higher levels of RS were significantly related to higher levels of the fast food consumption frequency via higher levels of external eating. Hence, children with high levels of RS and external eating may be at higher risk of palatable food consumption particularly when exposed to a lot of palatable food cues in their daily living environment. The results of the current observational study are in line with results of a laboratory study in children (Guerrieri et al., 2008). However, the results were not in line with results of a study in adolescents in which no significant interaction effect was found although including the interaction term between food cue responsiveness and the home availability of palatable foods explained 8% additional variance in palatable food consumption (De Cock, Van Lippevelde, Goossens, et al., 2016). However, adolescents receive more pocket money and already have more autonomy to decide when and which food they eat (Bruening et al., 2014). Therefore, the outside-home food environment, such as fast food restaurant availability, might also be strongly associated with the food consumption of adolescents with high RS and/or high external eating (Bruening et al., 2014).

These findings provide arguments for limiting the availability of unhealthy foods at home, and as such, decrease cues of rewarding food in children's daily environment that can trigger a strong 'wanting' of the foods (Berridge et al., 2010). In this way, parents may contribute to the protection of children with high levels of RS and/or external eating against unhealthy food consumption. Although the reduction of environmental food cues seems more important for children high in these traits, the recommendation of limiting palatable food purchase has also been proposed for all children since multiple studies reported associations between higher availability and higher intake (e.g. (L. Johnson, van Jaarsveld, & Wardle, 2011; McGowan, Croker, Wardle, & Cooke, 2012)). Of course, learning to self-regulate unhealthy food consumption when exposed to palatable food cues is crucial: when children become adolescents and gain more autonomy, they should be able to competently effectively deal with environments outside home with an abundance of palatable food cues. It was shown that keeping all energy-dense foods out of children's physical reach at home is associated with overconsumption in ad-libitum situations (Rollins, Loken, Savage, & Birch, 2014a). In contrast, setting limits on children's unhealthy food consumption (i.e. limiting purchase besides when and how much is eaten of the foods) without keeping all snack foods out of children's reach was found to be a successful approach to prevent overconsumption in ad-libitum situations as well as weight gain (Rollins, Loken, Savage, & Birch, 2014b). This parental approach of limiting (without prohibiting) palatable food consumption is also in line with the approach recommended by an effective family-based weight loss treatment for overweight and obese children, aiming to reduce temptation and intake without creating feelings of deprivation in the child (Holland et al., 2014). However, the current study only included the interaction of (food) reward motivation characteristics with the home availability of unhealthy snacks. Repeating the current study findings longitudinally and including the interaction of RS and food cue responsiveness with the other parenting practices used in the study of Rollins et al. (i.e. limiting when and how much is eaten, keeping all energy-dense snacks out of children's physical reach at home) (Rollins et al., 2014b) are important directions for future research to further elucidate effective preventive parenting strategies for children high in RS.

Second, the current results, indicating that children high in the traits RS and food cue responsiveness react differently to influences from the environment, support the notion of Belsky and van Ijzendoorn (2015) that not every intervention strategy works for everyone because of differential susceptibility to environmental influences. Therefore, interventions should be tailored on relevant traits. Already some evidence exists in preschool children and adults as to which elements to include in prevention interventions tailored to the RS trait, e.g. giving a tangible reward to encourage desired behavior, framing messages in terms of the benefits of adopting a recommendation rather than in terms of the disadvantages and costs of not adopting a recommendation (Covey, 2014; Vandeweghe, Verbeken, et al., 2016). Future research may determine which elements to include in prevention interventions tailored to school children high in RS and/or external eating.

In contrast to the findings with the subscale 'external eating' as mediator, no significant associations were found with the subscale 'food responsiveness'. Both subscales were included in the current study because they both were developed based on the theory of Schachter to measure the appetitive tendencies of children when confronted with external food cues (Schachter, 1968; Van Strien et al., 1986; Wardle et al., 2001). Remarkably, the association between both was to our knowledge only investigated by one study which reported a moderate correlation between the parental scores on both measures (Groppe & Elsner, 2014). In the current study, scores on the food responsiveness and external eating subscales were only trend significantly and weakly correlated, and food responsiveness was not significantly associated with RS. Possibly, parent-child informant discrepancies may underlie the unexpected lack of a significant correlation, since children self-reported on external eating and RS, while parents reported on children's food responsiveness (De Los Reyes et al., 2013). Conversely, both subscales might measure a different part of the food cue responsiveness construct. In nine of the ten items of external eating, the tendency to initiate eating when triggered by an environmental food cue is explicitly assessed; the tenth item seems to assess the tendency to eat more of a food when consumption is already initiated. In contrast, the food responsiveness subscale consists of two items reflecting overeating (one in response to an environmental food cue and one possibly in response to the taste of food itself) and three items reflecting a general interest and desire to eat, without a reference to food cues. Although it is speculative to predict to what extent these differences in items measure differences in eating behavior, findings of one study suggest that food responsiveness is more related to overeating than to frequent cue-triggered consumption: the study reported that children with high food responsiveness consumed more energy with increasing portion sizes (Mooreville et al., 2015). Future research needs to further elucidate the nuances in the underlying constructs of the external eating and food responsiveness subscale, using parental report of both subscales or child report of both subscales to eliminate confounding due to parent-child discrepancies.

8.2.6 Strengths, limitations, and directions for future research

The limitations of the current study include its cross-sectional design. Future longitudinal research to endorse causality is needed. Additionally, all key variables were based on subjective questionnaires, and hence, responses may be influenced by social desirability. The fast food consumption frequency in the presence of the parents was reported, but some children may also consume fast food when parents are not present. Further, the parameter assessing palatable food consumption was only based on palatable food consumption frequencies, and not on portion sizes, which may underestimate the fast food intake in children who eat large portions and overestimate it in children who frequently eat small portions of fast food. Next, the average zBMI was slightly negative (i.e. healthier body composition), probably due to an overrepresentation of children from highly educated parents (Lamerz et al., 2005). The representativeness of the study was further limited due to recruitment of children from only one Belgian municipality, a municipality with high socioeconomic characteristics.

Strengths of this study include the testing of a moderated mediation model using two different questionnaires of the mediator and perspectives of children as well as parents, the general community sample of school children, and the inclusion of objectively measured zBMI as covariates in the analyses. In contrast with the behavioral task used in a laboratory study on this topic (Guerrieri et al., 2008), the current study used a short questionnaire measure of RS; also questionnaires of food cue responsiveness and the unhealthy home environment were short, and thus, easily applicable in epidemiologic research, obesity prevention interventions and clinical practice.

8.2.7 Conclusion

To conclude, this study was the first to investigate the interplay between RS, food cue responsiveness and the everyday food environment on palatable food consumption in children. Children high in RS were found to have a higher fast food consumption frequency because of higher external eating tendencies, but only when living in a high unhealthy home environment. The findings may be of great importance to inform parents of children high in these traits, and suggest to reduce palatable food cues in children's daily living environment in order to prevent unhealthy food consumption. Further, the findings may inform the development of tailored environmental obesity prevention interventions.

8.3 Fat and lean tissue accretion in relation to reward motivation in children[7]

[7] This section is based on De Decker, A., De Clercq, B., Verbeken, S., Wells, J.C.K, Braet, C., Michels, N., De Henauw, S., Sioen, I. (2017). Fat and lean tissue accretion in relation to reward motivation in children. Appetite, 108, 317-325.

8.3.1 Abstract

'Reward sensitivity' explains inter-individual differences in the motivation to obtain rewards when reward cues are perceived. This psychobiological trait has been linked to higher consumption of palatable food when exposed to palatable food cues. The current study aims to examine if reward sensitivity explains differences in patterns of fat and lean tissue accretion over time in children. A longitudinal observational study with measurement waves in 2011 (baseline), 2012, 2013, and 2015 was conducted. The sample was a population-based Flemish cohort of children (n=446, 50% boys and 5.5 to 12 years at baseline; 38.8% of the baseline sample also participated in 2015). Baseline reward sensitivity of the children was assessed by parent ratings on the drive subscale of the Behavioral Inhibition System/Behavioral Approach System scales. Age- and sex-independent Fat and Lean Mass Index z-scores (zFMI and zLMI respectively) were computed for each study wave based on air-displacement plethysmography. In girls, but not boys, reward sensitivity was positively associated with the baseline zFMI and zLMI (95% confidence intervals of unstandardized estimates: 0.01 to 0.11 and 0.01 to 0.10 respectively, P values 0.01 and 0.02 respectively). Further, reward sensitivity explained 14.8% and 11.6% of the change in girls' zFMI and zLMI respectively over four years: the zFMI and zLMI increased and decreased respectively in high reward sensitive girls (95% confidence intervals of unstandardized estimates: 0.01 to 0.11 and -0.12 to -0.01 respectively, P values 0.01 and 0.02 respectively). Hence, girls high in reward sensitivity had significantly higher adiposity gain over four years parallel with lower increase in lean mass than was expected on the basis of their age and height. These results may help to identify appropriate targets for interventions for obesity prevention.

8.3.2 Introduction

The psychobiological trait 'Reward sensitivity' (RS) explains inter-individual differences in motivation to approach rewards in response to reward-predicting-cues (Carver & White, 1994). Rewards can be presents, money, social factors (e.g. appraisal), palatable foods (such as sweet and fat rich foods) etc. Individuals learn that the possibility to obtain rewards is associated with certain cues (objects, pictures, smells etc.). These cues can trigger a motivated state in individuals that aims to generate behavior to approach and obtain the associated reward. Applied to palatable food, cues associated with the consumption of palatable food can evoke the tendency to approach and consume these foods, even in the absence of homeostatic hunger (A. W. Johnson, 2013). Individuals high in RS have a stronger tendency to approach and obtain rewards when perceiving reward-predicting-cues (Carver & White, 1994). Therefore, it has been proposed that RS contributes to the variability in adiposity gain in contexts in which food cues are highly present in the daily living environment (e.g. billboards, commercials, vending machines) (C. Davis, Strachan, & Berkson, 2004).

Considering the current high overweight and obesity prevalence in childhood (Lobstein, Baur, & Uauy, 2004) and its tracking into adulthood (Singh et al., 2008), the development of effective childhood obesity prevention strategies is of great importance. To identify appropriate targets for obesity prevention interventions, confirming and quantifying the association between RS and adiposity gain in children is critical. Different approaches to measure inter-individual differences in cue-triggered reward motivation exist, e.g. neuro-imaging techniques, laboratory-based behavioral tasks, and questionnaires that measure RS to all kinds of reward, i.e. 'general RS', as well as specifically to palatable food reward (Carnell et al., 2013). To use the information on this association for preventive purposes, the RS measure needs to be easily and practically applicable, and inexpensive; therefore, it is advisable to use questionnaires.

Using a general RS questionnaire, cross-sectional studies have reported higher consumption of palatable food (De Cock, Van Lippevelde, Vervoort, et al., 2016; De Decker et al., 2016; Paquet et al., 2010), food cravings (Franken & Muris, 2005), over-eating (C. Davis et al., 2007), and overweight (C. Davis & Fox, 2008; De Decker et al., 2016; Dietrich et al., 2014; Verbeken et al., 2012) with higher RS. Some of these studies differentiated by sex and reported that this relation was primarily present in females (De Cock, Van Lippevelde, Vervoort, et al., 2016; Dietrich et al., 2014). To confirm that higher scores on a general RS questionnaire indeed increase the risk of excess adiposity gain, longitudinal studies are needed but these are as far as we know absent. Therefore, the current study aimed to examine if inter-individual differences in general RS explain differences in fat and lean tissue accretion in children, and if the relation between RS and fat and lean tissue accretion differs in boys versus girls. The consideration of fat and lean tissue accretion instead of weight gain is an important advantage of this study, since lean tissue accretion can importantly contribute to weight gain (Wells, 2000). A positive association between RS and fat as well as between RS and lean tissue accretion over time was hypothesized, and it was hypothesized that this relation was stronger in girls.

8.3.3 Methods

a. Participants and procedure

Participants were 446 Dutch-speaking Belgian children (50% boys) aged 5.5 to 12 years at baseline (i.e. 2011). Baseline data on parental reports of children's RS as well as measurements of children's body composition in 2011, 2012, 2013, and 2015 were used (Figure 14). For all these study waves, children (in most cases accompanied by at least one parent) attended the survey center at a prefixed appointment, on which body composition measurements of the child were conducted and parental questionnaires were filled in. If no parent accompanied the child, one of the parents completed the questionnaires at home.

The children were recruited by random cluster design (all children of twelve primary schools of Aalter were contacted) for the longitudinal "Children's Body Composition and Stress" (ChiBS) study (Michels et al., 2012), with study surveys in 2010, 2011, and 2012. Data from 2010 were not used since RS was assessed for the first time in 2011. All children measured in the ChiBS study were invited via mail, email and, if no response, telephone calls to participate in the follow-up study "Rewarding-FOod ChoicES" (Forces), which is part of the REWARD-project (www.rewardstudy.be), with study surveys in 2013 and 2015. All participants for which baseline RS data were present were included in the current study (i.e. 446 of the 455 children who participated in the ChiBS survey of 2011).

The ChiBS and Forces studies were conducted according to the guidelines laid down in the Declaration of Helsinki and approved by the Ethics Committee of Ghent University Hospital. Written informed consent was obtained from all parents, and all children gave verbal assent.

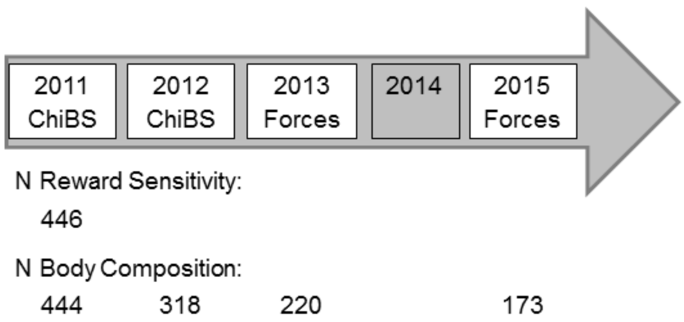


Figure 14 Number (N) of participants with RS data at baseline and body composition data at baseline and follow-up.

b. Measures

RS. The Behavioral Inhibition System (BIS) and Behavioral Approach System (BAS) scales (Carver & White, 1994) measure a person's behavioral and affective responses to (predicted) punishments and rewards respectively. The BAS scale consists of three subscales, i.e. fun seeking (measures the inclination to seek out new rewarding situations), reward responsiveness (measures positive affect and excitability when obtaining reward), and drive (measures the strength of pursuit to obtain reward in response to reward-predicting cues; e.g. our child does everything to get the things that he/she wants). Hence, the drive subscale is most strongly linked to the RS concept as described in the introduction section. Additionally, of the three BAS subscales, drive has the highest internal consistency; the validity of the fun seeking subscale is even questioned (De Cock, Van Lippevelde, Vervoort, et al., 2016; Vervoort et al., 2015). Furthermore, the Drive subscale, but not the Reward Responsiveness subscale, is strongly associated with neural responses to food-reward cues relative to bland food cues in the brain reward circuitry (Beaver et al., 2006). Therefore, the term RS in the text below refers to the sum score of the four items of the drive subscale, which were scored on a 4-point Likert scale (1=not true; 2=somewhat true; 3=true, 4=very true; total range on drive subscale: 4-16). Because the youngest children of the cohort were too young to answer the questionnaire themselves, parents answered a Dutch parent version of the BIS/BAS scale (Vervoort et al., 2015). The Cronbach alpha of RS in the current study (0.85) was comparable with the alpha reported by Vervoort et al. (i.e. 0.85) in children and adolescents aged 2-18 years (Vervoort et al., 2015).

Body composition. At least 2h before the measurement, children were asked to refrain from physical activity and food. Height was measured to the nearest 0.1cm. Body weight was measured with the BOD POD® balance, and body volume with the BOD POD® air-displacement plethysmography device (Software version 4.2.4, Life Measurement, Inc., Concord, California, USA), both using standardized procedures (McCrory, Gomez, Bernauer, & Mole, 1995). In accordance to the manufacturer's guidelines, the BOD POD® was calibrated daily and at each measurement, and children wore tight-fitting bathing suits with swimming caps during the measurement. Thoracic gas volume was predicted by the software with a validated child-specific equation (Fields, Hull, Cheline, Yao, & Higgins, 2004). Using weight, body volume, and thoracic gas volume, body density was calculated and converted into fat and lean masses using child-specific conversion factors (Wells et al., 2010). Then, fat and lean mass (kilogram) were divided by height squared (meter^2) to calculate fat mass index (FMI) and lean mass index (LMI), each in the same kilogram/meter^2 units as body mass index (BMI). Since no Flemish FMI and LMI reference curves for children are available, British reference curves were used to compute age- and sex-independent standard deviation scores of FMI (zFMI) and LMI (zLMI) (Wells et al., 2012). For descriptive purposes, also BMI was calculated and z-scores were computed based on Flemish reference curves (Roelants et al., 2009).

c. Data analyses

The two-sided level of significance was set at $p<0.05$. Descriptive analyses were performed using PASW Statistical Program version 20.0 (SPSS, IBM, IL, USA). Unpaired t-tests were conducted to test sex differences on age, RS, zFMI, and zLMI. To test drop-out differences, participants versus non-participants were compared on sex with a chi-square test and on age, RS, zFMI and zLMI with unpaired t-tests.

Longitudinal multilevel analyses were conducted in Mplus version 7.20 to examine change in zFMI and zLMI across time (Muthén & Muthén, 1998-2012). All models were calibrated using the default maximum likelihood estimation with robust standard errors. Multilevel modelling has significant advantages over traditional repeated measure techniques, since this does not require balanced data (i.e. number of available measurements do not have to be the same for all individuals) (Hox, 2010). A two-level model was used, with the repeated measures on the four time points at the lowest level (i.e. time level), and individual child parameters at the highest level (i.e. child level).

Preliminary multilevel analyses showed that sex significantly moderated the main effect of RS on zFMI. Furthermore, zLMI followed a different pattern in boys versus girls over time (Table 17), possibly due to slight differences in the accretion of lean mass between Flemish and British children. Therefore, the multilevel analyses were performed separately for boys and girls.

Four parallel series of incremental models were conducted, i.e. series for girls' zFMI change, series for girls' zLMI change, series for boys' zFMI change and series for boys' zLMI change. The incremental models, identical for each series, are explained in the following. Model 1 contained only the measurement occasion (time, split up in three time dummies) on the time level; this model provides the intraclass correlation (Hox, 2010). In model 2, the baseline centralized RS score (i.e. RS minus 9) was added on the child level. In model 3, the coefficients of the time dummies were allowed to be random. This model allows to evaluate the significance of the variance of the zFMI or zLMI slopes between time points (i.e. differences in the slopes of zFMI and zLMI between children over the time spans baseline-2012, baseline-2013 or baseline-2015). In model 4, cross-level interaction terms between RS and the time dummies were computed to assess whether RS explains differences in the slopes of zFMI and zLMI between children over time. Akaike's Information Criterion (AIC) was used to assess if an incremental model fitted the data better than the previous model (Burnham & Anderson, 2002). Parental education level was not included as covariate in the series of models since a preliminary t-test showed no mean difference on RS between children of parents with and without a tertiary education degree (t=0.468, p=0.640); age was not included as covariate since the outcomes zFMI and zLMI are age-independent parameters, and moreover, inclusion of age did worsen the model fit. Hence, no covariates were included in the models.

To rule out bias due to drop-out, sensitivity analyses were conducted by repeating the series of models on a subsample with zFMI and zLMI data at baseline and on the time point for which a significant cross-level interaction was present. The latter requirement was set and not the requirement of data on all time points in order to minimalize the reduction in sample size for the sensitivity analyses.

To illustrate the results graphically, the mean zFMI and zLMI of groups low and high in RS (lowest and highest tertiles respectively) were plotted as function of time.

8.3.4 Results

a. Descriptive and drop-out statistics

Table 17 shows descriptive statistics and parameter comparisons by sex. Only for zLMI, significant sex differences were present. Of the total study sample, 72.4% had minimum one tertiary educated parent, and 3.59% had missing data on parental education. At baseline, 8.1% of the children had overweight including obesity according to the International Obesity Task Force definition (T. J. Cole & Lobstein, 2012).

Of the children with body composition data in 2011, (1) the baseline zFMI was significantly higher in those who dropped out versus those who participated in 2013 (mean difference 0.24, 95% confidence interval (CI) [0.07,0.42], p<0.01), and (2) the baseline age was significantly higher in those who dropped out versus those who participated in 2013 (mean difference 0.48 years, 95% CI [0.21,0.75], p<0.01) and in 2015 (mean difference 0.54 years, 95% CI [0.26,0.81], p<0.01). No other significant drop-out differences on RS, zFMI, zLMI, age, and sex were found. Time-constraints and decreased motivation of older children to participate in the study were the main responses of participants when the unwillingness to participate was questioned in telephone calls.

Table 17 Descriptive statistics of age, RS and body composition variables

	Year	Boys			Girls			*P* value[a]
		N	Mean	sd	N	Mean	sd	
Age (years)	2011	223	8.83	1.51	223	8.87	1.45	0.79
RS (range 4-16)	2011	223	8.90	2.90	223	8.44	2.80	0.09
zBMI	2011	222	-0.25	0.88	222	-0.16	0.99	0.30
	2012	158	-0.34	0.89	160	-0.18	0.92	0.12
	2013	110	-0.57	0.90	110	-0.36	0.95	0.10
	2015	81	-0.46	0.87	92	-0.21	0.91	0.07
zFMI	2011	222	-0.25	0.89	222	-0.42	1.02	0.07
	2012	158	-0.33	0.94	160	-0.41	0.92	0.47
	2013	110	-0.58	0.87	110	-0.69	0.97	0.38
	2015	81	-0.28	0.95	92	-0.49	0.97	0.15
zLMI	2011	222	-0.25	1.04	222	-0.53	0.94	<0.01
	2012	158	-0.31	0.98	160	-0.49	0.90	0.08
	2013	110	-0.38	1.08	110	-0.43	0.98	0.69
	2015	81	-0.70	1.08	92	-0.38	1.00	0.05

Sd; standard deviation. RS; reward sensitivity. zBMI; standard deviation score of Body Mass Index based on Flemish reference curves. zFMI; standard deviation score of Fat Mass Index based on British reference curves. zLMI; standard deviation score of Lean Mass Index based on British reference curves.
[a] P value of unpaired t-test between boys and girls.

b. Explanation of between-child variability in the slopes of zFMI and zLMI over time by RS

Girls. Based on the AIC, model 4 of both zFMI and zLMI had the best data fit (Table 18). The results of model 4 demonstrated that RS significantly explained differences between girls (1) in baseline zFMI and zLMI, which is indicated by the significant positive coefficient of RS: with every one unit increase in RS, the baseline zFMI and zLMI of girls were 0.06 and 0.05 higher respectively; and (2) in the time slopes from baseline to 2015 of zFMI and zLMI, which is indicated by the significant interaction between time variable 2015 (reference time

2011) and RS: with every one unit increase in RS, the zFMI and zLMI change from 2011 to 2015 of girls were 0.06 higher and 0.07 lower respectively. RS explained 14.8% and 11.6% of the variance in the zFMI and zLMI time slopes from baseline to 2015 (proportions are computed by subtracting the not rounded 2015-time slope variance of model 4 from that of model 3, and then dividing by the variance of model 3). Figure 15 displays the direction of these significant effects.

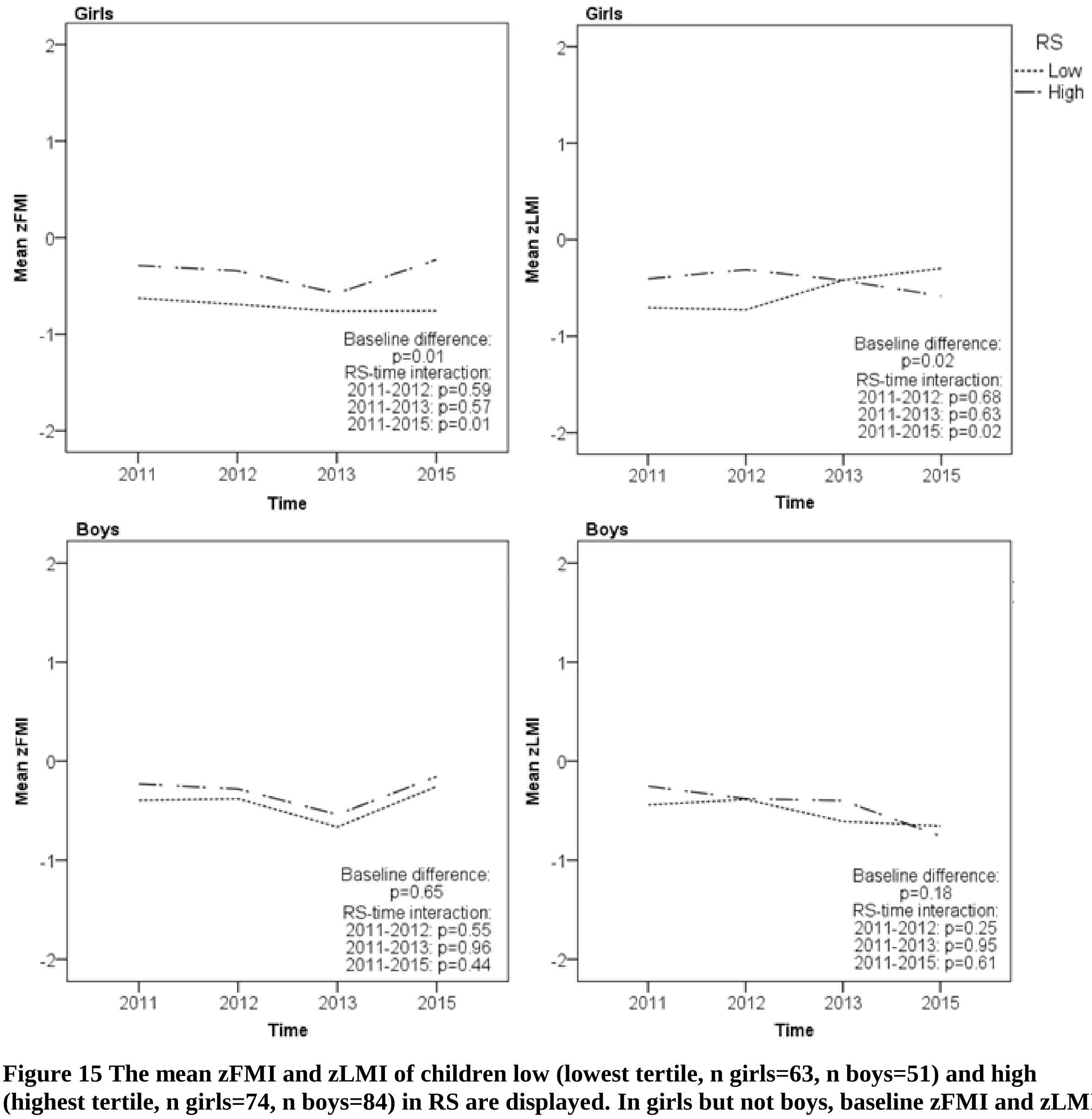


Figure 15 The mean zFMI and zLMI of children low (lowest tertile, n girls=63, n boys=51) and high (highest tertile, n girls=74, n boys=84) in RS are displayed. In girls but not boys, baseline zFMI and zLMI significantly increased with RS, and the zFMI and zLMI change from 2011 to 2015 significantly differed by RS. The figure illustrates an increase in zFMI and a decrease in zLMI in the high RS group.
zFMI; standard deviation score of Fat Mass Index based on British reference curves. zLMI; standard deviation score of Lean Mass Index based on British reference curves. RS; reward sensitivity.

Sensitivity analyses on a subsample with body composition data on 2011 as well as 2015 (n=92, n measurements=335) demonstrated a similar RS effect on the time slope from baseline to 2015 of zFMI (p=0.03) and of zLMI, but the effect on zLMI was trend significant (p=0.09).

Besides these main findings, the intraclass correlation demonstrated that zFMI and zLMI were stable characteristics over time: 84.8% and 76.3% of the differences on zFMI and zLMI respectively were due to individual differences between girls, and consequently, only 15.2% and 23.7% of the differences on zFMI and zLMI respectively were due to differences between the measurement occasions (Table 18, table note). Additionally, variances in the zFMI and zLMI time slopes were only significant when the time span between the measurements was the largest, i.e. from 2011 to 2015 (model 3).

Boys. Based on the AIC, model 3 had the best data fit (Table 19). RS did not significantly explain baseline zFMI or zLMI nor differences in the time slopes of zFMI and zLMI between boys (model 4).

Besides these main findings, the intraclass correlation demonstrated that zFMI and zLMI were stable characteristics over time: 71.7% and 78.2% of the differences on zFMI and zLMI respectively were due to individual differences between boys, and consequently, 28.3% and 21.8% of the differences on zFMI and zLMI respectively were due to differences between the measurement occasions (Table 19, table note). Additionally, significant time slope variances on zFMI and zLMI were also only present between 2011 and 2015 (model 3).

Table 18 Fixed and random effects of two series of four incremental multilevel models with zFMI and zLMI as outcomes in girls (n=223, n measurements on the four time points=584)

	Model 1 b (CI)	**Model 2** b (CI)	**Model 3** b (CI)	**Model 4** b (CI)
		Outcome: zFMI		
Fixed effects				
Intercept	-0.41 (-0.55,-0.28)***	-0.38 (-0.51, -0.24)***	-0.38 (-0.51, -0.25)***	-0.38 (-0.52, -0.25)***
Time-level				
Time[a]				
2012	-0.04 (-0.10, 0.03)	-0.04 (-0.11, 0.03)	-0.05 (-0.11, 0.02)	-0.05 (-0.12, 0.02)
2013	-0.18 (-0.27, -0.09)***	-0.18 (-0.27, -0.09)***	-0.18 (-0.28, -0.09)***	-0.18 (-0.27, -0.08)***
2015	-0.09 (-0.22, 0.05)	-0.09 (-0.22, 0.05)	-0.09 (-0.22, 0.05)	-0.06 (-0.19, 0.07)
Child-level				
RS[b]		0.07 (0.02, 0.11)**	0.06 (0.02, 0.11)**	0.06 (0.01, 0.11)*
Cross-level interaction				
Time[a] * RS[b]				
2012				-0.01 (-0.03, 0.02)
2013				0.01 (-0.02, 0.04)
2015				0.06 (0.01, 0.11)*
Random effects				
Time-level variance	0.15 (0.11, 0.19)***	0.15 (0.11, 0.19)***	0.11 (0.06, 0.15)***	0.11 (0.06, 0.15)***
Child-level variance	0.86 (0.69, 1.03)***	0.83 (0.66, 1.00)***	0.86 (0.70, 1.03)***	0.86 (0.70, 1.03)***
Time[a] slope variance				
2012			<0.01 (-0.08, 0.09)	<0.01 (-0.08, 0.09)
2013			0.02 (-0.07, 0.11)	0.02 (-0.07, 0.11)
2015			0.22 (0.05, 0.39)*	0.19 (0.03, 0.34)*
AIC	1162.70	1155.26	1134.50	1131.33
		Outcome: zLMI		
Fixed effects				
Intercept	-0.53 (-0.65, -0.40)***	-0.50 (-0.63, -0.38)***	-0.50 (-0.62, -0.37)***	-0.50 (-0.62, -0.37)***
Time-level				
Time[a]				
2012	0.04 (-0.04, 0.12)	0.04 (-0.04, 0.12)	0.03 (-0.05, 0.11)	0.04 (-0.04, 0.11)
2013	0.09 (-0.01, 0.20)	0.09 (-0.01, 0.20)	0.09 (-0.02, 0.19)	0.08 (-0.02, 0.19)
2015	0.18 (0.02, 0.34)*	0.18 (0.01, 0.34)*	0.18 (0.02, 0.34)*	0.15 (-0.01, 0.31)
Child-level				
RS[b]		0.045 (<0.01, 0.09)*	0.05 (0.01, 0.09)*	0.05 (0.01, 0.10)*
Cross-level interaction				
Time[a] * RS[b]				
2012				0.01 (-0.02, 0.03)
2013				-0.01 (-0.04, 0.03)
2015				-0.07 (-0.12, -0.01)*
Random effects				
Time-level variance	0.21 (0.17, 0.25)***	0.21 (0.17, 0.25)***	0.14 (0.08, 0.21)***	0.14 (0.08, 0.21)***
Child-level variance	0.68 (0.54, 0.83)***	0.67 (0.53, 0.81)***	0.69 (0.55, 0.82)***	0.68 (0.55, 0.82)***
Time[a] slope variance				
2012			<0.01 (-0.12, 0.12)	<0.01 (-0.12, 0.12)
2013			0.03 (-0.06, 0.12)	0.03 (-0.06, 0.12)
2015			0.33 (0.14, 0.51)***	0.29 (0.11, 0.47)**
AIC	1239.08	1236.12	1208.69	1207.49

b; unstandardized parameter estimate. CI; 95% confidence interval. zFMI; standard deviation score of Fat Mass Index based on British reference curves. zLMI; standard deviation score of Lean Mass Index based on British reference curves. RS; reward sensitivity, centered. AIC; Akaike's Information Criterion.
Intraclass correlation (=not rounded child level variance/(child+time level variance)) based on model 1 for zFMI=84.8%, for zLMI=76.3%.
[a]Reference time of time dummies is 2011. [b]Range -5 to 7.
**p<0.05, **p<0.01, ***p<0.001.*

Table 19 Fixed and random effects of two series of four incremental multilevel models with zFMI and zLMI as outcomes in boys (n=223, n measurements on the four time points=571)

	Model 1 b (CI)	**Model 2** b (CI)	**Model 3** b (CI)	**Model 4** b (CI)
		Outcome: zFMI		
Fixed effects				
Intercept	-0.26 (-0.38, -0.14)***	-0.26 (-0.38, -0.14)***	-0.26 (-0.38, -0.14)***	-0.26 (-0.38, -0.14)***
Lowest level: time-level				
Time[a]				
2012	-0.03 (-0.12, 0.05)	-0.03 (-0.11, 0.05)	-0.02 (-0.10, 0.05)	-0.02 (-0.10, 0.05)
2013	-0.19 (-0.31, -0.07)**	-0.19 (-0.31, -0.07)**	-0.17 (-0.29, -0.06)**	-0.17 (-0.29, -0.05)**
2015	0.08 (-0.10, 0.26)	0.08 (-0.10, 0.26)	0.09 (-0.10, 0.27)	0.09 (-0.10, 0.27)
Highest level: child-level				
RS[b]		0.01 (-0.03, 0.05)	0.01 (-0.03, 0.05)	0.01 (-0.03, 0.05)
Cross-level interaction				
Time[a] * RS[b]				
2012				0.01 (-0.02, 0.03)
2013				<0.01 (-0.04, 0.04)
2015				-0.02 (-0.08, 0.04)
Random effects				
Time-level variance	0.24 (0.18, 0.31)***	0.24 (0.18, 0.31)***	0.13 (0.06, 0.19)	0.13 (0.06, 0.19)
Child-level variance	0.63 (0.48, 0.77)***	0.63 (0.48, 0.77)***	0.69 (0.54, 0.85)	0.70 (0.54, 0.85)
Time[a] slope variance				
2012			0.03 (-0.07, 0.12)	0.03 (-0.07, 0.12)
2013			0.13 (>-0.01, 0.26)	0.13 (>-0.01, 0.26)
2015			0.46 (0.11, 0.80)**	0.45 (0.09, 0.81)*
AIC	1258.05	1259.92	1227.73	1232.52
		Outcome: zLMI		
Fixed effects				
Intercept	-0.25 (-0.38, -0.11)***	-0.25 (-0.38, -0.11)***	-0.24 (-0.38, -0.11)***	-0.24 (-0.38, -0.11)***
Lowest level: time-level				
Time[a]				
2012	-0.02 (-0.10, 0.07)	-0.02 (-0.10, 0.07)	-0.02 (-0.10, 0.06)	-0.02 (-0.10, 0.06)
2013	-0.10 (-0.21, 0.02)	-0.10 (-0.21, 0.02)	-0.10 (-0.21, 0.02)	-0.10 (-0.21, 0.02)
2015	-0.50 (-0.66, -0.33)***	-0.50 (-0.66, -0.33)***	-0.50 (-0.66, -0.33)***	-0.50 (-0.67, -0.34)***
Highest level: child-level				
RS[b]		0.03 (-0.02, 0.07)	0.03 (-0.02, 0.07)	0.03 (-0.02, 0.08)
Cross-level interaction				
Time[a] * RS[b]				
2012				-0.02 (-0.05, 0.01)
2013				<0.01 (-0.04, 0.04)
2015				-0.01 (-0.06, 0.04)
Random effects				
Time-level variance	0.22 (0.18, 0.25)***	0.22 (0.18, 0.25)***	0.16 (0.10, 0.21)***	0.15 (0.10, 0.20)***
Child-level variance	0.88 (0.70, 1.05)***	0.87 (0.70, 1.04)***	0.89 (0.72, 1.06)***	0.89 (0.72, 1.06)***
Time[a] slope variance				
2012			0.01 (-0.09, 0.10)	0.01 (-0.09, 0.10)
2013			0.07 (-0.03, 0.17)	0.07 (-0.03, 0.17)
2015			0.28 (0.10, 0.46)**	0.28 (0.10, 0.47)**
AIC	1280.48	1280.97	1272.76	1272.76

b; unstandardized parameter estimate. CI; 95% confidence interval. zFMI; standard deviation score of Fat Mass Index based on British reference curves. zLMI; standard deviation score of Lean Mass Index based on British reference curves. RS; reward sensitivity, centered. AIC; Akaike's Information Criterion.
Intraclass correlation (=not rounded child level variance/(child+time level variance)) based on model 1 for zFMI=71.7%, for zLMI=78.2%.
[a]Reference time of time dummies is 2011. [b]Range -5 to 7.
**p<0.05, **p<0.01, ***p<0.001.*

8.3.5 Discussion

The current study is to our knowledge the first to examine the longitudinal association of scores on a general RS-questionnaire with fat and lean tissue accretion in boys and girls. RS is a personality trait, conceptualized here as a trait explaining differences in motivation to approach rewards in response to reward-predicting-cues (Carver & White, 1994).

Girls but not boys with higher baseline RS had a significantly higher baseline relative fat mass and also experienced significantly more relative fat mass gain over time. These results suggest that natural variation in the trait RS contributes to the difference between remaining or not remaining on the same FMI percentile curve during growth in girls. However, the estimated increase in zFMI per unit increase in RS (i.e. 0.06), which equals an increase of 2.54 percentiles for children with a baseline zFMI of zero, appears to be relatively minor. The small change is possibly due to the use of a predominantly healthy-weight sample, resulting in less variety in FMI. Nevertheless, the relation between RS and zFMI change was significant, even in this sample. Further, the aim of the study was to identify appropriate targets for primary prevention of higher adiposity gain than expected on the basis of a child's age and height, and for this purpose, children who do not have a severe weight problem yet are suitable targets. Furthermore, RS can differ within a population over 12 units, and hence, the change in zFMI over time is estimated to differ with 0.72 points between girls at the lowest and highest extreme of RS. Moreover, RS explained a considerable amount of the variance in the zFMI change over four years, namely 14.8%.

Hence, the current results suggest that RS is a risk factor of higher fat tissue accretion than expected on the basis of their age and height. Thereby, RS was measured with a questionnaire that is easily and practically applicable for prevention purposes. The suggested increased risk for high RS girls is assumed to be explained by a higher vulnerability to palatable food cues in the environment (Paquet et al., 2010), followed by a higher motivation to obtain the food and resulting in higher consumption of these energy-dense foods (De Cock, Van Lippevelde, Vervoort, et al., 2016; De Decker et al., 2016). However, this was not tested in the current study.

The current results on the longitudinal association between a general RS-questionnaire and body composition cannot be compared to other studies in children since as far as we know, this longitudinal association has not been investigated yet. Cross-sectional studies on this association in children reported a positive association with BMI but did not consider sex differences (De Decker et al., 2016; Verbeken et al., 2012). In young adults, a longitudinal study did not find a significant relation between scores on a different general RS-questionnaire and FMI increase, but no sex differences were tested (Finlayson et al., 2012). One cross-sectional study in adults did consider sex differences and reported a similar finding, namely a positive association between RS and BMI in females but not males (Dietrich et al., 2009). As mentioned in the introduction, researchers have attempted to understand or measure cue-triggered reward motivation with various methods, other than general RS questionnaires. The to our knowledge available longitudinal studies with one of these methods in children are described below, but comparison with the current results has limitations since the methods differ drastically and do not necessarily measure the same construct. First, scores on a questionnaire that assesses to what extent a child is prepared to work towards obtaining food were found to predict increases in FMI (C. Hill et al., 2009). In contrast with the questionnaire used in the current study, the child questionnaire used in the study in children is less applicable for prevention purposes since individual guidance is needed (C. Hill et al., 2009) and the validity is lower in younger children (French, Epstein, Jeffery, Blundell, & Wardle, 2012). Second, no significant relation was found between reward circuitry responsivity to palatable food cues and onset of overweight or obesity (Stice, Yokum, & Burger, 2013). However, both studies did not differentiate by sex. In sum, comparison of the current results with previous studies is difficult due to the use of different measurement approaches and/or populations as well as the lack of investigating sex-differences.

The most striking finding of the present study was that girls but not boys higher in RS exhibited higher relative lean mass at baseline, but longitudinal higher relative loss of lean mass. This suggests that natural variation in the trait RS also contributes to the difference between remaining or not remaining on the same LMI percentile curve during growth in girls. Thereby, a 0.07 lower zLMI change over four years was seen with every one unit increase in RS, which is equal to 1.99 percentiles for children with a baseline zLMI of zero. Although this is rather minor, RS explained 11.6% of the variance in zLMI change, which indicates that even in a predominantly healthy-weight sample, this trait may be relevant for body composition changes during growth.

There is a paucity of studies on this association. In a mixed sample of young adults, longitudinal changes in LMI were not significantly associated with scores on a general RS questionnaire, but positively associated with scores on a food-specific RS questionnaire (Finlayson et al., 2012). However, methodological differences obstruct us from comparing these findings with the current results.

Generally, fat accretion is accompanied by lean mass accretion, since more muscle mass is needed to carry a heavier body (Wells et al., 2006). However, in the current study, the opposite is seen. Since this outcome has not been reported previously, explanations of this finding remain speculative. A possibility is that high RS girls have a stronger decrease in physical activity with age. Related to the latter is the trend of a much steeper decrease in physical activity with every year of age in girls compared to boys (Corder et al., 2016). However, this speculation need to be confirmed in future research, since this was not tested in the current study.

Underlying reasons for the sex-specific RS effect on zFMI and zLMI are not completely clear since these were not investigated and sex differences in food reward and eating behavior still represent a developing line of research (Figlewicz, 2015). Literature suggests that biological factors may play a role. For example, patterns of neural activation to palatable food-cues differ by sex (Asarian & Geary, 2013; Atalayer et al., 2014; Uher, Treasure, Heining, Brammer, & Campbell, 2006). Another example is that the distribution of fat and lean mass changes differentially in boys and girls during growth; e.g. in boys but not girls, lean mass accretion is the primary target of weight gain during puberty since lean mass is a secondary sexual characteristic (Wells et al., 2012; Wisniewski & Chernausek, 2009). Further, social factors may play a role. An example is the higher internalization of societal pressure to modify physical appearance, the higher body dissatisfaction and the higher drive for thinness in females compared to males (Yean et al., 2013). These factors compose a risk to develop disordered eating behavior via increases in weight control intentions (Stice & Shaw, 2002).

8.3.6 Strengths, limitations, and directions for future research

Limitations of the study include the lack of information on puberty status, since this hampers the interpretation of the changes in body composition: although the zFMI and zLMI parameters capture the average sex-specific and percentile-specific alterations in the balance between fat and lean mass with age, children may enter puberty earlier or later than average. Another limitation is the use of British FMI and LMI reference data due to absence of Flemish reference data. Nonetheless, only minor differences between neighboring British and Flemish populations were seen (standard deviation of zFMI and zLMI on all time points close to one in both sexes). Comparable with the average zBMI based on Flemish reference scores, the average zFMI and zLMI were slightly negative, probably due to an overrepresentation of children from highly educated parents and therefore, healthier body composition. This is a limitation since it reduces the variation in zFMI and zLMI. Further, the relatively high accretion of fat and low accretion of lean mass in high RS girls was not found over one or two years, likely because it is harder to detect proper body composition trajectories over short time periods. Additionally, a large amount of participants dropped-out during the study. Nevertheless, no drop-out differences were present on the main outcomes (no significant difference between 2011 and 2015 on zFMI and zLMI) and the sensitivity analyses confirmed the study findings. Next, the study did not consider food intake and physical activity, and therefore, the interpretation of the results remains speculative. Future research should include these factors and elucidate if the relation between RS and increased fat tissue accretion is mediated by food intake or physical activity behavior. Moreover, it is critical that future research includes data on puberty.

Strengths of this study include the use of FMI and LMI based on air-displacement plethysmography. This enabled us to capture the simultaneous zFMI increase and zLMI decrease in high RS girls. Due to these opposite patterns, RS did not explain the net change in zBMI. Hence, the zBMI measure is incapable to capture the less favorable body composition development seen in high RS girls, and therefore, it is not advised to use BMI in future research on this topic. Other strengths are the longitudinal design and modelling, the large community sample of children, the differentiation by sex, and the use of the short drive-subscale to measure RS, which is applicable for prevention purposes. Additionally, scores on this subscale have been positively associated with neural responsiveness in the brain reward system to food reward cues in young adults (Beaver et al., 2006). In children, an association with responsiveness to food reward has to our knowledge not been investigated yet, but a positive association between drive-scores and neural responsiveness to monetary reward has been reported in participants aged 8-27 years (Braams et al., 2015).

8.3.7 Conclusion

The current study findings suggest that girls but not boys high in RS are more vulnerable to unfavorable body composition development, i.e. higher adiposity gain parallel with lower lean mass accretion than expected on the basis of their age and height. The improved understanding on the contribution of a psychobiological trait to the variability in adiposity gain in obesogenic environments may inform pediatricians, parents, and policy makers, and support initiatives to better contain palatable food cues in the daily living environment of children. Further, several scientists recommend a shift toward targeted preventive interventions that focus on particularly vulnerable populations (e.g. Silveira et al. (2016)). The current study points out that girls high in RS might be more vulnerable, and may encourage future research to elucidate which prevention approaches are most effective for girls high in RS to timely reverse the unfavorable body composition development. For example, future research may determine if strengthening inhibitory control skills is an effective approach for girls high in RS, since good inhibitory control capacities are suggested to counteract reward-driven behavior (Vainik et al., 2013; Ziauddeen et al., 2015).

8.4 Fat tissue accretion in children and adolescents: interplay between food responsiveness, gender and the home availability of snacks[8]

[8] This section is based on De Decker, A., Verbeken, S., Sioen, I., Moens, E., Braet, C., De Henauw, S. (2017). Fat tissue accretion in children and adolescents: interplay between food responsiveness, gender and the home availability of snacks. Frontiers in Psychology, 7, 2041.

8.4.1 Abstract

The appetitive trait 'food responsiveness' is assumed to be a risk factor for adiposity gain primarily in obesogenic environments. So far, the reported results are inconsistent in school-aged children, possibly because these studies did not take into account important moderators such as gender and the food-environment. In order to better inform caregivers, clinicians and the developers of targeted obesity-prevention interventions on the conditions in which food responsiveness precedes adiposity gain, the current study investigated if this relationship is stronger in girls and in children exposed to a higher home availability of energy-dense snacks. Age- and sex-independent Fat and Lean Mass Index z-scores were computed based on air-displacement plethysmography at baseline and after two years in a community sample of 129 children (48.8% boys) aged 7.5-14 years at baseline. Parents reported at baseline on children's food responsiveness and the home availability of energy-dense snacks. Food responsiveness was a significant predictor of increases in Fat Mass Index z-scores over two years in girls but not boys. The home availability of energy-dense snacks did not significantly moderate the relation of food responsiveness with Fat Mass Index z-score changes. The results suggest that food responsiveness precedes accelerated fat tissue accretion in girls, and may inform targeted obesity-prevention interventions. Further, future research should investigate to which food-environmental parameters children high in food responsiveness mainly respond.

8.4.2 Introduction

The increase in the supply of cheap, energy-dense foods, coinciding with the rise in the global obesity prevalence, is seen as a major driver of the obesity epidemic (Swinburn et al., 2011). However, individual variability in body size exists also in populations exposed to the same food-environment. This variability is thought to be explained by the interaction between individual and environmental factors (French et al., 2012; Swinburn et al., 2011). Considering the current overweight and obesity prevalence in childhood, its health consequences, and its tracking into adulthood (S. R. Daniels, 2009; Singh et al., 2008), understanding which individual factors increase the susceptibility to adiposity gain when exposed to energy-dense foods is essential in order to develop effective obesity-prevention interventions (French et al., 2012).

Schachter's externality theory of obesity stated that food intake in obese people is externally controlled, or in other words, is more determined by external cues related to food compared to internal signals of hunger and satiety (Schachter, 1968, 1971). This responsiveness to food-cues was later on proposed to be an individual factor varying on a continuum in the total population, and is further on called 'food responsiveness'(FR) (Wardle et al., 2001). FR can be described as a characteristic that determines the interest and motivation to approach and consume food when food-cues are perceived (French et al., 2012). 'Food-cues' refer to external stimuli associated with food, such as pictures, smells, tastes or direct views of food. Hence, FR is assumed to be a risk factor for excess energy intake and adiposity gain primarily in obesogenic environments (French et al., 2012; Wardle et al., 2001). However, before developing interventions that target high FR children and their food-environment, longitudinal studies are needed to confirm this assumption.

In infants, two studies found that FR indeed antecedes accelerated weight gain (Quah et al., 2015; van Jaarsveld, Boniface, Llewellyn, & Wardle, 2014). Conversely, results of longitudinal studies in school-aged children, all using the FR-subscale of the Child Eating Behavior Questionnaire (CEBQ) to assess FR (Wardle et al., 2001), were inconsistent: (a) the association between FR and weight gain was non-significant or significant depending on the statistical model used in a community sample of children aged 6 years at baseline and followed over two years (this sample had more children with emotional and behavioral problems compared to the community, but was comparable to the community concerning parameters such as parental education level and children's body mass index) (Steinsbekk, Belsky, Guzey, Wardle, & Wichstrom, 2016; Steinsbekk & Wichstrom, 2015); and (b) the association between FR and weight gain was non-significant after one year of follow-up in a community sample of children aged 7 to 10 years at baseline (Rodenburg et al., 2012). Although it is suggested that FR may only predict accelerated weight gain in infancy, and from then, children high in FR remain on a higher Body Mass Index (BMI) percentile (Rodenburg et al., 2012), the previous studies have also limitations that may explain the inconsistent findings. First, the previous longitudinal studies did not consider an interaction between FR and the food-environment, although an effect of FR on weight gain is mainly assumed in environments plenty of energy-dense foods (French et al., 2012; Wardle et al., 2001). Second, the previous longitudinal studies did also not consider gender differences in the relation between FR and weight gain. There are clear gender differences in the regulation of body composition, which are assumed to be the result of gender differences in biological and socio-psychological processes (Cepeda-Benito, Fernandez, & Moreno, 2003; Davy, Benes, & Driskell, 2006; Shi & Clegg, 2009; Yean et al., 2013). Biological arguments to presume that the relation between FR and weight gain may differ in boys and girls are (a) that the effect of a genetic polymorphism related to higher FR scores, namely the fat and obesity-associated transcript (FTO) gene minor allele on rs9939609 (Velders et al., 2012), on weight and weight gain was only significant among girls in two studies (Jacobsson et al., 2008; M. X. Zhang et al., 2014), and (b) that gene versus food-environment interactions are recently suggested to be more pronounced in females compared to males (Silveira et al., 2016; van Strien, Levitan, Engels, & Homberg, 2015). An example of socio-psychological arguments to presume a gender difference is the higher internalization of societal pressure to modify physical appearance in girls compared to boys, leading via higher body dissatisfaction to dietary restraint, which is associated with disinhibited eating episodes (Ruderman, 1986; Stice & Shaw, 2002; Yean et al., 2013).

Knowledge on the interaction of FR with the food-environment and with gender on adiposity gain may help to adequately inform children, caregivers, clinicians, and developers of targeted childhood obesity-prevention interventions on the conditions in which FR precedes adiposity gain. Hence, the goal of this study was to provide, to our knowledge, the first examination of the moderating effect of gender and the food-environment on the relation between FR and adiposity gain in a community sample of children and adolescents aged 7.5 to 14 years at baseline and 9.5 to 16 at follow-up. Thereby, a stronger positive relation is hypothesized in girls and in children living in a food-environment plenty of energy-dense foods. Since an important part of these children's environment is the home environment, the parameter 'home availability of fat- and sugar-rich snacks' (HAS) was included as food-environmental parameter. Children can consume unhealthy foods at home only if these foods are available at home, which is mostly dependent on parental purchases (K. J. Campbell et al., 2007). Hence, when confirming an interaction, HAS can be targeted in interventions.

8.4.3 Methods

a. Participants and study design

Subjects were Dutch-speaking Belgian children and adolescents that participated in a population-based study called 'Rewarding-FOod ChoicES' (Forces; part of the REWARD-project, www.rewardstudy.be), with study surveys in the spring of 2013 (i.e. baseline) and 2015 (i.e. follow-up). Only children with full data on FR and HAS in 2013 and body composition in 2013 and 2015 were included, which was the case for 129 out of 300 children participating at baseline. These 129 children (in most cases accompanied by at least one parent) attended the survey center at a prefixed appointment both at baseline and follow-up, on which body composition measurements (see below) of the child were conducted. The parental Forces questionnaire of the survey of 2013 was filled in at the survey center or at home; this questionnaire started with socio-demographic questions, followed by the Behavioral Activation System/Behavioral Inhibition System scale, the Behavioral Rating Inventory of Executive Function, the Child Feeding Questionnaire, the Strengths and Difficulties questionnaire, the Environment subscale of the Comprehensive Feeding Practices Questionnaire, the Child Eating Behavior Questionnaire, questions on sleep duration, a 43-item food frequency questionnaire and questions on medical conditions. Of the other 171 participating children at baseline, 103 lacked body composition or FR data at baseline (due to time constraints of children or parents, a part of the children were measured at school instead of at the study center, and consequently, had no BOD POD® measurement), and the other 68 were lost at follow-up.

Participant-recruitment of the Forces study was conducted in two ways: (a) all participants of the control region Aalter of the preceding longitudinal ‘Identification and prevention of dietary- and lifestyle-induced health effects in children and infants’ study (IDEFICS) (Ahrens et al., 2011) were invited via mail, email and, if no response, telephone calls to participate, and (b) children outside of the IDEFICS-cohort of Aalter with an age similar to that of the existing cohort (i.e. 7.5 to 14 years) were invited at baseline to join the study via an advert on one Flemish television channel and in local newspapers. For the latter recruitment, the only inclusion criterion was age. For the recruitment of the preceding IDEFICS study, the inclusion criteria were age and being a pupil of the twelve schools located in the city Aalter.

The Forces study was conducted according to the guidelines laid down in the Declaration of Helsinki and its later amendments, and approved by the Ethics Committee of Ghent University Hospital. Written informed consent was obtained from all parents and from children older than twelve years. Younger children gave verbal assent.

b. Measures

FR. The mean score on the Dutch CEBQ-subscale ‘FR’, designed to measure how responsive a child is to external food-cues, was used. The five items (i.e. ‘even if my child is full up s/he finds room to eat his/her favorite food’) need to be scored on a five point Likert-scale anchored from ‘never’ (value ‘1’) to ‘always’ (value ‘5’) (Sleddens et al., 2008; Wardle et al., 2001), and were completed by parents at baseline. The Cronbach's alpha of the FR subscale in the current study was comparable to the alpha reported in a study on children aged 6 to 12 years (0.85 versus 0.89, respectively) (Santos et al., 2011).

HAS. HAS was indexed by the mean score of two items reflecting the home availability of fat- and sugar-rich snacks and originating from the subscale 'environment' of the 'Comprehensive Feeding Practices Questionnaire'. The items, i.e. 'I keep a lot of snack food (potato chips, Doritos, cheese puffs) in my house' and 'I keep a lot of sweets (candy, ice cream, cake, pies, pastries) in my house', need to be scored on a five point Likert-scale anchored from 'disagree' (value '1') to 'agree' (value '5') (Melbye et al., 2011). Only these two instead of the four items of the subscale 'environment' were used since Melbye et al. demonstrated that the four items load onto two different factors (one reflecting the availability at home of healthy foods and one of unhealthy foods) (Melbye et al., 2011), which was confirmed by a preliminary principal component analysis on the current study data. The mean score of the two items reflecting availability of energy-dense snacks has been positively related to the weekly consumption frequency of fast food (section 8.2). The Cronbach's alpha of the two items was 0.64 in the current study.

Body composition. At least 2h before the measurement, children had to refrain from physical activity and food. Height was measured barefooted to the nearest 0.1cm with a SECA® (model 213, SECA Corp., Hamburg, Germany). Body weight was measured with the BOD POD® balance, and body volume with the BOD POD® air-displacement plethysmography device (software version 4.2.4, Life Measurement, Inc., Concord, CA, 2007), both using standardized procedures.(McCrory et al., 1995) In accordance to the manufacturer's guidelines, the BOD POD® was calibrated daily and at each measurement, and children wore tight-fitting bathing suits with swimming caps during the measurement. Thoracic gas volume was predicted by the software with a validated child-specific equation (Fields et al., 2004). The body mass index (BMI, kg/m^2) and body density (kg/L) were calculated, and the latter was converted into body fat percentage using child-specific conversion factors (Wells et al., 2010). Based on body fat percentage and weight, the fat and fat-free masses (kg) were calculated, which were divided by height squared to obtain the fat mass index (FMI, kg/m^2) and fat-free mass index, also called lean mass index (LMI, kg/m^2). To compare BMI, FMI and LMI across children, age- and sex-independent z-scores were computed based on Flemish reference curves for BMI (zBMI) (Roelants et al., 2009), and British reference curves for FMI (zFMI) and LMI (zLMI) (Wells et al., 2012) due to absence of Flemish reference curves for these parameters.

Parental education level. The highest parental education level of both parents was first categorized according to the International Standard Classification of Education of 1997 (UNESCO, 1997), and, because of low number in some categories, further categorized in two groups: children with no tertiary educated parents (value '0') and children with minimum one tertiary educated parent (value '1').

c. Data analyses

The two-sided level of significance was set at $p<0.05$. Analyses were performed using SPSS (version 22.0, SPSS Inc., Chicago, IL, 2013). Normality of the study variables was checked based on visual inspection of histograms and boxplots, and was acceptable for all variables. Unpaired t-tests for gender differences were conducted on the study variables. To test drop-out differences, participants at baseline that were included versus non-included in the current study were compared with unpaired t-tests on baseline age, zBMI, and on FR and HAS if available.

To answer the research questions, hierarchic multiple regression models were conducted. In all models, the zFMI change over two-years follow-up was the dependent variable. Model 1 included all covariates: baseline zFMI, baseline zLMI, centralized age (i.e. age minus 10 years), gender and parental education level (baseline model). Thereby, baseline zLMI was included because it was significantly positively associated with FR in a preliminary analysis, probably because higher FR may also be caused by higher energy needs. In model 2, FR was added to model 1 to evaluate the main effect of FR. To test if the association between FR and adiposity gain is (a) moderated by gender, the interaction term of FR with gender was added to model 2 (model 3a), (b) moderated by HAS, HAS and the interaction term of FR with HAS were added to model 2 (model 3b), and (c) moderated by both gender and HAS, the two-way interactions of FR with gender and HAS with gender and the three-way interaction of FR, HAS and gender were added to model 3b (model 3c).

Table 20 Effects of FR, Gender, and HAS on zFMI Change over Two Years (n=129)

		Dependent variable: zFMI change over two years				
Model	R^2	Independent variables	b	SE	β	*P*
1	0.20	Constant	0.232	0.132		0.081
		Gender	**-0.228**	0.106	-0.176	0.033
2	0.24	Constant	-0.098	0.185		0.596
		Gender	**-0.262**	0.105	-0.202	0.013
		FR	**0.158**	0.063	0.213	0.014
3a	0.26	Constant	0.140	0.219		0.523
		Gender	**-0.763**	0.271	-0.588	0.006
		FR	0.026	0.091	0.035	0.777
		FR*Gender	**0.240**	0.120	0.344	0.048
3b	0.24	Constant	0.100	0.521		0.847
		Gender	**-0.262**	0.106	-0.202	0.015
		FR	0.115	0.246	0.154	0.643
		HAS	-0.080	0.196	-0.096	0.685
		FR*HAS	0.018	0.092	0.078	0.847
3c	0.28	Constant	0.471	0.709		0.508
		Gender	-1.380	1.035	-1.064	0.185
		FR	0.043	0.354	0.058	0.903
		HAS	-0.133	0.276	-0.160	0.631
		FR*HAS	-0.003	0.135	-0.015	0.980
		FR*Gender	0.286	0.486	0.561	0.558
		HAS*Gender	0.244	0.389	0.531	0.532
		FR*HAS*Gender	-0.021	0.182	-0.113	0.909

Note. Multiple hierarchic linear regression models adjusted for baseline zFMI, zLMI, centralized age (i.e. age minus 10 years), gender (shown in table; value zero for boys, value one for girls) and parental education level. zFMI and zLMI, age- and sex-independent z-score of the fat and lean mass index, respectively. b, unstandardized regression coefficient. SE, standard error of b. β, standardized regression coefficient. FR, Food responsiveness. HAS, home availability of fat- and sugar-rich snacks. Bold indicates coefficient is significantly different from zero at $p < 0.05$ level.

8.4.4 Results

First, the relation between FR and zFMI change was significantly different in boys versus girls (Table 20, model 3a; significant interaction term between FR and gender). In boys, the relation between FR and zFMI was not significant (Table 20, model 3a; non-significant coefficient of FR). In contrast, a significant positive relation between FR and zFMI change was found in girls: the mean zFMI change of girls over two years was 0.27 higher for each unit increase in FR (based on data resulting from a rerun of the analysis of model 3a with a recoded gender variable, i.e. value ‘0’ for girls and value ‘1’ for boys: unstandardized regression coefficient of FR=0.27, standard error=0.082, standardized regression coefficient=0.36, p=0.002). Hence, the results indicated FR as a significant predictor of zFMI increase over two years in girls, but not in boys. The estimated regression lines for boys and girls are displayed in Figure 16.

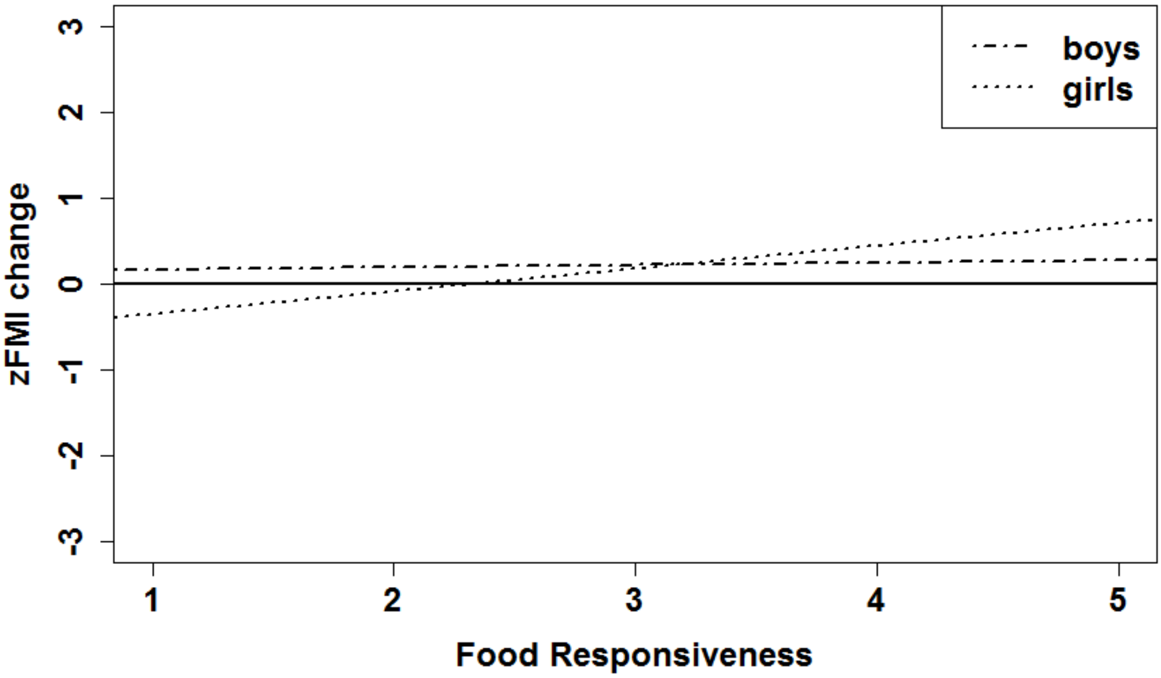


Figure 16 Estimated effect of FR on zFMI change over two years.
Note. Estimated regression lines are shown for boys and girls with a zFMI baseline=0, zLMI baseline=0, age=10 years, and parental education level=low (i.e. all covariates set at zero). zFMI and zLMI, age- and sex-independent z-score of the fat and lean mass index, respectively.

The sex-difference in the relation between FR and zFMI change could not be explained by sex-differences on parameters relevant for the analyses, as baseline age, FR, HAS, zFMI, zLMI and zBMI as well as follow-up zFMI, zLMI and zBMI of participating boys and girls did not significantly differ (Table 21). Further, the results could not be explained by drop-out differences, as no drop-out differences were found on the relevant parameters 'zBMI, FR and HAS'. Nevertheless, it was found that the 129 children who were included compared to the 171 children who were excluded from the current study had a lower baseline age, although this probably cannot explain the current result of a sex difference. Further, the study population mainly consisted of children with minimum one tertiary educated parent (79.8%) and of children without overweight or obesity (2.3% had overweight including obesity according to the International Obesity Task Force definition (T. J. Cole & Lobstein, 2012)).

Second, HAS (Table 20, model 3b) nor both HAS and gender (Table 20, model 3c) did significantly moderate the relation between FR and zFMI change.

Table 21 Descriptive Statistics of the Study Population

	Total sample (n=129)		Boys (n=63)		Girls (n=66)		T-test gender	
	Mean	**sd**	**Mean**	**sd**	**Mean**	**sd**	**t**	***P***
Age at baseline (years)	10.451	1.546	10.522	1.592	10.383	1.509	0.509	0.612
FR (range 1-5)	2.105	0.877	2.029	0.824	2.179	0.925	-0.972	0.333
HAS (range 1-5)	2.601	0.787	2.603	0.799	2.598	0.781	0.034	0.973
zFMI at baseline	-0.563	0.893	-0.514	0.905	-0.609	0.885	0.603	0.548
zFMI at follow-up	-0.351	0.888	-0.313	0.991	-0.456	0.895	1.814	0.072
zLMI at baseline	-0.386	0.942	-0.207	0.821	-0.489	0.934	0.861	0.391
zLMI at follow-up	-0.533	1.020	-0.678	1.085	-0.395	0.941	-1.589	0.114
zBMI at baseline	-0.369	0.792	-0.441	0.770	-0.300	0.812	-1.009	0.315
zBMI at follow-up	-0.316	0.827	-0.427	0.831	-0.209	0.816	-1.505	0.135

Note. sd, standard deviation of the mean. FR, food responsiveness. HAS, home availability of fat- and sugar-rich snacks. zFMI, age- and sex-independent z-score of the fat mass index based on British reference curves. zLMI, age- and sex-independent z-score of the lean mass index based on British reference curves. zBMI, age- and sex-independent z-score of the body mass index based on Flemish reference curves. Unpaired t-test for gender differences; degrees of freedom is 127.

8.4.5 Discussion

In the current study, gender was found to moderate the relation between FR and adiposity gain in a community sample of children and young adolescents. However, this relation was not moderated by HAS or by both HAS and gender.

First, a significant positive association between FR and zFMI change over two years was found in girls but not boys, independent of common age- and sex-related increases in fat tissue mass and of their baseline zFMI. To our knowledge, only one longitudinal study reported that FR preceded greater BMI gain in school-aged children (Steinsbekk & Wichstrom, 2015), whereas this association was non-significant in other studies (Rodenburg et al., 2012; Steinsbekk et al., 2016). The inconsistent results of the previous studies may be explained by not considering gender differences, or by using zBMI gain (which may represent zFMI gain but also zLMI gain) as outcome. Conversely, the findings of a gender difference in the current study may also be explained by methodological issues. For example, it is possible that parents have different perspectives on what is adequate responsiveness to food in boys compared to girls. However, food responsiveness scores did not significantly differ between boys and girls in the current study and neither in another study on children with a similar age range, namely 9 to 12 years (Goncalves, Silva, Gomes, & Machado, 2012). Additionally, the above mentioned previous studies did use the same questionnaire to assess FR (Rodenburg et al., 2012; Steinsbekk et al., 2016; Steinsbekk & Wichstrom, 2015). Furthermore, the current results suggesting a gender difference are consistent with findings of a similar gender difference on the association between weight (gain) and the FTO rs9939609 minor allele (Jacobsson et al., 2008; M. X. Zhang et al., 2014), which has been associated with FR (Velders et al., 2012). In sum, FR may precede an augmented adiposity gain over time, and therefore, may contribute to the risk of developing overweight in girls. The suggested augmented fat tissue accretion in girls might be explained by regular energy intake beyond energy needs as FR is per definition a tendency to be highly responsive to external food-cues, and the used FR measure (i.e. subscale 'FR' of the CEBQ) has been positively associated with energy intake (Carnell & Wardle, 2007; Hall et al., 2011). However, the found gender difference needs to be confirmed by future research.

Explanations of the gender difference found in the current study remain speculative. As mentioned in the introduction, clear gender differences in the regulation of body composition are assumed to be the result of biological as well as psychological processes (Cepeda-Benito et al., 2003; Davy et al., 2006; Shi & Clegg, 2009; Yean et al., 2013). One hypothesis based on biological factors to explain the gender difference may be that, due to adaptive importance for reproduction, the interaction between individual factors and the food-environment is more pronounced in females. This hypothesis was previously suggested by Silveira et al. to explain gender differences in the moderating effect of the environment on the relation between a genetic polymorphism and food consumption (Silveira et al., 2016). Further, socio-psychological factors may also play a role. An example is the higher internalization of societal pressure to modify physical appearance, the higher body dissatisfaction and the higher drive for thinness in girls compared to boys (Yean et al., 2013). These factors compose a risk to develop disordered eating behavior via increases in weight-control intentions: dietary restraint often precedes disinhibited eating episodes at instances when self-control ability decreases (Ruderman, 1986; Stice & Shaw, 2002).

If the relation between FR and adiposity gain in girls is confirmed, obesity-prevention efforts may benefit from targeting high FR girls with tailored interventions and psycho-education. In school-aged children, interventions tailored to high FR girls may consist of recent innovative strategies aiming to reduce overeating in response to external food cues based on Schachter's externality theory (Schachter, 1971): (a) strategies to increase the girls' appetitive awareness by developing a greater sensitivity to hunger and satiety (Boutelle, Zucker, et al., 2014); (b) strategies to strengthen self-control skills to inhibit automatic approach responses to external food cues (Appelhans et al., 2011; Verbeken et al., 2013); (c) strategies to extinguish the learned response of eating in response to external food cues (Boutelle & Bouton, 2015; Boutelle, Zucker, et al., 2014); (d) strategies to train attention away from food to non-food cues (Boutelle, Kuckertz, Carlson, & Amir, 2014; Boutelle, Monreal, Strong, & Amir, 2016), and (e) strategies in order to adapt the food-environment, e.g. reduce portion sizes (Mooreville et al., 2015). Hence, the previous strategies aim to learn high FR children and their parents to adequately handle the children's high responsiveness to external food cues. Certainly in young adolescents that gain autonomy over their food intake, it is important that the high FR adolescents themselves learn all of the above mentioned strategies (Todd, Street, Ziviani, Byrne, & Hills, 2015). As such, they learn how to rely on internal hunger and satiety signals for the self-regulation of food intake (also called 'intuitive eating', an eating style that is inversely related to BMI) and how to prevent that external cues influence food intake (Herbert, Blechert, Hautzinger, Matthias, & Herbert, 2013). Furthermore, recent research in infants and toddlers suggest that it may even be possible to prevent the development of excessive FR levels by means of early psycho-education to parents, which (a) promotes the use of early feeding practices such as mere exposure to healthy food, limiting exposure to unhealthy food and feeding that recognizes and responds appropriately to cues of hunger and satiety (L. A. Daniels et al., 2014; Magarey et al., 2016), and (b) discourage the parenting strategies 'using food as reward for children's behavior' and 'using food to influence a child's emotions' (Carnell, Benson, Driggin, & Kolbe, 2014; Mallan, Sullivan, de Jersey, & Daniels, 2016).

Secondly, this study investigated the assumption that FR precedes adiposity mainly in environments plenty of energy-dense foods, using HAS as food-environmental parameter (French et al., 2012; Wardle et al., 2001). However, no significant moderating effect of HAS or of HAS and gender was found. It is difficult to explain these results, since the current study is to our knowledge the first to investigate this with the distal outcome 'adiposity gain'. However, the assumption has already been experimentally investigated with the more proximal outcome 'energy-intake' (Mooreville et al., 2015), whereby high FR children were found to be susceptible to excess energy intake when portion sizes increase. Possibly, high FR children may be more vulnerable to the amounts of food being served or to still other parameters of the home food-environment (e.g. parameters that also include drinks or foods eaten at mealtime) than to the mere availability of energy-dense snacks at home. Further, only one element of the enormous diversity of food-environmental elements that currently can influence eating behaviors of children and adolescents was assessed in the present study.

Although the importance of the home food availability for children's and adolescents' food consumption has been shown in previous research (K. J. Campbell et al., 2007; Cutler, Flood, Hannan, & Neumark-Sztainer, 2011; L. Johnson et al., 2011; Pearson et al., 2014; Vereecken, Haerens, De Bourdeaudhuij, & Maes, 2010), the influence of the obesogenic environment outside home on adiposity gain in high FR primary school children and adolescents might be preponderant over the influence of the home food-environment (Chopra et al., 2002). Children may be exposed to energy-dense foods when spending time with their peers, at school, on the way to and from school, at sports clubs, at the homes of other family members, etc. For example, the availability of unhealthy snacks and drinks at school has already been reported to moderate the association between peer group and individual consumption in adolescents (Wouters, Larsen, Kremers, Dagnelie, & Geenen, 2010). At last, the validity of the HAS measure could be questioned since it is just a two-item measure and since HAS was reported by the parents, which may have a tendency to trivialize an unhealthy food-environment created by themselves. Nonetheless, HAS has already been related to the parent-reported weekly consumption frequency of fast food (De Decker A, Verbeken S, Sioen I, Van Lippevelde W, Braet C, Eiben G, Pala V, Reisch L, De Henauw S, manuscript in review, 2016; section 8.2). Anyhow, it is of interest to use a more comprehensive measure of the food-environment in future studies, including diverse food-environmental aspects in multiple settings (e.g. school, school neighborhood, residential neighborhood, etc.).

8.4.6 Strengths and limitations

The current study was to our knowledge the first longitudinal study on the moderating effect of gender and HAS in the relation between the appetitive trait FR and adiposity gain in primary school children and young adolescents. Strengths of this study include the use of zFMI-scores based on air-displacement plethysmography instead of zBMI-scores, the longitudinal design, the community sample of children, and the use of the short FR-subscale which is easily and practically applicable for prevention purposes. Other limitations of the current study, besides the limitations mentioned in the previous paragraph, include the use of British FMI and LMI reference data due to absence of Flemish reference data. Nevertheless, only minor differences between neighboring British and Flemish populations were seen (standard deviation of zFMI and zLMI on all time points close to one in both sexes). Another limitation is the lack of information on puberty, since the parameter zFMI is adjusted for age and sex, but not puberty. Comparable with the average zBMI based on Flemish reference scores, the average zFMI and zLMI were slightly negative, probably due to an overrepresentation of children from highly educated parents, and therefore, healthier body composition (Lamerz et al., 2005). Furthermore, parental scoring of FR as well as HAS may be influenced by social desirability, the study did not take into account other parental feeding practices, and a time span of two years may be too short to find effects of HAS on a distal measure such as fat tissue.

8.4.7 Conclusion

In conclusion, although it remains speculative why the appetitive trait FR might be a risk factor for higher fat tissue accretion in girls but not boys, obesity-prevention efforts may benefit from targeting high FR girls with tailored interventions. Future research is needed (a) to further investigate to which food-environmental parameters children high in FR mainly respond, (b) to evaluate if the above mentioned intervention strategies are effective in preventing excess adiposity gain in high FR girls, (c) to confirm the gender-specific effect, best in larger cohorts, and if so, (d) to investigate the mechanisms underlying the gender difference.

GENERAL DISCUSSION

9. Overall discussion

The general introduction described how the interaction between panhuman reward mechanisms and the drastically changed food environment contributes to increased consumption of energy-dense, micronutrient-poor foods. In adolescents and adults, evidence suggests that individual differences in reward motivation partly explain why some individuals are more vulnerable to palatable food overconsumption in our current food environment, which in turn may result in adiposity gain. In the context of the search for efficient strategies to prevent (a) overconsumption of energy-dense, micronutrient-poor foods and (b) excess adiposity in childhood, this thesis investigated in school children the role of reward motivation traits in palatable food consumption and body composition development. Two reward motivation traits were considered, namely 'reward sensitivity' and 'food cue responsiveness'. The relations displayed in Figure 17 were found. In Table 22, an overview of the study population, the considered measure of reward sensitivity or food cue responsiveness, and the results of each study can be found.

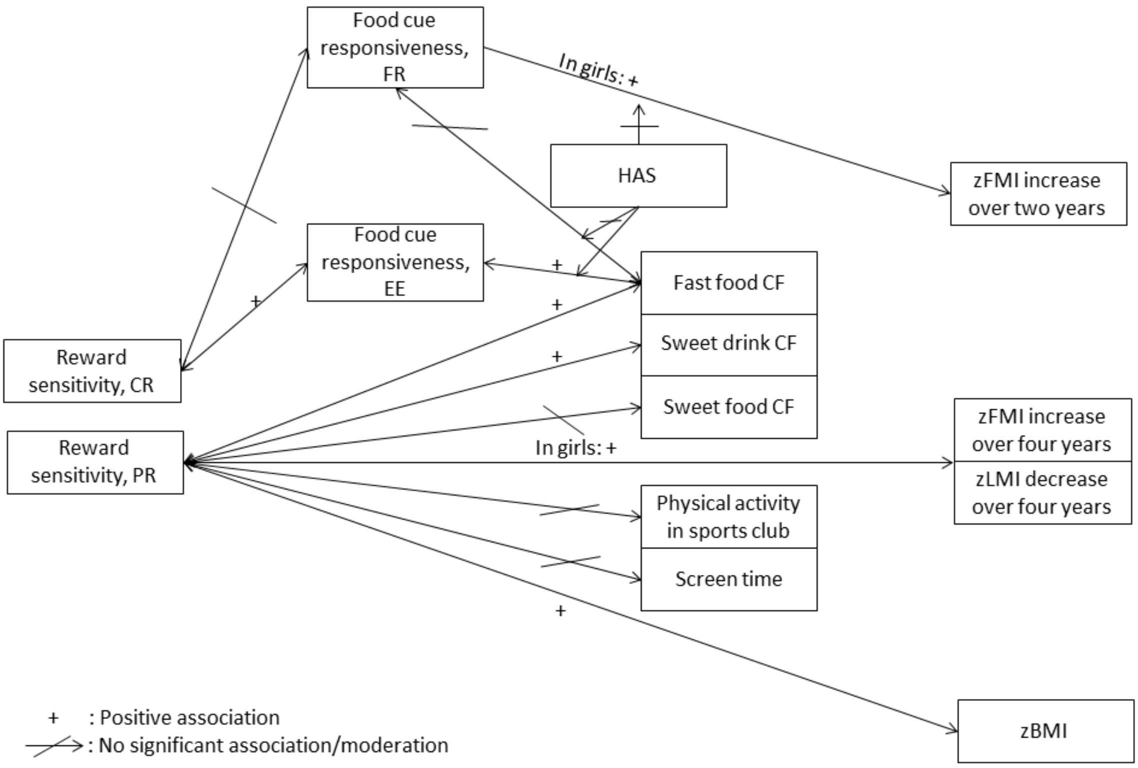


Figure 17 Relations investigated in the current thesis.
Note: CR, child report. PR, parent report. FR, food responsiveness. EE, external eating. HAS, home availability of fat- and sugar-rich snacks. CF, consumption frequency. zFMI, age- and sex-independent z-score of Fat Mass Index. zLMI, age- and sex-independent z-score of Lean Mass Index. zBMI, age- and sex-independent z-score of Body Mass Index.

Table 22 Overview of studies, study populations, measures and results

Section	Study population	Measure	Results
Methodological investigation			
7.1 BIS/BAS scale in school children: parent-child agreement and longitudinal stability	5.5-12y, N=446	PR BIS/BAS scale 2011	-No adequate fit of four factor structure
	7.5-14y, N=272	PR BIS/BAS scale 2013	-Adequate fit of four factor structure
	7.5-14y, N=238	CR BIS/BAS scale 2013	-Adequate fit of the four factor structure
	7.5-14y, N=217	PR and CR of -BIS, BAS and BAS fun seeking -BAS drive and BAS reward responsiveness	 -Not measurement invariant -Measurement invariant but discrepant; discrepancy dependent on child-age and parent-gender
	5.5-12y at baseline, N=207	Mother-report at baseline and two years later of -BAS, BAS reward responsiveness and BAS fun seeking -BIS and BAS drive	 -Not measurement invariant -Measurement invariant and stable
Results on palatable food consumption and body composition			
8.1 Associations of Reward Sensitivity with Food Consumption, Activity Pattern, and BMI in Children.	5.5-12y, N=443	PR BAS drive	Reward sensitivity was -significantly positively related to fast food CF, sweet drink CF and zBMI -not significantly related to sweet food CF, hours of screen time and sport in sports clubs
8.2 Palatable food consumption in children: interplay between (food) reward motivation and the home food environment	7.5-14y, N=159	CR BAS drive CR external eating	-Reward sensitivity was significantly positively related to fast food CF through food cue responsiveness when HAS is high
	7.5-14y, N=174	CR BAS drive PR food responsiveness	-No significant relation of reward sensitivity with food cue responsiveness -No significant relation of food cue responsiveness with fast food CF and no significant moderation by HAS
8.3 Fat and lean tissue accretion in relation to reward motivation in children.	5.5-12y at baseline, N=222 girls	PR BAS drive	-Reward sensitivity was significantly positively related to zFMI increase and zLMI decrease over 4 years in girls
	5.5-12y at baseline, N=222 boys	PR BAS drive	-No significant relation between reward sensitivity and relative adiposity gain or increase in lean mass over 4 years in boys
8.4 Fat tissue accretion in children and adolescents: interplay between food responsiveness, gender and the home availability of snacks	7.5-14y at baseline, N=129	PR food responsiveness	-Food cue responsiveness was significantly positively related to zFMI increase over two years in girls, but not in boys -No moderation by HAS

Note y, year. N, number. CR, child report. PR, parent report. BIS, Behavioral Inhibition system. BAS, Behavioral Activation System. HAS, home availability of fat- and sugar-rich snacks. CF, consumption frequency. zFMI, age- and sex-independent z-score of Fat Mass Index. zLMI, age- and sex-independent z-score of Lean Mass Index. zBMI, age- and sex-independent z-score of Body Mass Index.

Section 9.1 gives a written overview of the main research findings, followed by an overall discussion in section 9.2. Next, methodological findings and issues are discussed (9.3).

9.1 Overview of research findings for major and minor research questions

Two cross-sectional studies were conducted on the relation between reward motivation traits and **palatable food consumption**. In the first study (section 8.1), children with higher reward sensitivity (PR) were found to consume more frequently fast food and sweetened beverages, but not sweet foods. Thereby, reward sensitivity explained 1% of the variance in the fast food as well as in the sweet drink consumption frequency. The second study (section 8.2) aimed to investigate the interplay between reward sensitivity, food cue responsiveness and the food environment on fast food consumption. First, no significant main relation with fast food consumption was found for reward sensitivity (CR) and for food cue responsiveness, measured with both the subscale 'external eating' (CR) and 'food responsiveness' (PR). However, children with a higher home availability of snacks were found to consume fast food more frequently. Second, children with higher levels of external eating consumed fast food more frequently only when a lot of fat- and sugar-rich snacks were available at home. The home availability of snacks, reward sensitivity, external eating and the interaction between the home availability of snacks and external eating explained 8.4% of the variance in the fast food consumption frequency. Using food responsiveness as food cue responsiveness measure, no significant interaction was found with the home availability of snacks. Third, children who reported higher reward sensitivity also reported higher external eating, but their parents did not report higher levels of food responsiveness. Fourth, a moderated mediation model demonstrated that higher reward sensitivity is related to a higher consumption frequency of fast food via higher levels of external eating, but only when a lot of fat- and sugar-rich snacks were available at home. This indirect conditional relation was not found when food responsiveness was used as food cue responsiveness measure.

Furthermore, **one cross-sectional and two longitudinal studies** were conducted to investigate the relation of reward motivation traits with weight and change in **body composition** respectively.

In the cross-sectional study, a significant positive association between reward sensitivity (PR) and relative weight was demonstrated in a sample of boys and girls (section 8.1). Thereby, reward sensitivity explained an extra 2% of the variance in relative weight on top of the 8% variance explained by the frequency of palatable food consumption, hours of physical activity in sports clubs, hours of screen time and PEL.

Findings of the first longitudinal study indicated that reward sensitivity (PR) explained differences between girls but not boys in baseline relative fat and lean mass and in the time slopes of relative fat and lean mass over four years (section 8.3). Thereby, reward sensitivity explained 14.8% and 11.6% of the time slope variance of relative fat and lean mass respectively over four years. Girls with higher reward sensitivity had a higher baseline relative fat and lean mass. Further, they had significantly higher adiposity gain over four years parallel with a lower increase in lean mass than was expected on the basis of their age and height.

In the second longitudinal study, a similar sex difference was found on the relation between food cue responsiveness, measured with the subscale 'food responsiveness', and relative fat tissue accretion over two years (section 8.4). The results suggested that in girls but not boys, food responsiveness precedes higher adiposity gain than expected on the basis of their age and height, and this independent of the home availability of fat- and sugar-rich snacks. Thereby, food responsiveness and the interaction term between food responsiveness and sex explained an additional 6% of the variance in relative fat mass change.

A minor research question was if reward sensitivity was significantly associated with two behaviors that contribute to the level of energy expenditure. However, no significant relation was found between PR reward sensitivity and PR hours of **physical activity** in sports clubs and **screen time.**

9.2 Overall discussion of findings for major and minor research questions

9.2.1 Reward motivation and palatable food consumption

The original research in this thesis demonstrated the role of school children's reward motivation traits in explaining fast food and sweet drink consumption frequency. In the first study (section 8.1), the relations were small, which may be explained by the fact that children's access to food and drinks is strongly determined by social environmental factors (e.g. parents, grandparents) and physical environmental factors (e.g. schools). The second study (section 8.2) confirmed the latter with the finding that the relations were **conditional on children's food environment**:

(a) when a lot of fat- and sugar-rich snacks were available at home, reward sensitivity was indirectly positively related to the fast food consumption frequency through external eating;
(b) when the home snack environment was more favorable, the fast food consumption frequency of children was not dependent on these reward motivation traits, probably because the opportunity for the reward motivation traits to be expressed in food consumption was low.

Thereby, the variance in the fast food consumption frequency was explained for 8.4% when considering the interplay between reward sensitivity, external eating and the home availability of snacks (section 8.2), compared to only 1% when only reward sensitivity was considered (section 8.1). Hence, it seems critical to take into account the availability of palatable food when investigating the relation between children's reward motivation traits and palatable food consumption.

These findings also seem to support the assumption that the used measure of reward sensitivity indeed **captures approach behavior in response to environmental food cues**. In a laboratory study in children (Guerrieri et al., 2008) and an observational study in adults (Paquet et al., 2010), reward sensitivity was also found to interact with environmental food cues, namely exposure to a variety of foods and exposure to a lot of fast food restaurants in the participant's residence, respectively. However, in adolescents, the interaction of reward sensitivity and food cue responsiveness with the home availability of palatable foods as well as the school availability of palatable foods was not significant (De Cock, Van Lippevelde, Goossens, et al., 2016). Explanations may be the higher autonomy and amounts of pocket money in adolescents compared to children, making it possible to be influenced by e.g. the fast food restaurant availability in the environment (Bruening et al., 2014), as was also the case in adults (Paquet et al., 2010).

Next, **external eating may be a better predictor** of food consumption **than reward sensitivity**: when a lot of fat- and sugar-rich snacks were available at home, the difference in the fast food consumption frequency between a child on percentile 75 versus 25 of reward sensitivity (PR) was 0.7 times a week, whereas the difference in the fast food consumption frequency between a child on percentile 75 versus 25 of external eating was 2.8 times a week.

Further, it should be noted that no associations were found between reward sensitivity and the sweet food consumption frequency, and this was also the case when the availability of fat-and sugar-rich snacks at home was taken into account (data available on request). A possible explanation is that the sweet food consumption frequency is determined by other parameters such as cultural habits (e.g. eating biscuits and/or chocolate bars as snacks during school breaks in Flanders was common at the time of the data collection). Moreover, no relation with the palatable food consumption frequency was found when using food responsiveness as food cue responsiveness measure, which is further discussed in section 9.3.1.

Finally, since **sex differences** were found in the studies with adiposity gain as outcome, we tested in extra analyses if the associations of reward sensitivity (PR) with fast food consumption frequency and sweet drink consumption frequency were modulated by sex. The interaction terms were not significant, comparable to a study in adolescents using the CR reward sensitivity questionnaire (De Cock, Van Lippevelde, Vervoort, et al., 2016). However, when stratifying the data according to sex in the extra analyses (i.e. investigating the data of boys and girls separately), the relation between reward sensitivity and the sweet drink consumption frequency was only significant in girls ($\beta=0.035$, $p=0.012$) but not in boys ($\beta=0.008$, $p=0.522$) (data available upon request). The sex difference is further discussed in section 9.2.3a.

Overall, the study results suggest that already in childhood, child traits are relevant in explaining fast food and sweet drink consumption frequency. The interplay between reward motivation traits and the food environment seems to play a role in palatable food consumption. This interplay may shape unfavorable food habits, which may track further into adulthood (Craigie et al., 2011).

9.2.2 Reward motivation, physical activity and sedentary behavior

No associations were found between reward sensitivity (PR) and the potentially rewarding behaviors ‘screen time’ and ‘physical activity in sports clubs’. However, since these behaviors were **not objectively measured** with accelerometers and since previous research on these specific associations is to our knowledge absent in school children, it is too early to make conclusions. Anyhow, the finding is in contrast with findings that suggest a positive relation between physical activity and neural activation in reward areas in rodents (Herrera et al., 2016), and between gaming and neural activation in reward areas in adults (Katsyri et al., 2013). Further, the finding is in contrast with findings that suggest a positive relation of reward sensitivity with physical activity in adults and with screen time in adolescents. Concerning screen time, one study reported a positive association between reward sensitivity and playing computer/console games; this relation was mediated by engagement in the game (Vangeel et al., 2016). The contradictory findings of the study in section 8.2 versus the study of Vangeel et al. (2016) may be explained by differences in the measurement of reward sensitivity and screen time (BAS drive subscale versus the total BAS scale, respectively, and hours of screen time versus frequency of computer/console game use, respectively). Concerning physical activity, Voigt et al. (2009) reported a positive association between reward sensitivity and self-reported physical activity in adults. Further, Ekkekakis, Hall, and Petruzzello (2005) found that reward sensitivity positively related to self-reported preference and tolerance for intensive exercise in adults. As liking of a stimulus and learning of associations between a cue and a stimulus are in general prerequisites for reward motivation (see theoretical model in section 2.2.1), previous screen time and exercise experiences associated with pleasure may influence reward motivation for these behaviors (K. E. Wilson & Dishman, 2015), and consequently, may influence the relation between reward sensitivity and these behaviors. However, a pleasure response to exercise seems to be subject to multiple influences, whereby results show complex interactions of psychological and physiological influences in producing an affective response to exercise (Rose & Parfitt, 2010; K. E. Wilson & Dishman, 2015). Therefore, the relations between reward sensitivity and several kinds of physical activity may be less clear as they more strongly depend on prior experiences. Further, systematic reviews suggest that physical and social environmental characteristics (e.g. availability of exercise facilities in the neighborhood, parental control, parental logistic support) influence physical activity and sedentary behavior in children (de Vet et al., 2011; Stierlin et al., 2015; Verloigne, Van Lippevelde, Maes, Brug, & De Bourdeaudhuij, 2012). Hence, future research may benefit from taking into account **physical and social environmental factors** as well as pleasure ratings of children for different kinds of physical activity and sedentary behaviors when investigating the relation of reward sensitivity with physical activity and sedentary behavior.

9.2.3 Reward motivation and body composition

The longitudinal studies of this thesis found that differences in the strength of reward motivation traits contributed to explain differences in consistency with regard to FMI percentile curve positions during growth in girls. The results suggest that a girls' level of reward motivation traits may be a **risk factor for higher fat tissue accretion** than expected on the basis of her age and height. Since the reward sensitivity (i.e. PR) and the food cue responsiveness measure (i.e. food responsiveness) have been associated with respectively a higher consumption frequency of energy-dense foods (section 8.1) and higher energy intake (Carnell & Wardle, 2007; De Cock, Van Lippevelde, Vervoort, et al., 2016), the current findings of augmented fat tissue accretion might be explained by regular food intake beyond energy needs (Hall et al., 2011). The development of overweight or obesity is a consequence of prolonged excess fat tissue accretion. Hence, having a high reward motivation level may be a risk factor for developing overweight in girls, but this hypothesis needs to be tested in future research.

Although the increased risk for higher fat tissue accretion in girls high in reward motivation traits is assumed to be explained by higher approach behavior in response to palatable food cues in the environment, **food responsiveness and the home availability of fat- and sugar-rich snacks did not significantly interact** to explain adiposity gain in girls. Three possible reasons are given to explain this finding. First, adiposity gain is a distal measure, and the effects of the environment on this distal measure may not be apparent after a period of two years. In other words, longitudinal studies with a longer study period are needed to investigate this in depth. Second, the non-significant finding could be due to the used measure of food cue responsiveness, namely food responsiveness; we elaborate further on this topic in section 9.3.1. Third, the 'home availability of snacks' measure contains only one food-exposure aspect of the complex food-environment nowadays: (a) also non-snack food that is available at home can be palatable and energy-dense, (b) the measure does not questions the availability of sugar sweetened beverages, although sweetened beverages have consistently been linked to weight in children (Malik et al., 2013), (c) also portion sizes play a role in excessive energy intake, and (d) a review of Lucan (2015) concluded that "it is a ratio or the proportional contribution of multiple food sources acting in concert that may matter more than any one type of food source acting alone" (p. 207). Hence, a **more comprehensive measure**, including also availability and accessibility of foods at school, at sports clubs, on the way to and from school, with friends, … may be necessary to uncover an interactive effect on adiposity gain.

The **estimated increases** in zFMI in section 8.3 and 8.4 appear to be relatively small. However, it is quite considerable given the relatively low variability of zFMI in this sample and given the large range of the reward sensitivity and food cue responsiveness questionnaire scores. In the first longitudinal study performed within this thesis (section 8.3), the change in zFMI **over four years** is estimated to differ with 0.72 points between girls at the lowest and highest extreme of the reward sensitivity measure. In the second study (section 8.4), the change in zFMI **over two years** is estimated to differ with 1.03 points between girls at the lowest and highest extreme of the food cue responsiveness measure. Hence, the construct 'food cue responsiveness', measured by food responsiveness, seems to predict a steeper increase in adiposity in girls compared to the construct 'reward sensitivity', measured by the PR drive subscale. Although the explained variance by reward sensitivity (i.e. 14.8%) seems to be higher than by food cue responsiveness (i.e. 6%), these percentages cannot be compared due to methodological differences (explained time slope variance versus the explained total variance, respectively). However, acknowledging the population based research design, both variances are already considerable.

The study in section 8.3 also investigated if reward sensitivity is able to explain lean mass accretion over time. These results suggest that natural variation in this trait contributes considerably to explain differences between remaining or not remaining on the same LMI percentile curve during growth in girls but not boys. Thereby, a high level of reward sensitivity in girls may be a **risk factor for lower lean tissue accretion** than expected on the basis of their age and height. Since this outcome has not been reported previously, explanations remain speculative. A hypothesis is that girls high in reward sensitivity have a stronger disinterest in physical activity and a higher tendency for sedentary behavior with age compared to girls low in reward sensitivity.[9] However, this hypothesis contradicts the results of previous studies in adults that suggested a positive association between reward sensitivity and physical activity (Ekkekakis et al., 2005; Voigt et al., 2009). Future research should investigate the relations of reward sensitivity with physical activity and sedentary behavior using objectively measured data on physical activity and sedentary behavior.

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[9] Compared to boys, girls are more sedentary, seem to have a steeper increase in sedentary behavior with age (Bel et al., 2016; Cooper et al., 2015) and have a much steeper decrease in physical activity with age (Corder et al., 2016).

In sum, the study results suggest that during childhood, reward motivation traits may contribute to differences in body composition changes between girls, but not boys. Girls high in reward motivation traits may be more vulnerable to exhibit an unfavorable body composition development. The section below elaborates on the findings of a sex difference on the relation between reward motivation traits and body composition.

a. Sex difference

In both the longitudinal studies, effects of reward sensitivity and food cue responsiveness on adiposity gain were only found in girls. Other studies investigating sex differences on this association in school-aged children are to our knowledge absent. Hence, the findings are **preliminary** since the sex-specific effect may be due to a cohort-effect, or may be a bias due to the lack of data on puberty status (see section 10.2). They should be confirmed in future research before a conclusion can be drawn. Anyhow, a cross-sectional study in adults investigated sex differences and found the same pattern (Dietrich et al., 2014).

Moreover, if the sex differences would be confirmed in future studies, also more research is needed to clarify the underlying mechanisms. The modulation of food reward by sex is in general still a developing line of research (Figlewicz, 2015). Three **speculative hypotheses** to explain the sex difference are mentioned below.
First, according to the age range of the children in both longitudinal studies, part of the children should have entered puberty at the end of the study. During puberty, the ratio of fat and lean mass changes differentially in boys and girls: (a) the relative lean mass increases, and this increase is steeper in boys than in girls, and (b) the relative fat mass increases gradually in girls but this is not the case in boys (Wells et al., 2012). Hence, as lean mass is the primary target for weight gain in boys during puberty, and the steep increase in lean mass obviously depends on a typical growth related positive energy balance (Giovannini, Agostoni, Gianni, Bernardo, & Riva, 2000), fat and lean mass accretion during this period might be relatively **impervious to reward motivation traits** in boys.
Second, the **sex difference in levels of physical activity and sedentary behavior** (see footnote 9) may explain the sex-specific effect of reward motivation traits on adiposity gain.
Third, the sex specific effect on adiposity gain may be explained by **sex differences in the neural system that modulates reward motivation to food cues** (Asarian & Geary, 2013;

Atalayer et al., 2014; Uher et al., 2006), which are possibly based on sex chromosomes and/or sex-specific gene expressions (Ngun, Ghahramani, Sanchez, Bocklandt, & Vilain, 2011). One illustration of sex-specific gene effects may be the relation between the fat and obesity-associated transcript (FTO) gene minor allele on rs9939609 and weight gain, which was only significant among girls but not boys (Jacobsson et al., 2008; M. X. Zhang et al., 2014) (no sex difference was found by Hallman et al. (2012)). This FTO polymorphism has been related to higher scores on food responsiveness (Velders et al., 2012). Sex-specific effects are also found with the Dopamine[10] Receptor D4 (DRD4) 7-repeat polymorphism, which is suggested to be a plasticity gene (i.e. the differential susceptibility theory postulates that individuals carrying this plasticity polymorphism may be most negatively affected by negative environments but may also benefit most from positive environments; hence, the gene polymorphism underlies a higher sensitivity to environmental influences) (Belsky et al., 2009). A positive relation between the DRD4 7-repeat polymorphism and fat intake has been reported in girls but not boys. Moreover, this positive effect was only found in girls living in adverse socioeconomic conditions, whereas in girls with this polymorphism that live in a better socioeconomic condition, a negative relation with fat intake was found (Silveira et al., 2016). Additionally, women but not man with the same DRD4 polymorphism were found to have higher emotional overeating, but this only in women born in fall (van Strien et al., 2015). Based on these findings, Silveira et al. (2016) suggested that **gene - (food) environment interactions may be more pronounced in females compared to males**. This may result from natural selection during evolution, since behaviors needed to enhance reproductive success are different for males and females. Success in reproduction in females may depend strongly on a beneficial food environment. Therefore, motivational systems of females compared to males might be more focused on food reward to prepare them for pregnancy and feeding of the newborn (J. B. Becker, Taylor, J.R., 2008). The higher internalization of societal pressure to modify physical appearance in females compared to males, which is related to body dissatisfaction and drive for thinness, may also be an expression of this higher vulnerability in females to environmental factors (Yean et al., 2013).

[10] Dopamine is assumed to underlie reward processing in the brain, see section 2.2.1.

9.3 Methodological issues

9.3.1 Reward motivation traits: construct and measures

'Reward motivation state' refers to a supposed process in the brain, namely an activation of a neuronal circuitry that is triggered by reward-associated cues or the reward-stimulus itself, and that can drive behavior aiming to obtain the reward (section 2.2.1). To measure individual differences in reward motivation, i.e. reward motivation traits, an **abundancy of measurement methods** exists.

Some of these methods try to **directly measure the underlying brain process**, which is not evident in humans. Although a lot of scientific progress is made based on these **brain imaging** studies, they also have limitations. For example, the brain imaging technique that is most widely used is blood-oxygen-level dependent (BOLD) functional magnetic resonance imaging (fMRI). Using BOLD fMRI, areas are identified that e.g. are stronger activated to food versus non-food images. Based on previous research (also in animals), some of these areas are thought to be implicated in reward processes. However, it is not possible to directly infer specific functions from neural activation patterns shown in fMRI studies (for example, one area can have different functions, such as the amygdala (Fernando, Murray, & Milton, 2013); activation measured by fMRI does not differentiate between the firing of inhibitory versus excitatory neurons (J. M. Richards, Plate, & Ernst, 2013)). Researchers have to interpret the findings based on previous research (in animals) or on other measurement methods, such as questionnaires or behavioral tasks (Carnell, Gibson, Benson, Ochner, & Geliebter, 2012; Martin et al., 2010; K. S. Wang, Smith, & Delgado, 2016). Further, different methodologies exist within brain imaging research, which produce different and sometimes discrepant findings (Carnell et al., 2012). To conclude, even with neuroimaging techniques, a golden standard to measure reward motivation traits is absent. Additionally, the use of neuroimaging has specific disadvantages in children, for instance the still developing brain, anxiety in the scanner environment, and head movement in the scanner (Greene, Black, & Schlaggar, 2016). Moreover, neuroimaging is an expensive method and therefore less suitable for epidemiologic research based on large samples.

Besides neuroimaging techniques, experimental tasks and questionnaires are used that assess behaviors associated with reward motivation. Both have disadvantages. **Experimental tasks** are often time consuming, need trained personal assistants that accompany the child, the availability of specific equipment, a computer and/or a stimuli-free room. As no stimuli-free rooms were available at the study center and a large sample was followed over time, behavioral tasks were not suited for the epidemiologic research presented in this thesis. Conversely, **questionnaires** are inexpensive and easily applicable. Examples of disadvantages related to the use of questionnaires are subjectivity, doubt about which informant is best, and doubt about the observability of reward motivation traits by parents and children.

Evidently, all these very different methods probably do not measure exactly the same construct. Nonetheless, **research into the extent to which all these measures overlap** and what the nuances are of each measurement method is **scarce** in children. In adults, Vainik et al. (2013) recently investigated how the different measurement methods interrelate and relate to BMI, and Vainik, Neseliler, Konstabel, Fellows, and Dagher (2015) reported that several food-specific trait questionnaires load onto one factor, which they called ‘Uncontrolled eating’.

Since all the methods have limitations, and the questionnaire method was the most suitable for the current research design, it was **chosen to use behavioral questionnaire measures** in this thesis. Besides a presentation of the limitations related to questionnaire methods, the use of questionnaires is also presented as a strength in section 10.3.

A second consideration of this chapter is the **interrelation between the used reward sensitivity and food cue responsiveness measures** and the **measure-specificity in the food cue responsiveness – palatable food consumption association**.

In the original research of this thesis, reward sensitivity (CR) was only related to external eating but not to food responsiveness (section 8.2). Hence, the assumption that food cue responsiveness is a sub-trait of the broader reward sensitivity (section 2.5.1) seems not true when the constructs are measured with the food responsiveness subscale and the CR drive subscale, respectively. Further, scores on food responsiveness and external eating were only trend significantly related. Table 23 lists findings of other studies on the interrelations between the used measures (performing a systematic review on this topic was beyond the scope of this thesis).

Since a small relation was found between food responsiveness and drive (Vandeweghe, Vervoort, Verbeken, Moens, & Braet, 2016) and a moderate relation between food responsiveness and external eating when both subscales were reported by a parent (Groppe & Elsner, 2014), the absence of a significant relation in study 8.2 may be caused by informant discrepancies (see 9.3.2).

Table 23 Interrelations between reward sensitivity and food cue responsiveness measures used in this thesis

Study	Study population	Investigated measures	Relation
Vandeweghe, Vervoort, et al. (2016)	4.9±1.1y, N=98	food responsiveness - drive (both PR) drive – external eating (both PR)	r=0.21, p<0.05 r=0.31, p<0.01
Groppe and Elsner (2014)	6-11y, N=1657	food responsiveness – external eating (both PR)	r=0.48, p<0.01
De Cock, Van Lippevelde, Goossens, et al. (2016)	14.7+-0.8y, N=1104	drive – external eating (self-report)	b(SE)=0.34 (0.001), p<0.001

Note. y, years. N, number. PR, parent report. r, correlation coefficient. b(SE), unstandardized regression coefficient with standard error in brackets.

However, food responsiveness was also not related to the parent-reported fast food consumption frequency and this relation was not conditional on the home availability of fat- and sugar-rich snacks, as was the case for drive and external eating (8). Hence, is it possible that the food responsiveness and external eating subscales assess slightly different constructs? Both subscales were included in the current thesis as measures of food cue responsiveness since they were both developed to measure the appetitive tendencies of children to external food cues based on the Externality Theory of Schachter (Schachter, 1968; Van Strien et al., 1986; Wardle et al., 2001). Nevertheless, food responsiveness has - as far as we know - not significantly been linked to a higher consumption frequency of energy-dense foods in previous research (Rodenburg et al., 2012). But food responsiveness has been linked to eating rate and total energy intake (Carnell & Wardle, 2007). Furthermore, a higher energy intake was seen in children high in food responsiveness when portion sizes increased (Mooreville et al., 2015). Conversely, drive and external eating have been positively related to the consumption (frequency) of energy-dense foods in the original research of this thesis and in previous literature in children (Elfhag et al., 2008) and adolescents (De Cock, Van Lippevelde, Goossens, et al., 2016; De Cock, Van Lippevelde, Vervoort, et al., 2016).

To conclude, although both subscales were developed based on the Externality theory, the above mentioned measure-specific findings suggest that the subscales **assess slightly different constructs**. However, future research is needed as the nuances in the underlying construct are not clear. Only some observations can be made: (a) in nine of the ten items of external eating, the tendency to initiate eating when triggered by an environmental food cue is explicitly assessed, but this is only the case in two out of five items of food responsiveness; the other three items of food responsiveness seem to reflect a general interest and desire to eat; (b) food responsiveness scores have to our knowledge not been related to neural responsiveness or attentional bias to food cues, while this was the case for drive and external eating scores. The latter is illustrated in Table 24, which shows the – as far as we know - available studies reporting strong relations of drive and external eating with other measures of responsiveness to (food) reward cues (a systematic review was out of the scope of this thesis). These findings strengthen the **validity of the drive and external eating questionnaire**.

Table 24 Relations of drive and external eating with other measures related to reward motivation traits

Study	Study population	Other measures of reward processes	Relation
Drive subscale (measure of reward sensitivity used in this thesis)			
Beaver et al. (2006)	22±2.4y, N=12	Neural activity to the view of appetizing relative to bland foods in: -Right ventral striatum -Left amygdala -Substantia nigra -Ventral tegmental area -Left orbitofrontal cortex, posterior -Left orbitofrontal cortex, anterior -Left ventral pallidum	 r=0.80, p<0.001 r=0.74, p<0.01 r=0.81, p<0.001 r=0.77, p<0.01 r=0.81, p<0.01 r=0.79, p<0.01 r=0.83, p<0.001
Braams et al. (2015)	8-27y, N=299	Neural activity to obtainment of monetary reward in: -Left nucleus accumbens -Right nucleus accumbens	 β=5.83, p=0.02 β=6.72, p=0.01
Tapper, Pothos, and Lawrence (2010)	23y, N=92	Attentional bias to appetitive food cues	r=0.23, p<0.05
van Rijn, Griffioen-Roose, de Graaf, and Smeets (2016)	Healthy-weight women 18-30y, N=30	Neural activity to taste of an artificial sweetened solution with versus without a non-sweet carbohydrate; when participants were hungry: -Right caudate -Right anterior cingulate cortex -Left anterior cingulate cortex -Right amygdala When participants were satiated: -Left caudate	 r=-0.62, p<0.001 r=-0.59, p<0.001 r=-0.63, p<0.001 r=-0.48, p<0.001 r=0.60, p<0.001
van Rijn et al. (2016)	18-30 y, N=18	Neural activity to taste of soft drink with versus without calories	No significant correlation
Li et al. (2015)	Female 20.1±1.3y, N=50 20.2±1.2y, N=46	Attentional bias for ice cream in: -High ice-cream cravers -Low ice-cream cravers	 r=0.54, p<0.01 r=0.40, p<0.01
Watson and Garvey (2013)	21.6±2.3y, N=48	Difference in amplitude of N200 event-related potentials on EEG during exposure to food versus non-food pictures	Only in males: r=-0.54, p=0.05
External eating subscale (one of the food cue responsiveness measures used in this thesis)			
Nijs, Franken, and Muris (2009)	Young adult women, N=49	Difference in amplitude of P300 event-related potentials on EEG during exposure to food versus non-food pictures	Enhanced in high compared to low external eaters (p<0.05)
Watson and Garvey (2013)	21.6±2.3y, N=48	Difference in amplitude of N200 event-related potentials on EEG during exposure to food versus non-food pictures	Only in females: r=0.39, p=0.04
Hou et al. (2011)	22±4.7y, N=44	Attentional bias to appetitive food cues	r=0.36, p<0.05
Brignell, Griffiths, Bradley, and Mogg (2009)	Average 34.5y, N=55	Attentional bias to food cues	Greater attentional bias to food cues in high compared to low external eaters (p<0.01)

Price, Higgs, and Lee (2015)	27.4±10.2y, N=496	Power of food scale, total Yale Food Addiction Scale	r=0.67, p<0.0001 r=0.52, p<0.0001
Passamonti et al. (2009)	19-39y; N=21	Modulation of change in neural connectivity to the sight of appetizing versus bland foods between: -Ventral striatum-amygdala -Ventral striatum-premotor cortex -Ventral striatum-dorsal anterior cingulate cortex: -Amygdala-ventral anterior cingulate cortex -Amygdala-dorsal anterior cingulate cortex	 r=0.79, p<0.001 r=0.66, p<0.001 r=-0.78, p<0.001 r=-0.58, p<0.005 r=-0.59, p<0.004

Note. y, years. N, number. r, correlation coefficient. β, standardized regression coefficient. EEG, electroencephalography. ±..., indicates standard deviation of the mean.

9.3.2 Multiple informants

To measure reward sensitivity, section 8.1 and 8.2 used the PR drive subscale because some children could not read yet at the time of the assessment (wave 2011, sample age: 5.5-11 years). The study in section 8.2 used the CR, since the study was based on data of the wave in 2013, when children were between 7.5 and 14 years. Reasons for this choice are that the CR has been more frequently used in this age group than the PR. Further, children have the unique position to observe their own behavior across all possible contexts (e.g. home, school), which is not the case for parents (De Los Reyes et al., 2015; Johnston & Murray, 2003). Disadvantages of the use of the CR compared to the PR include developmental factors, e.g. young children's cognitive capacities may not support reliable reporting on behavior or behavioral tendencies. However, the CR was developed and validated for community samples of children between 8 and 12 years (Muris et al., 2005).

Although in clinical settings, a multi-informant approach is seen as the 'best practice' in evidence-based assessment, it was not chosen to use a combined measure of the PR and CR when these data were both available (i.e. in 2013). As found in section 7.1 and reported consistently in previous studies , multi-informant ratings are often **discrepant** (De Los Reyes et al., 2015). However, techniques to deal with discrepant multi-informant ratings in research are still investigated and discussed. It is currently unclear how this information must be combined. De Los Reyes et al. (2013) have proposed a theoretical model to handle informant discrepancy's, namely the Operations Triad Model. The model states that the discrepancy can represent (a) meaningful information about behavior (e.g. informants observe the child in different contexts, have different perspectives, interpretations, biases, and different reasons for social desirability), or (b) measurement error. Following the model, these different sources of discrepancy call for different techniques to deal with the discrepant data. However, as a golden standard to measure reward motivation traits does not exist, it is unclear if the developmental pattern found in section 7.1 (i.e. younger children tended to rate reward sensitivity higher than parent ratings whereas this pattern was opposite in older children) represents (a) or (b). Future research should bring more clarity on these issues.

The direct relation of the fast food consumption frequency with reward sensitivity was significant but small when the latter was measured with the PR (section 8.1), and non-significant when measured with the CR (section 8.2). This inconsistency may be due to the use of a different informant, since section 7.1 demonstrated that the PR and CR do not completely agree about the reward sensitivity level of the child. However, since the relation in section 8.1 was small although the sample size was large (N=443), the small sample size in section 8.2 (N=174) may also explain the non-significant findings.

Further, other questionnaire measures used in this thesis were completed by parents (i.e. food responsiveness, home availability of snacks, food frequency questionnaire, physical activity in sports clubs, screen time) or children (external eating). Usually, **parameters reported by the same informant relate more strongly** than parameters reported by a disparate reporter (Izquierdo-Sotorrio, Holgado-Tello, & Carrasco, 2016), which may have caused the non-significant finding between child-reported reward sensitivity and parent-reported food responsiveness in section 8.2. Nevertheless, parent-reported food responsiveness was also not related to parent-reported fast food consumption frequency, while child-reported external eating was.

A methodological issue related to multiple informant ratings is that in the survey in 2011, the identity of the parent who completed the PR drive subscale was not registered. Hence, the **gender of the parent** could not be included as covariate in the studies using the PR 2011 (section 8.1 and 8.2), although the results of section 7.1 suggest that fathers and mothers rate a child's reward sensitivity differently. However, field workers reported that in most visits the mothers accompanied their child to the study center, and hence, father-mother discrepancies may not have biased the results too much.

9.3.3 Conceptualization of reward motivation traits as stable characteristics

In the original research of this thesis, reward sensitivity and food cue responsiveness were conceptualized as stable characteristics. However, we below elaborate on three parameters that may influence an individual's level of reward motivation.

A first parameter that may cause change in children's reward motivation trait levels is the **age**. Reward sensitivity is suggested to **peak in late adolescence** (Braams et al., 2015; Cauffman et al., 2010; Figner et al., 2009; Urosevic et al., 2012). Although these findings suggest that reward sensitivity is not stable, two longitudinal studies over two years, one in individuals 8-27 years and one in 9-23 years, did not find a significant linear, quadratic or cubic relationship between age and scores on the drive subscale, the reward sensitivity measure used in this thesis (Braams et al., 2015; Urosevic et al., 2012). Nonetheless, it was found that nucleus accumbens responsivity was linearly related to drive scores and in the meantime, peak in late adolescence (the nucleus accumbens is a structure of the brain reward system). Based on these results, Braams et al. (2015) suggested that the drive subscale is an individual difference measure that is related to brain reward responsivity but not related to age. Possibly, the respondent answers the questionnaire age-adequately, i.e. compares the level of reward sensitivity to other children of the same age. Further, section 7.1 investigated the stability in the PR drive scores: they were found to remain stable over two years in children between 5.5 and 14 years. Hence, it seems allowed to use the drive scores as a parameter that does not change with age in the analyses.

A second parameter that recently is proposed to cause change in reward motivation levels of females is the **menstrual cycle**. Results of one study suggest that reward motivation levels were enhanced in the follicular phase relative to the luteal phase (Diekhof & Ratnayake, 2016). Another study demonstrated that the tendency to choose immediate reward over larger, delayed rewards was higher in the menstrual phase compared to the follicular phase; this pattern was dependent on estradiol levels (Smith, Sierra, Oppler, & Boettiger, 2014). This recent evidence was not apparent at the start of this thesis project, and therefore, data on the phase of the menstrual cycle were not collected and included in the studies. As parts of the study population had an early pubertal status, whereby the menstrual cycle just had started, it would also have been difficult to determine the phase of the menstrual cycle.

Third, recent animal research suggests that a **high-fat diet** may cause change in reward motivation levels independent of weight gain (J. F. Davis et al., 2008; Figlewicz et al., 2006; Kaczmarczyk et al., 2013) (see section 2.5.2). However, this has to our knowledge not been confirmed in humans, and was not apparent at the start of this thesis project. Therefore, we did not model a bidirectional relation between on the one hand reward sensitivity and food cue responsiveness and on the other hand a high-fat diet.

10. Strengths and limitations

This section will describe the strengths and limitations of the original research related to the study design, the assessment of children's body composition and the used questionnaires.

10.1 Study design

A first major **strength** of the original research in this thesis is the **longitudinal** design, enabling to make a first conclusion about the directionality of the studied relations. Although experimental studies are needed to confirm the findings as unmeasured confounding still can result in biased predictor-outcome relations, investigating the long-term effects of personality characteristics on body composition parameters using an experimental design is very challenging. Therefore, longitudinal designs provide a valuable alternative. A second strength is the focus specifically on **school children**: reward motivation traits in school children may have the potential to shape unhealthy food habits and unfavorably influence the body composition, which both can last and have consequences later in life (Craigie et al., 2011; Singh et al., 2008). Although the above mentioned importance, studies on the relations of reward motivation traits with palatable food consumption and adiposity gain in children were until now sparse; furthermore, studies on the moderating role of the common food environment in these relations were to our knowledge absent. Hence, a third strength is the first explorative investigation on the role of the **common food environment** of children in the current thesis. Fourth, the use of a **Belgian** sample has an important added value since existing research on reward motivation traits has been mainly conducted in North America. The findings of a positive relation of reward sensitivity and food cue responsiveness levels with palatable food consumption and adiposity gain in the Belgian sample adds to the confidence in the generalizability and replicability of previously reported findings in adolescents and adults. A fifth strength is the relatively **large sample** size in the studies using data of 2011 (section 7.1, 8.1, and 8.3). Sixth, the sample was based on the **general population**. Since treatment of excess adiposity is difficult and tracking into adulthood is high (McGuire et al., 1999; Singh et al., 2008), primary prevention is critical. It cannot be learned how individuals obtain the excess adiposity based on research in clinical, obese samples. To identify behaviors or traits that are appropriate targets for primary prevention interventions, it is an advantage that the absolute majority of children in the sample did not have obesity yet (only 0.6% were categorized as obese in 2011, 0.3% in 2012 and 2013, and 0% in 2015 based on the cut-offs of the IOTF). Hence, this thesis helps in shedding a new light on the process of gaining fat in a sensitive period of the life course.

The **method of participant recruitment** for the ChiBS and Forces Projects was a **strength as well as a limitation** of this thesis. The data for the Forces project were collected primarily in children from an existing cohort, which was initially recruited for the IDEFICS project (see section 4). This was a strength as data on reward motivation traits and body composition were already collected before the Forces project officially started, resulting in the possibility to investigate body composition changes over a **time span of 4 years**.
However, the **initial sampling** in the municipality of Aalter, a rural region with rather high socioeconomic characteristics, may have introduced a **selection bias**. This may have implications on the validity of the results in low socio-economic populations and urban areas: (a) lower socio-economic status has been related to unhealthier eating patterns (Fernandez-Alvira et al., 2015) and higher weight status in rich countries (Barriuso et al., 2015), and (b) urban compared to rural regions have a higher prevalence of childhood obesity in Belgium (Drieskens, 2014). Second, the **annual body composition measurements** between 2011 and 2013 might have influenced children or their parents to respectively **conduct or promote healthier food and physical activity behaviors**, since a significant decrease in average zFMI was found in 2013 (section 8.3). Third, the measurement battery of the IDEFICS, ChiBS and I.Family project was very **burdensome** for the participants, which contributed to decreased willingness of children and parents to participate in the Forces project. To improve the participation rate in the campaign of 2013 consisting of the I.Family and the Forces project, four examination options were offered. Moreover, participants could refuse each single examination module. Using this strategy in combination with the allowance of new children, we succeeded to collect core data of 300 children in 2013 (i.e. parental reported reward motivation traits and children's' BMI). Thereby, the allowance of new children to the study was advantageous for analyses techniques such as longitudinal multilevel modelling. Nevertheless, this strategy had the disadvantage of **disparate participation rates** for each parameter. As a consequence, the research questions of this thesis were investigated on diverse subgroups of the Forces participants. For example for the study in section 8.3, only for 220 out of 300 participants in the survey in 2013, BOD POD data were available. Further, unless the high efforts to retain children of the cohort, the remaining **drop-out** of children led to a **reduction in sample size**. This hampered the inclusion of more parameters in the

regression models as well as the use of statistical models that call for a higher sample size. Additionally, the drop-out since the start of the IDEFICS project may have resulted in a **further selection bias**: (a) possibly, only children of parents with a high interest in a healthy lifestyle remained in the cohort; (b) the drop-out was higher in older children, who indicated to lack time after transition from primary to secondary school or to lack motivation; furthermore, peripubescent children might be more ashamed of being investigated in their underwear; (c) the drop-out between 2011 and 2015 was significantly higher in children with low parental education level; (d) the prevalence of overweight (excluding obesity) in the cohort based on the cut-offs of the IOTF (i.e. 7.4% in 2011, 4.4% in 2012, 3.0% in T4 and even smaller when considering the selection criteria of the study in section 8.4, 4.5% in T5) was much lower than in the Belgian population (i.e. between 12.4% and 15.3% dependent on the age range) (Lebacq, 2015). Hence, the representativeness for the Belgian population could be questioned. Nonetheless, no drop-out differences were seen on the main predictors, i.e. reward sensitivity and food cue responsiveness, and on the outcome parameters of the main longitudinal findings (see section 8.3 and 8.4). Further, reward sensitivity and food cue responsiveness were not related to parental education level, and all analyses were controlled for child-age.

In sum, the sample drop-out and selection bias possibly had no effects on the main findings. Anyhow, the results should be confirmed in populations with lower parental education level as well as in populations with a higher variability in body composition.

Another **limitation** is the **time span** of only two years to investigate the effect of food cue responsiveness and the home food environment on fat tissue accretion, as it is harder to detect proper body composition trajectories over short time periods. A further limitation is that only parental education level was included in the studies and not **parental income** or other socio-demographic parameters (e.g. family situation, family size, parental occupation, origin), because (a) a high number of children had no data on these parameters, (b) the sample size limited the inclusion of all parameters as confounders, or (c) groups were too small (e.g. only a minority of the children were born outside Belgium or had parents born outside Belgium). Nonetheless, a systematic review concluded that parental education level has the most consistent inverse relationship with weight status in children and adolescents compared to other socio-demographic parameters (Barriuso et al., 2015). Additionally, the studies have limitations due to the **multifactorial etiology** of food consumption and adiposity gain. It was not possible to include all known influencing factors of the energy balance equation (section

1.2 and 2.4). A resting metabolic rate assessment was not conducted. Further, although physical activity and sedentary behavior were objectively assessed with accelerometers in 2012, 2013, and 2015, (a) this was not the case in 2011, (b) the data of 2013 and 2015 were not available yet at the time of the data analyses since processing of accelerometer data had to be outsourced and was not timely finished, (c) not all children wanted to wear an accelerometer; hence, inclusion of these data would have reduced the sample size considerably. Moreover, some influencing factors were not assessed to not overburden the participating children and their parents, and furthermore, the sample size would have limited the inclusion of these confounders. Finally, the macro-system was not included as a covariate since macro-system parameters would lack in variability because all study participants lived in the same region.

10.2 Body composition

Another major **strength** of this thesis is the use of the technology '**air-displacement plethysmography**' using the BOD POD system for the measurement of body volume, which enabled the division of body mass into the fat and lean tissue masses using child-specific conversion factors for lean tissue density and hydration (Wells et al., 2010). Obviously, the ability to make this division is important when adiposity is the main outcome. The importance is reflected in the findings of section 8.3 of an unfavorable body composition development in girls, namely a simultaneous relative fat mass increase and lean mass decrease, which could not have been detected using only relative body mass as outcome. A limitation of the use of air-displacement plethysmography to estimate fat and lean tissue masses in children is a lack of validation studies on the used child-specific conversion factors to transform body density into fat and lean tissue masses, as the used conversion factors are only recently developed. Although the child-specific conversion factors were derived based on a large sample of individuals aged 4-23 years using the golden standard to assess body composition (i.e. 4-compartment model), more validation studies are necessary on large samples of children to confirm the validity. Further, for an assessment of the body volume using the BOD POD system, an estimate of the thoracic gas volume is required. However, as it is difficult for many children to comply with a thoracic gas volume measurement, the thoracic gas volume was predicted based on thoracic gas volume prediction equations specifically developed for children. Obviously, the prediction of thoracic gas volume is less precise than the measurement of thoracic gas volume (Fields et al., 2004; Radley, Fields, & Gately, 2007).

Since the absolute change in fat and lean tissue masses is dependent on the height of children, the fat and lean masses have been divided by height squared, resulting in the **FMI and LMI** parameter (comparable to BMI; note: FMI+LMI=BMI). These FMI and LMI values are mostly used as comparable indexes of adiposity across individuals, whereby the researchers control for age and sex by including age and sex as confounders in linear regressions. This method assumes a linear relation of fat percentage with age and sex, whereas the fat and lean masses vary non-linearly with age in childhood and this variation differs in boys and girls (see shape of the reference curves displayed in Figure 18). Hence, a further important step in obtaining data that are comparable between children of different ages and sex is the calculation of age- and sex-independent **z-scores** of FMI and LMI, which were computed in the original research based on FMI and LMI reference curves of British children (Wells et al., 2012). Although British reference curves were used since no Flemish reference curves are available, only minor differences between neighboring British and Flemish populations were seen.

To summarize, the availability of zFMI and zLMI data to answer the research questions on adiposity gain is a considerable added value, and hence, a major strength of this study.

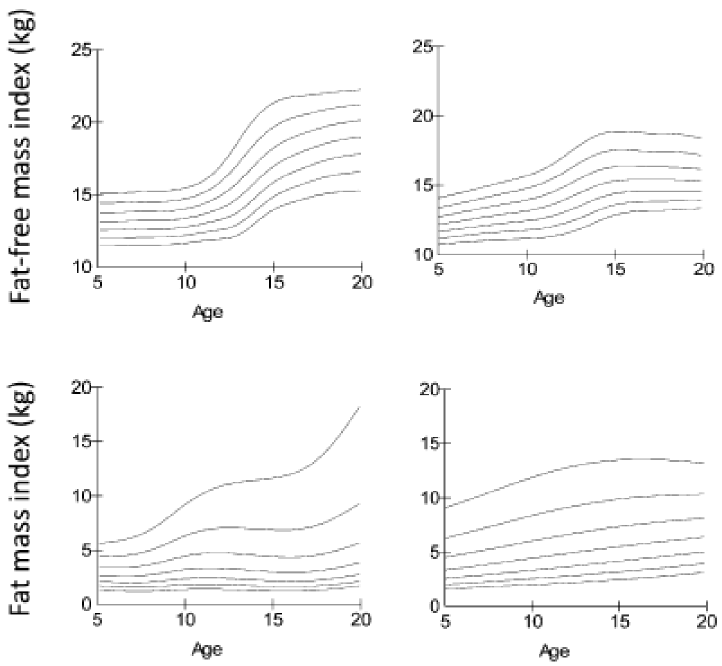

Figure 18 Percentiles of fat-free mass index (LMI) and fat mass index (FMI) by the 4-component model for males (n=261, left panels) and females (n=272, right panels).
The second, ninth, 25th, 75th, 91st, and 98th percentiles are displayed in ascending order (Wells et al., 2012).

Besides strengths, the studies with adiposity gain as outcome have some **limitations**. For a start, we had a self-report questionnaire on **puberty status** but due to the provision of multiple options in 2013, the completion rate of this questionnaire was very low. Therefore, inclusion of the puberty status in the studies on adiposity gain would have reduced the sample size considerably. Unfortunately, this hampered the interpretation of the changes in body composition: although the zFMI and zLMI parameters capture the average sex-specific and percentile-specific alterations in the balance between fat and lean mass with age, children may enter puberty earlier or later than average. Further, the zBMI, zFMI and zLMI were calculated based on **reference curves of contemporary populations** (measured after the year 2000) (Roelants et al., 2009; Wells et al., 2012). Since the prevalence of overweight and obesity has increased in the last decades, reference data based on contemporary populations may underestimate the overweight and obesity problem (de Onis & Lobstein, 2010).

Finally, body composition parameters were always used as continuous variables in all studies. Hence, the studies did not estimate the **odds on overweight** due to variation in reward motivation traits.

10.3 Questionnaire measures

In this study, multiple predictor parameters and the outcome parameter ‘palatable food consumption’ were assessed using questionnaires. First the strengths of this methodological approach and then the limitations are described.

The main rationale to conduct the presented research is informing primary prevention on the role of reward motivation traits in palatable food consumption and adiposity gain. As mentioned in section 1.3, interventions may be more effective when tailored on characteristics of vulnerable groups. To identify children with an increased vulnerability, an **inexpensive and easily and practically applicable** screening tool is necessary. Hence, it is a strength that the predictors are indexed with short questionnaire measures in the current study. Other non-questionnaire methods to assess reward motivation traits were not suitable for this purpose (see 3 and 9.3.1).

However, questionnaires are **subjective** measures. Additionally, parents as well as children may be influenced by **social desirability** in their reporting. Further, limitations should be mentioned specifically to the measurement of:

- **Reward motivation**: see section 9.3.1

- The **food environment**: see second paragraph of section 9.2.3
- **Physical activity**: the used measure did not include physical activity of the child outside of sports clubs.
- **Food consumption**: inclusion of 24-hour recalls or portion size assessments in a cohort study is a high burden for participants. Although a 24-h recall was included in the data collection of the study wave in 2013, this was optional for participants. Hence, inclusion of these data would have considerably reduced the sample size. Further, the data were not available yet at the time of the data analyses, since processing of 24-hour recall data asks quite a lot of work and time. Therefore, the food indices were only based on consumption frequency assessments, and total energy intake and the proportion of energy that was consumed in the form of palatable foods and drinks could not be computed. The used consumption frequency measures may underestimate the palatable food intake in children who eat large portions and overestimate it in children who frequently eat small portions. A further limitation is that the consumption frequencies were reported by parents, since children younger than 10 years are limited in the ability to validly respond to a food frequency questionnaire covering periods greater than one day (Livingstone, Robson, & Wallace, 2004).

11. Public health perspectives

The results of the epidemiologic studies in this thesis suggest a role of reward motivation traits in children's palatable food consumption and in girls' unfavorable body composition development. Because both may track into adulthood and are related to multiple health consequences, and because weight loss as well as the maintenance of weight loss is difficult, primary prevention is critical (see section 1). In this section, approaches that may help to **prevent palatable, energy-dense but micronutrient-poor food overconsumption** in high reward motivated children are presented.
The first set of approaches are specifically for children high in reward motivation traits (section 11.1). However, as the generation of reward motivation in response to food cues is a panhuman mechanism, **not only children high in reward motivation traits but the average child may be tempted to overconsume** palatable food when perceiving associated cues. This may be reflected in the large amount of children who overconsume calories from foods "to be consumed sparingly" according to the food guide pyramid (section 1.1). Therefore, section 11.2 elaborates on strategies that apply to the general population, but are supposed to be even more helpful for children high in reward motivation traits. Finally, section 11.3 contains some information for the developers of primary prevention interventions targeting children high in reward motivation traits.

In the original research of this thesis, a large part of the variance in palatable food consumption and adiposity gain is not explained by the association with reward motivation traits. This was expected as the etiology of both palatable food consumption and adiposity gain is multifactorial (see section 2.4 and 2.5). As displayed in the transactional model of Story et al. (2002), lifestyle factors such as physical activity and sedentary behavior, socio-economic status, biological factors, psychological factors, parenting practices, family habits, peers, the surrounding built environment, cultural factors, economic factors, policy factors etc. play also a role in children's food consumption and body composition development (Figure 19). We recognize that interventions focusing on all these factors are necessary, e.g. interventions aiming to increase physical activity and decrease sedentary behavior. However, listing such interventions is beyond the scope of this thesis.

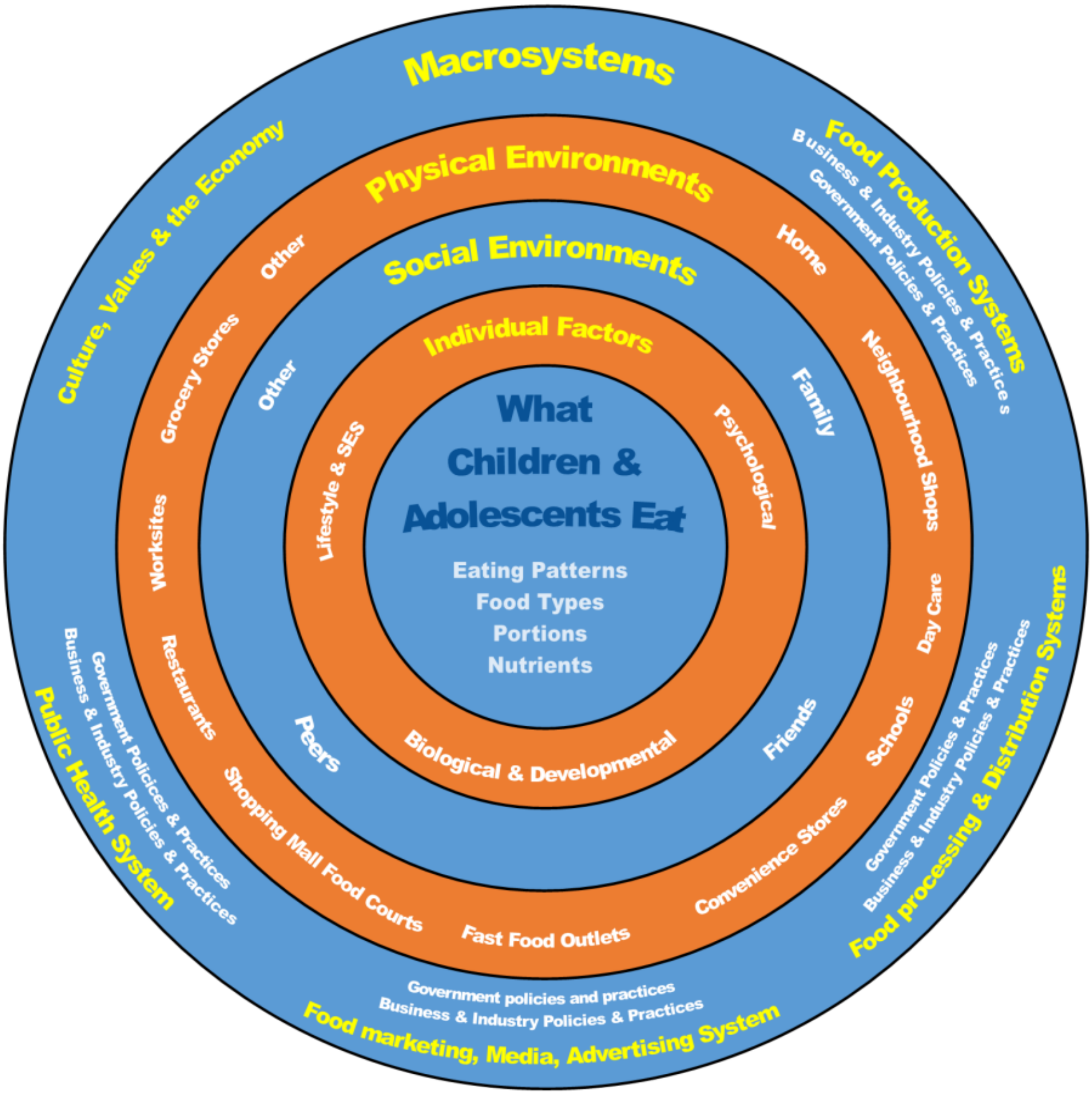

Figure 19 Transactional model to explain individual differences in food consumption (adapted based on Story et al. (2002))

11.1 Approaches specifically for children high in reward motivation traits

In this section, approaches specifically for children high in reward motivation traits are described. The approaches aim to decrease palatable food overconsumption by targeting (neuro-)psychological processes related to reward motivation in these children (individual level of the transactional model, see Figure 19). We first elaborate on three approaches that can be **applied by parents** in everyday life. Two of these approaches try to **change the automatic responding to food cues**. One is '**exposure and response prevention**', whereby the aim is extinction of the association between the conditioned palatable food cue and consumption of the food. The other is '**counterconditioning**', whereby the conditioned cue is paired with a non-food reward instead of with food consumption (Boutelle & Bouton, 2015). Counterconditioning is possibly more effective in children high in reward motivation traits, as rewards are potent in determining these children's behavior (Vandeweghe, Verbeken, et al., 2016). Besides that relapse may occur, a disadvantage of these techniques is context-specificity. For example, using exposure and response prevention, a child that always eats potato chips when watching television may learn over time that watching television at home is not associated with eating potato chips; however, when the child sees a television in another place than at home, the urge to eat potato chips can reappear (Boutelle & Bouton, 2015). Further, the balance between reward motivation and inhibitory control capacities at a certain moment is supposed to determine actual food consumption (see section 2.5.3). Hence, instead of changing the automatic responding to food cues, **strengthening the cognitive ability to inhibit this automatic approach responding** may prevent palatable food overconsumption. Children learn this ability in daily life by interactions with parents and teachers, e.g. (a) children learn in school to stay seated on a chair, although they want to approach rewarding stimuli in the environment, (b) when children are exposed to a bowl of cookies while visiting friends, children practice their inhibitory control capacities when limits are set on the amount of cookies they are allowed to eat. Children high in reward motivation traits may benefit from extra inhibitory control exercises in non-food as well as food domains.

Second, several **computer-based training** approaches to decrease palatable food overconsumption are currently developed and tested. They aim to **change automatic responding to food cues**. One is **attention bias** training, whereby the attention is trained away from food to non-food cues (Boutelle, Kuckertz, et al., 2014; Boutelle et al., 2016). Another one is **approach-avoidance** training, which intent to modify the behavioral response of the approach itself. For example, participants are trained to avoid instead of approach the palatable food stimuli by pushing a joystick away (D. Becker, Jostmann, Wiers, & Holland, 2015; Schumacher, Kemps, & Tiggemann, 2016). A third one is **inhibition training**, in which children are trained to inhibit automatic motor responses. Using this technique amongst other training techniques, obese children were significantly more capable to maintain weight loss until 8 weeks post-training compared to obese children receiving care as usual (Verbeken et al., 2013). If future research confirms the effectivity of these programs in children, the development of a child-friendly computer tool integrating these approaches may be useful for primary prevention.

11.2 Strategies that apply to the general population

As part of prevention efforts targeting palatable food overconsumption in the general population of children, we first elaborate on strategies that apply to **caregivers**. Caregivers are environmental agents at the social environmental level (Figure 19). But caregivers also have an influence on biological and psychological processes in the child (see section 11.1) and on parts of the physical environment of children, e.g. parents determine the home food environment.

A first important recommendation for all parents, grandparents, teachers etc. is **limiting the availability and visibility** of palatable but energy-dense foods. When palatable foods are not available, reward motivation for food is not triggered (Blechert et al., 2016). Therefore, the child will not demonstrate behavior to obtain these foods. As suggested by the study results of section 8.2, limiting the availability may be in particular helpful for children high in reward motivation traits. Besides limiting purchases and/or visibility, **limiting the consumption frequency and quantity** of energy-dense food has to be recommended (Rollins et al., 2014b). Thereby, it seems important that parents **not prohibit** the consumption of all energy-dense foods, since this is associated with overconsumption in ad-libitum situations (Rollins et al., 2014a).

Further, palatable but energy-dense foods should **not** be **offered to reward children's behavior**, irrespective of the question whether it is food or non-food related behavior. Such practice induces a higher consumption of unhealthy foods in all children, even more in children high in reward motivation traits (Kroller & Warschburger, 2009; Lu et al., 2015; Remy, Issanchou, Chabanet, Boggio, & Nicklaus, 2015). Additionally, food should also **not** be **offered in the context of a child's emotions**: both "using food as reward for children's behavior" and "using food to influence a child's emotions" have been associated with higher levels of food cue responsiveness in children (Carnell et al., 2014; Mallan et al., 2016).

Conversely, the reward motivation mechanism may be used by caregivers to direct children to healthier food choices: using **tangible (e.g. stickers) or non-tangible rewards (e.g. praise)** is found **to encourage children to taste** new or less liked healthy foods (Cooke, Chambers, Anez, Croker, et al., 2011; Cooke, Chambers, Anez, & Wardle, 2011). Furthermore, this strategy was found to be more effective in children high in reward motivation traits (Vandeweghe, Verbeken, et al., 2016). Tasting of new or less liked foods is important, since children mostly learn to accept them after repeated exposure (Anzman-Frasca, Savage, Marini, Fisher, & Birch, 2012).

Further, differences in children's attraction to food versus non-food rewarding alternatives can be already seen in infancy (Kong, Feda, Eiden, & Epstein, 2015). The ratio between attraction to food versus non-food reward in infants was found to improve when the **environment** was **enriched with a non-food alternative** (Kong et al., 2016). If confirmed in future research, parents should be encouraged to create a home environment that is **stimulating and distracting from food** as early as infancy. Most of the above mentioned recommendations are especially important for parents. Interventions may help to put the recommendations into practice through psycho-education and learning skills to parents (e.g. skills to resist persuasive behavior of their child to receive more of the palatable food, skills to inhibit their own approach behavior to palatable food when purchasing food).

However, the above mentioned strategies targeted to caregivers as well as to children high in reward motivation traits (section 11.1) are highly effortful for all. Moreover, population effects of prevention programs targeting individuals and their behavior are small compared to **policy interventions targeting the drastically changed food environment**, which is seen as the major driver of the rise of the global obesity epidemic during the past 3-4 decades (Swinburn et al., 2011). Hence, policy interventions may have more effects and meanwhile, may make it easier for individuals to adhere to an adequate dietary pattern. The food environment is determined by multiple factors that are situated in the transactional model on the level of the physical environment and of the macrosystem (Figure 19). As Lucan (2015) concluded that "it is a ratio or the proportional contribution of multiple food sources acting in concert that may matter more than any one type of food source acting alone" (p. 207), interventions on all domains are needed to reduce the omnipresent food-reward cues.
Settings on the **physical environmental level** (see Figure 19) may help to improve children's dietary pattern by **limiting the availability, visibility, and marketing** of palatable but unhealthy foods (e.g. no or only a small variety of unhealthy foods in schools, no unhealthy foods at the pay desk or on shelves at or below eye level) (Afshin et al., 2015; Blechert et al., 2016; D. A. Cohen & Babey, 2012). Further, interventions such as increasing availability, visibility and appeal (e.g. using a cartoon character on the label) of healthy food items may **make the choice for a healthy food option more obvious**, (Anzman-Frasca, Mueller, Lynskey, Harelick, & Economos, 2015; Anzman-Frasca, Mueller, Sliwa, et al., 2015; Enax et al., 2015; Keller et al., 2012). Altering the presentation of options (availability, visibility, salience etc.) with the purpose to influence habitual behaviors is also called '**nudging**'. Although there is already some evidence for particular nudging interventions (e.g. the

implementation of healthier children's menu's in restaurants (Anzman-Frasca, Mueller, Lynskey, et al., 2015)), more research reports are needed to conclude on the effectiveness of multiple nudge interventions in a range of settings (Nornberg, Houlby, Skov, & Perez-Cueto, 2016; A. L. Wilson, Buckley, Buckley, & Bogomolova, 2016).

Also on the macrosystem level, actions are needed. For example, the food industry should **reduce the levels of refined sugars, salt and fat** in their processed food products, as high amounts of these components increase reward motivation states (see section 2.2.2). Further, consistent evidence exists that **increasing the retail price of unhealthy foods**, preferably in tandem with a decrease in the retail price of healthy foods improves the diet (Niebylski, Redburn, Duhaney, & Campbell, 2015; WHO, 2016b)[11]. Furthermore, advertising of food, for instance through television commercials or so-called 'advergames' on the internet, provides also food cues. It is consistently found that exposure to these cues increases food intake in children (Boyland et al., 2016; Folkvord, Anschutz, Buijzen, & Valkenburg, 2013). It is also found that **a ban on fast food advertisements directed to children** can decrease the purchase propensity of households (Dhar & Baylis, 2011). As the Belgian Food Consumption Survey 2014 demonstrated that 64% of the Belgian adults supports the prohibition of junk and fast food advertisement to children, it is highly advised to Belgian policy makers to take action (Teppers, 2015).

11.3 Points for the development of interventions

Some **points important for the development of primary prevention interventions** should be mentioned. First, an **increased general awareness** on reward motivation mechanisms and traits may help children high in reward motivation traits and their parents to understand why they are more tempted by palatable food. This understanding may initiate a search for ways to deal with the higher motivation to consume palatable food. However, a drawback of informing the population on individual differences is possible **stigmatization** of children high in reward motivation. Talking about characteristics that render some children more vulnerable may induce the perception of a deviant condition in these children, which may trigger negative emotions and behavioral reactions (Dijker & Koomem, 2003). Stigmatization is

[11] The systematic review of Niebylski et al. (2015) concluded that a price increase of unhealthy foods and a price decrease of healthy foods of minimum 10 to 15% is necessary to improve the diet. The report of the WHO (2016b) concluded that a price increase of sugary drinks of minimum 20% and a reduction of the price of fresh fruits and vegetables of minimum 10-30% is necessary.

worse with higher perceived seriousness and perceived personal responsibility (Dijker & Koomem, 2003). Hence, when informing the population, it is important to stress that the drastically changed environment has made the reward mechanisms to food maladaptive. Children high in reward motivation traits or their parents do not have a personal responsibility on this matter and are not to blame. Because of the changed food environment, resisting food temptation is more difficult for them. Further, it should be stressed that variation in reward motivation traits among the population is an enrichment for the society on multiple non-food domains (e.g. reward sensitivity in adults has been positively related to job satisfaction, organizational commitment, and senior-executive performance (Hutchison, Burch, & Boxall, 2013; Izadikhah & Jackson, 2010; van der Linden, Taris, Beckers, & Kindt, 2007)).

Second, many scientists currently suggest to move from a one-size-fits-all approach towards targeted interventions that focus on populations that are particularly vulnerable (e.g. Silveira et al. (2016)). Targeted interventions enable to tailor interventions on specific characteristics, such as reward motivation traits. This has advantages because not every intervention strategy works for everyone, as there is differential susceptibility to environmental influences (Belsky & van Ijzendoorn, 2015). There is already some evidence in adults as to which elements to include in prevention interventions tailored to this reward motivation feature (see two examples in the discussion of section 8.1 on messages framed in a gain- versus loss-frame and on control-based strategies versus acceptance-based strategies). Future research in children needs to evaluate which approaches work best for children high in reward motivation traits, although some indications are already available, e.g. using non-food rewards may motivate these children stronger to conduct healthier behavior (see above). Unfortunately, also interventions targeting only vulnerable children may induce stigmatization. With the rise of new technologies (computer programs or mobile applications), it should be possible to create **interventions for the general population** that **measure** individual characteristics and **tailor** intervention strategies and their intensity on these characteristics, **without the knowledge of the target population**.

However, notwithstanding effortful interventions targeted to the individual level (section 11.1), the newly learned behaviors in particular vulnerable children may **relapse if the food environment will not be changed**. Therefore, **interventions that target the physical environment and macrosystem** are **most strongly recommended**. The ultimate goal should be a society in which the healthy choice is the most obvious choice and a healthy life style is the standard.

12. Future research

As mentioned before, the findings of the current thesis should be **replicated** in future research. For future research on similar research hypotheses as investigated in this thesis, the following is recommended (section numbers with more information are provided in brackets):

- The recruitment of a more **representative population** sample, both on weight status and socio-economic status (10.1), e.g. by recruiting children living in urban areas and measuring children at school instead of at a study center.
- The consideration of the relation between reward motivation traits and different socio-demographic parameters (section 10.1).
- The inclusion of **puberty status** and investigation over a **larger time span**, best from childhood to young adulthood (9.2.3a and 10.2).
- The inclusion of children's **inhibitory control capacity**, as children high in reward motivation traits may be less vulnerable if they have strong inhibitory control capacities (2.5.3).
- The inclusion of measures of children's **food preferences**. Food preferences have also been related to diet and adiposity (Cox, Hendrie, & Carty, 2016). Children with high levels of reward motivation traits in combination with a strong preference for energy-dense foods can be expected to have higher palatable food consumption and adiposity gain than in combination with a (probably learned, see 2.2.2a) preference for foods low in energy such as vegetables.
- The inclusion of a **resting metabolic rate measurement** in studies with adiposity gain as outcome.
- The inclusion of objectively measured physical activity data using **accelerometers** (9.2.2, 9.2.3 and 10.1).
- The consideration of the **menstrual phase** of females (9.3.3).
- The use of a **comprehensive general and feeding parenting practices measure** to take into account interactions between reward motivation traits and the social environment on food consumption and adiposity gain.
- The use of a more **comprehensive questionnaire of the food environment** (9.2.3 and 10.3), or even more interesting, an **observational measure** of the everyday exposure to food cues, which can be obtained using wearable automated cameras (Barr, Signal, Jenkin, & Smith, 2015). This may confirm the presumption that also food-reward cues

in the public environment initiate food consumption in children high in reward motivation traits. The results may provide strong arguments for policy makers to regulate the presence of food-reward cues in the public environment. Further, the inclusion of an observational measure may reveal to which kind of food cues children high in external eating versus food responsiveness reacts, and as such, can help to disentangle the nuances in the constructs they measure.

Concerning **reward motivation mechanisms, measures and the etiology** of individual differences in reward motivation traits, more research is needed into the underlying **neuronal circuits and neurotransmitters** (section 2.2.1). Additionally, the role of **appetite hormones** (e.g. the orexigenic hormone ghrelin) in the induction of hedonic hunger by food-reward cues should be further investigated. Furthermore, future longitudinal research should test if **high-fat diets** influence the strength of reward motivation traits (see 9.3.3). Thereby, it is important to elucidate if possible diet-induced changes reflect a pathological change that eventually may further lead to overconsumption of unhealthy foods and adiposity gain (i.e. a vicious circle) or reflect a change aiming to restore the inadequate dietary pattern (Berridge et al., 2010). Longitudinal research may also further elucidate **nature and nurture influences** as well as **gene-environment interactions** that determine reward motivation levels (see 2.5.2) (J. S. Richards et al., 2016). Additionally, a systematic review on the interrelations between the large amount of human reward motivation measures should be conducted (9.3.1).

Concerning **public health interventions**, more research is needed to confirm the effectiveness of the mentioned intervention approaches on the individual level and on nudging (see section 11). To evaluate the need for and success of policy interventions, monitoring of different food environmental aspects over time is highly needed. Recently, the ‘International Network for Food and Obesity/non-communicable diseases Research and Action Support’ was founded to support international monitoring of several aspects of food environments, such as food composition, food labelling, exposure of children to unhealthy food promotion and food prices (Swinburn et al., 2013). Monitoring makes it possible to evaluate the effectiveness of self-regulation (i.e. economic operators that adopt among themselves common codes of practice or sectoral agreements), co-regulation (i.e. a combination of industry and government regulation), and government regulation (i.e. laws). Moreover, international monitoring makes it possible to compare data between countries. For example, it has been found that the salt content in food products of specific international fast food chains vary substantially between countries (Dunford et al., 2012). With these data, the effectiveness of food environmental regulations in facilitating low salt content in food products of fast food chains can be evaluated. To our opinion, these food monitoring practices should also be conducted in Belgium.

Further, even if a ban on food advertisement targeting children is installed, children can be exposed to food advertisements targeting adults. Therefore, it should be investigated if there is sufficient support for a ban on all advertisements for foods belonging to the top of the food guide pyramid (see section 1.1). If not, the effectiveness of prohibition of advertising palatable food as rewarding or in rewarding social environments could be investigated. Furthermore, research may elucidate if palatable foods given by shops to reward behavior (e.g. buy certain products or buy products for a certain amount) influence palatable food consumption in individuals high in reward motivation traits. While waiting for new and effective self-, co- and government regulations, further research is needed into how individuals can be effectively empowered to influence and resist the obesogenic food environment (through social media, through mobile applications that e.g. alert you when the variety of unhealthy foods in your shopping basket is too high, etc.).

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CURRICULUM VITAE

Personalia

Name: Annelies De Decker

Date of Birth: June 21th, 1986; place of Birth: Wilrijk

Office address: UZ Gent, de Pintelaan 185 4K3, 9000 Gent, Belgium

Email address: Annelies.DeDecker@UGent.Be

Education

2004-2011: **Master of Medicine**

University of Leuven

- Master thesis 1 2009-2010: Etiology, prognosis, and therapeutic aspects of multiple food allergy as unexpected complication of the disease of Hirschsprung
- Master thesis 2 2010-2011: Positive affectivity, the reward system and the development of depression in adolescence

2012-2016: **Doctoral Schools Training Program**

Life Sciences & Medicine, Ghent University

- Advanced academic English (Ghent University)
    - Writing skills
    - Conference skills – Academic Posters
- Statistische analyse met behulp van SPSS voor gevorderden (Ghent University)
- Introduction to structural equation modelling with Mplus (Utrecht University)
- Mplus workshop: theory into practice, growth and path models (Flames)
- Statistical analyses in R for health scientists (Ghent University)
- Intervention Mapping: designing theory-based and evidence-based programs (Maastricht University)
- Authentic networking (Ghent University)
- Project management (Ghent University)

- Beyond academia: career in the non-academic job market (Ghent University)
- From PhD to Job Market (Ghent University)
- Workshop competenties voor een niet-academische carrière (Ghent University)

Experience

08-2007: **Research internship**
Laboratory of Clinical and Epidemiological Virology, University of Leuven

08-2008: **Research internship**
Laboratory of Experimental Medicine, Endocrinology, University of Leuven

2009-2011: **Clinical internships**: general medicine, internal medicine, pediatrics, surgical medicine, orthopedics, neurology, dermatology, gynecology, ophthalmology, adult psychiatry, child- and adolescent psychiatry
Multiple hospitals in Antwerp and department of child- and adolescent psychiatry at the University Hospital Leuven

2011-2012: **Medical doctor, first year of training for child- and adolescent psychiatrist**
Department of adult psychiatry, University Hospital Leuven

2012 – 2017: **Doctoral researcher in health sciences**
Unit of Nutrition and Food Safety, Public Health, Ghent University

A1 publications

De Decker, A., Sioen, I., Verbeken, S., Braet, C., Michels, N., & De Henauw, S. (2016). Associations of reward sensitivity with food consumption, activity pattern, and BMI in children. *Appetite, 100,* 189-196.

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A4 publications

De Decker, A., Verbeken, S., Sioen, I. (2016). Beloningsmechanismen: hoe interageren ze met de voedingsomgeving. *Nutrinews, extra.*

De Decker, A., Sioen, I., Verbeken, S., Braet, C., De Henauw, S. (2017). Beloningsmotivatie, voedingsgewoontes en veranderingen in lichaamssamenstelling bij schoolkinderen. *Tijdschrift voor voeding & diëtetiek.*

Presented congress abstracts

De Decker, A., Declercq, B., Verbeken, S., Wells, J., S., Braet, C., Michels, N., De Henauw, S. Fat and lean tissue accretion in relation to reward motivation in children. Belgian Nutrition Society, Annual Meeting, 2016, Brussel. Poster presentation.

De Decker A. & Descamps H., Sioen I., Verbeken S., Braet C. , De Henauw S. Associations between fruit intake and the executive functions 'Cognitive flexibility' and 'Inhibition' in children. 12th European Nutrition Conference of Fens, 2015, Berlin. Poster presentation.

De Decker, A., Sioen, I., Verbeken, S., Braet, C., Michels, N., De Henauw, S. Longitudinal associations between reward sensitivity and adiposity in childhood. International Society for Behavioral Nutrition and Physical Activity (ISBNPA) Annual Meeting, 2015, Edinburgh. Oral presentation.

De Decker, A., Sioen, I., Verbeken, S., Braet, C., Michels, N., De Henauw, S. How is reward sensitivity related to food intake and adiposity in children? Association for researchers in psychology and health (ARPH), annual conference, 2015, Gent. Oral presentation.

De Decker, A., Sioen, I., Verbeken, S., Michels, N., De Henauw, S. How is reward sensitivity related to food intake and adiposity? 24th ECOG Congress, 2014, Salzburg. Oral presentation.

De Decker, A., Sioen, I., Verbeken, S.,Michels, N., De Henauw, S. Reward sensitivity and consumption frequency of high-fat and high-sugar foods. Belgian Nutrition Society, Annual Meeting, 2014, Brussel. Poster presentation.

De Decker, A., Sioen, I., Verbeken, S.,Michels, N., De Henauw, S. Reward sensitivity and consumption frequency of high-fat and high-sugar foods. HabEat Symposium, 2014, Dijon. Poster presentation.