Using the rewarding value of food and sensitivity to reward to improve the snacking behavior of adolescents

Ir. Nathalie De Cock

Thesis submitted in fulfillment of the requirements for the degree of Doctor (PhD) in Applied Biological Sciences

Promotors

Prof. dr. ir. John Van Camp
Prof. dr. Carl Lachat
Dr. Wendy Van Lippevelde

Dean

Prof. dr. ir. Marc Van Meirvenne

Rector

Prof. dr. Anne Paepe

Members of the Jury

Prof. dr. ir. John Van Camp (Promotor)
Department of Food Safety and Food Quality, Ghent University

Prof. dr. Carl Lachat (Copromotor)
Department of Food Safety and Food Quality, Ghent University

Dr. Wendy Van Lippevelde (Copromotor)
Department of Public Health, Ghent University

Prof. dr. Patrick Kolsteren (PhD committee)
Department of Food Safety and Food Quality, Ghent University

Prof. dr. Steven Eggermont (PhD committee)
School for Mass Communication, KU Leuven

Prof. dr. Michelle Holdsworth (PhD committee)
Department of Public Health, ScHARR, University of Sheffield

Prof. dr. ir. Kris Verheyen (Chairman)
Department of Forest and Water Management, Ghent University

Prof dr. ir. Olivier Thas (Reading Committee, Secretary)
Department of Applied Mathematics, Biometrics and Process Control, Ghent University

Prof. dr. ir. Wim Verbeke (Reading Committee)
Department of Agricultural economics, Ghent University

Prof. dr. ir. Christophe Matthys (Reading Committee)
Department of Clinical and Experimental Medicine, KU Leuven

Prof. dr. Emely De Vet (Reading Committee)
Department of Strategic communication, Wageningen UR

Dr. Ann DeSmet (Reading Committee)
Department of Movement and Sports Sciences, Ghent University

Dutch title: Het gebruik van de beloningswaarde van voeding en de beloningsgevoeligheid om het snackgedrag van adolescenten te verbeteren

Cite as: De Cock N. Using the rewarding value of food and sensitivity to reward to improve the snacking behavior of adolescents. 2017. Doctoral thesis. Ghent University

Funding: Agency for Innovation and Entrepreneurship of Flanders (Belgium)

ISBN: 9789059899599

Printing: University Press-Zelzate

Acknowledgements

Bijna exact 4 jaar geleden (02/01/2013) begon ik aan dit doctoraat, ondertussen heb ik veel geleerd en heb ik ook een hoop mensen daarvoor te bedanken.

Eerst en vooral wil ik graag mijn promotoren Wendy, Carl en John bedanken om mij in te leiden in de wondere wereld van het doctoreren. John, bedankt om mij de kans te geven om aan dit doctoraat te beginnen, me bij te staan en me aan te moedigen. Carl, bedankt voor alles wat je me hebt geleerd, de vele inspirerende babbels en vooral je drive die me ertoe aan zette steeds het onderste uit de kan te halen. Wendy, bedankt om mij de interventie kneepjes van het vak te leren, zonder jou had die interventie er nooit gekomen.

Graag wil ik ook mijn begeleidingscommissie, Steven, Patrick en Michelle, bedanken voor hun steun en waardevolle feedback. Patrick, bedankt ook voor de vele “aha” of “zo kan het ook” momentjes, je bent een vat vol kennis, ervaring en goeie ideeën. Hierbij wil ook graag de leden van de jury bedanken voor hun ideeën en suggesties, die mijn werk nog verder hebben verbeterd.

Lea, jij verdient ook een vermelding, je hebt me bij het begin mijn doctoraat ook altijd van goeie raad voorzien en me met plezier opgenomen in je onderzoeksgroep. Ook nadat je zelf op pensioen ging, ben je me blijven volgen en steunen, waarvoor ik je zeer dankbaar ben. Je kritische kijk en ervaring hebben mijn onderzoek vaak naar een hoger niveau getild. Benedicte, ook jou wil bedanken, om me verder te betrekken bij de groep gezondheidspromotie en me meer te leren over gezondheidspromotie.

Ook de leden van het REWARD project hebben me van alles bijgebracht de voorbije jaren en hebben me ook steeds gesteund. In het bijzonder wil ik mijn doctoraatsmaatjes Laura, Annelies en Jolien bedanken voor de fijne tijden die we samen beleefd hebben. Het was fantastisch om 3 toffe en gelijkgestemde zielen te hebben om het doctoraatsproces mee te beleven.

Naast alle collega’s van het REWARD project had ik ook nog eens het privilege om deel uit te maken van niet één maar twee onderzoeksgroepen en had ik dubbel zoveel toffe collega’s. ladies van de GVO, bedankt voor de vele leuke girls momenten. Jelle en Joris, om het evenwicht te houden en al die vrouwen in toom te houden. Our office at the faculty can without a doubt be called international. Colleagues flying in from Ethiopia, Burkina Faso, etcera, thank you for the vibrant atmosphere, it is never boring with you guys there. Roos, Kimberly, Dana and Chen, thank you for all the laughs and fun moments. Christine, friend and colleague, our wonderful lunch breaks turned many of my bad days around with laughter.

Vriendjes en vriendinnetjes, bedankt voor alle leuke momenten die we samen beleefd hebben. Zonder jullie, zou ik er al 10 keer de brui aangegeven hebben. Ellen, Sara en Annelies, al van mijn 12de zijn jullie mijn steun en toeverlaat. Ik hoop dat we nog vele leuke momenten samen kunnen beleven. Ellen S, de vele gezellige en lekkere woensdagavondetentjes waren vaak een welgekomen ontspanning. Ilse, mijn loopmaatje, bedankt voor de vele sportieve loopjes. Al nam het tetteren al eens vaker de bovenhand.

Mama en Papa, bedankt voor jullie ondersteuning op werkelijk alle vlakken gedurende mijn doctoraatsloopbaan, maar ook in de periode ervoor. Jullie steun en aanmoediging om steeds voor het beste te gaan, hebben me telkens weer vooruit geholpen. Papa, ook bedankt om me in de juiste richting te sturen toen ik mijn studiekeuze moest maken, anders had ik hier misschien niet gestaan. Mama, bedankt om me altijd te steunen en van peptalks te voorzien wanneer ik weer eens een examen of deadline niet zag zitten. Graag wil ook mijn grootouders en peter, Philippe, bedanken die me ook steeds opgevangen en ondersteund hebben. Ook Dirk en Lut, de ouders van Bart, ben ik dankbaar voor hun steun en aanmoediging de voorbije jaren. En dan het laatste, maar zeker en vast niet het minste, familielid dat ik wil bedanken is mijn kleine broereman. Laurenz, merci voor er altijd te zijn voor je grote zus!

En dan rest er mij nog 1 iemand om te vermelden, Bart, wat zou ik zonder jou moeten beginnen? Bedankt om me steeds te steunen, op te vangen en op te peppen als ik het weer even niet zag zitten! Maar vooral om gewoon te zijn wie je bent, zonder jou zou niets nog hetzelfde zijn.

Abbreviations

WHO	World Health Organization
FSA	Food standard agency
SSB	Sugar-sweetened beverage
FFQ	Food frequency questionnaire
TPB	Theory of planned behavior
ASE model	Attitude, social influence and self-efficacy model
RV	Reinforcing value
SR	Sensitivity to reward
BAS	Behavioral activation system
BAS FS	BAS fun seeking
BAS RR	BAS reward responsiveness
BAS DRV	BAS drive
BAS TOT	BAS total
BCTs	Behavior change techniques
BCT	Behavioral change theory
Apps	Applications
WP	Work package
FRT	Food reinforcement task
BMI	Body mass index
CI	Confidence interval
LOA	Limit of agreement
PABAK	Prevalence-adjusted and bias-adjusted kappa
SD	Standard deviation
DEBQ	Dutch eating behavior questionnaire
MSEM	Multilevel structural equation modelling
GSEM	Generalized SEM
AIC	Akaike’s information criterion
y	Year
SE	Standard error
PR	Progressive ratio schedule
HR	Hazard ratio
ICC	Intraclass correlation
IC	Inhibitory control

Contents

Summary

Adolescence is a crucial period for the development of eating behaviors. Adolescents have higher demands for energy and nutrients due to their rapid physiological, psychosocial and cognitive development. At the same time they are more autonomously developing their eating habits. Adolescents however, typically adopt unhealthy eating behaviors such as a high intake of energy-dense snacks and beverages and a low consumption of fruit, dairy products and vegetables. High intakes of unhealthy snacks and beverages are known to contribute to excess energy, sugar and/or fat intake. Intake of healthy snacks such as fruits, raw vegetables or dairy products however, is associated with lower energy and a higher overall nutritional quality of the diet. Fostering healthy eating habits during adolescents is key as eating habits established in adolescence are likely to persist in adulthood and have implications for the development of chronic diseases later in life.

In the present obesogenic environment, consumption of palatable energy-dense snacks and beverages is usually driven by hedonic eating processes rather than by homeostasis. These hedonic eating processes are driven by the reinforcing value of food. Energy-dense foods are typically found to be more reinforcing than bland foods such as fruit or vegetables. As people differ in sensitivity towards noticing and approaching natural rewarding stimuli, not all people indulge in the consumption of these highly reinforcing snacks and beverages. Individual differences exist in a psychobiological trait called sensitivity to reward, which is defined as the tendency to engage in motivated approach behavior in the presence of rewarding stimuli. Sensitivity to reward not only differs between individuals, it also changes with human growth and development and increases from childhood to adulthood with a peak in adolescence. Sensitivity to reward and hedonic eating processes may thus have a significant impact on eating behavior in adolescence.

Previous attempts to improve adolescents' eating behavior and/or anthropometrics only had limited success. Different theoretical approaches and more attractive intervention channels are needed. This PhD thesis combines insights from different research disciplines. Sensitivity to reward and hedonic eating processes were incorporated into a health promotion framework with a dual process base. Thereby pleading for a reward-based approach in combination with known reflective behavioral change techniques. In addition the use of smartphone applications was explored as a possible more attractive intervention channel.

The aims of this PhD thesis were (i) to develop a short quantitative food frequency questionnaire to measure snack and beverage intake in adolescents and to update the prevalence in Flanders, (ii) to study the association between hedonic eating processes and snack and beverage intakes in adolescents, (iii) to investigate the association between the use

of commercial fitness and nutrition apps and adolescents' zBMI, snack and beverages intakes, (iv) to assess if the reinforcing value of healthy snacks can be increased using rewarding strategies and (v) to promote healthy snack choices in adolescents by rewarding strategies in combination with reflective strategies derived from the control theory delivered through a smartphone app.

A food frequency questionnaire, that contained 14 beverage and 28 snacks items, was developed to estimate snack and beverage intake of adolescents. The reliability and validation study showed that the reliability and the validity of the snack and beverage food frequency questionnaire were acceptable on a group level for the purpose of analyzing diet-disease relationships. However, caution should be exercised when presenting and researching absolute snack intakes. Only for the healthy snack and beverage ratios the reliability and the validity of the snack and beverage food frequency questionnaire was acceptable on a group level for the purpose of analyzing intervention effects. Flemish adolescent boys consumed on average 214 g of unhealthy snacks, 122 g of healthy snacks and 286 ml of sugar-sweetened beverages, girls respectively 162 g, 153 g and 182 ml.

A higher sensitivity to reward in adolescents was associated with higher intakes of unhealthy snacks and sugar-sweetened beverages. In addition external eating, or the eating triggered by environmental cues such as the sight and smell of food stimuli, and emotional eating, or the eating driven by emotional states, partially explained the association between SR and unhealthy snack intake. No interactions between SR and its related hedonic eating styles (external and emotional eating) and the availability of snacks at school or at home were observed. These findings highlight the importance of characterizing high sensitive to reward adolescents as a vulnerable group for eating and weight problems. Health promotion efforts should thus take this into account when designing healthy eating interventions for adolescents. As adolescents are also generally more sensitive to rewarding processes compared to adults and children, rewarding strategies might be a promising strategy to prevent obesity and promote healthy food choices in adolescents.

The frequency of use of commercially available fitness and/or nutrition apps was weakly associated with healthier snacking and beverage intakes. A high use of both fitness and nutrition apps was also associated with a lower zBMI. Mediation analyses showed that little relevant cognitive determinants were targeted. Current commercial apps insufficiently incorporate behavior change techniques or do not operationalize these techniques in an effective way. Health promotion experts and app developers should thus join hands to design more theory-based apps to be used in health promotion.

The use of rewarding strategies was shown to increase the reinforcing value of fruit in an experimental setting. An intangible reward, i.e. the participation in a class competition, increased the reinforcing value of fruit to a similar level as the reinforcing value of unhealthy snacks. Although reward-based strategies might be a promising strategy to promote healthy food choices, further evaluation in field studies is warranted.

The final aim of this PhD was to combine all of the above findings to develop an intervention in adolescents. A dual process model integrating control theory with behavioral choice theory, learning theory and reinforcement sensitivity theory was used as theoretical framework. A smartphone app, incorporating behavioral change methods to target the identified determinants along with game elements to create engagement and fun, was developed. The effect of the app was tested with a pre-post control clustered study. The effects of the "Snack Track School app" were inconclusive, a small positive effect on the healthy snack ratio was observed only for high SR boys. The findings of the feasibility study however, pave the way for future studies using apps to improve eating behaviors in adolescents by identifying several key issues to be addressed.

Samenvatting

Adolescentie is een cruciale periode voor de ontwikkeling van eetgedrag. Adolescenten hebben hogere noden voor energie en nutriënten als gevolg van hun snelle fysiologische, psychosociale en cognitieve ontwikkeling. Tegelijkertijd worden ze zelfstandiger bij het eten en kopen van voedsel. Adolescenten ontwikkelen spijtig genoeg meestal ongezonde eetgedragingen zoals een hoge inname van ongezonde snacks en dranken en een lage inname van fruit, groenten en melkproducten. Hoge innames aan suikerrijke dranken en energiedense snacks dragen bij tot een overmaat aan energie, suiker en/of vet; terwijl de inname van gezonde snacks zoals fruit, rauwe groenten en melkproducten geassocieerd wordt met een lagere totale energie-inname en een hogere kwaliteit van het totale dieet. Dit is jammer omdat eetgewoonten ontwikkeld tijdens de adolescentie aangehouden worden als volwassene en implicaties hebben voor de ontwikkeling van chronische ziekten later.

In een obesogene samenleving is de consumptie van lekkere energiedense snacks en dranken meestal gedreven door hedonische eetprocessen dan door homeostatische honger. Deze hedonische eetprocessen worden bepaald door de beloningswaarde van voedsel. Voedsel met een hoge energie inhoud is typisch meer belonend dan meer neutraal voedsel zoals fruit of groenten. Individuen verschillen echter in gevoeligheid naar belonende stimuli en dus niet iedereen doet zich te goed aan deze erg belonende smakelijke snacks en dranken. Individuele verschillen bestaan er in een psychobiologisch kenmerk genaamd beloningsgevoeligheid. Dit kenmerk kan gedefinieerd worden als de neiging om gemotiveerd naderingsgedrag te vertonen in de nabijheid van belonende stimuli. Beloningsgevoeligheid verschilt niet alleen tussen individuen, het veranderd ook gedurende de menselijke ontwikkeling en stijgt van in de kindertijd tot in de volwassenheid met een piek tijdens de adolescentie. Beloningsgevoeligheid en hedonische eetprocessen kunnen een grotere invloed hebben op gedrag in de adolescentie.

Vorige pogingen om het eetgedrag en/of antropometrie van adolescenten te verbeteren vertoonden slechts beperkte successen. Een andere theoretische aanpak en meer attractieve interventies zijn nodig. Dit doctoraatsonderzoek brengt theoretische inzichten uit verschillende onderzoeksdisciplines samen. Er werd gepoogd om beloningsgevoeligheid en hedonische eetprocessen te incorporeren in een gezondheidspromotie kader (duaal proces model) en te pleiten voor een het gebruik van beloningsstrategieën in combinatie met gekende reflectieve gedragsveranderingstechnieken. Ook werd het gebruik van smartphone applicaties onderzocht als mogelijks meer attractief interventie kanaal.

De doelstellingen van dit onderzoek waren (i) het ontwikkelen van een korte kwantitatieve voedselfrequentielijst om snack en dranken inname in jongeren te meten en de huidige prevalenties bij te werken, (ii) het bestuderen van de associatie tussen hedonische eetprocessen en de snack en dranken inname van adolescenten, (iii) het onderzoeken van de associatie tussen het gebruik van commerciële fitness en voeding apps en adolescenten hun zBMI, snack en drankeninname, (iv) te bestuderen of een beloningsstrategie de belonende waarde van gezonde snacks kan verhogen en (v) het promoten van gezonde snackkeuzes in adolescenten doormiddel van beloningsstrategieën, in combinatie met reflectieve strategieën ontleend van de controle theorie, verpakt in smartphone app.

Een voedselfrequentielijst, bestaande uit 14 drank en 28 snack items bevat, werd ontwikkeld om de snack en drankeninname van adolescenten in te schatten. De betrouwbaarheid en validatie studie toonde aan dat de voedselfrequentielijst betrouwbaar was op een groepsniveau voor het analyseren van dieet gebonden aandoeningen. Voorzichtigheid moet echter geboden worden bij het weergeven van absolute snack innames. Alleen voor de gezonde snack- en drankenratio konden worden aangetoond dat de betrouwbaarheid en validiteit aanvaardbaar was voor het evalueren van interventie effecten. Vlaamse mannelijke adolescenten consumeerden gemiddeld 214 g ongezonde, 122 g gezonde snacks en 286 ml suikerrijke dranken, terwijl Vlaamse meisjes overeenkomstig gemiddeld 162 g, 153 g en 182 ml consumeerden.

Een hogere beloningsgevoeligheid in adolescenten was geassocieerd met hogere inname van ongezonde snacks en suikerrijke dranken. Bovendien verklaarden extern eten, of het eten naar aanleiding van aanlokkelijke prikkels zoals de smaak en de geur van voeding, en emotioneel eten, of eten als gevolg van emoties, een deel van de relatie tussen beloningsgevoeligheid en ongezonde snackinname. Er waren geen interacties tussen beloningsgevoeligheid en de daaraan verbonden hedonische eetstijlen (extern en emotioneel eten) en de beschikbaarheid van ongezonde snacks op school of thuis. Deze bevindingen tonen aan dat hoog beloningsgevoelige individuen een risicogroep vormen voor eet-en gewichtsproblemen. Gezondheidspromotiecampagnes ontwikkeld om adolescenten gezonder te doen eten, houden dus best rekening met beloningsgevoeligheid. Gezien het feit dat adolescenten gevoeliger zijn voor belonende processen dan kinderen en volwassenen, kunnen beloningsstrategieën nog veelbelovender zijn in deze doelgroep voor het voorkomen van obesitas en het promoten van gezonde voedingskeuzes.

De frequentie van het gebruik van commerciële fitness en voeding apps was zwak geassocieerd met gezondere snack en dranken innames. Een hoog gebruik van zowel fitness als voeding apps was ook geassocieerd met een lager zBMI. Mediatie analyses toonden aan dat zulke apps op weinig relevante cognitieve determinanten inwerkten. De huidige commerciële apps incorporeerden te weinig gedragsverandering technieken of gebruiken deze niet op een efficiënte manier. Experten in gezondheidscampagnes en app ontwikkelaars werken beter samen om ervoor te zorgen dat apps voor gezondheidscampagnes beter gebaseerd zijn om op bestaande theorieën.

In een experimentele setting werd ook aangetoond dat het gebruik van beloningsstrategieën de beloningswaarde van fruit konden verhogen. Een niet-tastbare beloning, namelijk de deelname in een klascompetitie, kon de beloningswaarde van fruit verhogen zodat deze min or meer gelijkaardig was aan die van ongezonde snacks. Beloningsstrategieën vormen dus een veelbelovende strategie om gezonde voedingskeuzes te gaan promoten, maar moeten wel nog getest worden in een real-life setting.

Het finale doel van deze doctoraatsthesis was om alle bovenstaande bevindingen te combineren bij het ontwikkelen van een interventie voor adolescenten. Een duaal proces model dat controle theorie integreert met gedragskeuze theorie, leertheorieën en de theorie rond beloningsgevoeligheid werd hiervoor gebruikt. Een smartphone app, waarin de overeenkomstige gedragsveranderingstechnieken van de geïdentificeerde determinanten werden geïncorporeerd samen met enkele spel elementen om het leuk aantrekkelijk en innemend te maken, werd ontwikkeld. Het effect van de app werd getest met een pre-post geclusterde interventie studie met een controle groep. Het effect van de "Snack Track School app" was niet overtuigend, een klein positief effect op de gezonde snack inname werd enkel geobserveerd in jongens met een hoge beloningsgevoeligheid. De bevindingen van de haalbaarheidsstudie daarentegen, bieden wel leerpunten voor toekomstige interventies die adolescenten hun eetgewoonten willen verbeteren.

Chapter 1. Introduction, objectives and outline of the thesis

1.1. Background

1.1.1. Adolescents and their eating habits

Adolescence is defined by the World Health Organization (WHO) as the period in human growth and development that occurs after childhood and before adulthood, from ages 10 to 19 [1]. Adolescents have higher demands for energy and nutrients compared to children and adults due to their rapid physiological, psychosocial and cognitive development, while at the same time they are more autonomously developing their eating behaviors [2-4]. Thus adolescence forms a crucial period for the development of dietary behaviors [2-4]. Eating behaviors established in adolescence are likely to persist in adulthood and have implications for the development of chronic diseases later in life [5, 6]. Adolescents however, have shown to adopt unhealthy eating behaviors such as a high intake of energy-dense snacks and beverages and a low consumption of fruit, dairy products and vegetables [4, 7, 8].

The overconsumption of high energy-dense beverages such as sodas, sweetened milk beverages or fruit-based sugary drinks, has already been associated with excess sugar and energy intake and obesity in adolescence and adulthood [8-10]. Nevertheless, the association between the intake of snacks and obesity remains inconclusive as both positive as negative results have been stated [11-13]. This discrepancy is partly attributable to the inconsistency in the definition of snacking [11-13]. In some American studies snacking refers to the intake of specific “snack foods”, which are typically low in micronutrient quality and usually rich in fat and/or sugar [12, 13]. In other studies, snacking is defined as eating in between meals and thus any food eaten outside the three main meals is considered a snack [12, 13]. Some other studies also base their definition on the amount of food consumed, the location of food consumption or a combination of the previous factors [12, 13]. All studies however, agree that the prevalence of eating in between meals has increased and that the energy contribution from eating in between meals has increased over the years, as the preferred snacks are usually unhealthy such as cookies or crisps [12, 14]. As it is clear that the consequences of snacking are dependent of snacking frequency, portion size consumed and type of food eaten [14-18], it is important to make a clear distinction between unhealthy and healthy snacking and to take into account the amount of snacks eaten when investigating the consequences and causes of snacking. If mainly energy-dense foods such as cookies, chocolate or chips are consumed, energy, sugar and fat intake from snacks is substantial and nutrient intakes are inadequate [16, 18]. When more healthy foods such as fruits, raw vegetables or milk products are eaten as snacks, energy intake is lower and the overall nutritional quality of diet is higher [16, 18]. In the present PhD thesis, snacking is defined as eating in between the three main meals (breakfast, lunch and dinner) and can consist of both healthy, low energy-dense foods and unhealthy, energy-dense, fat and sugar rich foods [12, 19]. To differentiate unhealthy from healthy snacks nutrient profiling could be used. Nutrient profiling can be defined as the science of categorizing foods according to their nutritional composition [20]. Several approaches exist that differ according to nutrients used to classify the foods, the used cut-offs for the nutrients, the reference amount (100 kcal vs. 100 g) and the food category declination (same nutritional criteria for all foods (across the board scheme) or specific criteria according to the food category (category-wise scheme)) [20, 21]. In addition some models provide a continuous score to rank the foods' healthiness, while others purely categorize the food as unhealthy and healthy and some can be used as both categorical and continuous models [20]. Within this PhD thesis the UK Ofcom model [22], as developed by the food standard agency (FSA), was used. This model was chosen because it is an across the board scheme (snacks cover several categories of food), has both ranking (see chapter 7) and classifying (see chapters 2 until 7) properties and performed reasonably well within several nutrient profiling comparison studies [20, 21]. This model provides a score that represents the 'unhealthiness' of a beverage or food product. This score is based on the nutritional content of the beverages or food products (negative elements: saturated fat (g), Na (mg), total sugar (g) and energy (kJ); positive elements: protein (g), Non-Starch Polysaccharide /Association of Official Analytical Chemists fiber (g) and fruit, vegetables and nuts (%)). The scoring system consisted of two types of scores: an A subscore (based on the negative elements) and a C subscore (based on the positive elements) [22]. The total score is then calculated by subtracting the C subscore from the A subscore. The full calculation method is detailed elsewhere [22]. Food items that scored more than 4 points were considered to be unhealthy [22].

In some studies, energy-dense beverages are also considered as snacks [12]. In the current PhD thesis however, the intake of snacks and beverages are evaluated as a separate behaviors. The intake of energy-dense beverages contributes to excess energy intake throughout the full day, not only in between meals [19, 23]. Unhealthy energy-dense snacks and beverages do not only contribute independently to excess energy intake, their intakes are also related [24, 25]. Children and adolescents who drink a considerable amount of sugar-sweetened beverages (SSBs) were found to consume more sweet and salty snack foods than non SSB drinkers [24, 25]. **Decreasing both adolescents' intake of unhealthy snacks and beverages and increasing their consumption of healthy beverages and snacks is thus key to decrease the energy intake and to increase overall diet quality of adolescents.**

Most studies to date have focused on American, British or Australian data, currently there is insufficient data on the snack and beverage intake of European and specifically Flemish adolescents [5, 14, 18, 26]. Although some information on Flemish adolescents is available, it is either focused on the intake of specific snacks or beverages, such as intake of sweet or salty snacks and SSBs, or the assessment of the macro-nutrient contribution of snacks to the total diet [27-30]. Snacks between meals accounted for 20.0-24.0% of the total energy intake of Flemish adolescents in 2003 [27]. On average Flemish adolescent boys consumed 509 g of soft drinks, 91g of sweets such as cookies and chocolate and 21 g of salty snacks such as crisps in 2004; girls consumed respectively 285 g, 85 g and 11 g on a daily basis [28]. These estimates date back over 10 years and **new data is thus warranted to effectively monitor, study and/or design interventions or promotion campaigns to improve adolescents' snack and beverage intakes in Flanders.** In addition, an update of snack intake in Flemish adolescents is also needed as dietary behaviors change over time and new types of snacks are on the market. In addition, none of these studies did specifically consider the intake of snack foods at snack times, which is crucial to correctly describing snacking behavior [18, 31].

To date, snack and beverage intake in adolescents is typically measured as part of large food frequency questionnaires (FFQs) or 24-hour recalls assessing the total diet. Such instruments are time-consuming and burdensome for the respondents and provide unnecessary details [32-35]. To evaluate dietary intake in adolescents, rapidly administrable tools are necessary as they are less interested in giving accurate and long reports [33]. **A quantitative FFQ that measures both habitual snack and beverage intake, using the correct definition of snacking (e.g., snacks eaten at snack times) [18, 31], can facilitate research on snack and beverage intake in adolescents.**

1.1.2. Influencing factors of adolescents' snack and beverage intakes

In order to understand and change adolescents' snacking and drinking behaviors, an assessment of the factors associated with these behaviors is of interest [36, 37]. Several theoretical models exist to study eating behaviors and include among others the theory of planned behavior (TPB) [38]; the attitude, social influence and self-efficacy (ASE) model [39]; the transtheoretical model [40] and the I-change model [41]. However, currently more and more (socio)ecological models incorporating multiple (interacting) levels of influences have been adopted [42-44]. Such models state that individual level factors interact with (social) environmental factors to influence behavior [42-44]. In 2002, Story and colleagues proposed a composite theoretical framework, combining social cognitive theory with an ecological perspective, resulting in a biopsychological model that incorporates four interacting levels (see Figure 1) of influence on adolescents' eating behavior [43]. These levels comprise individual characteristics, social environmental influences, physical environmental influences and macrosystem influences [43]. The main focus of this PhD thesis will be the influence of individual characteristics on eating behavior, more specifically the influence of hedonic eating processes on eating behavior (see section 1.1.3.). Therefore, the influencing factors situated at the individual level will be discussed in more detail. The present document however, acknowledges that adolescents' eating behaviors are also influenced by social, physical and macro environments and that these environmental factors can interact with individual factors in influencing eating behaviors.

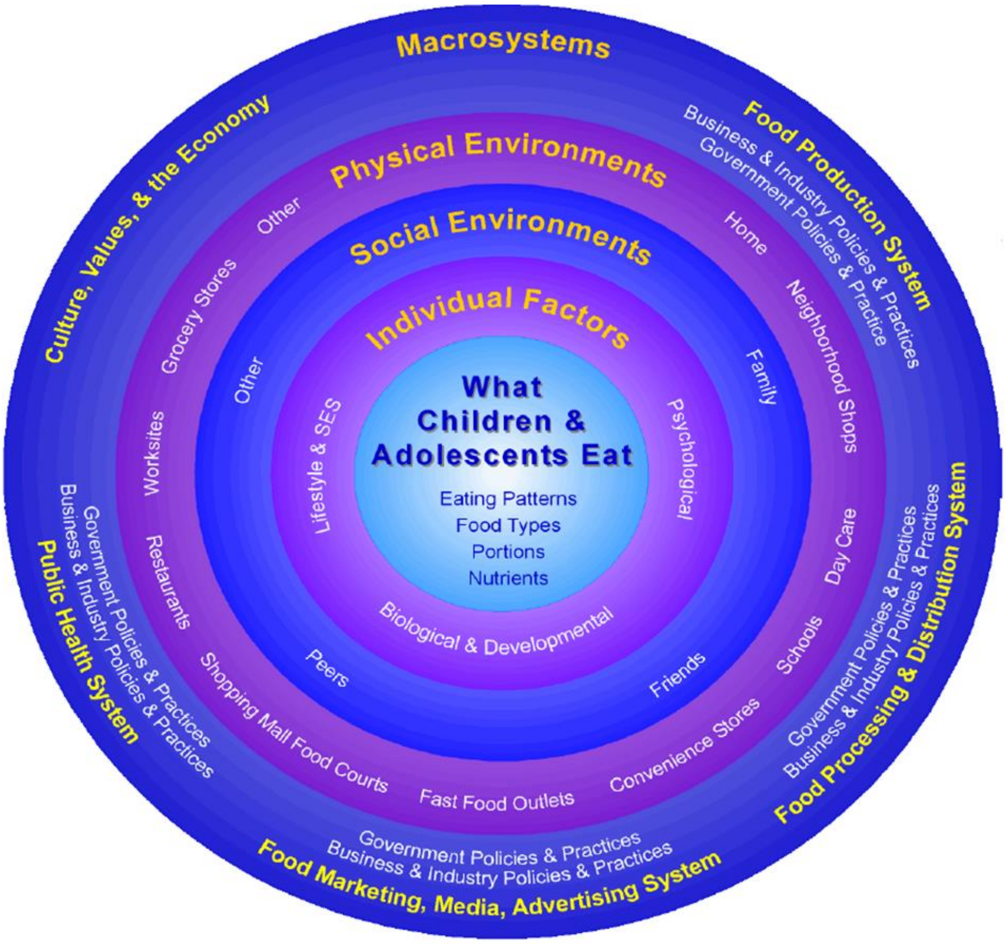


Figure 1: Biopsychosocial model by Story et al. (2002)

At the individual level both distal predisposing factors and proximal motivational factors play a role [39, 42, 43]. The proximal factors encompass intention, motivational factors such self-efficacy, and attitudes and pre-motivational factors such as awareness and knowledge [39, 41, 42, 45]. The motivational factors are thought to influence behavior through intention, while they themselves are being influenced by the pre-motivational factors such as awareness and knowledge [39, 41, 45]. Several authors conclude that mainly self-efficacy and attitudes are associated with adolescents' eating habits [7, 39, 46-49]. A higher self-efficacy to eat healthy or to limit the intake of energy-dense snacks has already been associated with healthier snacking behaviors or eating in general [7, 46, 50]. Positive attitudes towards healthy eating were associated with higher intakes of fruit and vegetables and lower intake of energy-dense snacks and beverages [7, 49]. However, also knowledge and awareness are related to adolescents' eating behaviors. Adolescents with a lower general health awareness consumed more unhealthy snacks and were less concerned with the healthiness of the snacks they consumed [51, 52]. Knowledge about healthy eating is also important. Although the ability to evaluate the healthiness of snacks is essential to making healthy choices [26], it cannot lead to healthy eating behaviors on its own [26, 43, 53]. Interventions that mainly focused on providing knowledge on healthy eating failed to change adolescents' eating habits and capture the complexity of food choice and eating [54-56]. Distal influencing factors can either influence behavior directly or indirectly through the psychosocial factors [39, 41, 42, 45]. Such distal factors can be biological or psychological in nature, snack and beverage intakes in adolescents are known to be influenced by food preferences and taste, homeostatic hunger and sex [43, 44, 57]. Self-reported food preferences and taste are some of the strongest predictors of food choice, especially for the choice and intake of unhealthy foods and beverages, but are difficult to change [43, 57, 58].

Eating behaviors are the result of a joint function between explicit and implicit processes [42, 59]. Dual-process models explain health behaviors as two interconnected systems: a reflective system including cognitive efforts to build beliefs and decisions (explicit processes) and an impulsive/automatic system (i.e., habits) in which certain stimuli or cues are linked to certain behaviors based on earlier learned associations (implicit processes) [42, 59]. Eating is a repetitive behavior that is done three to five times per day and can thus be assumed to be for a large part habitual [56, 60]. Recently it was shown that at least a part of snack or beverages intakes is also habitual in nature, unhealthy eating habits should thus be lowered and healthy eating habits should be learned [61, 62]. Habits can be defined as learned sequences of acts that have been reinforced in the past by rewarding experiences and that are triggered by the environment to produce this behavior [56]. Determinants driving this habitual/implicit pathways should thus also be addressed next to the psychosocial or proximal factors that drive the explicit pathways that guide eating behaviors [39, 41, 42, 45]. The concept of habits it is being adopted more and more into health promotion, but more research is still needed to understand what drives the formation of habits [56, 60]. Such unhealthy eating habits could possibly arise from hedonic eating processes [56, 60, 63, 64] (see section 1.1.3).

Physical and social environmental influences on adolescents' snack and beverage intakes mainly comprise the school [65] and home [66] environment. Adolescents spend a large amount of their time at school and consume at least one snack or beverage at school [43]. The school environment mainly influences adolescents' snacking and drinking behaviors by the presence of peers and friends [44, 67] and the offering of energy-dense snacks and beverages via vending machines or school shops [65]. Peers and friends are an important influence on adolescents' eating behaviors, especially related snack and beverage consumption [43, 51, 67, 68]. This influence comprises social norms, peer support and peer pressures [43, 51, 67, 68]. Those adolescents who overestimate the snack intake of peers, consume more snacks themselves [67, 69]. Adolescents also choose more frequently snacks that were consumed by their "cool" peers [70]. Parents on the other hand influence the snack and beverage intake of their adolescents by the availability and accessibility of snacks and beverages at home [46, 66, 68], modeling [70], parenting styles and practices [71, 72].

The macro environmental influences on adolescents' snack and beverages intakes mainly constitute the effects of food advertisement delivered by mass media such as television [43].

An overview of the theories used to understand adolescents' snack and beverage choices within this PhD thesis are given in Figure 2 (determinants).

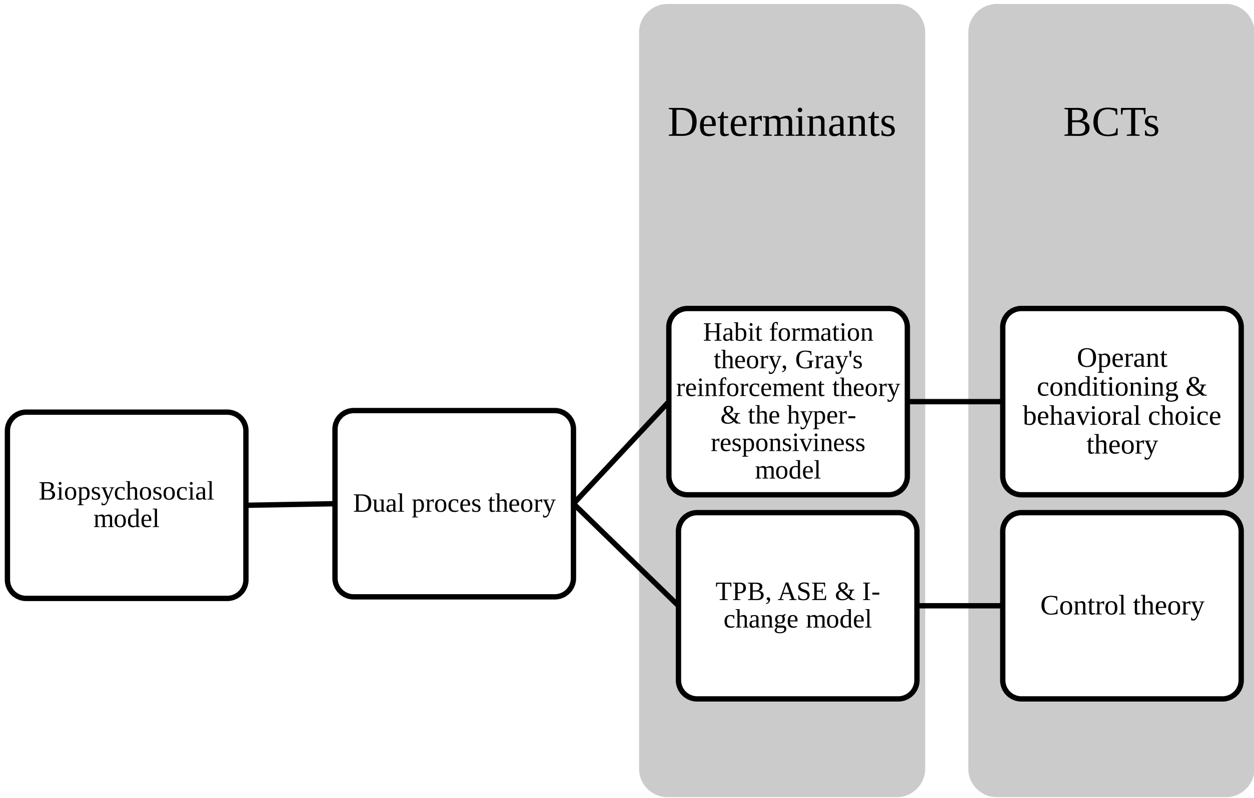


Figure 2: Overview of theories used to understand and change adolescents' snack and/or beverage choices

1.1.3. Hedonic influences on adolescents' snack and beverage intakes

In obesogenic environments, where palatable energy-dense foods are omnipresent, eating behaviors are commonly not driven by homeostasis but rather motivated by hedonic eating processes originating from the rewarding value of food [73-75]. The reward value of foods is typically expressed by its reinforcing value (RV) [76]. The reinforcing value (RV), reinforcing efficacy or motivation to eat a food refers to how much behavior the food will support [76]. It is typically assessed as the amount of work an individual is willing to perform to gain access to food [76]. A higher RV of food has already been associated with an increased risk for obesity in children, adults and adolescents [77-80]. Palatable unhealthy foods, such as energy-dense snacks and SSBs, typically have a higher RV than neutral healthy foods such as fruit and vegetables [81-83]. However, not all people indulge in these highly palatable or rewarding foods. There is growing evidence that people differ in their sensitivity toward noticing and approaching natural rewarding stimuli such as these highly palatable foods [73, 74, 84]. Gray, in his reinforcement sensitivity theory, describes the psychobiological trait sensitivity to reward (SR) that reflects the functional outcomes of the Behavioral Activation System (BAS) [85]. The BAS is primarily organized by the neurotransmitter dopamine and can be defined as the tendency to engage in motivated approach behavior in the presence of rewarding stimuli [85-87]. A high SR has already been associated with a higher activation of brain areas implicated in food reward, more food cravings and a greater risk to be overweight [75, 84, 86-89]. Moreover, compared to children and adults, adolescents show higher activity in the reward-related brain regions [90, 91]. Hence, vulnerability to rewards is higher in adolescence than in childhood or adulthood, and SR and rewarding/hedonic processes might thus play an even more substantive role in explaining eating behaviors in adolescents. **To date however, little is known on the relation between the RV of food, SR and eating behaviors, such as snack and beverage intake in adolescents.**

SR (BAS) is typically measured with the BAS scales as developed by Carver and White (2004) [92] in adults and with the child version as developed by Muris et al. (2005) [93] in children and adolescents. These scales measure BAS through three activational factors [92], fun seeking (BAS FS), reward responsiveness (BAS RR) and drive (BAS DRV) and a composite scale BAS total (BAS TOT). BAS DRV is defined as the persistent pursuit of desired goals, BAS FS as the desire for new rewards and a willingness to approach potentially rewarding events on the spur of the moment and BAS RR as positive responses to the occurrence or anticipation of reward [85]. BAS DRV has already been linked to an increased BMI, food approach behavior, fat intake and a higher activity in the reward-related brain regions in children and adults and is considered the strongest predictor of responses to food cues [87, 88, 94, 95]. BAS RR was found to be correlated to food enjoyment [96], while BAS FS has been mainly considered in regard to smoking and alcohol abuse [94, 97]. The composite BAS scale has already been associated with BMI, food preferences, external and emotional eating [75, 86]. Within this PhD only BAS DRV (chapters 3,4,6 and 7) and BAS RR (chapter 3) were explored as measures of SR, as BAS FS was not related to food intake in previous studies.

More recently the hyper-responsiveness model was developed, which attempts to explain how a high level of SR might be associated with hedonic eating beyond caloric need and ultimately overweight and obesity [74, 75, 86]. Hedonic eating can take several forms; it can be driven by emotional states (e.g. the emotional or comfort eaters) or triggered by environmental cues such as the sight and smell of food stimuli (e.g. the external eaters) [75, 86]. Hedonic eating has also already been reported under the form of food cravings, binge eating and enhanced preferences for palatable foods [75, 84, 86, 98]. Previous research was however limited to adults, except for the study by Loxton and Dawe (2001). External and emotional eating have already been described as stable eating styles in children and adolescents, that could result in habitual patterns of (over)eating [99]. **These hedonic eating styles might further explain how a heightened SR fosters palatable and typically unhealthy food intake in adolescents. However these relations remain unexplored in adolescents.**

The biopsychosocial model also postulates that different determinants of food intake often interact with each other within each and between levels of influence [43]. SR and hedonic eating processes at the individual level might thus interact with the other levels such as the physical environment. The (over) availability of palatable foods in the environment could trigger individual differences in SR [84, 86, 88, 100] and might thus interact with SR and its related hedonic eating processes (i.e., the hedonic eating styles external and emotional eating) in promoting intake of energy-dense foods. To date, only one study has assessed and reported an interaction between SR and fast food exposure on fast food intake in adults [100]. **However little or no research has focused on the interplay of SR, hedonic eating styles and environmental influences in adolescents.**

1.1.4. Promotion of healthy snack choices

Considerable attention has already been given to the prevalence and the consequences of the intake of energy-dense beverages such as SSBs, their detrimental influence on adolescent health is generally acknowledged and its agreed upon that their consumption should be limited

[4, 23, 101, 102]. Also a reasonable amount of interventions have already targeted adolescents' consumption of SSBs [103-105]. A recent review by Lane et al. (2016) to determine the external and internal validity of such interventions, identified a total of 55 trials that targeted SSB consumption in children or adolescents [105]. They concluded that the internal validity (effect) of such trials was properly described but that information regarding the external validity (implementation and dissemination) was lacking [105]. The repercussions of snacking however, remain unclear and are more complex as they depend on the type, portion and consumption frequency of the snacks eaten [14-18]. Designing interventions to improve snacking behavior are more complex, challenging and still needs more research [106]. Stice et al. (2006) also stated in their meta-analysis that interventions focusing on one behavior instead of an array of behaviors are more effective [107]. This PhD thesis hence first focused on promoting healthy snack intakes starting from the newly generated evidence regarding hedonic eating, before also attempting to decrease the intake of energy-dense beverages. The experimental and intervention studies presented within this PhD thesis (see chapter 6 and 7) were therefore concentrated on promoting healthy snack choices.

Until now school- and family-based interventions, targeting well-known cognitive and environmental determinants, have had only limited success in changing adolescents' eating patterns and anthropometrics [54, 55, 107]. Different approaches to change eating behaviors in adolescents should be considered, established effective behavior change strategies should be combined with recent theoretical insights (from other disciplines). Also the formats used in behavior change interventions might have been ineffective, because they have not been applied adequately or were not sufficiently connected to adolescents' rapidly changing youth culture [108].

1.1.4.1. Theoretical approach

Behavior is complex and multi-component and focusing on only one strategy increases the risk of being over simplistic and may produce little change [54, 55, 107]. As eating behaviors [42, 59] are dual processes by nature, this would imply that both the explicit reflective and the implicit habitual pathways should be targeted.

The explicit pathway is mainly determined by intention and the psychosocial factors [42, 60]. Behavior change strategies (BCTs) to target the identified psychosocial factors (cf. section 1.1.2.) could be derived from the control theory of Carver and Scheier [109]. The control theory provides a conceptual framework for understanding the functioning of living organisms [109]. At the conceptual core of the theory is the observation that people control their perceived environment by means of their behavior [109]. Michie and colleagues conducted a meta-regression to identify the most effective techniques derived from different behavioral change theories on healthy eating and physical activity interventions and found that interventions combining self-monitoring with at least one other technique derived from the control theory (i.e., goal setting, feedback, review goals) were more effective than other interventions [110].

Interventions targeting the cognitive pathway are abundant and effective strategies to target this cognitive pathway are well established [109]. However several authors have already concluded that focusing solely on the reflective pathway and overlooking the automatic habitual nature of eating is partially responsible for the lack of intervention effects across population groups [56, 60, 111]. Recently research has recognized the habitual nature of eating [56, 60, 62, 112] and more specifically of snacking in adolescents [113]. The concept of habits is increasingly being incorporated into intervention research, but more research is still needed to determine how to effectively inhibit/terminate unhealthy habits and promote/initiate healthy habits [56, 60]. As habits are behavioral responses, largely outside of people's conscious awareness, triggered by situational cues and repeatedly reinforced by contingent positive outcomes, interventions to change habits or create habits can target the situation, the response and/or the relevant contingencies [56]. Targeting relevant contingencies could be done by rewarding healthy food choices [56]. Rewarding strategies could be derived from the principles of operant conditioning [114-116]. Operant conditioning or instrumental learning is a process of learning that modifies the strength of a behavior by pairing a desired or undesired behavior with reward or punishment (positive or negative reinforcement and positive or negative punishment) [102]. In the case of positive reinforcement, a desired behavior is repeatedly rewarded or reinforced to achieve an increase in frequency of this desired behavior [117]. Previous studies have already shown that children's willingness to taste and consumption of healthy food items such as fruit could be enhanced by offering rewards or praise [115, 118, 119]. However when using rewards or incentives to achieve behavior change care should be taken, as both positive as negative effects have been documented [52, 110, 111, 114-116]. The effects are dependent on the outcome (liking vs. intake), the initial level of motivation towards the target foods (liked vs disliked) and the type of reward (food vs. non-food rewards) [114, 116]. In order for rewards to be effective, it is important that these are highly desirable (i.e. that they are potent reinforcers) and that it is clear that these are conditional on a behavior that is both enjoyable and high status [120]. **More research is needed to develop effective rewarding strategies to be used in health promotion interventions, especially in adolescents. To date, little is known about using reward-based strategies to promote healthy food habits over unhealthy ones in adolescents. Such strategies however, are particularly relevant for adolescents given their high susceptibility to rewards compared to children and adults [90, 91].**

As a higher RV of unhealthy snacks vs. healthy snacks is one of the factors that might be driving the habitual intake of unhealthy snacks, **an imperative first step in determining the effectiveness of reward-based strategies in health promotion is to assure that the chosen rewarding strategies can increase the RV of healthy snacks in adolescents.** This could be evaluated by means of the experimental framework provided by the behavioral choice theory (BCT) [76]. BCT allows to assess how people allocate choices among alternatives and can thus be used to provide insight into the mechanisms aimed at altering food choice [76]. The basic principle of BCT is the RV of a certain food [76], BCT states that the consumption of unhealthy snacks can be decreased by either decreasing the RV of unhealthy snacks or by increasing the RV of healthy alternatives [76, 81, 82, 121, 122]. Within a BCT framework, it can thus be investigated if and which rewarding strategies can effectively increase the RV of healthy snacks. **Once established that rewarding strategies may increase the RV of healthy snacks, the identified effective rewards could be implemented in an actual health promotion campaign to test its effectiveness in altering snacking habits in real-life situations.**

An overview of the theories used to change adolescents' snack choices within this PhD thesis are given in Figure 2 (BCTs).

1.1.4.2. Intervention format

Not only new theoretical insights were needed, but also new intervention formats could help increase the effects of behavior change interventions. Mobile applications (apps) could provide an engaging way to involve children and adolescents in behavior change interventions [123]. Apps provide an interesting medium for health promotion: users can be reached frequently and directly, they enable tailoring of communication, easy feedback opportunities are present and a more engaging way of behavior change is possible [123-125]. Adolescents frequently use smartphones and apps and are highly skilled in using digital devices [126-128]. In 2014, 86% of the adolescents in Flanders owned a smartphone and most had 10-20 apps on it [129]. **However to date little is known on adolescents' use of commercial health apps such as fitness and nutrition apps in order to alter their behavior and/or more specifically to eat healthier**. **Information on the use and mechanisms of action of commercial apps could help guide the development of smartphone apps to be used in health promotion interventions.**

To date, only a few apps to improve adolescents' eating habits have been developed and tested in intervention studies [130-132] and still need to be evaluated. However, their potential for health promotion in youth is commonly accepted [123]. Based on the results of several reviews on mhealth and serious games in adolescents and children, results are promising [133-135].

1.2. The rewarding healthy food choices project

This PhD research was imbedded in work package (WP) 3 of the rewarding healthy food choices project (www.rewardstudy.be). This project started the first of December 2013 (end November 2016) and was funded by the Agency for Innovation and Entrepreneurship of Flanders (Belgium).

1.2.1. General description

REWARD is a multidisciplinary project that combines expertise from developmental psychology and personality theory, health promotion, nutrition, food chemistry and human nutrition and mass communication sciences. The overall aim of the reward project is to assess and improve food choices in toddlers, children and adolescents. REWARD focuses on the role of SR, learning theory and rewarding paradigms and sought to incorporate these insights into novel attractive interventions such as serious games and smartphone apps. The REWARD project is organized in three WPs, each focusing on a different age group. In WP1 the target group was toddlers, while in WP2 and WP3 this was respectively children and adolescents.

The conceptualization and development of the project proposal of the REWARD project took place before the start of this PhD thesis and was performed by the promotors of the PhD thesis (John Van Camp and Carl Lachat) together with the other members of the REWARD scientific committee (www. rewardstudy.be).

1.2.2. Work package 3: adolescents

WP3 assessed how SR and rewarding strategies could be used to promote healthy food choices in adolescents. Four studies were set-up in order to systematically build an intervention to promote healthy snack choices (study 4) in adolescents. All four studies were incorporated in this PhD thesis.

The development and execution of all these studies were coordinated by one postdoctoral researcher (Wendy Van Lippevelde), aided by two junior PhD researchers (Nathalie De Cock and Jolien Vangeel). The WP3 scientific committee (including the promotors of the current PhD thesis) was also regularly consulted during the development of the studies.

1.2.2.1. Study 1: Reliability and validation study of the snack and beverage centered FFQ

The first study consisted of a reliability and validation study of the newly developed snack and beverage centered FFQ. The reliability was assessed comparing the repeated administration of the FFQ and the validity by comparing the FFQ with three 24-hour recalls in a sample of Flemish adolescents aged 14 until 16 years old.

1.2.2.2. Study 2: Cross-sectional study

The second study entailed a cross-sectional survey in a representative sample of adolescents of general, technical and vocational education in Flanders. The main purposes of this study were to estimate the variability in SR in a non-clinical sample of adolescents and to investigate if SR was related to unhealthy food intakes in these adolescents.

1.2.2.3. Study 3: Experimental study

The third study comprised an experimental study in adolescents that aimed to investigate if non-food reward schemas could compete with palatable foods. The combination of non-food reward and healthy food choice was evaluated against the choice of palatable food by means of a food reinforcement task (FRT). Such a task is designed to measure the RV of food by means of progressive or fixed ratio schedules, whether or not in concurrent paradigms. More specifically the RV of a healthy snack linked with a non-food reward was compared with the RV of the healthy snack alone and with the RV of an unhealthy snack.

1.2.2.4. Study 4: A smartphone based intervention study (pilot)

In the last study, an intervention to promote healthy snack choices in adolescents, using a gamified app for smartphones, was developed and evaluated. The app awarded points for each snack entered (rewarding implicit strategies) in combination with goal setting, monitoring and feedback (reflective explicit strategies). It was developed using the evidence gathered in studies 2 and 3. Both the app's feasibility (process-evaluation) and effectiveness were evaluated. The effect of the intervention was tested using a pre-post clustered controlled design.

1.3. Objectives and research questions of the thesis

Several gaps in literature are apparent to effectively alter adolescents' snacking and drinking behaviors. First, no short quantitative assessment tool to measure adolescents' snack and beverage intakes exists to date, while such a tool could greatly accelerate both epidemiological and observational evidence. **Therefore the first aim of this PhD thesis was to develop a quantitative snack and beverage FFQ.** Second, more (recent) information on the snack and beverage intake of Flemish adolescents is needed. **A second aim of this PhD thesis was to update the data on snacking and intake of SSBs in Flanders**. Third, it is evident that hedonic eating triggered by SR and the rewarding value of food is a possible important determinant of energy-dense snack and beverage intake, especially in adolescence. Yet little studies have investigated these associations. **This research assessed the relation between SR and the intake of snack and SSBs in adolescents**. **Additionally it investigated if hedonic eating styles could help explain the association between a higher SR and higher intakes of unhealthy foods and how hedonic eating processes interact with the**

(over) availability of energy-dense snacks and beverages (aim 3). Fourth, when acknowledging that hedonic principles are crucial to understanding snacking and drinking behaviors, an assessment on how to counter these hedonic influences on eating is needed. In this research the potential of rewarding strategies to increase healthy snack choices was explored. Following behavioral choice theory, a first step to alter food choice using rewards is, to assess if the reinforcing value of healthy snacks may be increased by means of rewards in order to increase its attractiveness. **This PhD thesis therefore aimed to assess if offering a reward to fruit choice increased the RV of fruit (aim 4).** A second step would be to test the use of rewarding strategies in an actual field study. Therefore a population intervention study using rewarding strategies among other strategies was developed within this PhD thesis. Smartphone applications provide an interesting medium for behavior change in adolescents, as the use smartphone apps is widespread in adolescents. However little is known about the relation between the use of health apps such as fitness and nutrition apps and adolescents' eating habits and anthropometrics. Information on the use and mechanisms of action of commercial apps could help guide the development of smartphone apps to be used in health promotion**, therefore this PhD thesis aimed to investigate if commercial app use was related to healthier snacking and drinking habits in adolescents and to which factors these associations could be attributed (aim 5).** To date only a few apps have been developed within intervention studies, despite their generally acknowledged potential for health promotion, especially in adolescents. **The final aim of this thesis was thus to develop and evaluate the feasibility and effectiveness of a smartphone gamified app on adolescents' snack intakes (aim 6).** At the basis of this app was a dual process framework, combining rewarding strategies with known effective reflective strategies to alter adolescent's snack choices.

In summary the objectives and research questions (RQs) of this PhD thesis were:

1. To develop a short quantitative FFQ to measure snack and beverage intake in adolescents.

RQ1: Is our newly developed FFQ valid and reliable to estimate snack and beverage intakes in adolescents?

2. To determine the current prevalence of snack and beverage intake in Flemish adolescents.

RQ2: What is the total amount and amount of unhealthy and healthy snacks and SSBs consumed by Flemish adolescents?

3. To study the association between hedonic influences and adolescents snack and beverage intakes.

RQ3: Is a higher SR associated with a higher intake of snacks and SSBs in adolescents?

RQ4: Do hedonic eating styles mediate the SR-unhealthy snack/beverage intake associations and is this mediation moderated by the availability of unhealthy snacks or SSBs at home or at school?

4. To investigate the association between the use of commercial fitness and nutrition apps and adolescents' body mass index (BMI), snack and beverage intakes.

RQ5: Is a higher use of fitness and nutrition apps use associated with healthier snack and beverage intakes and a lower BMI in adolescents and are these associations mediated by intermediate healthy diet determinants?

5. To investigate if the RV of healthy snacks can be increased by means of rewarding strategies.

RQ6: Can rewarding strategies increase the RV of fruit?

6. To evaluate the effectiveness and feasibility of a smartphone intervention to promote healthy snack choices in adolescents.

RQ7: Is a smartphone app that combines rewarding strategies with reflective methods to promote healthy snack choices in adolescents feasible and effective in increasing adolescents' healthy snack consumption?

1.4. PhD thesis outline

This PhD thesis is a compilation of original articles that have been published, accepted and/or submitted as contributions to international peer-reviewed journals. Articles vary by type of research designs and statistical evaluation methods used. The present section provides an overview of the chapters included in this PhD thesis. Figure 3 shows how the different chapters relate to the different studies and objectives mentioned in sections 1.2 and 1.3.

Chapter 1 introduces the theoretical background of this PhD thesis, describes the REWARD project in which this PhD research was embedded and details the different study objectives and research questions of this PhD thesis.

Chapter 2 describes the rationale, the development, the reliability and the validity of a newly developed snack and beverage centered FFQ that was used throughout the whole PhD thesis to measure the snack and/or beverage intake of adolescents. To date, this FFQ is the first comprehensive measurement instrument for snack intake in adolescents that evaluates snack consumption at snack times.

The results of the cross-sectional study are summarized in chapters 3 through 5. **Chapter 3** presents the relation between SR and (un)healthy snack and beverage intake in adolescents. C**hapter 4** specifies the role of external and emotional eating in this relation. Chapter 4 also describes the possible interaction between the environment and external or emotional eating styles emerging as a consequence of this increased SR. **Chapter 5** reports the relations between the frequency of use of commercial fitness and/or nutrition apps and the healthy snack and drinking behaviors and BMI of adolescents. Chapter 5 also attempts to clarify possible determinants that such apps (effectively) target or not target.

Chapter 6 presents the results of an experimental study that tested if the RV of a healthy snack, such as fruit, could be significantly increased by linking it with a reward to an at least comparable level as the RV of unhealthy snacks.

Chapter 7 describes the feasibility and effectiveness of a gamified app to promote healthy snack choices in adolescents. Results presented in chapter 2 until 6 all guided the development of this app, resulting in a gamified app that combines reward strategies with reflective strategies such as goal setting, monitoring and feedback.

Finally in **chapter 8** the main findings are summarized and critically discussed and implications, recommendations for future research and conclusions are given.

1.5. Individual contributions

C**hapter 2** presents the validation of a newly developed snack and beverage FFQ. This FFQ was developed in close collaboration with prof. dr. Carl Lachat, prof. dr. ir. John Van Camp and dr. Wendy Van Lippevelde. In addition several experts were consulted: prof. dr. em. Lea Maes, prof. dr. Stefaan Dehenauw, prof. dr. Ilse De Bourdeaudhuij, prof. dr. Inge Huybrechts and dietitians Mieke De Maeyer and Mia Bellemans. Data collection and data entering was done by students from the nutrition and dietetics program (HoGent). I have performed the reliability and validation analysis and wrote the paper, supported by the mentioned coauthors.

Chapters 3 until 5 presents results from the cross-sectional study. Together with dr. Van Lippevelde and Jolien Vangeel, I was involved in designing the study and collecting the data. All three papers were own contributions, for which I performed the analyses and wrote the manuscript (again with support from coauthors).

Chapter 6 shows the results of the experimental study, for which I coordinated the design of the experiment and the data collection (aided by Melissa Notebaert). The design was however, developed in close collaboration with dr. Leentje Vervoort, prof. dr. Carl Lachat and dr. Wendy Van Lippevelde. I again conducted the analyses and wrote the manuscript with feedback from the coauthors.

The development of the intervention described in **chapter 7** is a joint effort of multiple persons from several disciplines: psychology: prof. dr. Lien Goossens, prof. dr. Caroline Braet and dr. Leentje Vervoort; bioscience engineering: prof. dr. ir. John Van Camp, prof. dr. Carl Lachat, dr. Lieven Huybregts and myself; Public health: prof. dr. em. Lea Maes, prof. dr. Benedicte Deforche, dr. Wendy Van Lippevelde; and communication sciences: prof. dr. Steven

Eggermont, prof. dr. Kathleen Beullens and Jolien Vangeel. Jolien Vangeel and myself, aided by Melissa Notebaert, were responsible for the data collection. I conducted the effect and feasibility analyses and wrote the chapter, with feedback from the coauthors. Analysis strategies were determined together with Prof. dr. Carl Lachat and dr. Wendy Van Lippevelde.

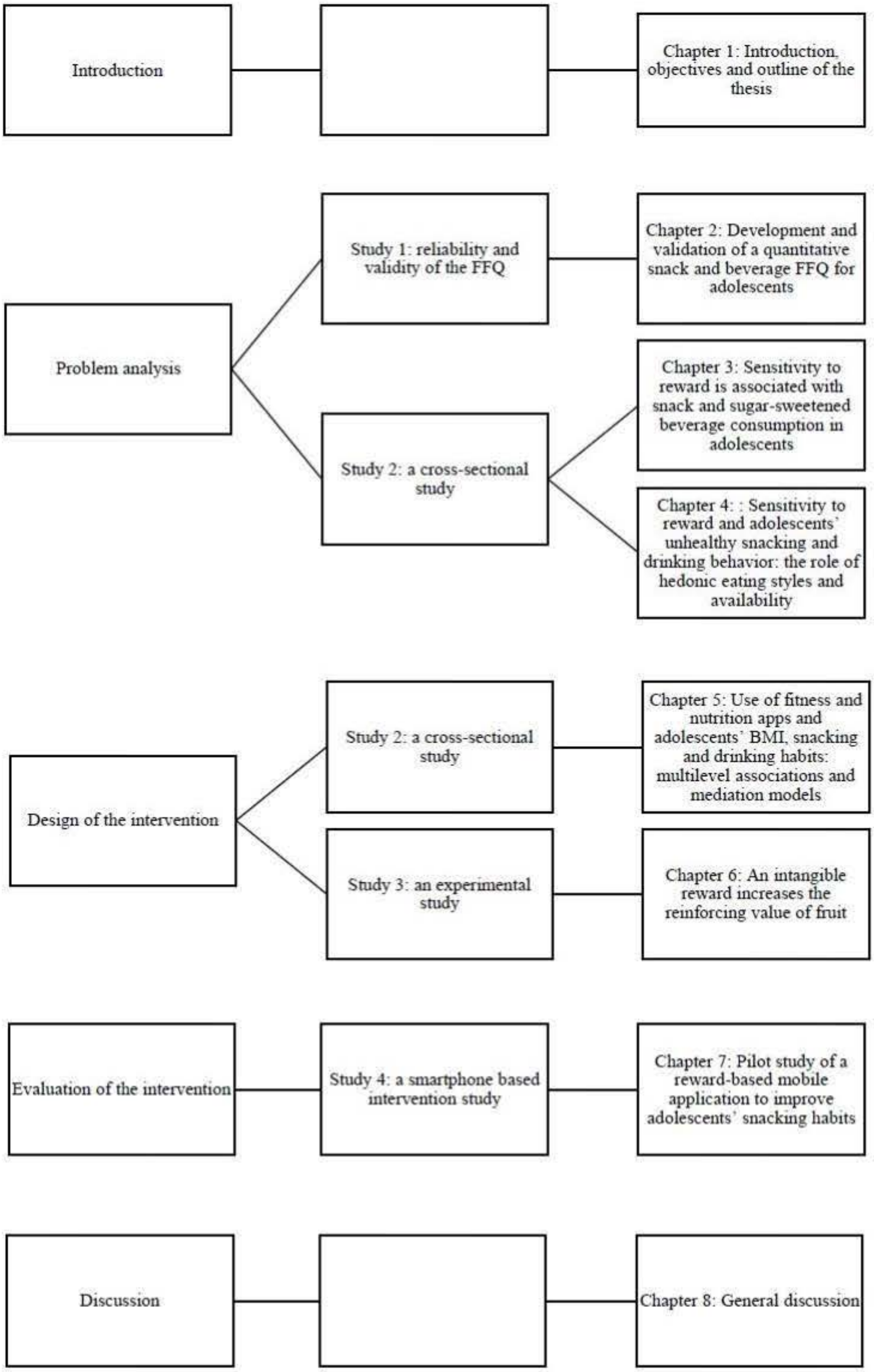


Figure 3: Overview of the different studies and chapters included in this PhD thesis

Chapter 2: Development and validation of a quantitative snack and beverage FFQ for adolescents

Redrafted after:

Nathalie De Cock, John Van Camp, Patrick Kolsteren, Carl Lachat, Lieven Huybregts, Lea Maes, Benedicte Deforche, Roosmarijn Verstraeten, Jolien Vangeel, Kathleen Beullens, Steven Eggermont and Wendy Van Lippevelde (2016). *Journal of Human Nutrition and Dietetics*.

Summary

Background: A short, reliable and valid tool to measure snack and beverage consumption in adolescents, taking into account the correct definitions, would benefit both epidemiological and intervention research. The current study aimed to develop a short quantitative beverage and snack food frequency questionnaire (FFQ) and to assess reliability and validity of this FFQ against three 24-hour recalls.

Method: Reliability was assessed by comparing estimates of the FFQ administered 14 days apart (FFQ1 and FFQ2) in a convenience sample of 179 adolescents (60.3% male; 14.7±0.9 years). Validity was assessed by comparing FFQ1 with three telephone-administered 24-hour recalls in a convenience sample of 99 adolescents (52.5% male, 14.8±0.9 years). Reliability and validity were assessed using Bland Altman plots, classification agreements and correlation coefficients for the amount and frequency of consumption of snacks, unhealthy snacks, healthy snacks, unhealthy beverages, healthy beverages and SSBs; for the healthy snack and beverage ratios; and for the energy and nutrients derived from snacks and SSBs.

Results: Small mean differences (FFQ1 vs. FFQ2) were observed for reliability, ranking ability ranged from fair to substantial and Spearman coefficients fell within normal ranges. For the validity mean differences (FFQ1 vs. recalls) were small for beverage intake but large for snack intake, except for the healthy snack ratio. Ranking ability ranged from slightly to moderate and Spearman coefficients fell within normal ranges.

Conclusion: Reliability and validity of the FFQ for all outcomes were found to be acceptable on group level for epidemiological purposes, while for intervention purposes only the healthy snack and beverage ratios were found to be acceptable on group level.

2.1. Introduction

Adolescents typically adopt unhealthy eating habits such as snacking, low consumption of dairy products, fruit, vegetables and high intake of energy-dense snacks, sugar-sweetened beverages (SSBs) and other high-caloric beverages [7, 136]. The overconsumption of high energy-dense beverages such as sodas, sweetened milk beverages, fruit-based drinks and alcohol, has already been associated with excess sugar and energy intake and obesity in adolescence and adulthood [8-10]. While snacking, or the eating in between meals, has been associated with both excess energy intake and overweight and improved diet quality and reduced obesity [14-17, 137]. Consequences are dependent on snacking frequency, food types eaten as snacks and portion sizes consumed [14-17, 137]. If mainly energy-dense foods such as cookies, chocolate, chips or fast-food are consumed, energy, sugar and fat intake from snacks is substantial and nutrient intakes are lower [16, 137]. While when more healthy foods such as fruits and milk products are eaten, energy intake from snacks is lower and the overall nutritional quality of diet is higher [16, 137]. Not only do unhealthy snack and beverage intake both contribute independently to excess energy intake, but their intakes are also related [24, 25]. High SSB drinking children and adolescents were found to consume more sweet and salty snack foods than non SSB drinkers [24, 25]. Effective evaluation of both habitual snack and beverage consumption is needed to determine important correlates of snack and beverage consumption, as well as to analyze interventions aimed at improving snack and/or beverage consumption.

Existing tools such as dietary records, 24-hour recalls or large FFQs assessing the total diet of adolescents are time-consuming, are burdensome for the respondents and provide unnecessary details [32-35]. Especially to evaluate dietary intake in adolescents rapidly administrable tools are necessary as they are less interested in giving accurate reports [33]. Short assessments tools, focusing on specific behaviors, have been used before in adolescent population to assess nutrient or food group intakes and were found to be easy to administer, reliable and valid [33, 34, 138-140]. To date only a brief questionnaire exists that measures snack and beverage intake in adolescents [34], however this questionnaire was developed for specifically evaluating school policies and does not contain all possible snack foods or high-calorie beverages. Nor does it contain portion size estimation or evaluates intake of snack foods at snack times. The latter is of crucial importance as the effects of snacking are determined by the type and the portion size of snacks. Snack intake should be measured as the consumption of typical snack foods, both healthy and unhealthy, at snack times (e.g. any food eaten in between the main meals) [18, 31].

The aim of this study was to develop and validate a short quantitative FFQ to measure both habitual snack and beverage intake, using the correct definition of snacking (e.g. snack foods eaten at snack times) [19]. The reliability and validity of this FFQ was assessed in a sample of Flemish adolescents aged 14-16 years old for both epidemiological and intervention purposes. Reliability and validity were assessed for the following variables: consumption frequency of unhealthy snacks, healthy snacks, unhealthy beverages and healthy beverages; the intake of snacks (g) unhealthy snacks (g), healthy snacks (g), unhealthy beverages (ml), healthy beverages (ml) and SSBs (ml); the healthy snack and beverage ratios; energy (kcal) and sugar (g) derived from snacks and SSBs; and fat (g) and Na (mg) derived from snacks.

2.2. Methods

This study is part of the REWARD project (www.rewardstudy.be), a multidisciplinary project that aims to increase healthy food choices in children and adolescents using reward-based mechanisms. In adolescents, the overall goal was to study and/or improve adolescents' snack and beverage choices. The first step was the development of a quantitative snack and beverage FFQ for adolescents, of which the present manuscript reports the development and the validation and reliability analyses. This FFQ will be used in the subsequent cross-sectional study to research adolescents' snacking an drinking behaviors, and the smartphone based intervention study to increase adolescents' healthy snack choices.

2.2.1. Development of the quantitative snack and beverage FFQ

The selection of surveyed food and beverages items consisted of two steps. In step 1 a review of survey items from existing research examining food intake in children and adolescents was conducted [48, 141-143]. From this review one FFQ was selected to be used as the basis for our FFQ [141, 143]. In step 2 it was assessed whether the items from this FFQ were commonly consumed as snacks or beverages by adolescents in Flanders. The frequent consumption of a food as snack or beverage was assessed based on the 24 hour recall data of Flemish adolescents from the HELENA study [144]. The latter study evaluated the food intake and eating patterns of European adolescents aged 12.5-17.5 years from 10 European countries including Belgium (Flanders) [144]. Items that were not commonly consumed as snacks or beverages by adolescents in the HELENA study were removed and snacks or beverages that were commonly consumed, but were not present, were added. In total the FFQ consists of 14 beverage items and 28 snack items. The FFQ was added as appendix (see Appendix 1).

Frequencies of consumption, portion sizes and examples of typical portions were adapted from the same quantitative FFQ that was used as basis for the selection of the items [141, 143].

The snack and beverage FFQ was pretested by 40 adolescents (±2 classes) on clearness and appropriateness of the items and examples. Wording of the items and examples was revised based on their feedback.

2.2.2. Validation and reliability study

2.2.2.1. Design

Reliability and validity of the FFQ were examined in a convenience sample of Flemish adolescents. Reliability was assessed by comparing measurement agreement of a repeated administration (FFQ at time 1 (FFQ1) vs. FFQ at time 2 (FFQ2)). Validity was evaluated by comparing measurement agreement between the FFQ1 and the average of three 24-hour dietary recalls. Executing the 24-hour dietary recall three times is considered sufficient to get an estimation of the habitual intake of adolescents for the purpose of validation studies in adolescents [145-147]. Administering the 24-hour dietary recalls by telephone is common and convenient in research with adolescents [146, 148-150]. Main outcomes were the consumption frequency of unhealthy snacks, healthy snacks, unhealthy beverages and healthy beverages; the intake of snacks (g) unhealthy snacks (g), healthy snacks (g), unhealthy beverages (ml), healthy beverages (ml) and SSBs (ml); the healthy snack and beverage ratios; energy (kcal) and sugar (g) derived from snacks and SSBs; and fat (g) and Na (mg) derived from snacks.

2.2.2.2. Recruitment of participants

Data were collected from February to March 2014 using a convenience sample of 14- to 16-year-old Flemish adolescents. These adolescents were recruited from three secondary schools, in each school three classes (±60 students per school) were selected by the principals to participate in the study. Adolescents were asked separately if they also wanted to participate in the validation study, as this required more effort. Incentives were raffled among adolescents that participated in both studies. Parents or legal guardians of the selected adolescents received a letter explaining the study purpose and were asked for passive consent for participation of their adolescent. Adolescents were also informed that they could withdraw from the study at any time without explanations. No inclusion or exclusion criteria were applied. The study protocol was approved by the Ethics Committees of the Ghent University Hospital. An overview of the recruitment is shown in Figure 4.

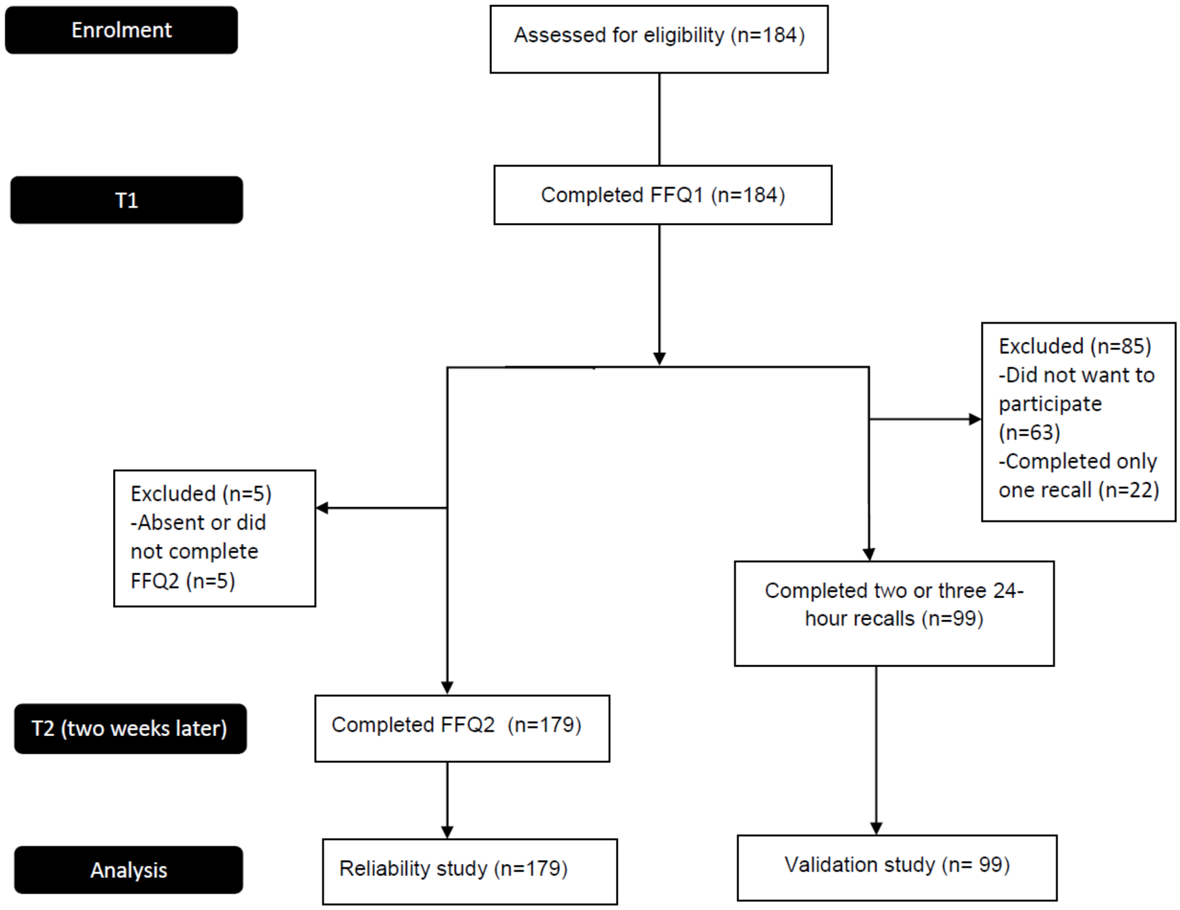


Figure 4: Overview of the recruitment procedure

2.2.2.3. Study procedure

A team of researchers visited the schools on a previously agreed time during school hours. Adolescents completed the FFQ (FFQ1) in the presence of a research assistant. Adolescents were instructed to carefully read the instructions (see Appendix 1*)* given with the FFQ and were informed that they could ask questions at any time. Adolescents also completed a short demographic questionnaire at the same time. Completing the FFQ took the adolescents about 20 minutes. Adolescents who agreed to participate in the validation study also provided a telephone number and the hours they were available for the 24-hour recalls at this time point.

For the purpose of the reliability study, the FFQ was administered a second time (FFQ2), 14 days after the first administration (FFQ1) following the same procedures.

For the purpose of the validation study three 24-hours recalls were administered between FFQ1 and FFQ2 (see Figure 4) in such a way that all participants provided data for two weekdays and one weekend day. At group level, a balanced representation of each week day was obtained. Participants were called in between the agreed hours and were asked about food consumption of the previous day. Participants were unaware at which days they would be called. The administration of the 24-hour recall took about 15 minutes each time. The 24-hour recalls were conducted by dieticians, who were trained to administer these recalls in a standardized way [143, 151]. No specific automatized procedure such as the multiple-pass method [152] was used. Adolescents were called three times on different days before being regarded as dropped out.

2.2.3. Instruments

2.2.3.1. The quantitative beverage and snack FFQ

The FFQ assessed usual food intake with a reference period of one month. The six frequency categories used were: never or seldom; 1-3 days/month; 1 day/week; 2-4 days/week; 5-6 days/week; every day. Depending on the item, 4-6 portion size categories were provided together with a list of common standard portion measures as examples.

The FFQ comprised of two sections: beverages (14 categories) and snacks (28 categories). The intake of beverages was evaluated over the whole day, as beverages such as soft and fruit drinks provide additional calories and sugars throughout the whole day and not only at snack times [23]. The intake of snacks was evaluated in terms of all food items consumed outside (>30 min) of breakfast, lunch and dinner, in accordance with Rodriguez and Moreno's definition of snacking [19]. Items in both sections were presented in such a way that closely related items were presented on the same page with the more specific items presented before the general ones [140].

Snacks and beverages were classified as either healthy or unhealthy using the UK Ofcom Nutrient Profiling model [22]. This model provides a score as a proxy for 'unhealthiness' of a beverage or food product, food items that scored 4 points or more and beverage items that scored 1 point or more were considered to be unhealthy [22]. Following this scoring system, the snack and beverage items, sport drinks, energy drinks, soft drinks, sweetened milk drinks, cocktails, aperitif drinks, liquor, crisps, other salty snacks, sausage/cheese rolls and pizza, other fried snacks, fries, hamburgers, cheese or meat cubes, sandwich with sweet or savoury spread, ice-cream, popsicles, breakfast cereals, pudding, mousses, chocolate, candy bars, candy, dry cookies, other cookies, breakfast rolls and pastries were considered to be unhealthy. The items water, fruit juice, coffee, milk substitutes, milk, beer, wine, fruit, dried fruit, nuts, raw vegetables, pitta, pasta cups, unsweetened and sweetened yoghurt were considered healthy.

The daily intake of each snack and beverage item of the FFQ was obtained by multiplying frequency of consumption with quantity of consumption per week (g) divided by 7. These daily estimates were then summed to obtain the daily intake of snacks (g), healthy snacks (g), unhealthy snacks (g) unhealthy beverages (ml) and healthy beverages (ml). The consumption frequency of unhealthy and healthy snacks or beverages was calculated by summing the frequencies of the different food or beverage items and dividing this sum by 7. Finally, healthy snack and beverage ratios were calculated. These ratios represent how much percent of the total snack or beverage intake was healthy. The higher these ratios the more healthy the snack or beverage intake of the adolescents was.

$$Healthy\ snack\ ratio = \left(\frac{daily\ intake\ of\ healthy\ snacks}{daily\ intake\ healthy\ and\ unhealthy\ snacks}\right) \times 100$$

$$Healthy\ beverage\ ratio = \left(\frac{daily\ intake\ of\ healthy\ beverages}{daily\ intake\ healthy\ and\ unhealthy\ beverages}\right) \times 100$$

The daily amount of energy and nutrients derived from snacks and SSBs was calculated using the Belgian food composition table (NUBEL, 2009) [153]. For all FFQ items, an average nutrient composition was calculated by averaging the nutritional composition from NUBEL

[153] of the most frequently consumed foods by adolescents in the HELENA study [144]. The actual energy, sugar and fat and Na intakes per FFQ item of the individuals were then calculated by using the amounts (g) of the food consumed and the averaged nutrient consumption expressed per 100 g of food. The daily energy, sugar, fat and Na intakes per FFQ item were then summed to obtain the daily intake of energy (kcal) and sugar (g) from SSBs; and the daily intake of energy (kcal), fat (g), sugar (g), Na (mg) from snacks.

2.2.3.2. The 24-hour recalls

All information obtained during the telephone administered 24-hour recalls was noted on paper subdivided into six eating occasions, namely breakfast, morning snacks, lunch, afternoon snacks, dinner and evening snacks. For each of these occasions detailed information was asked from the adolescent by the researcher regarding the type of food consumed, the brand (with description) and the quantity consumed. For each of these occasions also product categories were provided depending on the type of meal, for instance for breakfast these are: cereal, bread, spreads/meat/cheese/etc., margarine/butter/etc., drinks and others.

Since the focus of our FFQ was only on snacks (all food items consumed outside the three main meals) and beverages (evaluated over the whole day), only the 24-hour recall data regarding food items obtained in the sections morning, afternoon and evening snacks and beverage items from all sections were used and imported into Lucille (Lucille software 0.1, 2010 [154]). Lucille is a software package designed to process food intake developed by our own research group [154]. It was opted to however question all eating occasions and not only snack occasions because beverage intake was evaluated over the whole day and also to not interfere with the normal way of performing a telephone-administered 24-hour recall.

All foods and beverages consumed by the adolescents in the 24-hour recalls were summed to obtain the intakes per snack and beverage item from the FFQ and per recall day. These intakes per item were then summed to again obtain the daily intake of snacks (g), healthy snacks (g), unhealthy snacks (g) unhealthy beverages (ml) and healthy beverages (ml) per recall day. The latter where then averaged to obtain an average of the three recall days to represent the habitual intake of healthy snacks (g), unhealthy snacks (g) unhealthy beverages (ml) and healthy beverages (ml) comparable with the data obtained via the FFQ. Also the consumption frequencies of unhealthy or healthy beverage or snack items were calculated by summing the different snack or beverage items consumed each recall day and then again averaging these numbers over the three recall days to obtain the usual consumption frequencies of unhealthy or healthy snack and beverage items consumed per day. Finally, also here the healthy snack and beverage ratios were calculated in the same manner as stated above.

The daily amount of nutrients and energy derived from snacks and SBBs was calculated using Lucille. Lucille provides the actual energy, sugar and fat and Na intakes per food item consumed by the adolescents, based on NUBEL [153].The amount of energy, sugar, fat and Na of all food items consumed by the adolescents in the 24-hour recalls were then summed to obtain the intakes per FFQ category and per recall day. The daily energy, sugar, fat and Na intakes per FFQ item were then summed to obtain the daily intake of energy (kcal) and sugar (g) from SSBs; and the daily intake of energy (kcal), fat (g), sugar (g), Na (mg) from snacks.

2.2.4. Data Analysis

All analyses were performed in Stata version 13.1 (Stata Corporation, Texas, USA). Although correlation coefficients are a poor estimate of measurement agreement, they are provided in the present paper to allow comparison with other studies [155, 156].

2.2.4.1. Reliability analysis

Only participants who completed both FFQ1 and FFQ2 were retained for the reliability analysis. Descriptive analyses were used to evaluate the characteristics of the participants (mean age and sex) in the reliability study and to describe the mean intakes and frequencies obtained via FFQ1 and FFQ2.

Reliability was assessed firstly by determining the correlation coefficients, Spearman's rho, between the outcomes derived from FFQ1 and FFQ2. Correlation can be considered very high (0.90 to 1.00), high (0.70 to .90), moderate (0.50 to 0.70), low (0.30 to 0.50) or negligible (0.00-0.30) [157]. Second the agreement between the repeated administration for each of the outcomes was evaluated using Bland Altman plots [158]. The same procedure to determine mean difference, its confidence interval (CI) and the 95% Limits Of Agreement (LOA) was followed as proposed by Ambrosini et al. (2009) and Bland & Altman (1999), including the transformation of all outcomes to their natural logarithms before analyses because of the usual skewness in intake distributions [158, 159]. First all outcomes from both measures (FFQ1 and FFQ2) were log transformed. Second mean differences, CI's and LOA's were computed. Third mean differences (FFQ1-FFQ2), CI's and LOA's were back transformed by taking the antilog and values were presented as percentages ((10^log estimate) *100). Mean agreement of 100% for energy intake would suggest exact agreement, whereas mean agreement of 120% indicated that the FFQ1 overestimated unhealthy snack intake by 20% compared to FFQ2, on average. Furthermore, 95% LOA's of 55–184% for unhealthy snack intake would suggest that 95% of all subjects' FFQ1 estimates are between 55 and 184% of their FFQ2 unhealthy snack intake estimate [158, 159]. Third the classification agreement between FFQ1 and FFQ2 was assessed using weighted Kappa statistics and its standard deviation by comparing classifications of the outcomes into low, medium and high tertiles [160] using the standards as proposed by Landis and Koch (1977) [161]. These standards are less than 0 "less than chance agreement", 0.01–0.20 "slight agreement", 0.21– 0.40 "fair agreement", 0.41–0.60 "moderate agreement", 0.61–0.80 "substantial agreement" and 0.81–0.99 "almost perfect agreement". To account for prevalence and bias effects, the prevalence-adjusted and bias-adjusted Kappa (PABAK) was presented alongside the Kappa statistics [162].

2.2.4.2. Validation analysis

Only participants who completed at least two 24-hour recalls and FFQ1 were retained for the validation analysis. Descriptive analyses were used to evaluate the characteristics of the participants (mean age and sex) in the validation study and to describe their mean intakes and frequencies obtained via FFQ1 and the 24-hour recalls (average of the three evaluated days).

Validity was assessed by first determining correlation coefficients (Spearman's rho) between the outcomes derived from FFQ1 and the average of the three 24-hour recalls. Second by comparing the agreement for all outcomes between FFQ1 and the average of the recalls by means of Bland Altman plots, in the same manner as explained above for the reliability study. Third by determining the classification agreement for all outcomes between FFQ1 and the recalls by means of kappa statistics as explained above.

2.2.4.3. Sensitivity analysis

A sensitivity analysis was also performed by repeating all analyses for both reliability and validity according to four scenarios: outliers present and no infrequent consumption condition (1), outliers removed and no infrequent consumption condition (2), outliers present and infrequent consumption condition (3) and outliers removed and infrequent consumption condition (4). The infrequent consumption scenario accounts for the fact that not frequently consumed snack or beverage items are harder to measure and evaluate, as these are often missed in a 24-hour recall or food diary [33]. To verify the influence of this phenomenon on the validity and reliability estimates, items that were consumed less than 3 times/week were recoded to missing and excluded from the analyses. Outliers for snack and beverage items were removed, if they were larger than the mean +3SD's for both methods. Spearman's rho, mean differences, and Kappa statistics for both the validation as the reliability were comparable across the four scenarios, therefore only the results for the baseline scenario (1) were presented.

2.3. Results

2.3.1. Reliability study

2.3.1.1. Participants and descriptives

179 adolescents (60.3% male; mean age=14.7±0.9 years), 97% of 184 adolescents sampled in the reliability, provided valid data for both administrations of the FFQ (see Figure 4). Table 1 and Table 2 show the estimates for the outcomes obtained from FFQ1 and FFQ2. FFQ1 had higher estimates for all outcomes except for the healthy snack ratio.

Table 1: Mean snack and beverage intakes for the reliability (n=179) and validation study (n=99)

	Reliability (n=179)				Validity (n=99)			
	FFQ1		FFQ2		FFQ1		Average of the Recalls	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Frequency of unhealthy snacks per day	2.8	1.9	2.4	1.8	2.4	1.5	0.8	0.7
Frequency of healthy snacks per day	1.1	0.7	0.9	0.7	1.1	0.7	0.5	0.7
Quantity of unhealthy snacks consumed per day (g)	225.8	237.1	220.9	308.9	180.0	154.4	44.7	41.5
Quantity of healthy snacks consumed per day (g)	195.6	173.0	181.0	190.8	201.6	160.7	65.0	104.3
Healthy snack ratio (%)	45.5	27.8	46.3	27.7	51.5	26.8	26.6	32.7
Frequency of unhealthy beverages per day	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.8
Frequency of healthy beverages per day	2.0	0.8	1.8	0.8	2.0	0.8	2.7	1.1
Quantity of unhealthy beverages consumed per day (ml)	295.2	390.2	269.3	388.1	286.0	436.9	185.2	260.6
Quantity of healthy beverages consumed per day (ml)	987.0	542.5	841.2	559.8	988.9	504.3	921.8	481.2
Healthy beverage ratio (%)	77.3	24.0	76.5	24.3	79.1	24.1	76.7	24.3

Table 2: Mean snack and beverage intakes for the reliability (n=179) and validation study (n=99) (continued)

	Reliability (n=179)				Validity (n=99)			
	FFQ1		FFQ2		FFQ1		Average of the Recalls	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Quantity of snacks consumed per day (g)	421.4	303.4	421.4	303.4	381.5	209.7	109.67	111.2
Energy from snacks per day (kcal)	965.0	880.6	911.72	1012.8	811.1	562.6	216.3	177.2
Sugar from snacks per day (g)	62.2	43.3	58.1	51.7	56.2	31.8	17.2	14.6
Fat from snacks per day (g)	42.2	44.5	39.7	49.5	34.3	28.2	9.4	9.5
Na from snacks per day (mg)	965.2	1069.9	926.4	1417.4	778.8	723.1	120.2	127.4
Quantity of SSBs consumed per day (ml)	244.0	330.4	209.1	319.6	241.1	401.7	159.4	251.0
Energy from SSBs per day (kcal)	104.8	145.4	89.2	141.3	106.5	189.7	85.8	167.4
Sugar from SSBs per day (g)	25.0	34.6	21.3	33.2	25.3	44.4	16.0	24.7

2.3.1.2. Reliability

Mean differences for all outcomes were small (less than 30% difference), the largest mean difference observed was +28.8%, for the quantity of healthy beverages consumed; and the smallest +3.8%, for the healthy beverage ratio (see Table 3 and Table 4). FFQ1 thus overestimated the quantity of healthy beverages by 28.8% or FFQ1 measured 128.8ml and FFQ2 100ml. Except for the healthy snack ratio, all mean differences were positive and different from 100%, indicating that FFQ1 overestimated intakes compared to FFQ2. 95% CI's included 100% agreement except for the frequency of unhealthy and healthy snacks, the quantity of unhealthy and healthy snacks and the quantity of unhealthy beverages, indicating non-significant differences between FFQ1 and FFQ2. LOA's (Table 3 and Table 4) were wide for all outcomes. Bland Altman plots for all outcomes are shown in Appendix 2.

Moderate classification agreement (Kappa in Table 3 and Table 4) was observed for all outcomes except for the frequency of healthy beverages and the quantity of SSBs and energy and sugar from SSBs, where respectively near perfect and substantial agreement was observed. The Kappa coefficient improved for all outcomes when it adjusted for prevalence and bias (PABAK) (Table 3 and Table 4).

Spearman's rho's (Table 3 and Table 4) ranged from 0.62 (healthy snacks g/d) to 0.75 (unhealthy snacks g/d), indicating moderate to high correlation.

Table 3: Mean differences , CI's, LOA's, Kappa's, PABAK's and Spearman's rho's for the reliability study (n=179)

	Mean agreement (%)*	95% CI (%)*	LOA (%)*	Kappa	PABAK	Spearman's rho
Frequency of unhealthy snacks per day	118.9	[109.1, 129.4]	[37.7, 375.0]	0.51	0.56	0.69
Frequency of healthy snacks per day	119.1	[106.2, 133.4]	[26.4, 537.0]	0.49	0.55	0.69
Quantity of unhealthy snacks consumed per day (g)	119.1	[106.7, 133.1]	[16.0, 843.3]	0.57	0.62	0.75
Quantity of healthy snacks consumed per day (g)	115.1	[99.1, 133.4]	[16.3, 812.8]	0.49	0.55	0.62
Healthy snack ratio (%)	95.3	[85.1, 106.7]	[21.8, 415.9]	0.54	0.59	0.73
Frequency of unhealthy beverages per day	107.4	[93.3, 123.6]	[18.3, 629.5]	0.56	0.61	0.68
Frequency of healthy beverages per day	113.2	[105.7, 121.1]	[45.1, 283.8]	1.00	1.00	0.71
Quantity of unhealthy beverages consumed per day (ml)	107.9	[91.2, 127.7]	[13.2, 885.1]	0.55	0.60	0.70
Quantity of healthy beverages consumed per day (ml)	128.8	[117.2, 141.9]	[35.2, 472.1]	0.53	0.59	0.67
Healthy beverage ratio (%)	103.8	[96.8, 111.2]	[41.1, 261.8]	0.52	0.58	0.69

*antilogs in percentages: mean agreement of 100% for quantity of unhealthy snacks would suggest exact agreement, whereas mean agreement of 119.1% indicates that the FFQ1 overestimates the quantity of unhealthy snacks by 20%, on average

Table 4: Mean differences , CI's, LOA's, Kappa's, PABAK's and Spearman's rho's for the reliability study (n=179) (continued)

	Mean agreement (%)*	95% CI (%)*	LOA (%)*	Kappa	PABAK	Spearman's rho
Quantity of snacks consumed per day (g)	117.8	[107.3, 129.1]	[33.3, 415.9]	0.46	0.52	0.66
Energy from snacks per day (kcal)	119.4	[108.4, 131.5]	[32.5, 437.5]	0.5	0.55	0.72
Sugar from snacks per day (g)	118.58	[108.6, 129.1]	[37.2, 378.4]	0.5	0.55	0.68
Fat from snacks per day (g)	122.2	[109.1, 136.8]	[26.7, 558.5]	0.5	0.55	0.72
Na from snacks per day (mg)	123.9	[108.9, 140.9]	[21.9, 701.5]	0.56	0.61	0.74
Quantity of SSBs consumed per day (ml)	119.2	[101.4, 141.6]	[17.0, 843.3]	0.64	0.68	0.73
Energy from SSBs per day (kcal)	121.6	[102.8, 144.2]	[16.8, 879.0]	0.68	0.72	0.74
Sugar from SSBs per day (g)	121.6	[102.3, 144.2]	[16.6, 891.3]	0.65	0.69	0.74

*antilogs in percentages: mean agreement of 100% for quantity of unhealthy snacks would suggest exact agreement, whereas mean agreement of 119.1% indicates that the FFQ1 overestimates the quantity of unhealthy snacks by 20%, on average

2.3.2. Validation study

2.3.2.1. Participants and descriptives

99 adolescents (52.5% male, mean age= 14.8±0.9 years), or 82% of 121 adolescents sampled in the validation study, provided valid data for at least two 24-hour recalls and FFQ1 (see Figure 4). Of these 99 participants, 88 (88.9%) completed three recalls and 11 (11.1%) complete only two. Table 1 and Table 2 indicate that the FFQ provided higher estimates than the 24-hour recalls for snack intake in terms of frequencies, quantities consumed (total snacks, unhealthy snacks and healthy snacks), energy and nutrients derived from snacks, and the healthy snack ratio. For beverage intake the FFQ provided lower estimates for the frequencies of unhealthy and healthy beverages, but higher estimates for the quantities consumed (unhealthy beverages, healthy beverages and SSBs), energy from SSBs, sugar from SSBs and the healthy beverage ratio.

2.3.2.2. Validity

Small mean differences (less than 30%) were observed for unhealthy and healthy beverages (frequencies and quantities), ranging from -24.7% to +7.6% (see Table 5) The FFQ overestimated the quantities consumed by 9 ml or 4 ml, while it underestimated the frequency of unhealthy and healthy beverages by 0.25 or 0.17 times. The FFQ and the 24-hour recalls showed nearly perfect agreement for the healthy beverage ratio (mean difference=100.5%). Small mean differences were also observed for the quantity of SSBs consumed and the energy and sugar derived from them (see Table 6). The FFQ underestimated the quantity of SSBs consumed and the energy and sugar derived from SSBs by respectively 2 ml, 11 kcal and 4 g. Large mean differences were however observed (see Table 5) for the intake of healthy and unhealthy snacks, especially the quantity and the frequency of unhealthy snacks was overestimated by the FFQ (+152.9% and 225.8% respectively). The FFQ overestimated the frequency of eating unhealthy snacks by 1.5 times and the quantity consumed by 226g. For the healthy snack ratio the difference between both methods was small, +11.2%. Mean differences were also large for the quantity of snacks and energy and nutrients (fat, sugar and Na) derived from them (see Table 6). 95% CI’s did not include 100% agreement except for the healthy snack ratio, the frequency of unhealthy beverages, the quantity of unhealthy and healthy beverages, the healthy beverage ratio, the quantity of SSBs and energy and sugar derived from SSBs, indicating significant differences between both methods. LOA’s (see Table 5 and Table 6) were wide for all outcomes. Bland Altman plots are presented in Appendix 3.

Slight to moderate classification agreement was observed between the FFQ and the recalls. Classification agreement improved for all outcomes when adjusted for prevalence and bias (see Table 5 and Table 6).

Spearman’s rho’s (see Table 5 and Table 6) ranged from 0.17 (healthy beverages frequency/d) to 0.69 (unhealthy beverages g/d), indicating negligible to moderate correlation.

Table 5: Mean difference, CI, LOA's, Kappa's, PABAK's and Spearman's rho for the validation study (n=99)

	Mean agreement (%)*	95% CI (%)*	LOA (%)*	Kappa	PABAK	Spearman's rho
Frequency of unhealthy snacks per day	252.9	[214.8, 297.9]	[58.9, 1088.9]	0.13	0.24	0.27
Frequency of healthy snacks per day	142.9	[112.2, 182.4]	[26.4, 776.3]	0.16	0.25	0.39
Quantity of unhealthy snacks consumed per day (g)	325.8	[261.8, 404.6]	[47.4, 2238.7]	0.18	0.27	0.31
Quantity of healthy snacks consumed per day (g)	214.3	[161.1, 285.8]	[29.7, 1548.8]	0.28	0.32	0.42
Healthy snack ratio (%)	111.2	[89.5, 138.4]	[24.8, 500.0]	0.25	0.30	0.35
Frequency of unhealthy beverages per day	82.6	[67.1, 101.9]	[14.8, 460.3]	0.33	0.39	0.63
Frequency of healthy beverages per day	75.3	[66.5, 85.3]	[21.6, 262.4]	0.13	0.27	0.17
Quantity of unhealthy beverages consumed per day (ml)	108.9	[84.3, 140.6]	[15.0, 790.7]	0.49	0.55	0.69
Quantity of healthy beverages consumed per day (ml)	104.0	[90.0, 120.0]	[24.4, 441.6]	0.31	0.38	0.44
Healthy beverage ratio (%)	100.5	[91.4, 110.7]	[38.7, 261.2]	0.43	0.48	0.68

*antilogs in percentages: mean agreement of 100% for quantity of unhealthy snacks would suggest exact agreement, whereas mean agreement of 325.8% indicates that the FFQ overestimates the quantity of unhealthy snacks by 285%, on average

Table 6: Mean difference, CI, LOA's, Kappa's, PABAK's and Spearman's rho for the validation study (n=99) (continued)

	Mean agreement (%)*	***95% CI (%)****	***LOA (%)****	***Kappa***	***PABAK***	***Spearman's rho***
Quantity of snacks consumed per day (g)	425.6	[353.2, 514.0]	[70.5, 2576.3]	0.26	0.33	0.40
Energy from snacks per day (kcal)	375.0	[307.6, 458.1]	[56.2, 2506.1]	0.20	0.29	0.31
Sugar from snacks per day (g)	385.48	[317.7, 466.7]	[61.24, 2421.0]	0.30	0.37	0.36
Fat from snacks per day (g)	358.10	[277.3, 462.4]	[35.7, 3589.2]	0.23	0.31	0.32
Na from snacks per day (mg)	737.90	[483.1, 1127.2]	[13.2, 41020.4]	0.18	0.27	0.18
Quantity of SSBs consumed per day (ml)	98.40	[74.1, 130.6]	[14.3, 677.],	0.43	0.46	0.60
Energy from SSBs per day (kcal)	88.51	[65.0, 120.2]	[10.9, 716.1]	0.41	0.44	0.59
Sugar from SSBs per day (g)	96.38	[71.3, 130.3]	[12.36, 753.36]	0.41	0.44	0.60

*antilogs in percentages: mean agreement of 100% for quantity of unhealthy snacks would suggest exact agreement, whereas mean agreement of 325.8% indicates that the FFQ overestimates the quantity of unhealthy snacks by 285%, on average

2.4. Discussion

This study reports on the reliability and validity of a newly developed quantitative snack and beverage FFQ for adolescents.

The reliability of the FFQ was adequate at a group level for snack and beverage intake, as mean differences were small and kappa's and correlation coefficients fell within the common range [140]. Significant mean differences between both administrations of the FFQ were observed for the frequency of unhealthy and healthy snacks; the quantity of unhealthy and healthy snacks, unhealthy beverages, snacks and SSBs; and energy and nutrients derived from snacks and SSBs. These differences however, were small and not higher than 30%, indicating a discrepancy of only 0.3 snacks or 30 grams eaten more per day. LOA's, on the other hand, were large indicating that reliability is inadequate at an individual level. As this study is the first to specifically measure snack and beverage intakes, no comparable reliability studies could be found. Findings were therefore compared with reliability studies that capture total food intake in adolescents. The study by Watson et al. (2009) also used Bland Altman plots to test reliability of a FFQ in adolescents and found similar results, small mean differences but large LOA's [163]. Other reliability studies of FFQ's in adolescents, reported similar ranges of kappa's and correlation coefficients [145, 156, 159].

The results of the validation analyses showed that mean differences for beverage intake (frequencies, intakes and energy and sugar from SSBs) were small. A significant mean difference between the FFQ and the 24-hour recalls was only observed for the frequency of healthy beverages. This difference however, was small and not higher than 25%, indicating a discrepancy of only 0.25 beverages consumed more per day. For the healthy beverage ratio nearly perfect agreement (mean difference=100.5%) was observed. Mean differences for snack intakes (frequencies, intakes and energy and nutrients derived from snacks) were large, while mean difference for the healthy snack ratio (mean difference=111.2%) was small. Snack foods are abundant in our environment [164] and adolescents are thus presented with wide range of snack options each day, making it difficult for adolescents to estimate their snack consumption of the past month. In addition adolescents may have ticked several snacks for a small frequency in the FFQ, leading to a larger overall amount estimated in the FFQ than actually consumed. Twenty-eight different snack options were presented in the FFQ. To limit the ticking of too many snacks and the related overestimation of absolute snack intake, it might be better to offer less choice and to group some of the snack items. Other studies also already reported that it is difficult to capture the highly variable food intake pattern of adolescents [139, 165]. Adolescents consume more food outside the home, experience greater peer influence on their food intake and show more variation in intake over time [166, 167]. Adolescent boys and girls are known to share snacks with their friends and class mates[168]. This snack sharing together with adolescents' general highly variable food intake over time could explain the ticking of many snacks for only small frequencies. For all outcomes however Spearman's correlation coefficients and ranking ability were considered acceptable. Here also findings were compared with validation studies in adolescents that measured total food intakes with a FFQ by lack of comparable studies. Other FFQ validation studies also found rather large discrepancies between both methods of food intake estimation but found acceptable ranking ability [145, 156, 159, 163]. LOA's, obtained via Bland Altman plots, were wide for all outcomes of the validation study. This indicates that the FFQ is thus inadequate to estimate snack and beverage intake at an individual level. The latter is also in concordance with these other validation studies of FFQ's in adolescents [27, 44, 38, 40].

For means of intervention evaluation a good test-retest reliability and precise estimates of intakes on group level are necessary to detect changes [32, 33]. Small mean differences were observed between the repeated administration of the FFQ for all outcomes, however large differences were observed between the FFQ and the 24-hour recalls except for the healthy snack and beverage ratio. Thus only the healthy snack and beverage ratio are appropriate to evaluate dietary change in intervention studies. For means of cross-sectional research mainly a moderate to good ranking ability [32, 33] is needed, which was achieved for all outcomes.

This study was the first to develop and report on the reliability and validity of quantitative snack and beverage FFQ, incorporating the evaluation of snack food at snack times, for the purpose of epidemiological or intervention studies. Other strengths of this study were its use of standard portion sizes to help the portion size estimation, a sample that contained a balanced amount of boys and girls and the use of Bland Altman plots alongside correlation coefficients to assess reliability and validity. Previous research already showed that correlation coefficients can be misleading indicators of agreement [156]. Our study however also had some limitations. First the sample population was obtained via convenience sampling and therefore the results might not be generalizable to other populations. Second the selection of the items of the snack-and-beverage centered FFQ was based on the frequency of consumption by the general population of adolescents, thus it could be possible that not every adolescent feels that he or she is able to fully describe his or hers snack and/or beverage intake. Third the source of error of a 24-hour recalls tends to be more correlated with the error in an FFQ due to reliance upon memory and conceptualization of portion sizes [140]. The use of for instance bio-markers, whose errors are uncorrelated with FFQ's, would however have greatly increased both respondent and researchers burden. Fourth a possible memory effect could have occurred in the reliability study, some adolescents might have remembered their answers of the FFQ1 when completing the second FFQ. Cade et al. (2002) stated that when there is a very short interval between the repeated administration of the FFQ, participants could indeed remember their previous responses [140]. Two weeks is however a not uncommon interval in reliability studies in adolescents [169]. A larger interval between both FFQs was also not possible as the Easter exam period was approaching. Fifth and final when using this FFQ to estimate the effect of interventions, this FFQ should be complemented with a 24h recall or another instrument that captures the total diet to account for possible spillover effects on other eating behaviors.

2.5. Conclusion

The reliability and the validity of the snack and beverage FFQ were found to be acceptable on a group level for the purpose of analyzing diet-disease relationships. Caution, however, should be exercised when presenting and researching absolute snack intakes. The reliability and the validity of the snack and beverage FFQ was also found to be acceptable on a group level for the purpose of analyzing intervention effects, however only for the healthy snack and beverage ratios.

Chapter 3: Sensitivity to reward is associated with snack and sugar sweetened beverage consumption in adolescents

Redrafted after:

Nathalie De Cock, Wendy Van Lippevelde, Leentje Vervoort, Jolien Vangeel, Lea Maes, Steven Eggermont, Caroline Braet, Carl Lachat, Lieven Huybregts and Lien Goossens, Kathleen Beullens, Patrick Kolsteren and John Van Camp (2016). *European Journal Of Nutrition.* 55(4). p.1623-1632

Summary

Purpose: High intake of palatable foods, such as energy-dense snacks and sugar-sweetened beverages (SSBs), is common among adolescents. An individual's sensitivity to reward (SR) may influence these intakes. The main objective of this study was to investigate the association between SR and both snack and SSB intake among adolescents.

Methods: A representative cross-sectional survey was conducted among 1104 14- to 16-years-olds (Mean age=14.7±0.8 years; 50.9% boys; 18.0% overweight) in Flanders. Daily intakes were measured by a food frequency questionnaire (FFQ). SR was assessed using the behavioral activation system (BAS) scales. Multilevel regression analyses (two level: adolescent-school) were conducted using STATA version 13.

Results: BAS drive (DRV) was positively associated with daily intakes of SSBs (13.79%, $p<0.01$), unhealthy snacks (5.42%, $p<0.001$), and energy and nutrients derived from SSBs ($p<0.001$) and snacks ($p<0.01$). BAS reward responsiveness (RR) was only positively associated with intake of unhealthy snacks (3.85%, $p<0.05$), healthy snacks (6.41%, $p<0.05$) and fat (4.05%, $p<0.01$) and Na (3.89%, $p<0.05$) from snacks. Interaction effects of sex and BAS RR ($p<0.05$) were found. Significant positive associations between BAS RR and daily intakes of energy from snacks (6.48%, $p<0.01$) and fat from snacks (7.22%, $p<0.001$) were found only for girls.

Conclusion: SR was associated with snack and SSB consumption in adolescents, especially in girls. These findings suggest that SR should be taken into account when designing interventions to improve the snack and SSB intake of adolescents.

3.1. Introduction

Adolescence is characterized by higher demands for energy and nutrients due to rapid physiological, psychosocial and cognitive development [2, 3]. At the same time, adolescents are in the process of more autonomously developing their eating habits, which are likely to persist in adulthood [4, 7]. However, adolescents typically adopt unhealthy eating habits such as low fruit and vegetables consumption, high intake of energy-dense snacks and sugar-sweetened beverages (SSBs) [4, 7]. In Flanders, 27.0% of the adolescents consume sweet snacks every day [29] and respectively 43.8% and 32.8% of the adolescent boys and girls consume SSBs on a daily basis [170]. Snacks between meals accounted for 20.0-24.0% of the total energy intake in adolescents [27]. Overconsumption of energy-dense snacks and SSBs in adolescents is on the rise [5, 8] and is known to be associated with obesity, and other health problems such as concentration problems, dental carries and other chronic diseases [19, 23].

In our current obesogenic environment, where energy-dense foods and drinks are omnipresent, eating behaviors are most of the time not driven by homeostasis but rather motivated by the rewarding value of food [73, 74, 84]. The rewarding value, evaluated in terms of reinforcing value, of palatable foods is higher than that of bland foods [81, 171-173]. However, not all people indulge in highly palatable or reinforcing foods such as energy-dense snacks and SSBs. There is growing evidence that people differ in their sensitivity toward noticing and approaching natural rewarding stimuli such as highly palatable foods [73, 74, 84]. A theory frequently used to explain these differences is Gray's reinforcement sensitivity theory [85]. Gray describes a psychobiological trait, called sensitivity to reward (SR), which reflects the functional outcomes of the behavioral activation system (BAS) [85]. The BAS is primarily organized by the neurotransmitter dopamine and can be defined as the tendency to engage in motivated approach behavior in the presence of rewarding stimuli [85-87]. BAS is typically measured with the BAS scales as developed by Carver and White (2004) [92] in adults and with the child version as developed by Franken et al. (2005) [174] in children and adolescents. These scales measure BAS through three activational factors [92], fun seeking (BAS FS), reward responsiveness (BAS RR) and drive (BAS DRV). Previous research has yielded evidence for the psychometric properties of the BAS Scales [92, 174-177]. Previous research has also however, shown that mainly BAS RR and DRV are associated with food intake and not BAS FS [87, 88, 97]. The reinforcement sensitivity theory has already been used to explain several unhealthy behaviors such as alcohol abuse and smoking and recently this theory is also increasingly being used to explain eating behaviors. Studies showed that individuals higher in SR have a greater risk to be overweight, experience more food cravings and episodes of emotional eating and have a higher activation of brain areas implicated in food reward [75, 84, 86-89]. The few studies that addressed SR in adolescence concentrated mainly on dysfunctional eating [98, 178]. This scarcity is unfortunate as SR increases from childhood to adulthood with a peak in adolescence, while at the same time inhibitory control matures at a slower pace [90].

It is generally known that adolescent boys and girls differ in eating behaviors, girls tend to eat healthier (i.e. more fruit and vegetables and less SSBs and energy-dense snacks), are more concerned with their weight and are more prone to develop eating disorders [43, 178, 179]. Sex differences in SR and activation of brain reward circuits were also reported [87, 178, 180]. Although these few studies are inconclusive, it seems that boys have a higher SR and brain activation towards appetitive food pictures [87, 178, 180]. It is thus likely that SR influences food intake differently in boys than in girls.

Research on eating habits in adolescence is relevant since during this period typically unhealthy eating habits are adopted.[4, 7] The influence of SR on these eating habits is expected to be considerable, as adolescents are characterized by a high vulnerability to rewarding processes [88, 90]. To our knowledge, no studies have investigated the association between SR and intake of snacks and SSBs in adolescents. The main aim of this study was to investigate this association (1). It was hypothesized that the intake of snacks and SSBs would be higher in high reward-sensitive adolescents. In addition the present study aims to assess the relationship between SR and the energetic value and nutrients derived from snacks and SSBs (2). It was expected that the intake of snacks and SSBs and the energetic value and nutrients derived from them would be higher if adolescent's SR was higher. This study also assessed the moderating effect of sex on the relation between SR and both SSB and snack intake (3). It was predicted that this association would be stronger in boys as these tend to have higher SR scores.

3.2. Methods

This research was conducted in the context of REWARD (www.rewardstudy.be), a multidisciplinary project that aims to develop reward-based interventions to improve the nutritional status of children and adolescents.

3.2.1. Study procedure and participants

Data were collected from September to December 2013 using a representative cross-sectional survey in 14- to 16-year-old adolescents (3rd and 4th grade) from 20 schools in the Flemish region in Belgium. The study protocol was approved by the Ethics Committee of the Ghent University Hospital. A minimum sample size of 900 was needed to estimate the variance in SR score with a relative error of 10%, 95% Confidence Interval (CI) and an anticipated drop-out of 15%. Taking into account the design of the study (design effect=1.2), the final minimum sample was set to 1100 adolescents. The design effect was calculated using a cluster size of 60 students per school and an intra-cluster correlation coefficient of 0.003, estimated from the pilot test of the study in 5 schools not belonging to the study sample. To assure this anticipated sample size of 1100 adolescents, we oversampled by 10%. Sample size calculation was performed using the PASS software package (NCSS, Kaysville, UT). As previous experience with surveys in secondary schools indicated that the response rate of secondary schools is often low [181], we oversampled schools by 50%. The sampling procedure consisted of two steps. Firstly, a sample of 40 schools in Flanders was selected, stratified by different education networks (public and private), from a list of all secondary schools in Flanders. Schools were selected using a probability proportionate to the number of students in the 3rd and 4th grade. School recruitment letters were sent to the principals or headmasters of the 40 selected schools, followed by a personal call. The 20 schools that agreed to participate provided a list of all students in the 3rd and 4th grade. A sample of ± 60 students per school was selected from this list, again using a probability proportional to size sampling. Information letters and passive consent forms were sent to the parents of the selected adolescents. Parents who did not wish for their child to participate sent the passive consent form back to the school. Eligible adolescents were given two class hours (100 minutes) on a pre-agreed date to complete the survey in the presence of the research staff.

3.2.2. Measures

The adolescent questionnaire assessed demographics, SR, snack and SSB intake. In addition height and weight were measured.

3.2.2.1. Demographics

Age and sex were assessed by one-item questions, “what is your birthdate?” and “are you a boy or a girl?” The education type of each adolescent (general/technical/vocational) was obtained from the schools.

3.2.2.2. Sensitivity to Reward

SR was assessed with the Dutch child version of the Carver and White BAS scales as developed by Muris and colleagues [93]. These scales consisted of three subscales, the BAS reward responsiveness (RR) subscale (5 items), the BAS drive (DRV) subscale (4 items) and the BAS Fun Seeking (FS) (4 items) and a composite scale, the BAS total (TOT) scale (all 13 BAS items). These scales assess the three dimensions of BAS sensitivity, namely the persistence to obtain goals (BAS DRV), the willingness to seek out and spontaneously approach potentially rewarding experiences (BAS FS), and the anticipation of and positive response towards reward (BAS RR) [182]. All items are to be answered on a 4-point scale, ranging from totally disagree to totally agree, examples of items are “I crave excitement and new sensations” (BAS FS);“When I get something I want, I feel excited and energized” (BAS RR) and “When I want something, I usually go all-out to get it” (BAS DRV). SR in this study was assessed by the BAS RR and BAS DRV scores, as these two subscales have been previously related to food intake [87, 88]. The study by Voigt et al. examined the associations of the different BAS subscales to risky health behaviors and found no association between BAS FS and diet [97]. Convergent validity and internal consistency of these BAS scales in adolescents have been confirmed in previous studies [175-177]. In the present sample the Cronbach’s Alpha’s were assessed as good for BAS DRV (α=0.81) and acceptable for BAS RR (α=0.69). BAS FS and therefore also BAS TOT was omitted, as its internal consistency is poor (α=0.51 in the present study) and is unlikely to be related to food intake.

3.2.2.3. Snack and Sugar Sweetened Beverage intake

Snack and SSB intake were assessed using the snack and beverage FFQ developed within this PhD thesis (see chapter 2) [183]. The six categories used were: never or seldom; 1-3 days/month; 1 days/week; 2-4 days/week; 5-6 days/week; every day. Depending on the item, 4-6 portion size categories were provided together with a list of common standard measures as examples. It probes usual food intake with a reference period of one month. The FFQ comprised two sections: beverages (14 items) and snacks (28 items). The intake of beverages was evaluated over the whole day. The 14 beverage items were: water, fruit- or vegetable juice, energy drinks, sport drinks, soft drinks, coffee or tea, milk substitutes, sweetened milk beverages, milk, beer, cocktails, aperitif drinks, wine and liquor. As the focus of this study is on the consumption of SSBs, only the items soft drinks, energy and sport drinks were used in accordance with the definition of Malik et al. [23]. Based on Rodriguez and Moreno [19], snacks were defined as all food items that are consumed outside (>30 min) of breakfast, lunch and dinner. The 28 snack items were: chocolate and pralines, candy bars, candy, dry cookies, other cookies such as chocolate cookies, breakfast rolls, pastries, breakfast cereals, unsweetened yoghurt, sweetened yoghurt, pudding, mousses, ice-cream, popsicles, dried fruit, fruit, raw vegetables, nuts and seeds, sandwiches with sweet or savory spread, cheese or meat cubes, chips and similar products, other savory snacks such as bread sticks, sausage/cheese rolls and pizza, other fried snacks such as spring rolls and cheese croquettes, fries, kebab, hamburgers and pasta cups.

3.2.2.4. Snack classification

Snacks were classified as either healthy or unhealthy using the UK Ofcom nutrient profiling model [22] (see chapter 1). This model provides a score that represents the 'unhealthiness' of a beverage or food product, food items that scored more than 4 points were considered to be unhealthy [22]. Following this scoring system, the FFQ snack items crisps, other salty snacks, sausage/cheese rolls and pizza, other fried snacks, fries, hamburgers, cheese or meat cubes, ice-cream, popsicles, breakfast cereals, pudding, sandwiches with sweet or savory spread, mousses, chocolate, candy bars, candy, dry cookies, other cookies, breakfast rolls and pastries were considered to be unhealthy and the other FFQ snack items healthy.

3.2.2.5. Calculation of daily intake

The daily intake of each FFQ item was obtained by multiplying the frequency of consumption with the quantity of consumption per week (g) divided by 7. For all FFQ categories an average nutrient composition was calculated by averaging the nutritional composition (obtained from the Belgian food composition table (NUBEL, 2009) expressed per 100 g [153] of the most frequently consumed food items by adolescents within that category, as reported in the HELENA study [184]. The actual energy, sugar, fat and Na intakes per FFQ item of the individuals were then calculated by multiplying the amounts (g) of the food consumed and the average nutritional values expressed per g (the average values per 100g divided by 100) [153]. These daily overall, energy, sugar, fat and Na intakes per item were then summed to obtain the daily intakes of unhealthy snacks (g), healthy snacks (g) and SSBs (ml); the daily intakes of energy (kcal) and sugar (g) from SSBs; and the daily intakes of energy (kcal), fat (g), sugar (g), Na (mg) from snacks.

3.2.2.6. Height and weight

Two trained research assistants measured body height and weight using a standardized protocol [185]. Adolescents were measured without shoes and were allowed to wear light clothing. Body height was measured with a SECA Leicester Portable Stadiometer with an accuracy of 1 mm. Weight was measured with a calibrated electronic scale SECA 861 with an accuracy of 100 g. Two readings of each measurement were taken. If the two readings differed more than 1%, a third measurement was taken, after which the outlying value was excluded. The average of the two retained measurements was used for analysis. Age and sex-specific body mass index z-scores (zBMI) were calculated using Flemish 2004 growth reference data [186]. According to the International Obesity Task Force cut-off points, adolescents were classified as either non-overweight or overweight [187].

3.2.3. Statistical analyses

To assess the difference in BAS (DRV and RR) scores and SSB and snack intake, descriptive statistics and independent sample t-tests were computed, relevant t-statistics (t) were also reported.

Multilevel linear regression analyses were conducted to assess the associations between SR (BAS DRV and RR) and the dependent variables (daily intake of unhealthy snacks (g), healthy snacks (g) and SSBs (ml); daily intake of energy (kcal) and sugar (g) from SSBs; daily intake of energy (kcal), fat (g), sugar (g) and Na (mg) from snacks); and to assess the moderation effect of sex on these associations. Logarithmic transformations (log10) were applied to all dependent variables that were not normally distributed. Continuous explanatory variables were centered on the grand mean to ease the interpretation of interactions. Unstandardized coefficients (b's) were backtransformed by taking the antilog (10^b) and then expressed as percentage differences ((antilog-1)*100) [188]. All analyses were adjusted for age, education type, sex and zBMI, as these were significantly associated with the outcomes. Associations with p-values <0.05 were considered statistically significant and all statistical tests were two-sided. Moderation by sex was assessed by adding interaction terms between sex and BAS DRV and BAS RR respectively in the different regression models. Separate analyses were performed for each of the two BAS scales, BAS DRV and BAS RR. When evidence of moderation by sex was found, separate regression models for boys and girls were run to determine the regression coefficients for boys and girls.

All multilevel analyses were conducted with a two-level structure (adolescent-school). As the standard IGLS algorithm (maximum likelihood based method) was employed in STATA 13, missing data were omitted from the analyses. The models accounted for clustering of the data, as the variance at school level was considerable for all dependent variables.

All analyses described below were executed using Stata version 13 SE (Stata Corporation, Texas, USA).

3.3. Results

3.3.1. Study characteristics

Of the 1210 selected adolescents, 6% were absent or not allowed to participate and 3% returned a questionnaire of unsatisfactory quality (defined as more than 33% of the questions not completed or straight-lining responses) for further use. The final study sample consisted of 1104 adolescents with a mean (SD) age of 14.73 (0.82) years, 50.9% were boys and 18.0% was overweight (see also Table 7). Boys had a significantly higher daily intake of SSBs (t=6.93, p<0.001) and unhealthy snacks (t=6.25, p<0.001) compared to girls. This translated into higher daily energy (t=6.37, p<0.001) and sugar (t=6.20, p<0.001) intakes from SSBs and energy (t=5.49, p<0.001), fat (t=6.25, p<0.001) and Na (t=6.63, p<0.001) intakes from snacks. Girls had a significantly higher BAS RR score (t=-2.34, p<0.01) and a higher healthy snack intake compared to boys (t=-3.88, p<0.001).

Table 7: Sample characteristics and mean BAS scores, snack and SSB intake

	Mean (SD)	
	Boys (50.87%)[1]	**Girls (49.13%)[1]**
Age	14.73 (0.86)	14.72(0.79)
% Overweight	16.63	19.39
% General education	39.82	52.24
% Technical education	40.54	27.43
% Vocational education	19.64	20.34
zBMI	0.24(1.05)	0.29(1.09)
BAS DRV	9.14(2.82)	9.35(3.02)
BAS RR	13.02(2.91)**	13.43(2.93)**
SSB intake per day (ml)	285.59(271.77)***	181.81(217.42)***
Energy intake from SSBs per day (kcal)	118.30(115.04)***	77.64(93.71)***
Energy intake from snacks per day (kcal)	865.64(566.40)***	688.30(496.44)***
Sugar intake from SSBs per day (g)	28.10(27.52)***	18.63(22.47)***
Sugar intake from snacks per day (g)	50.64(36.01)	47.51(33.54)
Na intake from snacks per day (mg)	914.39(667.81)***	665.29(567.27)***
Fat intake from snacks per day (g)	37.81 (26.15)***	28.47(23.05)***
Healthy snack intake (g)	121.95(133.36)***	153.36(133.40)***
Unhealthy snack intake (g)	214.44(147.28)***	162.34(127.06)***

[1]Two sided t-tests; *p<0.05,**p<0.01,***p<0.001; BAS DRV= Behavioral Activation DRiVe scores, BAS RR= Behavioral Activation Reward Responsiveness scores, SSB= Sugar Sweetened Beverage, SSBs=Sugar Sweetened Beverages

3.3.2. Associations of SR with snack and SSB intake

BAS DRV was positively associated with daily intakes of SSBs, unhealthy snacks and energy, sugar, fat and Na derived from both SSBs and snacks (Table 8). BAS RR was positively associated with intake of unhealthy snacks, healthy snacks, fat from snacks and Na from snacks.

3.3.3. Moderation effect of sex

An interaction effect of sex and BAS RR (see Table 9) was found for the daily intake of SSBs, energy and sugar from SSBs, energy and fat from snacks. For the significant interaction effects, margin plots are shown in Figure 5. Significant positive associations between BAS RR and the daily intake of energy from snacks (6.48%, CI (1.76%, 11.42%), $p<0.01$) and fat from snacks (7.22%, CI (2.97%, 11.65%), $p<0.001$) were found for girls. The latter relations were not significant for boys. Despite the observed interaction effect, the associations between BAS RR and intake of SSBs, energy from SSBs and sugar from SSBs were not significant when stratified for sex. No interaction effects of sex and BAS DRV were found (see Table 9).

Table 8: Associations BAS DRV and RR and SSB and snack intake

	SSBs			Snacks					
	Daily overall intake	Daily energy intake	Daily sugar intake	Daily unhealthy snack intake	Daily healthy snack intake	Daily energy intake	Daily sugar intake	Daily fat intake	Daily Na intake
	b% (CI%)[1]	b% (CI%)[1]	b% (CI%)[1]	b% CI%)[1]	b% (CI%)[1]	b% (CI%)[1]	b% (CI%)[1]	b% (CI%)[1]	b% (CI%)[1]
BAS DRV[2]	13.79 (5.37,22.88)***	12.77 (5.08,21.02)***	10.95 (4.45,17.85)***	5.42 (2.06,8.88)***	5.81 (0.28,12.28)	4.97 (1.54,8.51)**	3.68 (0.74,6.71)**	5.68 (2.63,8.82)***	5.94 (2.20,9.82)**
BAS RR[2]	1.92 (5.67,10.12)	1.78 (-5.21,9.28)	1.21 (-38.59,7.56)	3.85 (0.53,7.28)*	6.41 (0.27,12.93)*	3.31 (-0.08,6.81)	2.36 (-0.55,5.36)	4.05 (1.03,7.16)**	3.89 (0.20,7.71)*

[1]Multilevel regression with sex, zBMI, type of education and age as control variables; [2]BAS DRV and BAS RR were regressed on the dependent variables in separate models; *p<0.05**p<0.01,***p<0.001; BAS DRV= Behavioral Activation DRiVe scores, BAS RR= Behavioral Activation Reward Responsiveness scores, SSBs= Sugar Sweetened Beverages

Table 9: Moderation effect of sex on the BAS DRV/BAS RR-SSB/snack intake associations

	SSBs			Snacks					
	Daily overall intake	**Daily energy intake**	**Daily sugar intake**	**Daily unhealthy snack intake**	**Daily healthy snack intake**	**Daily energy intake**	**Daily sugar intake**	**Daily fat intake**	**Daily Na intake**
	b% (CI%)[1]	**b% (CI%)[1]**	**b% (CI%)[1]**	**b% CI%)[1]**	**b% (CI%)[1]**	**b% (CI%)[1]**	**b% (CI%)[1]**	**b% (CI%)[1]**	**b% (CI%)[1]**
BAS DRV*sex[2]	7.40 (-7.77, 25.06)	7.78 (-6.29, 23.97)	7.37 (-4.73, 21.01)	5.89 (-0.65, 12.86)	4.37 (-7.16, 17.34)	5.53 (-1.15, 12.66)	4.29 (-1.46, 10.39)	5.90 (-0.04, 12.20)	6.93 (-0.38, 14.78)
BAS RR*sex[2]	17.57 (0.77, 37.17)*	16.67 (1.26, 34.44)*	14.73 (1.64, 29.51)*	6.06 (-0.58, 13.15)	0.09 (11.10, 12.68)	6.90 (0.04, 14.23)*	4.58 (-1.27, 10.77)	6.64 (0.57, 13.08)*	7.12 (-0.30, 15.11)

[1]Multilevel regression with sex, zBMI, type of education and age as control variables; [2]BAS DRV and BAS RR were regressed on the dependent variables in separate models; *p<0.05**p<0.01,***p<0.001; BAS DRV= Behavioral Activation DRiVe scores, BAS RR= Behavioral Activation Reward Responsiveness scores, SSBs= Sugar Sweetened Beverages

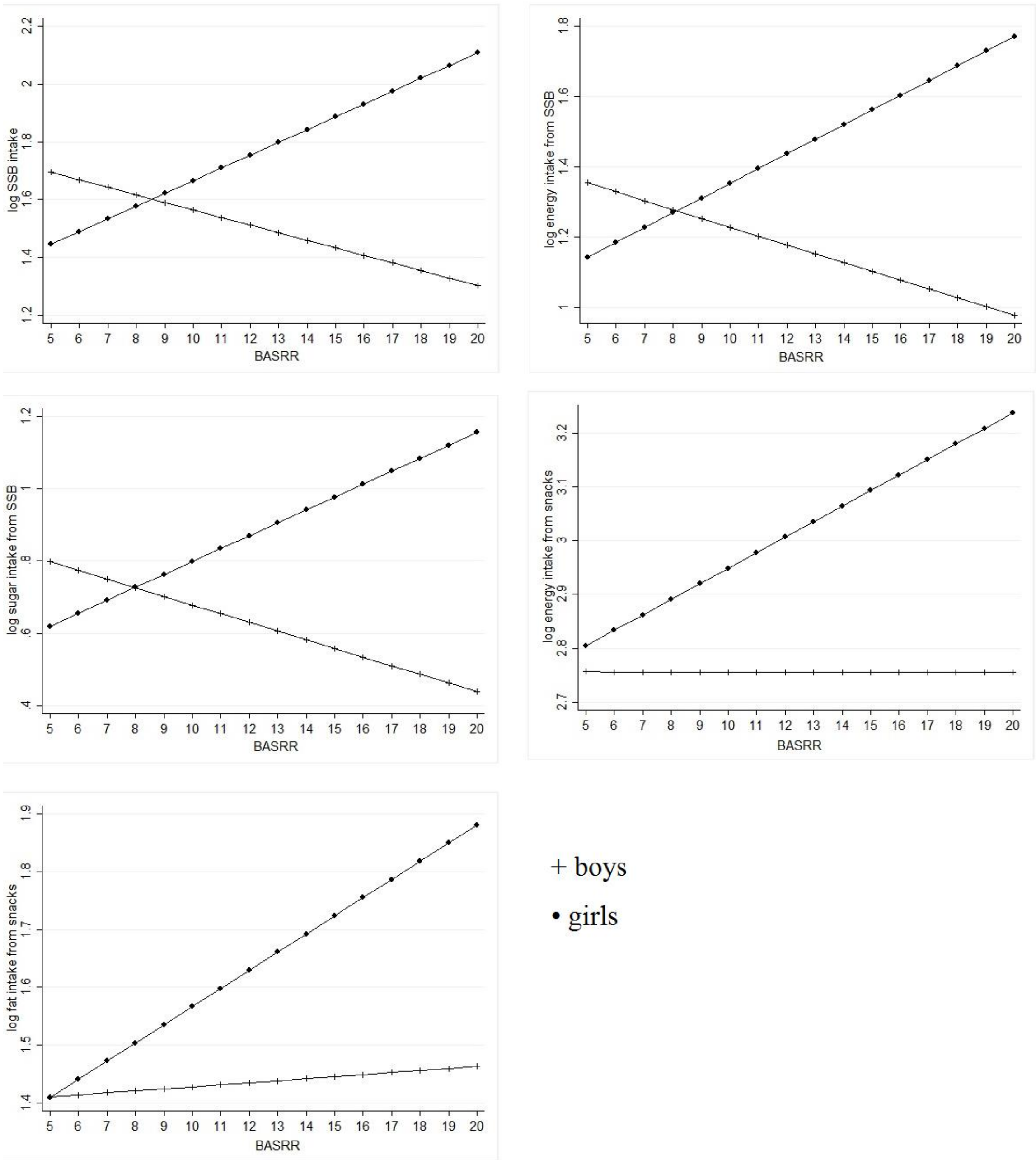


Figure 5: Margin plots for the interaction of BAS RR and sex for snack & SSB intakes (boys=+, girls=●)
Analyses controlled for sex, zBMI, type of education and age

3.4. Discussion

High consumption of energy-dense snacks and SSBs is commonly observed in adolescents and contributes considerably to their overall energy, sugar and fat intake [4, 8, 19, 23]. To our knowledge, the present study is the first to show that SR was positively associated with both snack and SSB consumption in 14- to 16-year-old adolescents.

First, we report a positive association between BAS DRV and daily intakes of unhealthy snacks and energy and nutrients (sugar, fat and Na) derived from snacks. A one unit increase in BAS DRV was associated with a 5% increase in unhealthy snack intake. Previous research in adults by Davis et al. reported a relation between SR (BAS TOT) and high sugar and fat preferences, namely a higher SR predicted a higher preference for sweet and fatty foods [86]. Our results confirm these findings in adolescents. BAS RR was only positively associated with intake of unhealthy snacks, healthy snacks, fat from snacks and Na from snacks. The positive association with healthy snack intake was in contrast with our expectation that only a positive association would be found with unhealthy snack intake, since palatable (i.e., sugar- and/or fat-rich) foods are typically more rewarding [74, 81, 171-173]. However this positive association can be explained as food itself (independent of its characteristics) is a natural reinforcer [74, 81, 171-173]. BAS DRV was significantly associated with SSB intake and sugar and energy derived from them, a one unit increase in BAS DRV was associated with a 13% increase in SSB intake. BAS RR was not associated with SSB intake and was also not associated to sugar and energy from SSBs and snacks. Earlier studies already showed that the relation of SR with eating or weight related behaviors is mainly found in BAS DRV rather than in BAS RR [87]. Associations between BAS DRV and unhealthy snack and SSB intake were small, respectively an increase of 5% and 13%. Consistent with the multicomponent etiology of overweight/obesity [189] and the biopsychosocial model of eating behaviors [43], also other factors such as peer or parental influence might be related to unhealthy snacking and drinking behaviors [43].

Second, we observed that the association between SR and snack and SSB consumption was moderated by sex, but only for SR measured in terms of BAS RR. Interaction effects were observed for the intake of SSBs, energy and sugar from SSBs and energy and fat from snacks. Margin plots showed that for intake of SSBs, energy from SSBs and sugar from SSBs that the intake increased as BAS RR scores increased for girls, while for boys the opposite was observed. When the regression analyses were repeated for boys and girls separately however, no significant associations were found. For the intake of energy and fat from snacks, intakes increased more for girls then for boys as BAS RR scores increased. When the regression analyses were repeated for boys and girls separately however, only significant associations were found for girls. No interaction effects of sex and BAS DRV on SSB and snack intake were found. These findings are in discordance with our expectations that the relation SR-snack intake would be stronger for boys as SR is normally higher in males. As no interaction was found of sex with BAS DRV, it seems that boys and girls mainly differ in the BAS RR-snack intake association. As BAS RR reflects positive responses to the occurrence or anticipation of reward and BAS DRV reflects the persistent pursuit of desired goals [178], it seems that only in girls responsiveness to reward is positively related to intake. Another possible explanation for this moderation effect is that for boys the effect of SR, in terms of BAS RR, is suppressed by hunger feelings. Adolescents report being hungry as one of the main determinants of their food choice and as energy requirements for boys in adolescence are larger than for girls, boys will most likely have a larger appetite and a greater sense of hunger than girls [43, 190, 191]. Regarding the intake of SSBs, energy from SSBs and sugar from SSBs, the association between BAS RR and intake was negative in boys, but not significant. Thus, it seems that for boys intake of SSBs is motivated by other factors than SR. Consequently, it appears that boys and girls differ in their food reward responsiveness but not in their motivation towards obtaining food or beverages. More research will be needed to explore why the association between BAS RR, and SSB/snack intake is different for boys and girls, why BAS RR is negatively related to intake of SSBs, energy from SSBs and sugar from SBBs in boys and why, in contrast, the BAS DRV-SSB/snack intake is not moderated by sex.

Last, we also observed that girls had a significantly higher BAS RR score than boys. This finding is however in discordance with previous research where boys tended to have a higher BAS scores [87, 178, 180]. This discordance could be a consequence of the fact that girls of our age group (14-16 years old) may already have reached the typical peak of sensitivity to reward in adolescence, while boys have not. However this is only an assumption since tanner stage (indicative of adolescence) was not measured in the present study.

This study fills a current research gap by examining the link between self-reported intakes of snacks and SSBs and SR in adolescents. The positive associations found, emphasize the importance of SR for future research in adolescents and intervention design. Another strength of this study was its large and representative sample size. This study also has several limitations. First, the study design was cross-sectional so no statements about the causality of the present relations could be made. Second, all collected data except the anthropometrics were self-reported and were thus subject to the social-desirability bias. The latter is especially true regarding food intake, where people tend to misreport their intake [167]. It was attempted to counter this bias by emphasizing anonymity of the data collection. A third limitation of this study was the length of the survey (±75min), which could have led to lesser quality of the data due to a lack of concentration or boredom at the end of the session. By creating three versions of the questionnaires where sections were presented in a random order we aimed at averaging this bias over all sections. A fourth limitation was that total energy intake was not measured. This would have increased the burden on the respondents even more, potentially jeopardizing reporting quality for the key variables. However all regression analyses were adjusted for bodyweight (zBMI), which according to Jakes et al. (2004) has considerable advantages over adjusting for energy intake [192]. A final limitation was that no measures of pubertal stage or menstrual cycle were taken into account as these could possible affect energy intake and SR [90, 193-195].

3.5. Conclusion

In conclusion, the present study suggests that a high SR is a potential risk factor for high consumption of energy-dense snacks and SSB, especially in girls. SR is a factor that should be considered when designing interventions to improve the snacking and SSB consumption habits of adolescents as it could be a moderator of the effect of interventions, for instance rewarding adolescents for good behavior could work better in adolescents with a high SR than with a low SR. As SR is also in general higher in adolescent populations than in children or adults, using reward-based strategies in interventions to improve healthy snacking habits of adolescents could be useful, like rewarding adolescents for good behavior or offering interventions in a rewarding context (like a game environment).

Chapter 4: Sensitivity to reward and adolescents' unhealthy snacking and drinking behavior: the role of hedonic eating styles and availability

Redrafted after:

Nathalie De Cock, Wendy Van Lippevelde, Lien Goossens, Bart De Clercq, Jolien Vangeel, Carl Lachat, Kathleen Beullens, Lieven Huybregts, Leentje Vervoort, Steven Eggermont, Lea Maes, Caroline Braet, Benedicte Deforche, Patrick Kolsteren and John Van Camp (2016). *International Journal of Behavioral Nutrition and Physical Activity.* 13:17.

Summary

Background: Although previous research found a positive association between sensitivity to reward (SR) and adolescents' unhealthy snacking and drinking behavior, mechanisms explaining these associations remain to be explored. The present study will therefore examine whether the associations between SR and unhealthy snack and/or sugar-sweetened beverage (SSB) intake are mediated by external and/or emotional eating and if this mediation is moderated by availability at home or at school.

Methods: Cross-sectional data on snacking, availability of snacks at home and at school, SR (BAS drive scale) and external and emotional eating (Dutch eating behavior questionnaire) of Flemish adolescents (n=1104, mean age = 14.7±0.8 years; 51% boys; 18.0% overweight) in 20 schools spread across Flanders were collected. Moderated mediation analyses were conducted using generalized structural equation modeling in three steps: (1) direct association between SR and unhealthy snack or SSB intake, (2) mediation of either external or emotional eating and (3) interaction of home or school availability and emotional or external eating.

Results: Partial mediation of external eating (a*b=0.69, p<0.05) and of emotional eating (a*b=0.92, p<0.01) in the relation between SR and intake of unhealthy snacks was found (step 2). The relation between SR and SSB intake was not mediated by external or emotional eating (step 2). No moderation effects of home or school availability were found (step 3).

Conclusion: Our findings indicate that the association between SR and the consumption of unhealthy snacks is partially explained by external and emotional eating in a population-based sample of adolescents irrespective of the home or school availability of these foods.

4.1. Background

Adolescents often adopt unhealthy eating habits such as a low consumption of dairy products, fruit, vegetables and grains and a high intake of energy-dense snacks and sugar-sweetened beverages (SSBs) [4, 7]. Especially the overconsumption of energy-dense snacks and SSBs in adolescents is on the rise [5, 8, 196] and is known to be associated with an excess intake of energy and sugar and a diet failing to meet the national recommendations for adolescence [4, 18, 102, 197, 198]. The overconsumption of SSBs has also been linked to overweight and obesity, however for the intake of energy-dense snacks the evidence on its association with obesity is still inconclusive [4, 102]. In Flanders, 27.0% of adolescents consume sweet snacks every day [29] and respectively 43.8% and 32.8% of adolescent boys and girls consume SSBs on a daily basis [170]. Palatable foods, such as energy-dense snacks and SSBs, are found to be particularly rewarding compared to other foods such as fruit [81]. An obesogenic environment, characterized by the omnipresence of palatable foods, is therefore likely to stimulate reward-driven eating at the expense of homeostatic processes [75, 84].

Adolescents' food choices may be explained by both individual and environmental characteristics [43]. At the individual level, sensitivity to reward (SR) reflects the functional outcomes of the behavioral activation system (BAS) [85]. The reinforcement sensitivity theory explains how BAS is primarily organized by the neurotransmitter dopamine and can be defined as the tendency to engage in motivated approach behavior in the presence or in search of rewarding stimuli such as highly palatable foods [85-87]. SR is higher in adolescence than in childhood or adulthood, SR and rewarding processes might thus play a substantive role in explaining adolescents' behaviors [90]. However, the level of BAS also differs between individuals, reflected in individual differences in noticing and approaching natural rewarding stimuli [75, 84]. Previous studies have shown that adolescents higher in SR have a higher activation of brain areas implicated in food reward, have higher intakes of energy-dense snack foods and have a greater risk to be overweight [84, 86-88, 199].

The more recently developed hyper-responsiveness model on SR describes further how a high level of SR might be associated with hedonic eating beyond caloric need and ultimately overweight and obesity [74, 75, 86]. Two different pathways are proposed: eating driven by emotional states (e.g. the emotional eaters) or eating triggered by environmental cues such as the sight and smell of food stimuli (e.g. the external eaters) [75, 86]. To the best of our knowledge, only one study already investigated this hypothesis in adults and found that both overeating (determined by external, emotional and binge eating) and food preferences mediated the positive association between BAS and body mass index (BMI) [86]. External and emotional eating have already been described as stable eating styles in children and adolescents, that could result in habitual patterns of (over)eating [99]. Therefore, these eating styles might explain how a heightened SR fosters palatable and typically unhealthy food and drink intake in adolescents.

At the environmental level, previous research has already shown that the home [66] and school [65] environment are associated with adolescents' food intake. Access to or availability of palatable snacks and drinks in these environments was associated with higher intakes of these products [65, 66]. The availability of palatable food cues in the environment could trigger individual differences in hedonic eating processes and thereby promote energy-dense snack and SSB intake [84, 86, 88, 100]. Therefore, the environment might interact with SR and its related eating styles, and promote the consumption of energy-dense snacks and SSBs. To the best of our knowledge, only one study found an interaction between SR and fast food exposure on fast food intake in adults [100]. To date no research has focused on the complex interplay between SR, hedonic eating styles and environmental influences in adolescents.

Therefore the present study assessed if the availability of unhealthy snacks or SSBs interacted with elevated levels of hedonic eating styles (external eating and emotional eating) in explaining unhealthy snack and SSB intake. First, the direct association between SR and unhealthy snack and SSB intake was investigated (see Figure 6). Second, mediation of external or emotional eating on the association of SR with unhealthy snack or SSB intake was examined. Finally, it was assessed if the availability of unhealthy snacks or SSBs at home or at school moderated these mediational pathways.

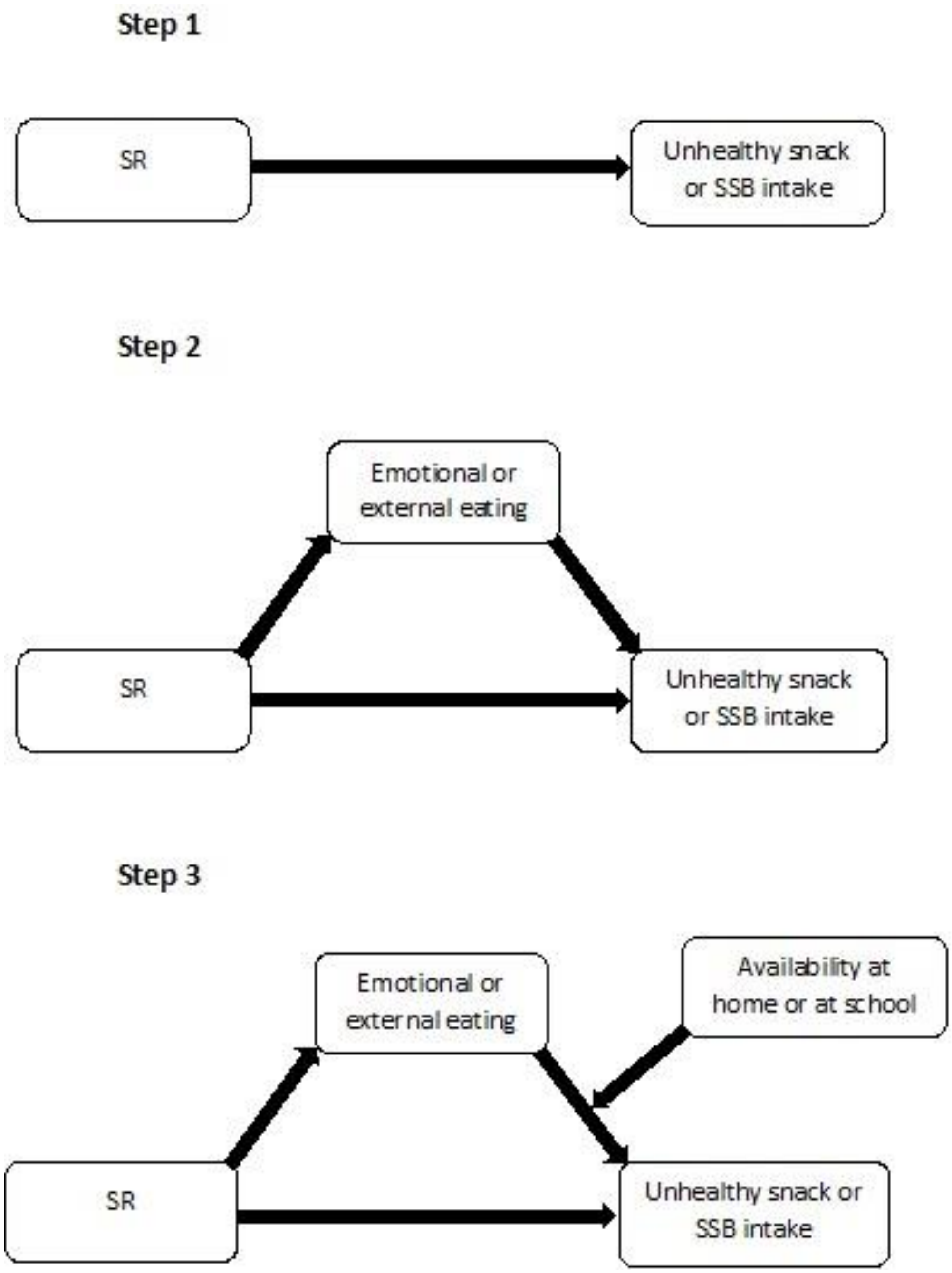


Figure 6: Analytical process

4.2. Methods

This research was conducted in the context of the REWARD project, a multidisciplinary project that aims to develop reward-based interventions to improve the nutritional status of children and adolescents (www.rewardstudy.be).

4.2.1. Study procedure and participants

Data were collected from September to December 2013 using a cross-sectional survey in 14- to 16-year-old adolescents from 20 schools in the Flemish region in Belgium. To estimate the variance in SR score with a relative error of 10% and a 95% confidence interval (CI), a minimum sample size of 765 adolescents was needed. Further considering a drop out of 15%, this minimum sample size was set to 900 adolescents. Finally taking into account the design of the study (design effect=1.2), the final sample size was determined to be 1100 adolescents. The design effect was calculated using a cluster size of 60 students per school and an intra-cluster correlation coefficient of 0.003, estimated from the pilot test of the study in 5 schools not belonging to the study sample. Sample size calculation was executed with the PASS software package (NCSS, Kaysville, UT). To assure a sample size of 1100 adolescents an extra 10% was sampled. Schools and adolescents were selected using a two-step probability proportional to size sampling procedure. First, schools were randomly selected, stratified by different education networks (public and private), from a list of all secondary schools in Flanders. Second, ± 60 adolescents from each school were randomly selected from a list containing all students in the 3rd and 4th grade. Passive consent was obtained from the parents of the selected adolescents. Eligible adolescents were given two class hours (100 min) on a pre-agreed date to complete the questionnaires in the presence of the research staff in a classroom at their school. The study protocol was approved by the Medical Ethics Committee of the University Hospital Ghent.

4.2.2. Measures

4.2.2.1. Demographics

Sex was assessed by a one-item question, "are you a boy or a girl?". Girls were coded as one and boys as zero. Date of birth was asked with an open-ended question, "what is your birthdate?". Age was then derived by subtracting the date of birth from the date the survey took place. The education type of each adolescent (general/technical/vocational) was obtained from the schools.

4.2.2.2. Sensitivity to reward

SR was assessed with the Dutch version of the Carver and White BAS scales for children [93], consisting of three subscales, the BAS reward responsiveness (5 items), the BAS drive (4 items) and the BAS fun seeking subscale (4 items) and a composite scale, the BAS total (all 13 BAS items). All items are answered on a 4-point scale, ranging from totally disagree (1) to totally agree (4). Previous research in children, adolescents and adults has already shown that mainly the BAS drive (DRV) subscale is associated with food intake and eating styles [87, 97, 199] and will therefore be used in this research. Convergent validity and internal consistency of these BAS scales in adolescents have been confirmed in previous studies [175, 177]. In the present sample the Cronbach's Alpha's for BAS DRV was 0.81. Scores on the items of BAS DRV subscale were summed and presented as a sum score ranging from 4 until 16.

4.2.2.3. Snack and Sugar-Sweetened Beverage intake

Snack and SSB intake were assessed using the snack and beverage FFQ developed within this PhD thesis (see chapter 2) [183]. The six categories used were: never or seldom; 1-3 days/month; 1 days/week; 2-4 days/week; 5-6 days/week; every day. Depending on the item, 4-6 portion size categories were provided together with a list of common standard measures as examples. For instance for candy the following portion sizes were given 9g or less, 10-34g, 35-59g, 60-84g, 85-109g and 110g or more, together with the following examples of portions 1 small bag of M&M's=45g and 1 winegum=4g. The FFQ probes usual food intake with a reference period of one month. In accordance with the definition of Malik and colleagues (2006) of SSBs, the items soft drinks, energy and sport drinks were used to define SSB intake [23]. Unhealthy snacks were defined by classifying the snack items as either healthy or unhealthy using the UK Ofcom nutrient profiling model (see chapter 1). This model provides a score that represents the 'unhealthiness' of a beverage or food product [22]. Food items that scored more than 4 points were considered to be unhealthy [22]. Following this scoring system, the FFQ snack items crisps, other salty snacks, sausage/cheese rolls and pizza, other fried snacks, fries, hamburgers, cheese or meat cubes, ice-cream, popsicles, breakfast cereals, pudding, sandwiches with sweet or savory spread, mousses, chocolate, candy bars, candy, dry cookies, other cookies, breakfast rolls and pastries were considered to be unhealthy.

The daily intake of each FFQ item was obtained by multiplying the frequency of consumption with the quantity of consumption per week (g) divided by 7. These daily intakes per item were then summed to obtain the daily intakes of unhealthy snacks (g) and SSBs (ml).

4.2.2.4. External and emotional eating

External and emotional eating were measured by means of the Dutch eating behavior questionnaire (DEBQ) [200]. All items were answered on a 5-point scale, ranging from never (1) to very often (5). The DEBQ has been shown to have good factorial validity and dimensional stability and to be suitable for use in an adolescent sample [200, 201]. In the present sample the Cronbach's Alpha's were 0.82 and 0.95 for external and emotional eating, respectively[1]. The average score (ranging from 1 to 5) for both emotional and external eating was calculated by summing the item scores and dividing the sum scores by the number of items.

4.2.2.5. Availability at home

For all unhealthy snack and SSB FFQ items adolescents were asked to the rate the availability of these items at their home on a 4-point scale ranging from never available (0) to always available (3). The different availability items were recoded into binary variables (0= never and sometimes and 1= often and always) and summed to obtain the availability of unhealthy snacks at home (ranging from 0 till 20) and the availability of SSBs at home (ranging from 0 till 3).

4.2.2.6. Availability at school

Availability of unhealthy snacks and SSBs at school was measured using an audit instrument, based on that of the ENERGY project [202]. It comprised the following parts: food and beverages available in the cafeteria/school shop and food and drinks available in the vending machines. Using this instrument a listing was made of all products sold in the cafeteria or in the vending machines. For each school a list was therefore obtained with the number of

[1] Item 10 of the external eating subscale, which corresponds to item 33 of the full DEBQ, fell of the questionnaire when printing. This an unfortunate consequence of the magnitude of our study , the long questionnaire and the use of three versions of this questionnaire. However the implications on the results are minimal since 9 other items to measure external eating were present, this tenth item "do you want to eat when you are preparing the food?" is less relevant as a predictor of snack intake as it refers more to the preparation of a meal and this item also showed a low loading factor (0.45) compared to the other items of the external eating scale (0.48-0.66) in a recent validation study of the DEBQ-C by Van Strien et al. (2008). The Cronbach's alpha for external eating and the external eating mean score are therefore only based on nine items instead of ten.

beverages and snacks sold together with the actual names of all products sold. Based on this document an availability score for SSBs or unhealthy snacks for each school was computed by counting the number of different unhealthy snacks or SSB FFQ items sold at school (either via vending machines or via the school shop) [67].

4.2.2.7. Height and weight

Two trained research assistants measured body height and weight using a standardized protocol [185]. Adolescents were measured without shoes and were allowed to wear light clothing. Body height was measured with a SECA Leicester Portable Stadiometer with an accuracy of 1 mm. Weight was measured with a calibrated electronic scale SECA 861 with an accuracy of 100 g. Age and sex-specific body mass index z-scores (zBMI) were calculated using Flemish 2004 growth reference data [186]. According to the International Obesity Task Force cut-off points, adolescents were classified as either normal weight or overweight [187].

4.2.3. Statistical analyses

Moderated mediation path analyses were conducted within a multilevel structural equation modelling (MSEM) framework in three steps (see Figure 6) with three levels of analysis (adolescents within classes within schools). First, the direct association between SR and unhealthy snack and SSB intake was evaluated. In a second step, the mediation pathway of external or emotional eating in the relation between SR-intake and unhealthy snacks or SSBs was evaluated in two separate models (one for each eating style). Mediation was assessed following Preacher, Zyphur and Zhang [203, 204] for the multilevel 1-1-1 model, using bootstrapped standard errors for the indirect effects. The proportion of the total effect that is mediated, was computed by dividing the indirect effect by the total effect. Step 3 evaluated whether availability of unhealthy snacks or SSBs at school or at home moderated the association between external or emotional eating and unhealthy snack or SSB intake, when evidence of mediation was found in step 2. Moderated mediation was tested using following

Hayes (2013) [205], including bootstrapped conditional indirect effects when evidence of moderation was found. No evidence of mediation through emotional or external eating was found for the intake of SSBs, therefore moderation mediation was only explored for the intake of unhealthy snacks.

In all steps parameters were mean centered, outliers were removed, unstandardized coefficients and their standard errors were displayed and associations with P-values <0.05 were considered statistically significant. Also in all steps sex, education type and zBMI, were added as covariates, as these were significantly related to the outcomes and we wanted to control for the known influences of demographics (sex and education type) and BMI on food intake. First, the correlation coefficients for zBMI were respectively -0.05 (p=0.09) and -0.08 (p<0.01) for intake of SSBs and unhealthy snacks. Second, the point bi-serial correlations for sex were respectively -0.19 (p<0.001) and -0.20 (p<0.001) for the intake of unhealthy snacks and SSBs respectively. Third and finally, for education type technical the point bi-serial correlations for the intake of unhealthy snacks and SSBs were respectively 0.06 (p=0.06) and 0.02 (p=0.57) and for education type BSO these were respectively 0.11 (p<0.001) and 0.07 (p<0.05). The coefficients shown in the results section are the result of single level generalized SEM (GSEM) as the multilevel models did not provide substantial higher efficiency, based on Akaike's information criterion (AIC). The multilevel models also did not provide reliable estimates due to the small sample size. The explained variance of the different models was evaluated compared to a null model with no predictors.

A missing value analysis was performed and the missing values, which were in general low (only for zBMI the percentage of missing values was larger than 5%), were considered to be missing at random. Therefore, no specific adjustment, other than the default missing value procedure of Stata (equationwise deletion), of the analyses was performed.

All analyses were performed using Stata 13.1 (Stata Corporation, Texas, USA).

4.3. Results

4.3.1. Participants

Of the 1210 selected adolescents, 6% were absent or not allowed to participate and 3% returned a questionnaire of unsatisfactory quality (defined as more than 33% of the questions not completed or straight-lining responses) for further use. The final study sample consisted of 1104 adolescents with a mean age of 14.72 years, 51% males, 18% overweight or obese, 46% following general education, 34% technical and 20% vocational. This sample is representative for Flanders regarding sex (51%, z=0.11 p=0.92), education type (general: 46%, z=0.00, p=1.00; technical 32%, z=1.42; p=0.16; vocational 22%, z=1.60, p=0.11) and the prevalence of overweight or obesity (16%, z=1.26, p=0.21) [206, 207].

Other descriptives can be found in Table 10.

Table 10: Participant characteristics

N=1104	Mean	SD
Age (y)	14.7	0.8
SR[range 4-16]	9.2	2.9
External eating [range 1-5]	**3.0**	**0.6**
Emotional eating [range 1-5]	**2.4**	**0.9**
Intake of unhealthy snacks (g/day)	189.9	141.2
Intake of SSBs (ml/day)	234.8	252.4
Availability at home of unhealthy snacks[range 0-20]	8.8	4.9
Availability at home of SSBs[range 0-3]	1.1	0.9
Availability at school of unhealthy snacks[range 0-20]	1.8	2.2
Availability at school of SSBs[range 0-3]	1.2	0.8

4.3.2. Direct association (Step 1)

SR was significantly positively associated to both intake of unhealthy snacks (b=7.09, SE=1.44, p<0.001) and SSBs (b=8.56, SE=2.64, p<0.001). 13% of the total variance in the intake of unhealthy snacks and 9% of the total variance in the intake of SSBs was explained by SR and the covariates (zBMI, education type and sex), this is an additional 4% or 1% respectively compared to the model with only the covariates.

4.3.3. Mediation analyses (Step 2)

The results of the mediation analyses for both unhealthy snack and SSB intake are shown in Figure 7. Indirect effects and bootstrapped standard errors are presented in Table 11. Both external eating and emotional eating were partial mediators in the SR- unhealthy snack intake relation. However, neither external nor emotional eating mediated the SR-SSB intake association. Adding the mediational pathway explained an extra 4% of the variance in unhealthy snack intake for the model with external eating and 4% for the model with emotional eating. Emotional and external eating respectively mediated 25% and 23% of the total effect of SR on unhealthy snack intake.

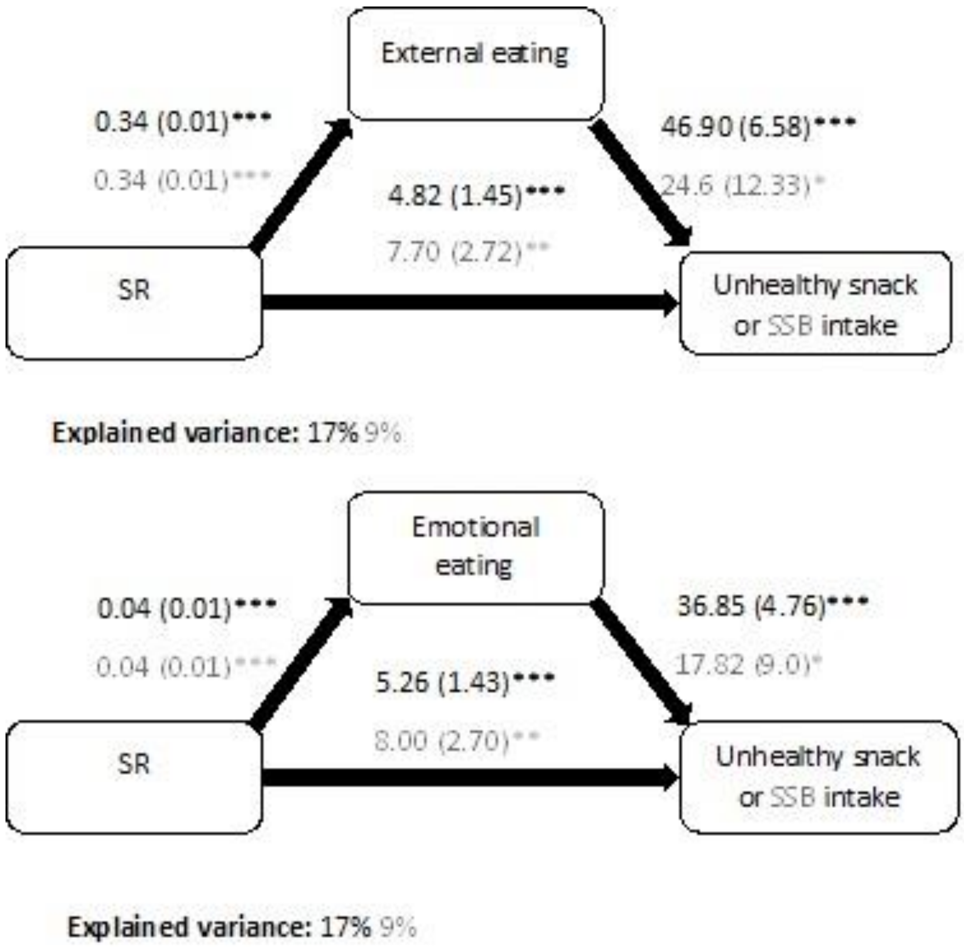


Figure 7: Mediation results

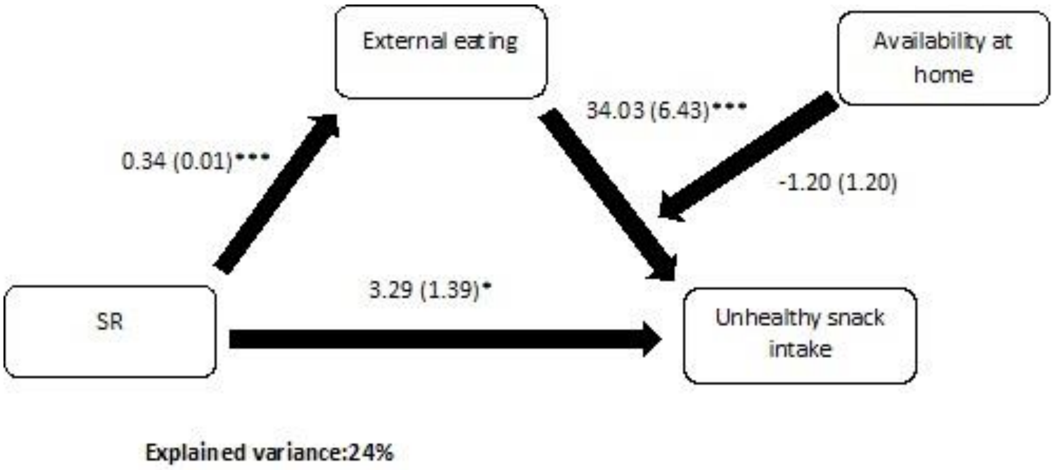
Coefficients are unstandardized and shown in the figure in the format b(SE); * p<0.05, ** p<0.01 and *** p<0.001; All analyses were controlled for sex, zBMI and education type

Table 11: indirect effect and bootstrapped standard errors for the mediation analyses

	Intake of unhealthy snacks				
	Indirect effect (a*b)	**Bootstrapped SE**	**Z**	**p**	**Normal-based 95% CI**
External	1.60	0.42	3.79	0.000	[0.77, 2.42]
Emotional	1.54	0.43	3.59	0.000	[0.70, 2.38]
	Intake of SSBs				
	Indirect effect (a*b)	**Bootstrapped SE**	**Z**	**p**	**Normal-based 95% CI**
External	0.84	0.49	1.71	0.088	[-0.12, 1.79]
Emotional	0.75	0.45	1.66	0.098	[-0.13, 1.63]

4.3.4. Moderated mediation analyses (Step 3)

As no evidence of mediation by emotional or external eating on the intake of SSBs was found, moderated mediation was only explored for the intake of unhealthy snacks. Interaction effects of availability at home or at school of unhealthy snacks and external or emotional eating on unhealthy snack intake were non-significant. Coefficients and explained variances are shown in Figure 8 and Figure 9.



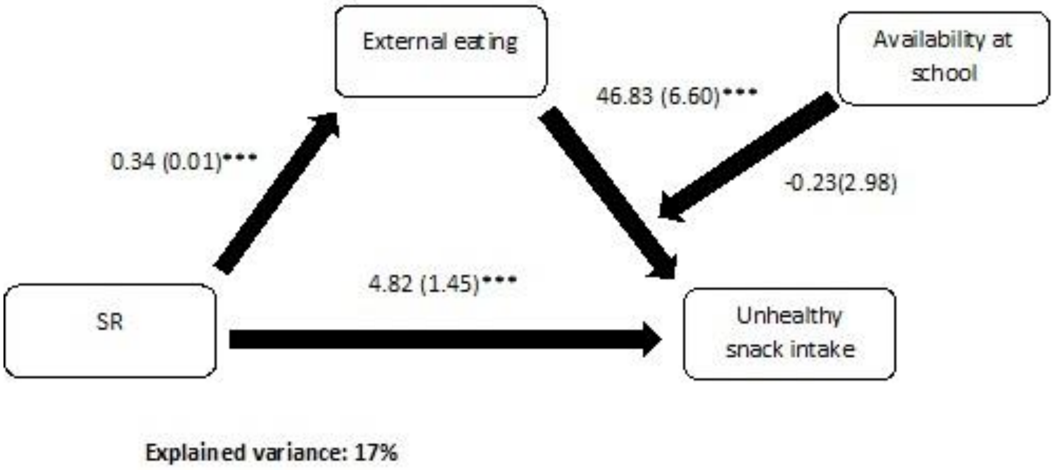


Figure 8: Moderated mediation results with mediator external eating

Coefficients are unstandardized and shown in the figure in the format b(SE); * $p<0.05$, ** $p<0.01$ and *** $p<0.001$; All analyses were controlled for sex, zBMI and education type

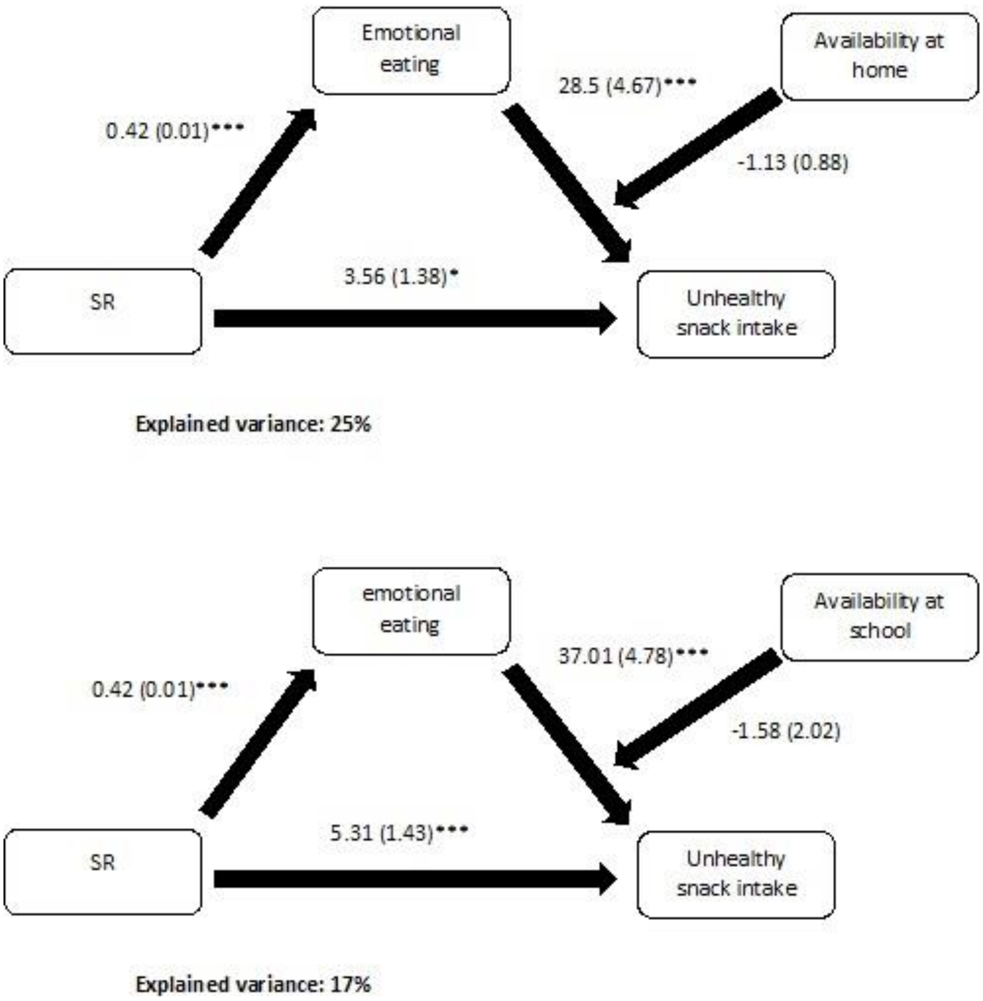


Figure 9: Moderated mediation results with mediator emotional eating

Coefficients are unstandardized and shown in the figure in the format b(SE); * p<0.05, ** p<0.01 and *** p<0.001; All analyses were controlled for sex, zBMI and education type

4.4. Discussion

The hyper-responsiveness model depicted how a high SR is associated with hedonic eating (emotional and external eating) and could lead to habitual (over)eating. It was therefore assumed that a high SR would be associated with a higher occurrence of hedonic eating processes, resulting in higher intakes of unhealthy snacks and SSBs. In addition it was expected that the environment in terms of availability would interact with these hedonic eating styles, thereby enhancing their influence on unhealthy snack and SSB intake.

First, the current study found that SR is significantly and positively related to unhealthy snack and SSB intake in adolescents, which is line with previous studies [199]. The present findings therefore provide further evidence for characterizing specifically high SR adolescents as a possible risk group for developing eating and weight problems [86]. The latter is especially important in adolescence, given their overall vulnerability to rewarding processes, as well as to the development of eating problems [90, 208]. However, the explained variance was rather small (unhealthy snacks 9%, SSBs 8%). Therefore, and consistent with the multicomponent etiology of overweight/obesity [189] and the biopsychosocial model of eating behaviors [43], it is important to also study other factors such as eating styles, peer influence, parental behaviors and media in relation to unhealthy snacking and drinking behaviors [43].

Second, in line with the hypotheses, two different eating styles were very common in this age group and partially mediated the SR-intake of unhealthy snacks association, namely: external and emotional eating. Davis and colleagues (2004, 2007) previously reported that SR was related to external and emotional eating in adults [75, 86]. The current study extends this observation to the case of adolescents. In addition, the present study also shows how a higher SR is associated with the intake of unhealthy snacks through external or emotional eating. However, external eating mediated only 18% and emotional eating only 23% of the total effect of SR, therefore other additional mediators should be examined in order to gain more insight into the SR-unhealthy snack intake associations. Examples of other possible mediators are food cravings and food preferences [84, 86]. No mediation by either external or emotional eating of the association between SR and SSB intake was observed. The lack of a mediational pathway through external or emotional eating could be a consequence of the fact that all items of the DEBQ (the scale that was used to measure external and emotional eating) question eating in relation to foods and not drinks [200]. As our results only explained part of the association between SR and unhealthy snack intake and none for the SR-SSB intake association, future research should focus on examining through which other mechanisms SR might influence adolescents' eating and drinking habits.

Finally, we found no moderation of the association between emotional or external eating with unhealthy snack intake by either availability at home or at school. It thus seems that availability of unhealthy snacks does not interact with external or emotional eating in promoting unhealthy snack intake. This suggests that hedonic eating processes influence adolescents' snack intake independent of the environment adolescents live in. One other study reported a significant interaction effect on the intake of fast food in adults when examining the interaction between the environment in terms of fast-food exposure and hedonic factors in terms of SR [100]. The latter discrepancy could be a consequence of the different constructs used to operationalize the environment: exposure implies availability, but not the other way around. Availability just refers to the presence of items in the environment (for example cookies in the highest kitchen cabinet), while exposure also implies access to it (for example the cookies in the highest kitchen cabinet are reachable and visible) [209]. Another possible explanation for this discrepancy when considering availability of unhealthy snacks school, might be that the variability in these scores was too low to actually observe a moderation. The low variability in availability at school might be due to the design of the study. Data regarding availability was collected at school level (20 schools), the within school variance for these availability measures is therefore zero and the variance is therefore only due to the between-school variance. In order to model the moderation of the school availability of unhealthy snacks it would have been better to use a multilevel model with school as a separate level, but when the whole moderated mediation model was evaluated it was more efficient to stick to a single-level model. The multilevel expansion did not lead to an improvement of BIC or AIC, lead to large computational times and is still considered as a difficult expansion of the normal mediation models [204, 210]. More research is thus needed to investigate how individual hedonic and environmental factors influence adolescents' food choice alone and/or in combination, particularly regarding the school environment. However it might be if more schools would be sampled and the models could be efficiently estimated as MSEM models that still there would be little or no moderation, as the low variability in availability at schools could also be a consequence of the fact that most schools implemented already similar policies regarding the sales of unhealthy snacks at their school. Therefore it is important to also study the influence of other environments, such as sports or scouting clubs, on adolescents' snack and drink intake, as these might have a more substantive or a different interaction effect with hedonic eating styles.

This study provides additional insight into how SR, evaluated in terms of BAS DRV, influences unhealthy snack intake in adolescents. External and emotional eating partially mediated the associations between SR and unhealthy snack intake and did not interact with the availability of such items in the environment in promoting unhealthy snack intake. The latter findings emphasize that hedonic eating processes are well-established in adolescents and influence adolescents' snacking behavior independent of the environment adolescents live in. Other strengths of this study were the use of a population-based sample, the application of age appropriate instruments, the objective measurements of height and weight and the combination of biopsychological and environmental factors in examining adolescents' eating behaviors. This study also has some limitations. First, the study design was cross-sectional, so no statements about the causality of the present relations could be made. Second, all collected data except the anthropometrics and snack and SSB availability at school were self-reported and were thus subject to social-desirability bias. We attempted to counter this bias by emphasizing anonymity of the data collection. A third limitation of this study was the length of the survey (±75min), which could have increased the chance of poor quality answers at the end of the survey e.g. more hurried answers, higher item-nonresponse rates and less variability to items arranged in grids [211]. To avoid this bias, caused by the survey length, three versions of the questionnaire were prepared and administered randomly (except for the demographics, these always came first). A fourth limitation was that total daily energy intake was not measured. This would have increased the burden on the respondents even more, potentially jeopardizing reporting quality for the key variables. However all analyses were adjusted for bodyweight (zBMI), which according to Jakes and colleagues (2004) has considerable advantages over adjusting for total daily energy intake [192]. A fifth and final limitation was that no measures of pubertal stage or menstrual cycle were taken into account although these could possibly affect energy intake and SR [193, 194].

4.5. Conclusion

First, our findings provide further evidence for characterizing high SR individuals as a vulnerable group for eating and weight problems. Second, our findings also showed that hedonic eating processes may partially explain how a heightened SR leads to unhealthy eating habits and ultimately to overweight and obesity. Finally, we found no evidence that an obesogenic environment, characterized by a high availability of unhealthy palatable foods, enhanced the influence of hedonic eating processes on unhealthy snack intake. For the intake of SSBs no evidence was found that emotional or external eating mediated the SR-SSB intake association. Future research should therefore focus on also exploring other processes that might explain the association between SR and unhealthy eating habits or overweight, and on further examining the possible unique and interactive influences of individual and environmental factors in explaining adolescents' food choice. Our findings highlight the importance of taking into account individual risk factors, such as sensitivity to reward, in obesity prevention in our current society. As the environment did not interact with SR's related hedonic eating processes in adolescents, individual strategies will be needed to counter the influence of hedonic eating processes on obesity and overall health. For instance, using positive reinforcement and rewarding strategies to chance eating habits, might be more effective in individuals with high levels SR (Vandeweghe et al. 2015, unpublished observations). As adolescents are also generally more sensitive to rewarding processes compared to adults and children [90], tailoring based on SR might be an even more promising strategy to prevent obesity and promote healthy food choices in adolescents.

Chapter 5: Use of fitness and nutrition apps and adolescents' BMI, snacking and drinking habits: multilevel associations and mediation models

Redrafted after:

Nathalie De Cock, Jolien Vangeel, Carl Lachat, Kathleen Beullens, Leentje Vervoort, Lien Goossens, Lea Maes, Benedicte Deforche, Stefaan De Henauw, Caroline Braet, Patrick Kolsteren, Steven Eggermont, John Van Camp and Wendy Van Lippevelde (2016). *Journal of Medical Internet Research.* In revision.

Summary

Background: Efforts to improve snacking and drinking habits are needed to promote a healthy body mass index (BMI) in adolescents. Although commercial fitness and nutrition smartphone apps are widely used, little is known regarding their potential to improve health behaviors, especially in adolescents. In addition, evidence on the mechanisms through which such fitness and nutrition apps influence behavior is lacking.

Objectives: This study assessed if the use of commercial fitness and/or nutrition apps was associated with a lower BMI and healthier snacking and drinking habits in adolescents. Additionally, it explored if perceived behavioral control to eat healthy; attitudes to eat healthy for the good taste of healthy foods, for overall health or for appearance; social norm on healthy eating and social support to eat healthy mediated the associations between the frequency of use of fitness or nutrition apps and BMI, the healthy snack, and beverage ratio.

Method: Cross-sectional self-reported data on snack and beverage consumption, healthy eating determinants and fitness and nutrition app use of adolescents (n=889, mean age = 14.7±0.8 years; 51% boys; 18.0% overweight) were collected in a representative sample of 20 schools in Flanders, Belgium. Height and weight were measured by the researchers. The healthy snack ratio and the healthy beverage ratio were calculated as followed: (gram healthy snacks or beverages/(gram healthy snacks or beverages + gram unhealthy snacks or beverages))*100. Multilevel regression and structural equation modelling were used to analyze the proposed associations and to explore multiple mediation.

Results: A total of 37% of the adolescents used fitness and/or nutrition apps. Frequency of using nutrition apps was positively associated with a higher healthy beverage ratio (b=0.16(0.04), *P*=.001) and a higher zBMI (b=0.16(0.04), *P*<.001). The frequency of using nutrition apps interacted with fitness app use frequency in influencing zBMI (b=-0.03(0.02), *P*=.03) and the healthy snack ratio (b=-0.84(0.37), p=.03). Attitude to eat healthy for appearance mediated both the fitness app use frequency-zBMI (a*b=0.02(0.01), *P*=.02) and the nutrition app use frequency-zBMI (a*b=0.04(0.01), *P*=.001) associations. No mediation was observed for the associations between the frequency of use of fitness or nutrition apps and the healthy snack or beverage ratio.

Conclusion: Commercial fitness and/or nutrition apps show some positive association with healthier eating behaviors in adolescents. However, effective behavior change techniques should be included to affect key determinants of healthy eating.

5.1. Background

In Flanders, 18% of adolescents between 14- and 16-years are overweight [212]. An unhealthy lifestyle characterized by physical inactivity [213], sedentary behavior [214] and unhealthy eating habits [215], plays an important role in the development of overweight and obesity. Typical unhealthy eating habits during adolescence are a low consumption of fruit, vegetables and dairy products and an overconsumption of energy-dense snacks and sugar- and fat-rich beverages [4, 5, 7, 8, 196]. Health promotion programs to improve snack and beverage intakes are needed to promote a healthy body mass index (BMI) in adolescents.

Smartphone use has significantly increased over the last decades, especially among adolescents and children [216-218]. With this increase, health-related applications (apps) have become widely spread [216, 219-221]. Currently, 79,298 apps are available in the health and fitness category of iTunes and 75,058 in Google Play [222, 223], the two leading app stores in Europe [220]. These apps are usually available in English or Dutch [220]. Amongst these apps, fitness and nutrition apps are the most popular and are typically used to improve fitness or eating habits [216, 219]. Fitness and nutrition apps allow users to monitor their physical activity or food intake, provide information on the nutritional content of specific food items and/or give instructions or demo videos for physical exercises [219, 224, 225]. Adolescents are highly skilled in using smartphones and apps [126, 127]. In 2014, 86% of the adolescents in Flanders owned a smartphone and on average had 10-20 apps installed on the device [129]. Fitness and nutrition apps, may thus be promising, engaging and affordable ways to promote healthy lifestyle behaviors in adolescents [123, 217, 218].

Despite their potential for health promotion, little information exists about the use and effectiveness of commercially available fitness and nutrition apps [218, 226]. Only a handful of studies, mostly in adults, have investigated the use of such apps and/or their relation with health [124, 216, 219, 224, 227]. The use of commercially available fitness apps was found to be associated with higher exercise levels, lower BMI, weight loss and healthier eating [124, 224], while the use of nutrition apps has been associated with better diet monitoring and weight loss [228, 229]. Among adolescents, no differences in physical fitness were observed between fitness app users and non-users during a randomized controlled trial [126]. To the best of our knowledge, no studies have investigated the use of existing fitness and nutrition apps and their relation with healthy eating habits and/or a lower BMI in adolescents.

Most existing fitness and nutrition apps for children, adolescents, and adults only contain a few effective behavior change techniques and might therefore have a limited capacity to facilitate behavior change [123, 218, 226, 230]. Nevertheless, these apps are popular and perceived as useful and effective by the users [227]. Better evidence gathered via population-based studies on the usage patterns of such apps, their perceived utilities and benefits and associations with health behaviors and body mass index (BMI) is needed [216, 219, 227, 231].

To more fully comprehend the possible effects of nutrition and fitness apps on health behaviors, the mechanisms through which such apps might influence behavior should also be explored [218, 224, 230]. Fitness and nutrition apps usually do not alter behavior directly, but contain specific features that focus on key behavioral determinants [124, 224, 225, 232]. Important intermediate determinants of healthy eating habits in adolescents are attitude to eat healthy, behavioral control, social norm and social support [7, 46, 49, 233]. Adolescents' attitude to eat healthy is mainly determined by taste, appearance and health concerns [43, 47, 234]. An assessment of intermediate determinants in adults found that the use of fitness apps was associated with a lower BMI through a higher self-efficacy to exercise and higher levels of exercise [224]. To the best of our knowledge no study has investigated if commercially available fitness and nutrition apps target and/or positively influence key intermediate determinants of adolescents' eating behaviors and anthropometrics.

The current study first aimed to examine the use of fitness and/or nutrition apps and the associations between fitness and/or nutrition app use frequency and BMI, healthy snacking and drinking habits (healthy snack or beverage ratio) in adolescents. It was expected that app use frequency would be related to a lower BMI and a higher healthy snack and/or beverage ratio. The combined influence of fitness and nutrition apps was also considered, as adolescents might use both fitness and nutrition albeit not always to the same extent [216, 219]. Second, the present study aimed to explore if the key behavioral determinants to eat healthy mediated the associations between fitness and/or nutrition app use and BMI, the healthy snack or beverage ratio. Perceived behavioral control to eat healthy; attitudes to eat healthy for the good taste of healthy foods, for overall health and for appearance; social norm on healthy eating or social support to eat healthy were examined in this regard. It was hypothesized that more frequent use of these apps would be associated with higher scores for the mentioned determinants, which in turn would be associated with lower BMI and healthier snacking and drinking habits.

5.2. Methods

This research was conducted within the context of REWARD (www.rewardstudy.be), a multidisciplinary project that aims to investigate and improve the nutritional status of children and adolescents. REWARD combines rewarding paradigms with learning theory and typical behavior change techniques such as monitoring and goal setting, through novel methods such as serious games and smartphone apps.

5.2.1. Study procedure and participants

The data were collected using a pencil-and-paper survey from September to December 2013 in 14- to 16-year-old adolescents from 20 schools in Flanders, Belgium. A total of 1210 adolescents was sampled, the detailed sample size calculation and sampling procedure was already described elsewhere [212]. The adolescents completed the survey in the classroom in the presence of two researchers, who provided clarification where necessary. Confidentiality and anonymity were assured by the researchers before, during and after the completion of the survey. Passive consent was obtained from the parents or legal guardians of the sampled adolescents and the adolescents were informed that they could withdraw from the study at any time without explanation. The study protocol was approved by the Ethics Committee of the Ghent University Hospital.

5.2.2. Measures

5.2.2.1. Demographics

Both sex and date of birth of the participants were collected. Age was then derived by subtracting the date of birth from the date the survey took place. The education type of each adolescent (general/technical/vocational) was obtained from the schools.

5.2.2.2. Snack and beverage intake

Snack and beverage intake were assessed using the food frequency questionnaire (FFQ) designed to measure snack and beverage intake of adolescents within this PhD thesis (see chapter 2) [183]. The FFQ probes for usual food intake with a reference period of one month and comprises two sections: beverages and snacks. The intake of beverages was evaluated over the whole day, as drinks such as soft drinks and fruit juice provide additional calories not only at snack times, but rather throughout the whole day [23]. While the intake of snacks was evaluated in terms of all food items consumed outside (>30 min) of breakfast, lunch and dinner [19].

Snacks and beverages were classified as either unhealthy or healthy using the UK Ofcom Nutrient Profiling model (see chapter 1) [22]. This model provides a score that represents the 'unhealthiness' of a beverage or food product [22]. Following this scoring system, the snack and beverage items are: sport drinks, energy drinks, soft drinks, sweetened milk drinks, crisps, other salty snacks, sausage/cheese rolls and pizza, other fried snacks, fries, hamburgers, cheese or meat cubes, sandwich with sweet or savory spread, ice-cream, popsicles, breakfast cereals, pudding, mousses, chocolate, candy bars, candy, dry cookies, other cookies, breakfast rolls and pastries were considered to be unhealthy and the items: water, fruit or vegetable juice, coffee/tea, milk, milk substitutes, unsweetened yoghurt, sweetened yoghurt, dried fruit, fruit, raw vegetables, nuts and seeds, kebab and pasta cups as healthy.

For each FFQ category the daily intake was calculated by multiplying the frequency of consumption with the quantity of consumption per week (g) divided by 7. These daily intakes were then summed to obtain the daily intake of healthy snacks (g), unhealthy snacks (g) unhealthy drinks (ml) and healthy drinks (ml). Subsequently a healthy snack and a healthy beverage ratio were then calculated. The higher this ratio, the more healthy the snack and beverage intake of the adolescents was.

$$Healthy\ snack\ ratio = \left(\frac{daily\ intake\ of\ healthy\ snacks}{daily\ intake\ healthy\ and\ unhealthy\ snacks}\right) \times 100$$

$$Healthy\ beverage\ ratio = \left(\frac{daily\ intake\ of\ healthy\ beverages}{daily\ intake\ healthy\ and\ unhealthy\ beverages}\right) \times 100$$

5.2.2.3. Fitness and nutrition app use

Frequency of using fitness or nutrition apps was assessed with the questions: “How often do you use fitness apps on your smartphone or tablet?” with examples Nike+Running and Fitness Pall and “How often do you use nutrition apps on your smartphone or tablet?” with examples Weight Watchers and Calorie Counter. Response categories were (almost) never, a few times a year, once a month, a few times per month, once every week, a few times per week and (almost) daily. The answer format was adapted from a previous study in adolescents on the change in the frequency of media use over time [235]. Response categories were rescaled to represent how many times such an app was used in one week. Never and a few times a year were set to 0, while other answer categories were given the following values: once a month=0.25 (reflected using the app once every 4 weeks), a few times per month=0.5 (midpoint of the interval), once every week=1 (reflected using the app one day a week), a few times per week=3.5 (midpoint of the interval) and daily=7 (reflected using the app every day of the week).

5.2.2.4. Perceived behavioral control, social influence and attitudes

Perceived behavioral control to eat healthy, social norm of healthy eating, social support to eat healthy and attitudes to eat healthy for the good taste of healthy foods, for overall health and for appearance were measured via 13 items taken from an existing valid and reliable healthy diet determinants questionnaire (Table 12) [234]. All items were evaluated using 5 point-Likert scales. For the constructs perceived behavioral control to eat healthy and attitude to eat healthy for overall health and for appearance mean scores ranging from 1 to 5 were computed by averaging the scores of the items used to measure these constructs.

5.2.2.5. Height and weight

Two trained research assistants measured body height and weight using a standardized protocol [185]. Adolescents were measured without shoes and were allowed to wear light clothing. Body height was measured with a SECA Leicester Portable Stadiometer with an accuracy of 1 mm. Weight was measured with a calibrated electronic scale SECA 861 with an accuracy of 100 g. Age and sex-specific BMI z-scores (zBMI) were calculated using Flemish 2004 growth reference data [186]. According to the International Obesity Task Force cut-off points, adolescents were classified as either normal weight or overweight [187].

Table 12: Overview used constructs, items and anchors of the healthy diet determinants questionnaire

Constructs	Questions	Anchors	Cronbach's alpha
Perceived behavioral control [1-5]	Suppose you want to eat healthy…How hard is it for you to eat healthy each day? How hard is it for you to eat a healthy diet at your home? How hard is it for you to eat a healthy diet at your school?	1=very hard and 5=not hard at all	0.71
Peer social norm [1-5]	How healthy does your best friend eat?	1=very unhealthy and 5=very unhealthy	/
Peer *social support [1-5]*	How often does your best friend encourage you to eat a healthy diet?	1=not at all and 5=very often	/
Attitude towards healthy eating for the good taste of healthy foods [1-5]	A reason or benefit for me to eat healthy is that I like the taste of healthy foods	1=completely disagree and 5=completely agree	/
Attitude towards healthy eating for overall health [1-5]	I think healthy eating is important for my overall health A reason or benefit for me to eat healthy is that I feel better eating healthy A reason or benefit for me to eat healthy is that I stay in good health	1=completely disagree and 5=completely agree 1=completely disagree and 5=completely agree 1=completely disagree and 5=completely agree	0.79
Attitude towards healthy eating for appearance [1-5]	A reason or benefit for me to eat healthy is… that I lose weight A reason or benefit for me to eat healthy is… that I can keep my weight as it is now and don't become overweight A reason or benefit for me to eat healthy is… that other people admire me A reason or benefit for me to eat healthy is… to have an attractive body	1=completely disagree and 5=completely agree	0.79

5.2.3. Statistical analyses

First, descriptive statistics of the sample were computed. Adolescents who completed and did not complete the app use questions were compared by t- and χ2-tests.

Second, the associations between the independent variables (fitness and/or nutrition app use frequency) and the dependent variables (zBMI, the healthy snack ratio and the healthy beverage ratio) were assessed by means of multilevel linear regression analyses with a three level structure (adolescents within classes within schools) to account for clustering of the data. Five consecutive models were tested. Model 0 was an intercept-only model without any level 1, level 2 or level 3 predictors and model 1 a covariates- (sex and education type) only model. Models 2 and 3 evaluated the singular associations of fitness or nutrition app use frequency with the dependent variables by adding the fitness app use frequency or nutrition app use frequency to model 1. Model 4 examined the independent influence of fitness and nutrition app use frequency by simultaneously adding both fitness app use frequency and nutrition app use frequency to model 1. Model 5 explored the interplay between fitness and nutrition app use frequency by adding the fitness app use frequency x nutrition app use frequency interaction term to model 4. When evidence of interaction was found in model 5, a margins plot was computed to allow easier interpretation. Sex and education type (two dummies) were operationalized as categorical variables with 0=boys or general education. Frequency of use of fitness and nutrition apps were treated as continuous predictors. As the intercept-and the covariates-only model (model 0 and model 1) were less relevant to test the postulated hypotheses only models two to five were presented.

Finally, to assess the mechanisms through which nutrition and/or fitness apps influence behavior mediation analyses were executed for each app separately. Mediation of the associations between the independent (zBMI, healthy snack ratio or healthy beverage ratio) and the dependent variables (fitness app use frequency or nutrition app use frequency) by the healthy diet determinants was explored with multiple mediation models. These models were fitted using multilevel structural equation modelling (MSEM) (path analyses) with three levels for each of the app-outcome combinations resulting in six models (see figures 1, 2 and 3 and tables 5 and 6). Mediation was assessed following Preacher, Zyphur and Zhang [203, 204] for the multilevel 1-1-1 model, using bootstrapped standard errors for the indirect effects (1000 replications). The coefficients shown in the results section however are the result of single level generalized SEM (GSEM) as the multilevel models did not provide substantial higher efficiency, based on Akaike's information criterion (AIC), and computationally simpler models were thus preferred.

For both the multilevel regression models as the multiple mediation models associations were controlled for sex and education type, continuous parameters were mean centered, outliers were removed, unstandardized coefficients and their standard errors were displayed and associations with p-values <0.05 were considered statistically significant. For all models also the log likelihoods and the log likelihood tests compared to the null model (intercept only), together with the explained variances compared to the null model were computed. All analyses were conducted using Stata version 13 SE (Stata Corporation, Texas, USA).

5.3. Results

5.3.1. Descriptives

Of the 1210 selected adolescents, 6% were absent or did not receive parental consent and 2.8% returned a questionnaire of unsatisfactory quality (more than 33% of the questions not completed or straight-lining responses). Only 889 (73%) of the 1104 adolescents who filled out the survey, completed the questions on app use and were considered for the analyses. No differences in type of education and overweight status were observed between the adolescents who completed and who did not complete the app use questions. The adolescents who did not complete the app use questions were however, more likely to be girls ($\chi 2= 27.55$ $p<0.001$) and to be older ($t=-2.99$, $p<0.01$).

The mean age of these 889 adolescents was 14.7 years, 55% were male, 18% overweight or obese, 46% enrolled in general, 35% in technical and 19% in vocational education (see Table 13). Table 13 also shows the mean and SDs for the dependent and independent variables. The mean zBMI was 0.28(1.02), the mean healthy snack ratio 37.16(25.39) and the mean healthy beverage ratio 72.76(24.79). Healthy snacks and beverages thus accounted for respectively 37% or 73% of the total snack or beverage intake in adolescents.

A total of 37% of the adolescents used fitness and nutrition apps, most of them used fitness apps (23%). A smaller group used both fitness and nutrition apps (11%) and merely 3% used only nutrition apps. The mean frequency of use is less than once a month for nutrition apps and between a few times per month and every week for fitness apps.

Table 13: Characteristics of the participants (n=889), zBMI, snack and beverage intake, perceived behavioral control, social influences and attitudes

Characteristics	
	% or mean(SD)
Overweight	18.06
Boys	54.78
General education	46.12
Technical education	34.65
Vocational education	19.24
Age	14.69(0.81)
App use	
	% or Mean(SD)
Use fitness apps	23.17%
Use nutrition apps	2.02%
Use both fitness and nutrition apps	11.36%
Frequency of use of fitness apps [0-7]	0.54(1.47)
Frequency of use of nutrition apps [0-7]	0.16(0.80)
zBMI, healthy snack &beverage ratio	
	Mean(SD)
zBMI	0.28(1.02)
Healthy snack ratio	37.16(25.39)
Healthy beverage ratio	72.67(24.79)
Healthy eating determinants	
	Mean(SD)
Perceived behavioral control to eat healthy [1-5]	3.36(0.82)
Attitude to eat healthy eating for the good taste of healthy foods [1-5]	3.70(0.78)
Attitude to eat healthy for overall health [1-5]	3.70(0.78)
Attitude to eat healthy for appearance [1-5]	3.03(0.90)
Social norm to eat healthy [1-5]	3.12(0.84)
Social support to eat healthy [1-5]	2.11(0.95)

5.3.2. Multilevel associations

5.3.2.1. zBMI

Both fitness and nutrition app use frequency were singularly associated with zBMI (see models 2 and 3 in Table 14). The more frequent adolescents used a fitness app (b=0.07(0.02), p=.001) or a nutrition app (b=0.18(0.03), p<.001), the higher the zBMI of the adolescents was. However when both the frequency of use of fitness and nutrition apps were considered simultaneously (model 4), only nutrition app use frequency was independently and directly associated with zBMI (b=0.16 (0.04), p=.001). In addition, a significant interaction between fitness app use frequency and nutrition app use frequency (b=-0.03(0.02), p=.03) in relation to zBMI was found (model 5), so that when a fitness app was more frequently used the association between nutrition app use frequency and zBMI decreased (see marginsplot in Figure 10). Together with the covariates the frequency of use of fitness and nutrition apps explained 7% of the variation in zBMI. Model 5 had the lowest log likelihood and was thus the best fitting model.

5.3.2.2. Healthy snack ratio

No significant singular or independent associations between the frequency of use of fitness and/or nutrition apps and the healthy snack ratio could be observed (see models 2, 3 and 4 in Table 14). However despite the lack of independent associations, there was an interactive influence of fitness and nutrition app use frequency (b=-0.84(0.37), p=.03) on the healthy snack ratio (model 5). More specifically the association between the nutrition app use frequency and the healthy beverage ratio was positive at low frequencies of use of a fitness app, while at high frequencies of use of a fitness app the association between the nutrition app use frequency was negative (see marginsplot in Figure 10). Here also model 5 was the best fitting model. The covariates together with the frequency of use of both fitness and nutrition apps explained 9% of the variation in the healthy snack ratio.

5.3.2.3. Healthy beverage ratio

Only nutrition app use frequency was significantly associated with the healthy beverage ratio, while fitness app use frequency was not (see models 2, 3 and 4 in Table 14). Adolescents who used a nutrition app more often had a higher healthy beverage ratio (b=2.96(1.11), p=.008). Also no significant interaction of fitness app use frequency and nutrition app use frequency could be observed (see model 5 in Table 14). Together sex, education type, fitness and nutrition app use frequency explained 5% of the variation in the healthy beverage ratio. Model 5 again had the lowest log likelihood and thus provided the best fit.

5.3.3. Multiple mediation

The multiple mediation analyses indicated that both the frequency of use of fitness and nutrition apps were positively associated with social support to eat healthy (fitness apps b=0.05(0.02), p=.03; nutrition apps (b=0.10(0.04), p=.01) and attitude to eat healthy for appearance (fitness apps b=0.05(0.02), p=.008; nutrition apps b=0.14(0.04), p<.001) (see a-path Figure 11, Figure 12 and Figure 13). The higher the frequency of use of the apps, the more positive the attitude to eat healthy for appearance and the felt social support. However only attitude to eat healthy for appearance was found to be a mediator. The attitude to eat healthy for appearance mediated both the fitness app use frequency-zBMI relation (a*b=0.02(0.01), p=.02) and the nutrition app use frequency-zBMI relation (a*b=0.04(0.01), p=.001) (see Figure 11, Table 15 and Table 16). The higher the frequency of use of fitness or nutrition apps, the more positive the attitude to eat healthy for appearance and the higher the zBMI. The associations between the frequencies of use of nutrition or fitness apps and the healthy snack ratio or the healthy beverage ratio were not mediated by any of the proposed mediators. The multiple mediation models explained respectively 9, 11 and 16% of the variance in zBMI, the healthy snack ratio and the healthy beverage ratio.

Table 14: Associations between zBMI, healthy snack ratio, healthy beverage ratio and fitness and diet app use frequency

				zBMI				
	Model 2		**Model 3**		**Model 4**		**Model 5**	
	b(SE)	p	b(SE)	P	b(SE)	p	b(SE)	p
Fixed effects								
Constant	0.12(0.07)	.08	0.13(0.07)	.04	0.13(0.06)	.04	0.15(0.07)	.02
Level 1								
Boys vs. girls	0.05(0.07)	.53	0.01(0.07)	.92	0.02(0.07)	.83	0.02(0.07)	.83
Technical vs. general education	0.17(0.08)	.04	0.17(0.08)	.04	0.17(0.08)	.04	0.17(0.08)	.04
Vocational vs. general education	0.42(0.10)	<.001	0.41(0.10)	<.001	0.41(0.10)	<.001	0.41(0.10)	<.001
Frequency of fitness app use	0.06(0.02)	.009			0.03(0.03)	.25	0.04(0.03)	.15
Frequency of nutrition app use			0.16(0.05)	<.001	0.13(0.05)	.008	0.28(0.09)	.001
Frequency of nutrition app use x frequency of fitness app use							-0.03(0.02)	.04
Log likelihood	-1139.82		-1136.98		-1136.33		-1134.14	
2 Δ Log likelihood (Δdf)	48.52(3)	<.001	54.2(3)	<.001	55.50(4)	<.001	59.88(5)	<.001
Explained variance	0,04		0,04		0,04		0,05	
				Healthy snack ratio				
	Model 2		**Model 3**		**Model 4**		**Model 5**	
	b(SE)	P	b(SE)	P	b(SE)	P	b(SE)	P
Fixed effects								
Constant	34.87(1.47)	<.001	35.06(1.48)	<.001	35.03(1.48)	<.001	35.49(1.49)	<.001
Level 1								
Boys vs. girls	12.59(1.68)	<.001	12.19(1.69)	<.001	12.31(1.70)	<.001	12.30(1.70)	<.001
Technical vs. general education	-4.21(1.87)	.02	-4.17(1.86)	.03	-4.23(1.87)	.02	-4.24(1.86)	.02
Vocational vs. general education	-9.85(2.27)	<.001	-10.00(2.28)	<.001	-9.99(2.28)	<.001	-10.24(2.27)	<.001
Frequency of fitness app use	0.72(0.56)	.20			0.47(0.62)	.45	0.70(0.62)	.26
Frequency of nutrition app use			1.45(1.03)	.15	1.09(1.14)	.34	4.31(1.83)	.02
Frequency of nutrition app use x frequency of fitness app use							-0.84(0.37)	.03
Log likelihood	-3983.32		-3983.14		-3982.86		-3980.34	
2 Δ Log likelihood (Δdf)	172.16(3)	<.001	172.52(3)	<.001	173.08(4)	<.001	178.12(5)	<.001
Explained variance	0,08		0,08		0,08		0,09	
				Healthy beverage ratio				
	Model 2		**Model 3**		**Model 4**		**Model 5**	
	b(SE)	P	b(SE)	P	b(SE)	P	b(SE)	P
Fixed effects								
Constant	74.06(1.96)	<.001	74.37(2.00)	<.001	74.42(1.97)	<.001	74.57(1.98)	<.001
Level 1								
Boys vs. girls	6.23(1.76)	<.001	5.78(1.77)	.001	5.52(1.77)	.002	5.53(1.77)	.002
Technical vs. general education	-6.64(2.56)	.009	-6.79(2.61)	.009	-6.65(2.57)	.01	-6.63(2.58)	.01
Vocational vs. general education	-11.45(2.91)	<.001	-11.77(2.96)	<.001	-11.75(2.92)	<.001	-11.81(2.93)	<.001
Frequency of fitness app use	-0.24(0.55)	.66			-0.92(0.61)	.13	-0.83(0.62)	.52
Frequency of nutrition app use			2.26(1.01)	.03	2.96(1.11)	.008	4.12(1.79)	.02
Frequency of nutrition app use x frequency of fitness app use							-0.30(0.37)	.41
Log likelihood	-4026.81		-4024.42		-4023.30		-4022.96	
2 Δ Log likelihood (Δdf)	123.26(3)	<.001	128.04(3)	<.001	130.28(4)	<.001	130.96(5)	<.001
Explained variance	0,04		0,05		0,05		0,05	

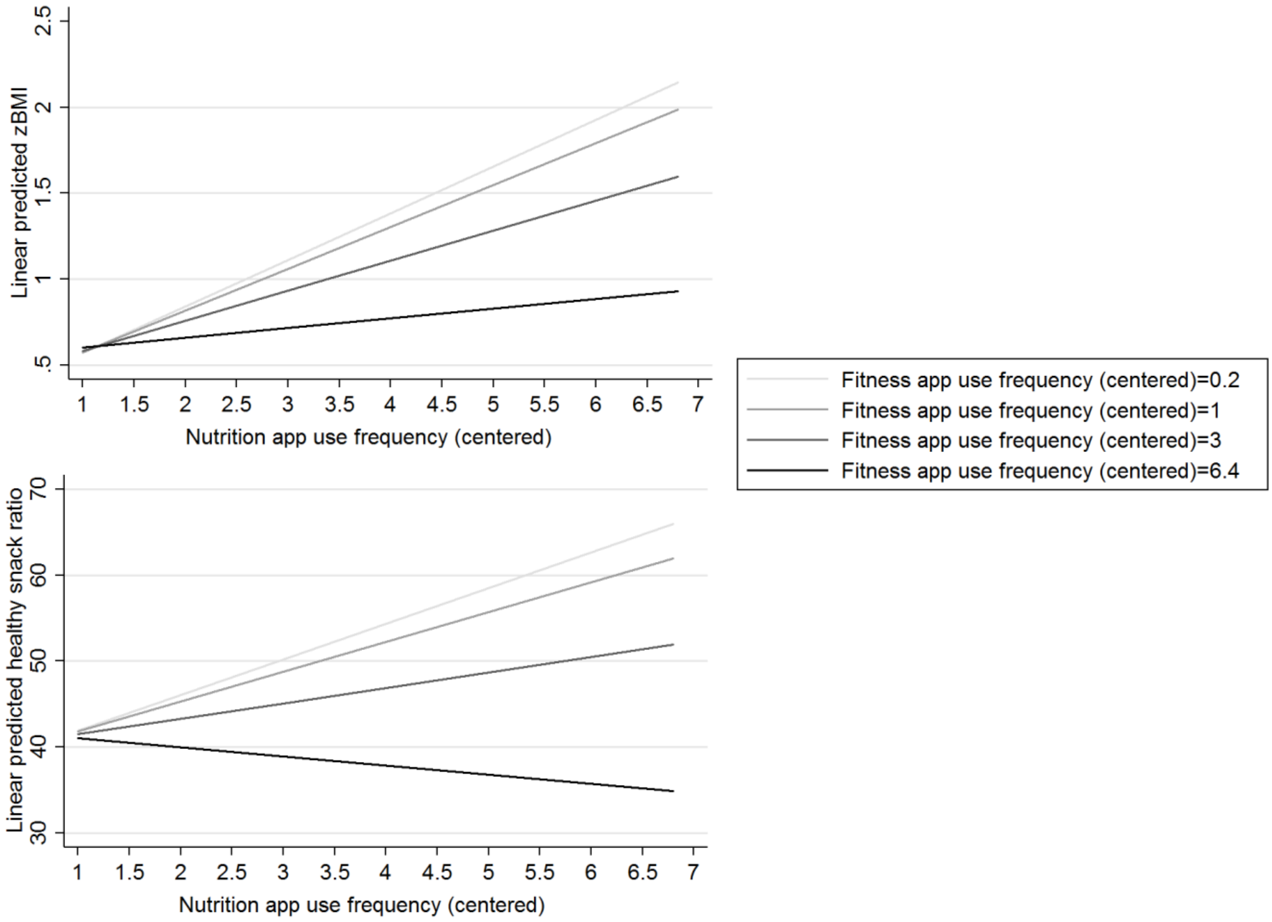


Figure 10: Margins plot zBMI and healthy snack ratio

Analyses controlled for sex and education type

Table 15: Indirect effects multiple mediation with fitness app use frequency

	zBMI				
	Indirect effect (a*b)	**Bootstrapped SE**	**z**	**p**	**Normal-based 95% CI**
Perceived behavioral control to eat healthy	-0.00	0.00	-0.89	.37	[-0.01, 0.00]
Attitude to eat healthy for the good taste of healthy foods	0.00	0.00	0.03	.98	[-0.00, 0.00]
Attitude to eat healthy for overall health	0.00	0.00	0.28	.78	[-0.00, 0.00]
Attitude to eat healthy for appearance	0.02	0.01	2.28	.02	[0.00, 0.03]
Social norm to eat healthy	0.00	0.00	0.28	.78	[-0.01, 0.01]
Social support to eat healthy	0.00	0.00	0.99	.32	[-0.00, 0.01]
Total indirect effect	0.02	0.01	2.00	.046	[0.00, 0.03]
	Healthy snack ratio				
	Indirect effect (a*b)	**Bootstrapped SE**	**z**	**p**	**Normal-based 95% CI**
Perceived behavioral control to eat healthy	0.11	0.11	1.01	.31	[-0.10, 0.32]
Attitude to eat healthy for the good taste of healthy foods	-0.01	0.05	-0.19	.85	[-0.11, 0.09]
Attitude to eat healthy for overall health	0.01	0.04	0.32	.75	[-0.07, 0.10]
Attitude to eat healthy for appearance	0.08	0.07	1.07	.29	[-0.06, 0.22]
Social norm to eat healthy	-0.00	0.03	-0.06	.96	[-0.05, 0.05]
Social support to eat healthy	0.05	0.06	0.81	.42	[-0.07, 0.17]
Total indirect effect	0.24	0.18	1.30	.20	[-0.12, 0.60]
	Healthy beverage ratio				
	Indirect effect (a*b)	**Bootstrapped SE**	**z**	**p**	**Normal-based 95% CI**
Perceived behavioral control to eat healthy	0.10	0.10	1.04	.30	[-0.09, 0.30]
Attitude to eat healthy for the good taste of healthy foods	0.01	0.04	0.15	.88	[-0.07, 0.08]
Attitude to eat healthy for overall health	0.04	0.06	0.62	.54	[-0.08, 0.15]
Attitude to eat healthy for appearance	0.09	0.08	1.11	.26	[-0.07, 0.27]
Social norm to eat healthy	0.01	0.05	0.24	.81	[-0.09, 0.12]
Social support to eat healthy	0.08	0.07	1.24	.22	[-0.05, 0.21]
Total indirect effect	0.33	0.17	1.97	0.049	[0.00, 0.66]

Table 16: Indirect effects multiple mediation with nutrition app use frequency

	Indirect effect (a*b)	Bootstrapped SE	Z	p	Normal-based 95% CI
			zBMI		
Perceived behavioral control to eat healthy	0.00	0.01	0.87	0.39	[-0.01, 0.02]
Attitude to eat healthy for the good taste of healthy foods	-0.00	0.00	0.05	0.69	[-0.00, 0.00]
Attitude to eat healthy for overall health	0.00	0.00	0.29	0.77	[-0.01, 0.01]
Attitude to eat healthy for appearance	0.04	0.01	3.23	0.001	[0.02, 0.07]
Social norm to eat healthy	0.00	0.00	0.99	0.32	[-0.00, 0.01]
Social support to eat healthy	0.01	0.01	0.97	0.33	[-0.01, 0.02]
Total indirect effect	0.06	0.02	3.75	0.000	[0.03, 0.09]
			Healthy snack ratio		
	Indirect effect (a*b)	**Bootstrapped SE**	**Z**	**p**	**Normal-based 95% CI**
Perceived behavioral control to eat healthy	-0.26	0.22	-1.17	0.24	[-0.70, 0.17]
Attitude to eat healthy for the good taste of healthy foods	-0.05	0.12	-0.42	0.68	[-0.29, 0.19]
Attitude to eat healthy for overall health	0.03	0.10	0.29	0.77	[-0.16, 0.22]
Attitude to eat healthy for appearance	0.19	0.17	1.12	0.26	[-0.14, 0.52]
Social norm to eat healthy	-0.01	0.05	-0.18	0.85	[-0.10, 0.08]
Social support to eat healthy	0.10	0.13	0.73	0.46	[-0.16, 0.36]
Total indirect effect	-0.01	0.38	0.02	0.99	[-0.30, 0.87]
			Healthy beverage ratio		
	Indirect effect (a*b)	**Bootstrapped SE**	**Z**	**p**	**Normal-based 95% CI**
Perceived behavioral control to eat healthy	-0.24	0.20	-1.23	.22	[-0.63, 0.15]
Attitude to eat healthy for the good taste of healthy foods	0.02	0.08	0.32	0.75	[-0.14, 0.19]
Attitude to eat healthy for overall health	0.08	0.14	0.56	0.58	[-0.19, 0.34]
Attitude to eat healthy for appearance	0.20	0.20	1.01	0.31	[-0.19, 0.58]
Social norm to eat healthy	0.06	0.07	0.91	0.37	[-0.08, 0.21]
Social support to eat healthy	0.15	0.14	1.12	0.26	[-0.12, 0.43]
Total indirect effect	0.28	0.35	0.79	0.43	[-0.41, 0.96]

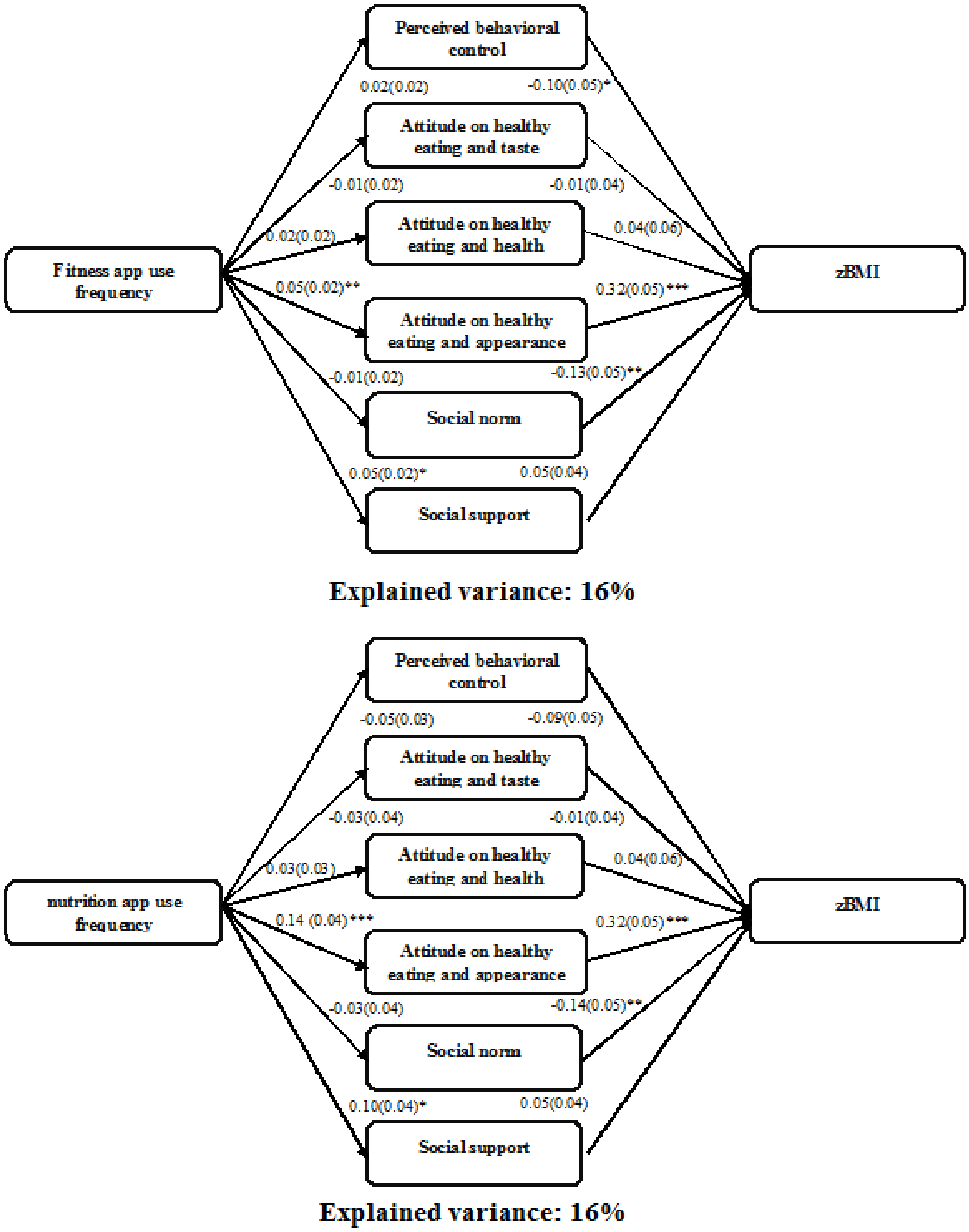


Figure 11: Multiple mediation zBMI

Analyses controlled for sex and education type

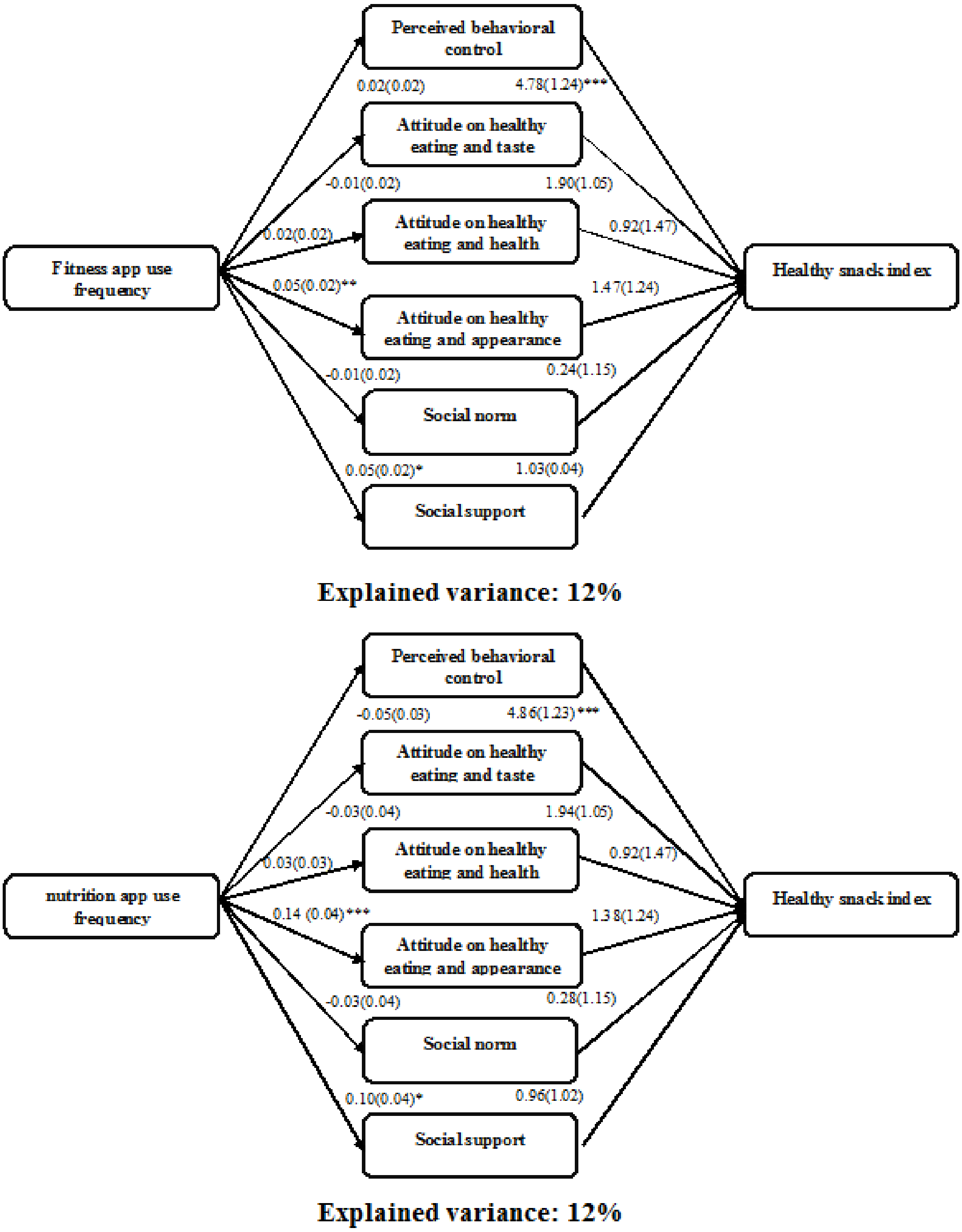


Figure 12: Multiple mediation healthy snack ratio

Analyses controlled for sex and education type

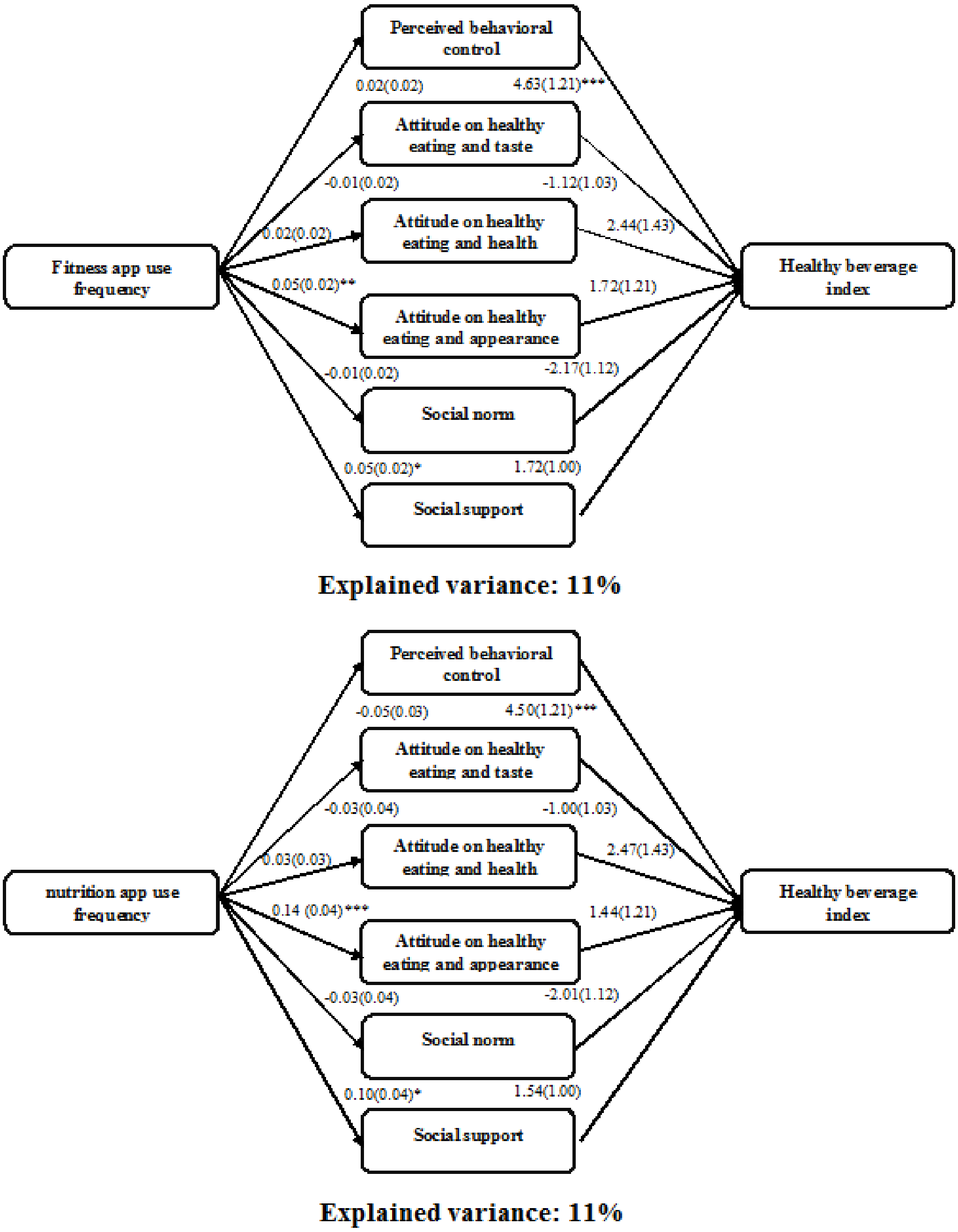


Figure 13: Multiple mediation healthy beverage ratio

Analyses controlled for sex and education type

5.4. Discussion

5.4.1. Principal findings

This study is one of the first to investigate associations, both independent and interactive, between commercial fitness and nutrition app use frequencies and adolescents' snacking and drinking behaviors and BMI. Commercial fitness and/or nutrition apps show some positive association with healthier eating behaviors in adolescents, but were also associated with a higher zBMI. The present study also assessed which determinants mediated the relations between the use of fitness or nutrition apps and BMI, healthy snacking or healthy drinking habits. Only attitude to eat healthy for appearance was found to be a mediator of the associations between the frequency of use of fitness or nutrition apps and zBMI.

First, a total of 37% of the Flemish adolescents in our sample reported to use fitness and/or nutrition apps in 2013. The mean frequency of using fitness apps was between a few times per month and every week and less than once a month for nutrition apps. A study conducted in the US in 2015 found that around 58% of the US adults had downloaded a health app and that 65% of these also used these apps daily [219]. Apart from the country and the timing of the survey, the discrepancy between our results and the 2015 US survey could also be attributed to the surveyed population group. Possibly adolescents use health apps less frequent compared to adults. More in-depth research on the motives of adolescents to use health apps will be needed in the future to understand why adolescents might be less inclined to use such app compared to adults.

Second a higher use of nutrition apps was independently associated with a higher zBMI. This was unexpected, possibly adolescents using nutrition apps in the present study were trying to lose weight. Results confirmed that nutrition app users were indeed more likely to be overweight (36% overweight) in comparison to adolescents who do not use these apps (16%

overweight). Using nutrition apps could thus be part of interventions to lose weight. A desire to lose weight was one of the most frequent reasons to download a nutrition app in the USA [219]. Also the more adolescents used nutrition apps the more healthy their beverage intake was (2.96% increase in healthy beverage ratio). No other studies are available to compare these findings with. No significant independent association between fitness apps use frequency and the healthy beverage ratio was found, nor were there significant independent associations observed between fitness or nutrition apps use frequency and the healthy snack ratio. The use of commercial fitness and/or nutrition apps was thus only weakly associated with healthier snacking and drinking habits in adolescents. These limited associations might be a consequence of their often limited theoretical ground. Our results support the conclusions from reviews and content analyses that indicated that commercial fitness and nutrition apps tend to lack a thorough theoretical base and therefore might not be effective in promoting good health [220, 221, 226, 230, 232].

Third, evidence of an interaction between the frequencies of use of fitness and nutrition apps was found for zBMI and the healthy snack ratio, but not for the healthy beverage ratio. Frequently using both fitness and nutrition apps was associated with a lower BMI, but also with a lower healthy snack ratio. The latter finding was unexpected, this could however be a consequence of the perceived higher energy-needs of those adolescents who frequently use fitness apps. These fitness app users might consume more energy-bars that contain large amounts of sugar and/or fat. More research will be needed to further confirm our findings and to explore the existence of such interactions for other health behaviors as well. Research on adolescents' motives for using and downloading fitness and/or nutrition apps would also be helpful for a better understanding and explanation of these interactions.

Fourth, higher frequencies of fitness and nutrition apps use were associated with a more positive attitude to eat healthy for appearance, which was in turn associated with a higher zBMI. Adolescents with a higher BMI might thus use fitness or nutrition apps to look good and/or to lose weight. Future research could investigate whether these adolescents show dieting or restrained eating practices and if these practices can (partially) explain the association between nutrition or fitness app use and a higher zBMI. No evidence of mediation was found for the associations between the fitness or nutrition apps use frequency and the healthy snack or beverage ratio. In general, little evidence of mediation was found, current commercially available fitness and nutrition apps seem to be associated with only a few key determinants of eating behaviors. The apps might hence not incorporate the corresponding behavior change techniques or use these techniques in an effective way. Our findings thereby add to those findings of several reviews and content analyses [220, 221, 226, 230, 232], that the capacity of commercial fitness and nutrition apps to change behavior is limited by their lack of (effective) behavior change techniques. Apps aimed to change behavior should thus focus more on targeting the key determinants identified in the literature and incorporate the corresponding behavior change techniques in an effective way [218, 230].

Fifth, explained variance for both the regression as the mediation models were small (ranging from 4 to 16%), indicating that many other factors are related to zBMI and healthy snacking and drinking habits in adolescents. This is consistent with these behaviors being multi-causal and subject to many to levels of influence [43].

5.4.2. Strengths and limitations

Strengths of the current study were the use of a representative sample, the objective measurements of height and weight, the use of multilevel regression models and SEM to research the associations and mediations. This study also has some limitations. First the present study considered the use of general fitness and nutrition apps with a 12+ rating. To date, only a few available health apps are specifically developed for adolescents and adolescents will thus use general health apps. No assessment of the developmental appropriateness of such apps was made. However, such an analysis is warranted given that adolescents have other needs than adults, for example simpler interfaces and different app features based on differentially identified BCTs compared to adults [218, 236, 237].

Unfortunately, at present, no coding system and legalities related to age appropriateness of apps for children and adolescents exist within the regulatory framework of the EU [238]. Second, given the cross sectional nature of the current study design no statements about the causality of the associations found could be made. Experimental research is therefore needed to further examine how nutrition and/or fitness app use influences BMI and eating behaviors or vice versa. Third, all collected data except the anthropometrics were self-reported and therefore subject to social-desirability bias. Fourth, physical activity and total energy intake were not assessed as this would have increased the participant burden considerably. The survey was already quite lengthy (±75 min), which could have increased the chance of poor quality answers at the end of the survey [211]. Three versions of the questionnaire, in which the question were placed in another order, were prepared and administered randomly (except for the demographics, these were always presented first).

5.4.3. Conclusion

A more frequent use of a commercial nutrition app was independently associated with healthier drinking habits in adolescents, but with a higher zBMI. While the interactive influence of frequently using both fitness and nutrition apps was associated with a lower zBMI and less healthy snacking habits. In addition no evidence of mediation by key determinants was found. Fitness and/or nutrition apps show some association with healthier eating behaviors in adolescents, but their potential for health promotion could probably be enhanced by incorporating more (effective) behavior change techniques.

5.4.4. Implications and future research

The present study was a first attempt to map adolescents' use of commercial health apps and to investigate the relation of using these apps with adolescents' health status in terms of snacking and drinking habits and BMI. Further research is needed to more fully comprehend adolescents' motives for using and downloading such apps. Future research should also continue to explore adolescents' use of commercial nutrition and fitness to determine the possible usefulness of the current fitness and nutrition apps for health promotion among adolescents.

Better understanding of commercial fitness and nutrition app use in adolescents can also guide efforts to develop effective smartphone interventions for healthy lifestyles. In addition to further researching the mechanisms of actions, future studies could also explore what features of commercial apps are deemed effective and liked by adolescents. Evidence from adults [216, 219, 227, 239] in this regard cannot be extended to adolescents, as adolescents have different preferences and need different behavior change techniques than adults [218].

The demand for apps that promote healthy habits is high and these apps are assumed to have a substantial potential for health promotion initiatives. At this point, however, our results together with several content analyses [217, 218], show that few effective theory-based apps are available on the app market, especially for adolescents. Public health professionals and app developers should collaborate to design more theory-based apps to be used in health promotion and fulfill the needs of the population [230]. Future research should thus focus on developing such apps, by translating and incorporate the already identified effective behavior change techniques into mobile applications and conduct experimental trials to investigate their effectiveness on the behavior of interest and its related determinants [230, 232].

Chapter 6: Adding a reward increases the reinforcing value of fruit

Redrafted after:

Nathalie De Cock; Leentje Vervoort, Patrick Kolsteren, Lieven Huybregts, Wendy Van Lippevelde, Jolien Vangeel, Melissa Notebaert, Kathleen Beullens, Lien Goossens, Lea Maes, Benedicte Deforche, Caroline Braet, Steven Eggermont, John Van Camp and Carl Lachat (2016). *British Journal of Nutrition.* In revision.

Summary

Adolescents' snack choices could be altered by increasing the reinforcing value (RV) of healthy snacks compared to unhealthy snacks. This study assessed whether the RV of fruit increased by linking it to a reward and if this increased RV was comparable to the RV of unhealthy snacks alone. Moderation effects of sex, hunger, zBMI and sensitivity to reward were also explored. The RV of snacks was assessed in a sample of 165 adolescents (15.1±1.5 years, 39.4% boys and 17.4% overweight) using a computerized food reinforcement task. Adolescents obtained points for snacks through mouse clicks (responses) following progressive ratio schedules of increasing response requirements. Participants were (computer) randomized to three experimental groups (1:1:1): fruit (n=53), fruit + reward (n=60) or unhealthy snacks (n=69). The RV was evaluated as total number of responses and breakpoint (schedule of terminating food reinforcement task). Multilevel regression analyses (total number of responses) and Cox's proportional hazard regression models (breakpoint) were used. The total number of responses made were not different between fruit + reward and fruit (b=-473 [-1152, 205], p=0.17) or unhealthy snacks (b=410 [-222, 1043], p=0.20). The breakpoint was slightly higher for fruit than fruit + reward (HR=1.34 [1.00, 1.79], p=0.050), while no difference between unhealthy snacks and fruit + reward (HR=0.86 [0.62, 1.18], p=0.34) was observed. No indication of moderation was found. Offering rewards slightly increases the RV of fruit and may be a promising strategy to increase healthy food choices. Future studies should however, explore if other rewards, could reach larger effect sizes.

6.1. Introduction

The overconsumption of energy-dense snacks contributes to excess energy intake in adolescents [18, 240]. Consumption of energy-dense snacks is primarily driven by hedonic processes such as food reinforcement rather than by homeostatic motives [76, 83]. The reinforcing value (RV) of a food or the motivation to eat, is usually assessed as the amount of work an individual is willing to perform to gain access to that food [76]. A higher RV of energy-dense snacks is associated with increased energy intake and an increased risk of obesity in children, adults and adolescents [77-80]. Unhealthy energy-dense snacks, such as chocolate and chips, have a higher RV than healthy snacks, such as fruit and vegetables, driving individuals towards unhealthy snack choices [81, 82].

Behavioral choice theory suggests that the consumption of unhealthy snacks can be decreased by either decreasing the RV of unhealthy snacks or by increasing the RV of alternatives or substitutes [81, 82, 122, 241]. To date, most research has focused on decreasing the RV of unhealthy snacks. Increasing the cost to obtain unhealthy snacks shifted choice towards healthy snacks in children and adults [81, 82]. The effect of increasing the RV of healthy snacks has not been assessed. Following the principles of operant conditioning, one might assume that adding a reward to the choice for fruit or other healthy snacks could be one possible strategy to increase the RV of healthy snacks in adolescents [114, 115, 242]. Offering rewards or praise has already been shown to enhance children's willingness to taste and consumption of healthy food items such as fruit [115, 242-244]. However, little is known about using reward-based strategies to promote healthy food consumption in adolescents. Such strategies are particularly relevant to evaluate in adolescents as they are highly susceptible to rewards and show higher activity in the reward related brain regions compared to children and adults [90, 91]. Therefore the first aim of the present study was to assess if the RV of fruit could be increased by linking fruit with a reward (RV fruit + reward vs. RV fruit alone). Second, we investigated whether the RV of fruit + reward was then comparable to the RV of unhealthy snacks (RV fruit + reward vs. unhealthy snacks).

Previous research has shown that the RV of food is influenced by individual characteristics such as sex [83, 245], weight [76, 77, 80] and hunger [83]. The RV of unhealthy snacks was found to be higher in hungry or obese participants, while the RV of caffeinated beverages was found to be higher in males [76, 77, 80, 83, 245]. Differences in hunger, sex and weight might also be related to the difference in RV of unhealthy and healthy foods [81, 83, 246, 247]. Hunger might only be associated with an increased RV of energy-dense snacks, while the RV of low-energy snacks such as fruit remain unchanged [83]. Obese or overweight individuals and boys found energy-dense and not low-energy dense snacks more reinforcing compared to their leaner peers or girls [81, 83, 246, 247]. A higher sensitivity to reward (SR), a psychobiological personality trait defined as one's ability to experience pleasure or reward on exposure to appetitive stimuli such as palatable foods [86], might also be associated with a higher RV of palatable foods. Consistent with this idea, SR was found to be associated with preferences for unhealthy snack intakes in children and adolescents [199, 248]. Individual differences in SR were already found to influence the use of rewards. Children with a high SR were more likely to taste healthy foods when rewarded [115]. High SR adolescents might thus show a higher RV for fruit + reward compared to fruit alone. The third aim of the present study was to explore whether the difference in RV between fruit + reward and unhealthy snacks or fruit was influenced by sex, BMI, hunger or SR.

6.2. Methods

This study was conducted in the context of the REWARD project, which aims to improve snacking habits of adolescents using a novel framework. REWARD combines reward sensitivity theory with behavior choice and learning theories, and focuses on the rewarding value of food and individual differences in SR to change behavior. Guided by the results of the present study, a reward-based intervention to improve adolescents' snack choices delivered through a game will be developed.

6.2.1. Participants and study design

A convenience sample of 14 to 16-year-old adolescents from five secondary schools in the vicinity of Ghent, Belgium participated in this study in November 2015. The school principle of each of the five schools selected one to five classes to participate in the present study. All students from 14 classes (±15 students per class) from the five schools were invited to participate. No exclusion or inclusion criteria were used. Participants were randomly allocated using a computer-generated sequence to one of three experimental groups (1:1:1). Participants were blinded to the group allocation, while research assistants were blinded to the study hypotheses.

To detect a difference of 25% in RV (total number of responses made) between three parallel-allocated experimental groups and possible interactions with a power of 80% a sample size of 159 adolescents was needed (PASS software version 14, NCSS, USA). Taking into account a possible non-participation due to absence, the anticipated sample size was increased to 210 students.

6.2.2. Study procedures

Participants completed the experiment together with their classmates in the school computer classroom on a weekday from 9.30 till 10.30 am (around the morning school break), from 2.30 to 3.30 pm (around the afternoon school break) or from 3.30-4.30 pm (just before the end of the school day), as these are typical times during which adolescents consume snacks [249]. Participants were asked to eat and drink normally, but to abstain from eating or drinking (except water) for at least 2 hours prior to the experimental session. At the beginning of the session participants were provided with a choice of two isocaloric preloads (sandwich with ham or cheese, ±180 kcal). The consumption of this standard preload diminishes the effects of hunger on food reinforcement and increases the ability of observing individual differences in food reinforcement [250]. After eating this preload, adolescents started the experiment. Half of the participants started the experiment with the general questionnaire and the height/weight measurements; while the other half, the adjacent sitting participants, started with the computerized food reinforcement task (FRT) to measure the RV of food and the hunger questionnaire. Adolescents completed the FRT to gain points to trade for fruit (experimental group 1), unhealthy snacks (experimental group 2) or fruit + reward (experimental group 3) at the end of the task. Participants could choose the fruit or unhealthy snacks they wanted to earn points for. The five fruits options were: grapes, apple, pear, plum or tangerine and the five unhealthy snacks: candy bar, chocolate, marshmallows, cookies or potato crisps. Adolescents in the fruit + reward group were informed that not only could they earn points to receive fruit portions at the end of the task, but also that the person with the highest number of points obtained could become the class winner. This message was displayed on a specific slide during the introduction of the FRT and was only visible to the fruit + reward group. The other two experimental group were unaware of the competition and were only informed that their points gathered in the FRT would earn them fruit or unhealthy snack portions at the end of the task. The possibility to become the class winner through a competition was chosen as reward, as intangible rewards are thought to not disturb intrinsic motivation [251] and competition and winning appeals to youngsters, especially in a game context [135, 252]. Before the experiment, participants were told that the study intended to examine participant's abilities to concentrate on a monotonous task and that this task would be different for everyone. After the experiment, adolescents were informed about the actual purpose and design of the study. A lottery was organized and some adolescents were rewarded with voucher worth 10€.

6.2.3. Ethics

Active written informed consent forms and study information folders for the parents were distributed a few days prior to study commencement and collected during the test. Before the test, adolescent participants were also asked to compile a written informed consent form. This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects were approved by the Ethics Committee of the Ghent University Hospital.

6.2.4. Measures

Both the general and hunger questionnaires were online questionnaires and administered on a computer. The general questionnaire assessed the individual characteristics of the participants and the hunger questionnaire the hunger feeling of the participants prior to the FRT.

6.2.4.1. Individual characteristics

Both sex and date of birth were assessed with one-item questions. Age was then derived by subtracting the date of birth from the date the survey took place.

Consumption frequency of snacks was measured with a one-item question ‘How often do you normally consume a snack?’ according to four categories 1=once a week or less, 2=more than once a week, 3=every day and 4=more than once a day.

SR was measured using the BAS drive subscale of the Dutch child version of Carver and White’s BIS/BAS scale [93]. This scale consists of four items, scored on a 4-point scale (1 = not at all true, 2 = somewhat not true, 3 = somewhat true, 4 = all true) and summed to obtain the BAS drive score, with a higher score indicating more SR (range 4-16). This BAS drive subscale was chosen to measure SR as previous research in children, adolescents and adults had already shown that mainly BAS drive (DRV) was associated with food intake and eating styles [87, 97, 212] and that it is a valid instrument to measure SR in children and adolescents [93, 253]. Internal consistency of the BAS drive score in the present sample was good (Cronbach’s α=0.83).

Height and weight were measured by two trained research assistants using a standardized protocol. Adolescents were measured wearing light clothing and without shoes. Body height was measured with a Leicester Portable Stadiometer (SECA, Hamburg) with an accuracy of 1 mm. Weight was measured with a calibrated electronic scale SECA 861 with an accuracy of 100g. Age and sex-specific BMI z-scores (zBMI) were calculated using Flemish 2004 growth reference data [186].

Hunger before the experiment was measured by a one-item question ‘How hungry do you feel at the moment?’, evaluated on a 7-point Likert scale with anchors 1=‘not hungry at all’ and 7=‘extremely hungry’ [76, 80].

6.2.4.2. Food reinforcement task

The RV of the different snack foods was measured using a FRT with a progressive ratio (PR) schedule. At the beginning of the FRT, participants received a brief introduction on the screen informing them that they could earn points to trade for food by clicking the mouse button (=response) and that increasingly more responses would be needed to obtain points. Subsequently adolescents in fruit + reward group additionally received the competition message on the screen. After this introduction and according to the allocated experimental group, the participants chose which specific unhealthy snack or fruit item they wanted to trade earned points for through the FRT. After indicating their preference, participants started the FRT. Points were earned according to a PR schedule that began at 2 (called PR2) and progressed through PR4, PR8, PR16, PR32, PR64, PR128, PR256 and PR512. In the first schedule (PR2), the participants gained 1 point for each second response, in the second level (PR4) participants gained 1 point after four responses and so on. When 20 points were obtained, the participant progressed to the next PR schedule. When participants were no longer motivated to work for food, they terminated the task by pressing the space bar. To avoid satiation and/or habituation, participants only received their food portions earned after they had decided to terminate the task. Participants were informed (during the introduction) that for each point earned, they either received 10 grams of fruit or 5 grams of unhealthy snacks (depending on their allocated experimental group) at the end of the task. Twice as many points were needed to obtain the same amount of unhealthy snacks compared to fruit, because a meaningful portion of fruit (e.g., a tangerine) usually weighs more than a meaningful portion of the unhealthy snacks (e.g., a handful of potato crisps). Similar to previous studies that assessed the RV of food using PR schedules [76, 254], the outcomes of the experiment were the total number of responses made across all PR schedules (=total number of mouse button clicks) and the breakpoint or the PR schedule, where the adolescent decided to terminate the FRT (=schedule of terminating the FRT)

6.2.5. Statistical analyses

First, the difference in the total number of responses made (=dependent variable) between the experimental groups and the subsequent moderation analyses were assessed using a multilevel linear regression model with two levels (adolescents nested within classes) to account for the clustering. Our analysis strategy entailed the computation of six models. Model 1 was an intercept-only model without any level 1 or level 2 independent variables. Model 2 evaluated the effect of the experimental group, which was added as a categorical independent variable with three categories (fruit + reward=reference category, fruit, and unhealthy snacks). Models 3 to 6 evaluated the possible moderation effects of sex, zBMI, hunger or SR in separate models by adding the moderator and the interaction moderator X experimental group as independent variables to model 2. Continuous parameters were mean centered, unstandardized coefficients and their standard errors were reported and associations with p-values <0.05 were considered statistically significant. As the total number of responses was positively skewed, square root transformations (best-fitting transformation) were applied to produce a normal distribution. The findings both for the raw and the square root transformed data were similar and hence the analyses of the raw data were presented to facilitate interpretation.

Second, the difference in the breakpoint (=dependent variable) between the experimental groups and the subsequent moderation by SR, sex, zBMI or hunger were assessed using survival analysis. Cox proportional hazards models were used to model the schedule reached when terminating the FRT (=breakpoint). Censoring was applied when adolescents reached the end of the FRT (PR 512), however no participant actually reached this schedule. In model 1 the hazard ratios (HR) of fruit vs. fruit + reward and unhealthy snacks vs. fruit + reward were computed and the estimated survival curves for each experimental group were plotted. For instance, a HR of 1.2 for fruit vs. fruit + reward indicates that at any given FR schedule, the risk of terminating the computer task is 1.2 times higher for fruit than fruit + reward. Models 2 until 5 assessed moderation effects of SR, sex, zBMI or hunger before the experiment. Separate models were developed by adding the moderator and the interaction term moderator x experimental group to model 1 as independent variables. Schedule of reinforcement reached was recoded to represent time until they stopped responding as followed PR2=1, PR4=2, PR8=3, PR16=4, PR32=5, PR64=6, PR128=7, PR256=8 and PR512=9. Standard errors and confidence intervals of the coefficients were adjusted for possible dependency of participants/observations within a class by using a clustered sandwich estimator. The Breslow method was used to handle ties. The proportional hazards assumption that the hazard or risk remains constant over time was tested with the Grambsch and Thernay test of the Schoenfeld residuals [255].

All analyses were conducted using Stata version 13 SE (Stata Corporation, Texas, USA).

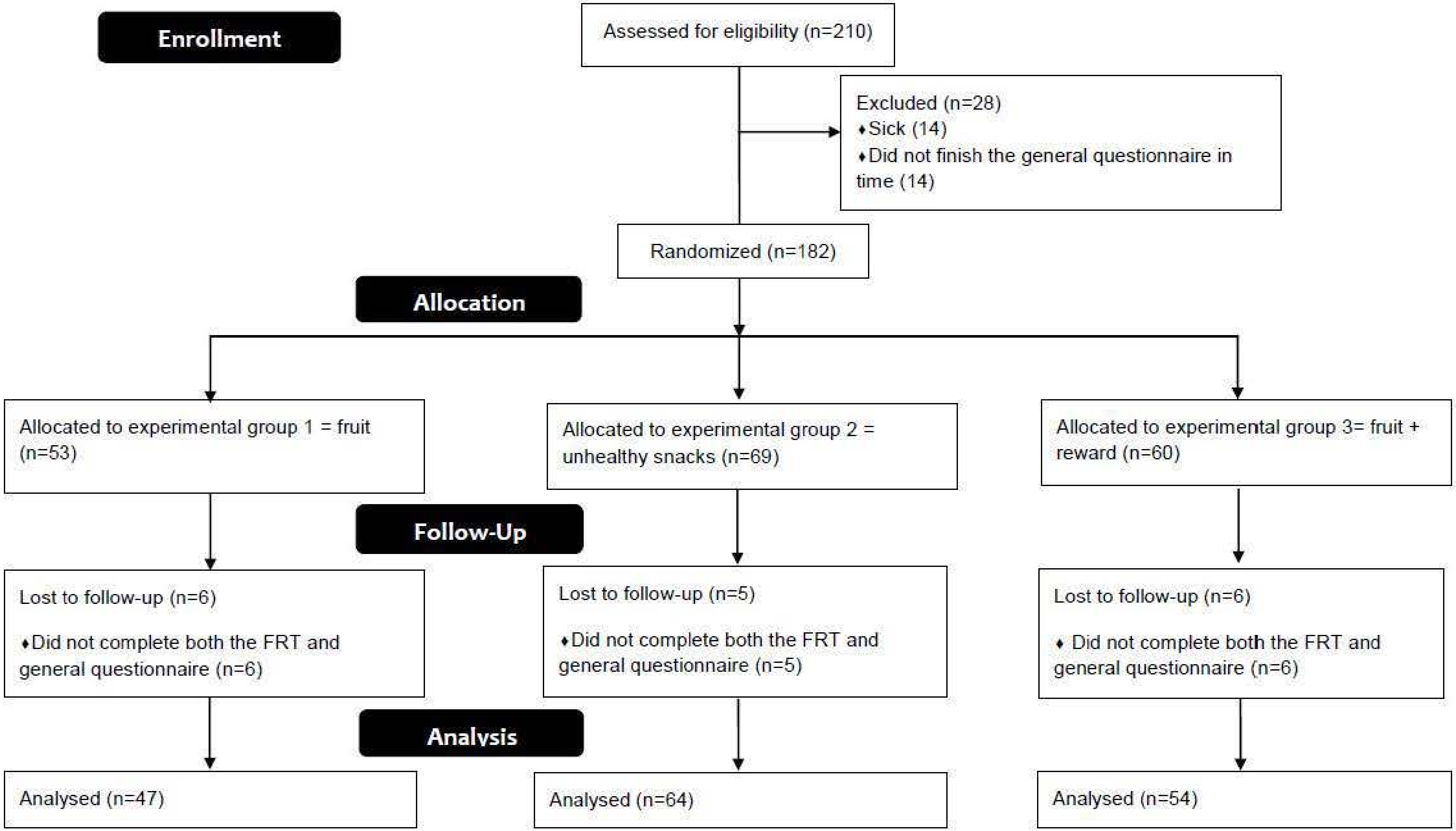


Figure 14: Consort flow chart

6.3. Results

6.3.1. Participants

Of the 210 selected adolescents, 14 (6.7%) were unable to participate due to school absence, thus 196 adolescents participated in the study. Of these 196 participating adolescents, 182 were randomized and completed the FRT (see Figure 14). 14 participants (7.1% of the 196), who started with the general questionnaire, did not complete this questionnaire and therefore could not start the FRT. 18 (9.9% of the 182 randomized participants) participants, who started with the FRT, did not finish the general questionnaire. A total of 165 adolescents thus completed both the FRT and the general questionnaire and were included in the analysis (see Figure 14). The mean age was 15.1±1.5 years, 39.4% were males. Of the adolescents 30.3% ate a snack every day and 22.4% ate two or more snacks per day. Percentages or mean scores and standard deviations (SDs) for age, snack frequency, sex, SR, hunger before the experiment, zBMI and total number of responses according to experimental group are presented in **Fout! Verwijzingsbron niet gevonden.**.

Table 17: Participant characteristics according to experimental group

	Fruit (n=47)	**Fruit + reward (n=54)**	**Unhealthy snack (n=64)**
	% or mean (SD)	**% or mean (SD)**	**% or mean (SD)**
Boys	40.4%	38.9%	39.1%
Ate a snack each day	27.7%	31.5%	31.3%
Ate two or more snacks per day	17.0%	24.1%	25.0%
Age	15.02(0.84)	15.21(0.87)	15.02(2.13)
Hunger feeling before the experiment [1-7]	3.12(1.68)	3.53(1.43)	3.28(1.52)
zBMI	0.41(0.96)	0.13(0.92)	0.38(0.91)
SR [4-16]	9.49 (2.64)	9.74 (3.22)	9.83 (2.96)
Total number of responses made	1712.68 (1412.84)	2270.93 (1853.91)	2672.88 (1822.66)

SR, sensitivity to reward; zBMI body mass index z-scores; SD, standard deviation

6.3.2. Total number of responses made

The intercept only model (model 1) showed that overall, adolescents made an average of 2254±191 responses in the FRT (Table 18). Model 2, with experimental group as independent variable, indicated that there are no significant differences in total number of responses between the fruit + reward and the fruit only (p=0.17) or the unhealthy snack (p=0.20) group. Adolescents in the fruit only group made on average 473 [-1152, 205] responses less than for fruit + reward and the unhealthy snacks group showed 410 [-222, 1043] responses more compared to the fruit + reward group.

6.3.3. Breakpoint

The HR was marginally significantly higher for the fruit only group compared to the fruit + reward group (Table 19). The risk of terminating the task at any schedule was 1.34 times higher when responding for fruit than for fruit + reward (HR=1.34 [1.00, 1.79], p=0.050). The risk of terminating the task for participants of the unhealthy snacks group was similar to the risk in the fruit + reward group (HR=0.86 [0.62, 1.18], p=0.34). The estimated survival function for each of the experimental groups is shown in Figure 15.

6.3.4. Moderation by sex, zBMI, hunger or RS

For total responses made, no indication of moderation by sex, zBMI, hunger or SR was found (p> 0.05 for all interaction terms, see Table 18). Model fit only significantly improved (compared to model 2) for the moderation models with zBMI (model 4) and hunger (model 5).

Similarly for the breakpoint no moderation by sex, zBMI, hunger or SR was observed (p> 0.05 for all interaction terms, see Table 19). Model fit only significantly improved (compared to model 1) for the moderation models with zBMI (model 3) and hunger (model 4).

Table 18: Effect of experimental group on the total number of responses made

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	b [CI 95%]	**b [CI 95%]**	**b [CI 95%]**	**b [CI 95%]**	**b [CI 95%]**	**b [CI 95%]**
Constant	2253.68 [1879.95, 2627.40]***	2233.29 [1700.76, 2765.81]***	1993.42 [1235.33, 2751.51]***	2135.85 [1593.87, 2677.83]***	2199.27 [1625.87, 2772.66]***	2234.69 [1707.22, 2762.17]***
Unhealthy snack vs. fruit + reward		410.3719 [-222.41, 1043.16]	287.65 [-685.02, 1260.34]	510.95 [-163.61, 1185.52]	400.00 [-221.88, 1021.88]	401.48 [-226.17, 1029.13]
Fruit vs. fruit + reward		-473.26 [-1151.94, 205.41]	-326.45 [-1367.10, 714.20]	-331.41 [-1058.31, 395.48]	-491.02 [-1141.76, 159.72]	-481.87 [-1154.94, 191.21
Sex (girl vs. boys)			379.07 [-535.48, 1293.62]			
Sex x snack			220.92 [-1037.25, 1479.09]			
Sex x fruit			-234.56 [-1565.58, 1096.46]			
zBMI				-55.26 [-576.79, 466.26]		
zBMI x snack				58.19 [-661.08, 777.46]		
zBMI x fruit				136.83 [-625.47, 899.13]		
Hunger					72.97 [-239.55, 385.50]	
Hunger x snack					196.48 [-208.79, 601.75]	
Hunger x fruit					68.62 [-346.81, 484.06]	
SR						70.90 [-68.85, 210.66]
SR x snack						30.84 [-166.34, 228.03]
SR x fruit						-104.95 [-335.30, 125.40]
Log likelihood	-1465.06	-1461.47	-1460.21	-1275.06	-1244.11	-1459.93
2 Δ Log pseudo likelihood (Δdf) [a]	na	na	2.52 (3)	372.82 (3)***	434.72 (3)***	3.08 (3)

SR, sensitivity to reward; zBMI body mass index z-scores; CI, confidence interval; * p<0.05, ** p<0.01, *** p<0.001; [a] compared to model 2; coefficients were obtained via multilevel modelling (adolescents nested within classes) with the total number of responses as dependent variable and experimental group as independent variable (fruit + reward=reference group)

Table 19: Effect of experimental group on the breakpoint

	Model 1	Model 2	Model 3	Model 4	Model 5
	HR [95%CI]	**HR [95%CI]**	**HR [95%CI]**	**HR [95%CI]**	**HR [95%CI]**
Unhealthy snack vs. fruit + reward	0.86 [0.62, 1.18]	0.95 [0.58, 1.55]	0.81 [0.63, 1.10]	0.83 [0.63, 1.10]	0.86 [0.62, 1.19]
Fruit vs. fruit + reward	1.34 [1.00, 1.79]*[a]	1.54 [0.97, 2.44]	1.22 [0.89, 1.67]	1.36 [1.03, 1.79]*	1.33 [1.00, 1.79]
Sex (girls vs. boys)		0.92 [0.61, 1.40]			
Sex x snack		0.85 [0.40, 1.78]			
Sex x fruit		0.81 [0.44, 1.46]			
zBMI			1.02 [0.74, 1.40]		
zBMI x snack			1.00 [0.67, 1.48]		
zBMI x fruit			0.88 [0.63, 1.24]		
Hunger				0.97 [0.83, 1.13]	
Hunger x snack				0.94 [0.78, 1.14]	
Hunger x fruit				0.99 [0.83, 1.17]	
SR					0.98 [0.96, 1.00]*
SR x snack					1.00 [0.94, 1.06]
SR x fruit					1.01 [0.93, 1.11]
Log pseudo likelihood	-734.81	-733.83	-621.73	-611.60	-734.51
2 Δ Log pseudo likelihood (Δdf) [a]	na	1.96 (3)	226.18 (3)***	246.42 (3)***	0.60 (3)

SR, sensitivity to reward; zBMI body mass index z-scores; HR, hazard ratio, CI, confidence interval; * p<0.05, ** p<0.01, *** p<0.001; *[a] p=0.050; [a] compared to model 1; coefficients were obtained via Cox's proportional hazard modelling with schedule of terminating the task as dependent variable and experimental group as an independent variable (fruit + reward=reference group) , robust SEs were calculated with a clustered sandwich estimator

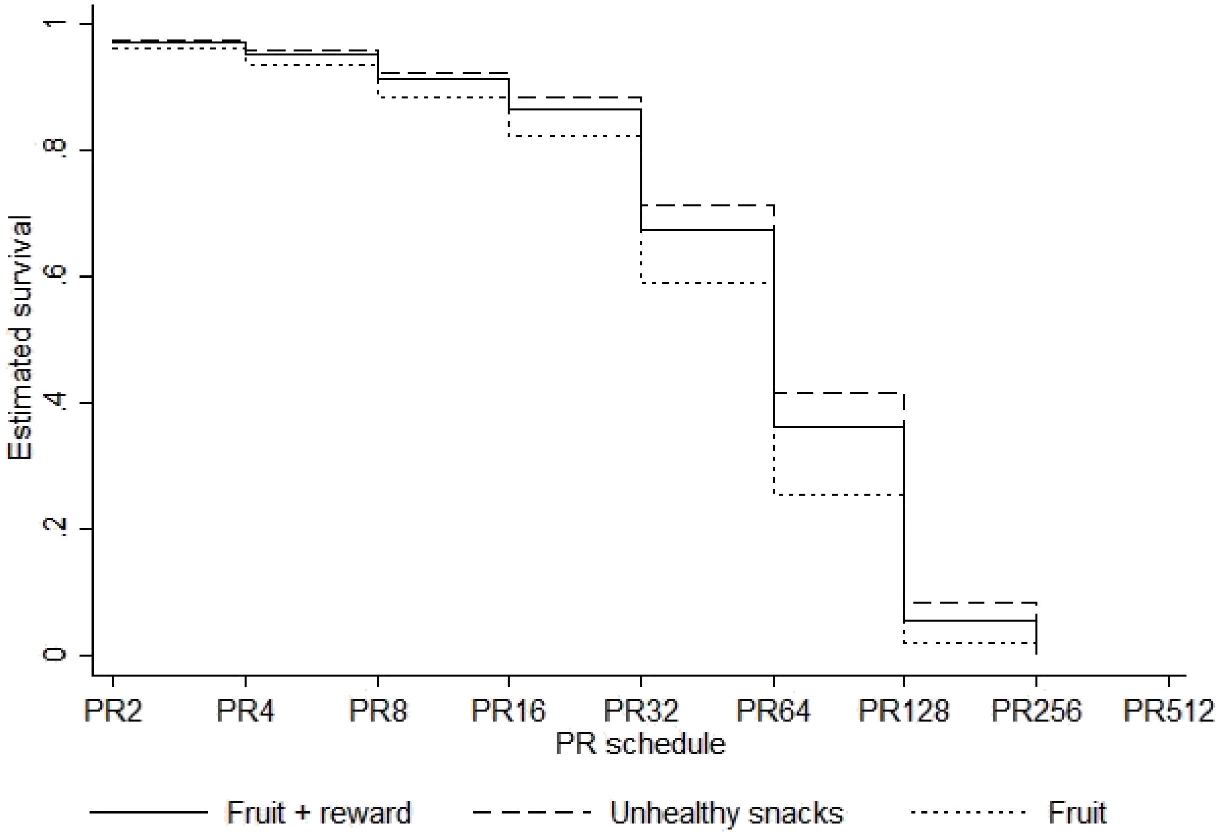


Figure 15: Estimated survival function for each of the experimental groups.

PR, progressive ratio; estimated survival functions were obtained from the Cox's proportional hazard model with schedule of terminating the task as dependent variable and experimental group as independent variable (fruit + reward=reference group)

6.4. Discussion

The present study investigated whether linking fruit with an intangible reward, could significantly increase the RV of fruit and if this observed increased RV was comparable to the RV of unhealthy snacks in an adolescent sample. The RV, in terms of breakpoint, of fruit + reward was found to be marginally higher by 34% than the RV of fruit and not significantly different from that of unhealthy snacks.

To date, no studies have evaluated the RV of fruit or unhealthy snacks in terms of breakpoint analyses. This is unfortunate as Bickel et al. (1999 and 2000) showed that peak response measures, such as the total number of responses made, are less robust than breakpoint to detect differences in reinforcing value between different reinforcers [256, 257]. Bickel found that the reinforcer (cigarettes vs. money) that had the highest peak response varied across participants, while the reinforcer with the largest breakpoint was the same in all participants [257].

The breakpoint in the present study was marginally higher for fruit + reward than for fruit and not significantly different from unhealthy snacks. The hazard ratio of the fruit group was however, 34% higher than for fruit + reward group and the unhealthy snacks group had hazard ratio that was 14% lower than the fruit + reward group. Adolescents in the fruit + reward group hence had a 34 % lower risk to stop responding at lower schedules of reinforcement. In other words, they were willing to do 34% more effort to obtain fruit than adolescents in the fruit only group. To our knowledge, no other studies have evaluated the breakpoint by means of survival analysis. The present analysis however is favorable over traditional approaches that compare the mean breakpoint, as it allows assessing the chance (the risk) of terminating the FRT at each schedule. The latter is of particular interest as chances to terminate the FRT are usually smaller for low PR schedules and higher for high PR schedules [258].

The RV, in terms of the total number of responses made, was not significantly different between the different experimental groups. The RV of fruit + reward was not significantly higher than fruit and not significantly different from unhealthy snacks. Adding a reward to fruit, the experiment diminished the difference in the total number of responses between fruit and unhealthy snacks by 38%. Adolescents responded on average 56% more for unhealthy snacks than for fruit and only responded 18% more for unhealthy snacks than for fruit + reward. Although previous studies already compared the RV of fruit and unhealthy snacks in terms of total number of responses made, no other studies have investigated the possibility to increase the RV of fruit [81, 82]. Previous experiments indicated that adults increased responses by 20 [81] or 15% [82] for unhealthy snacks compared to fruit, given equal response requirements [81, 82]. The smaller difference in RV observed compared to our study, maybe due to the fact that the latter studies evaluated the RVs of fruit and unhealthy snacks relative to another, while we measured the absolute RV [76]. Epstein et al. (2007) states that the absolute and relative RV of foods are however, similar when the alternative presented during the experiment is not very reinforcing. The relative RV can be smaller than the absolute RV when the alternative itself is also reinforcing [76]. Vervoort et al. (2016) also measured the absolute RV in adolescents, but found a larger difference in RV between fruit and unhealthy snacks compared to our study [247]. The larger difference in the study by Vervoort et al. (2016) could be explained by the sequential design of the study as the RV of fruit and unhealthy snacks were measured in the same participants in sequential order. In the group that responded for unhealthy snacks first, adolescents responded 162% more for unhealthy snacks than for fruit; while in the group that worked for fruit first, adolescents responded 16% less for unhealthy snacks than for fruit [247].

The RV of food is considered a good predictor of food choice, food consumption and obesity [76]. Therefore, our study suggests that offering intangible rewards may help to promote healthy food consumption. We thereby add to the findings from previous research conducted in children that using rewards may increase liking, wanting and consumption of healthy foods when used appropriately [115]. However, in this study we tested the RV of fruit + reward, fruit and unhealthy snacks as absolute, we did not take into account what would happen when an individual is presented with an actual choice between snack options [259]. Both clinical (relative choice experiments) and field studies are still needed to further confirm our findings and to conclude that increasing the RV of fruit by rewarding strategies may change adolescents' snack choices. Within this study only a small effect size (HR>1.3) [260] was achieved for the breakpoint of fruit + reward vs. fruit alone and both the breakpoint and total number of responses for unhealthy snacks were still larger than for fruit + reward. To maximize the chance that adolescents would actually favor healthy snacks over unhealthy snacks, the RV of fruit + reward should be further increased and other more potent type of rewards that could augment the RV of fruit should thus still be explored. Other studies have already showed that giving stickers increased fruit and vegetable intake on the short-term in children [118] and that providing access to high-preference activities increased physical activity [172]. Strategies other than adding an additional reward to increase the RV of fruit should also be explored. The RV of fruit could also be altered starting from the principles of classical conditioning, by influencing adolescents' affective associations about fruit [114, 261]. Previous research has shown that repeatedly pairing fruit stimuli (pictures of fruit) with positive stimuli (positive words or positive images), increased the chance of choosing fruit over unhealthy snacks when offered the choice [261]. Epstein et al. (2007), Vervoort et al. (2016) and Jacques-Tiura and Greenwald (2016) also suggested that strategies to increase the RV of healthy foods should be combined with strategies to decrease the RV of unhealthy foods. This would increase the chances that people would alter their food choice and consumption habits [76, 247, 262]. Known methods to decrease the consumption of unhealthy snacks are to increase the costs (for example food taxing), to decrease the variety of unhealthy snack options and to decrease the portion size [76, 247, 262, 263]. To increase the consumption of healthy snacks methods other than rewards include subsidies, increasing variety of healthy snack options and making healthy snacks the default option in restaurants and cafeterias [76, 247, 262, 263].

In addition it also known that individual characteristics influence the difference in RV of healthy foods and unhealthy foods [81, 83, 246, 247], the effect of rewarding strategies [115] and in general the RV of food [76, 77, 80, 83, 245]. We therefore assessed if individual characteristics such as sex, BMI, state of hunger or SR moderated the difference in RV of fruit + reward and unhealthy snacks or fruit in adolescents. In the present study neither sex, zBMI, hunger nor SR significantly moderated the difference in RV between the fruit+ reward and fruit or unhealthy snacks. To date, most research on the role of individual characteristics explaining differences in RV was carried out in children and adults, and focused solely on the RV of unhealthy snacks and not on the differences in RV between different alternatives [76, 83]. Only one other study researched the influence of individual characteristics (sex and SR) on the difference in RV of healthy and unhealthy snacks in adolescents [247]. Within this study also no moderation by SR could be documented, however a significant difference between boys and girls was found [247]. The difference in RV between fruit and unhealthy snacks was found to be larger for boys than girls [247]. As this is the first study that attempted to increase the RV of healthy snacks such as fruit, more research should be executed to further explore and confirm our findings that neither sex, BMI, the state of hunger or the SR influenced the difference in RV between fruit + reward and unhealthy snacks or fruit. Several additional individual characteristics such as restraint and habituation are also known to influence the RV of food in children and adults [83, 264], and are yet to be assessed in this regard.

This study is not without limitations. Adolescents completed the task together with their classmates in the same room. This set-up stimulated the desired competition feeling and made the possibility to be class winner realistic for the fruit + reward group. Nonetheless this set-up, also enabled interactions between the adolescents. The spillover effects were minimized as much as possible by the continuous presence of a researcher during the execution of the experiment. In addition, the order of completing the general questionnaire and the FRT was alternated for adjacent adolescents. Despite the fact that adolescents received a screen with snack choices according to their experimental group, it was possible that they observed differences in screens and thus realized that they were allocated to different groups. The researchers present in the room were also able to observe the different snack choice screens and were hence also not blinded to the allocation of the experimental groups. A discrepancy between the experimental setting and natural eating environments exists and generalizability to real life situations might be limited. However, experimentally measured RV has shown to have predictive validity for food intake and eating behaviors [76]. Several studies already showed that the RV of foods measured in the laboratory is related to both laboratory energy intake and usual energy intake outside of the laboratory [79, 265, 266]. This experiment was primarily powered to detect an increase in RV from the fruit group. To ascertain equality of RV between the fruit + reward and unhealthy snacks however, an equivalence hypothesis is assumed. Post-hoc power analysis in PASS 14 (NCSS, USA) showed that equivalence could be detected in a sample of 110 adolescents (n=54 for the fruit + reward group and n=64 for the unhealthy snacks group) with a power of 80% for a margin (Δ) of 900 responses. As this margin is more than double the actual observed difference between both groups, we are confident that adding reward to fruit increased RV to levels comparable to unhealthy snacks. The results of the present study are limited to 14-16 year old adolescents, to a specific reward (class competition) and to a range of specific healthy and unhealthy snacks. More research is needed to extend the current findings to other age-groups, rewards and types of snacks.

In conclusion, our results showed that linking an intangible reward to fruit increases the motivation to obtain fruit to an extent that it is comparable to the motivation to obtain unhealthy snacks. Offering rewards could thus be a promising strategy to increase healthy food choices, but it should still be tested in choice experiments and intervention studies whether or not combined with strategies to increase the cost of unhealthy foods. In addition future studies should also explore if other types of rewards, or other strategies to increase the RV of fruit, could reach larger effect sizes. Future research should also further explore the role of individual characteristics in light of the rewarding strategies proposed.

Chapter 7: Feasibility and effect of a reward-based mobile application to improve adolescents' snacking habits

Nathalie De Cock, Wendy Van Lippevelde, Jolien Vangeel, Melissa Notebaert, Kathleen Beullens, Steven Eggermont, Benedicte Deforche, Lea Maes, Lien Goossens, Sandra Verbeken, Ellen Moens, Leentje Vervoort, Caroline Braet, Patrick Kolsteren, Lieven Huybregts, John Van Camp and Carl Lachat

Summary

Background: Snacking habits are partly driven by hedonic processes and the reinforcing value of food. Interventions to improve the snacking behavior of adolescents should acknowledge hedonic pathways and differences in sensitivity to food rewards. Smartphone applications provide an interesting tool to reach adolescents individually. Applying both implicit rewarding strategies and explicit reflective strategies, this study evaluated the feasibility and effect of the “Snack Track School” app on adolescents’ snack intake.

Methods: A total of 1463 adolescents aged 14 to 16 years were sampled to participate in this pre-post clustered controlled trial. The adolescents in the intervention schools (n=3) could use the app for four weeks, while adolescents in the control schools (n=3) followed the regular curriculum. Outcomes were differences in healthy snacking ratio (intake healthy snacks over total intake snacks) and key determinants (awareness, intention, attitude, self-efficacy, habit and knowledge). Process evaluation data were collected via a questionnaire post intervention (satisfaction) and through log data of the app (exposure).

Results: Data of 988 adolescents (n=416 intervention and n=572 control, 3 schools (clusters) each) were analyzed. No significant positive effects of the intervention on the healthy snack ratio (b=-3.52±1.82, p>0.05) or targeted determinants could be observed. Only 268 adolescents in the intervention group started using the app, of which only 55 (20.5 %) still logged in after 4 weeks. Within this small group of users a higher exposure was also not significantly associated with positive intervention effects. Satisfaction ratings of the app were low in both the high and low user group. Moderation analyses revealed small positive intervention effects on the healthy snack ratio in high reward sensitivity boys.

Conclusion: The current application was not able to improve adolescents’ snack choices. Only a small group of adolescents used the app as intended. Several important modifications to the design of the app are warranted. Small positive intervention effects were however, observed within the subgroup of high SR adolescent boys, but not in girls. Tailoring the app depending on sex and SR might also thus be needed.

7.1. Background

Adolescence is a crucial period for the adoption of eating behaviors [2, 144]. Dietary patterns that develop during adolescence track into adulthood and have implications for the development of chronic diseases later in life [5, 6]. Adolescents have increased energy and nutrient requirements to account for growth and physiological, psychosocial and cognitive development [2, 144]. However adolescents typically adopt unhealthy eating behaviors. Especially the overconsumption of energy-dense snack foods in between meals [18, 26, 61] and the associated excess energy, sugar and fat intake [5, 18, 19] is of concern. On the other hand, healthy snacking could help meet the recommendations of essential food groups such as fruit and dairy [18, 26, 61].

Most of the interventions to improve the dietary behaviors of adolescents have focused mainly on changing psychosocial determinants [54, 107]. Eating behaviors however, are the result of joint function between explicit (reflective/psychosocial) and implicit (habitual/automatic) processes [42]. These two interconnected mental systems each operate according to different principles [42, 59], the top-down explicit/reflective system refers to the cognitive efforts to build beliefs and decisions and the bottom-up implicit/automatic system to the linkage of certain stimuli or cues to certain behaviors based on earlier learned associations [11, 26]. Both systems should thus be considered to alter eating behaviors effectively. Effective strategies to target the explicit pathway are well established and could be derived from the control theory of Carver and Scheier [109]. The control theory states that people control their perceived environment by means of their behavior [109]. Michie and colleagues reported that interventions combining self-monitoring with at least one other technique derived from the control theory (like goal setting) were the most effective to improve eating or physical activity behaviors [110].

Recently research has started to recognize the habitual nature of eating [56, 60, 62, 112] and more specifically of snacking in adolescents [113]. Habits can be defined as learned sequences of acts that have been reinforced in the past by rewarding experiences and that are triggered by the environment to produce behavior [56]. Habits might arise from hedonic eating processes driven by hedonic characteristics of foods, more specific its rewarding value [56, 60, 63, 64, 86, 173]. The rewarding value of energy-dense snacks is typically higher than that of healthy snacks such as fruit and vegetables [81, 171, 172, 247]. However, not everyone indulges in the consumption of highly rewarding foods. People differ in their sensitivity towards noticing and approaching natural rewarding stimuli such as highly palatable foods [73, 74, 84]. In particular, children, adolescents and adults with increased sensitivity to reward (SR) tend to consume more unhealthy snacks, overeat and have higher risk of becoming overweight or obese [75, 86, 87, 212, 248, 267]. SR is a psychobiological trait, which can be defined as the tendency to engage in motivated approach behavior in the presence of rewarding stimuli [85-87]. Compared to children and adults, individual SR characteristics and food-related hedonic processes have a stronger influence on eating behavior in adolescents [90, 91]. Therefore, targeting these habitual hedonic eating processes is crucial. Offering rewards has already shown to increase the RV, the liking, the wanting and the consumption of healthy foods in children and adolescents [115, 116, 118, 244] (De Cock el al. 2016, submitted) and might thus be effective to target the habitual/automatic pathway.

Children and adolescents may react differently to different behavior change strategies, depending on their personal characteristics [113, 115, 268, 269]. Personality theories assume that unique individual characteristics play a role in the expression of eating behavior [86, 270]. Individual differences in SR were shown to be associated with adolescents' snack intake [212]. Rewarding strategies were already found to work better in high SR vs. low SR toddlers in improving willingness to taste [115]. Following the definition of SR, it would thus be expected that rewarding strategies might work better in high SR adolescents in promoting healthy snack intakes. However, the relation between SR and adolescents' snack intake was found to be moderated by sex [115, 212] and also differences in SR between boys and girls exist [115, 270, 271], therefore both differences in SR and sex should be considered in the light of the effect of rewarding strategies in improving adolescents' snack intakes.

As most adolescents own a smartphone or tablet [14-16] and use health related apps (De Cock el al. 2016, submitted), mobile applications (apps) could provide an attractive tool for interventions in adolescents. Apps can reach a large number of users and provide new or more efficient opportunities for tailoring, multiple functionalities such as interactive possibilities and feedback opportunities and a more engaging way of behavior change [18-20]. Recent intervention studies using apps to change adults', adolescents' or children's health behaviors have already produced some promising findings [123, 272, 273].

The present study firstly evaluated both the feasibility (process evaluation) and effect of the "Snack Track School" app intervention to promote healthy snack intakes in adolescents. Positive effects were expected on adolescents' healthy snack intakes and targeted determinants (awareness, intention, attitude, self-efficacy, habit and knowledge). The app incorporated both rewarding strategies to influence the implicit/automatic processes and reflective methods derived from the control theory to target the explicit pathways. The process evaluation was considered as important as the assessment of the efficacy of the intervention. Second moderation of the intervention effects by SR and sex was also explored.

7.2. Methods

7.2.1. Overview and design

The intervention was a pre-post controlled clustered trial conducted from January until April 2016 in six secondary schools (3 intervention schools, 3 control schools) in two cities with comparable socio-economical characteristics, population density and size in Flanders, Belgium. The adolescents in the intervention schools received a four-week mobile app intervention, called "The Snack Track School". The control schools continued their usual school curriculum and practices. The full study period consisted of a pre-test, the four-week intervention and a post-test immediately after the intervention. The trial adhered to the Helsinki declaration. Approval for the trial was provided by the Ethics Committee of the University Hospital of Ghent University and the University of Leuven. Permission was asked from the school authorities (school board and headmasters) and the parents (passive informed consents). The trial was registered at clinicaltrials.gov (trial number NCT02622165). A full description of the protocol of the intervention study has been previously described [274].

7.2.2. Participants, sampling, allocation and blinding

The target population consisted of 14- to 16- year-old Flemish adolescents (i.e., grade 3 and 4 of Belgian secondary schools). The sample size was calculated based on the healthy snacking ratio (i.e., the primary outcome measure). Assuming an intraclass correlation (ICC) of 0.02 at school level and an ICC of 0.03 at class level with a mean and standard deviation of the healthy snacking ratio of 37.8±20.2, at least 12 classes with 15 adolescents per school (3 intervention schools and 3 control schools) were needed to detect a difference of 20% between intervention and control in healthy snacking ratio at the 5% significance level with a power of 80% [275]. The ICC's, mean and standard deviation of the healthy snacking ratio were based on the earlier cross-sectional REWARD study and the test-retest of the REWARD FFQ to measure snack intake [183, 212]. To account for attrition an additional 33% of study subjects were sampled, leading to a total sample of 1,436 adolescents (control and intervention) in 16 classes per school. No exclusion criteria were applied.

7.2.3. Procedure

he baseline assessment took place in January 2016. The app was launched at the schools in February 2016. Smartphones (Microsoft Lumia 435) were provided to adolescents without smartphone, enabling participation of all adolescents. During the launch of the app a tutorial on how to download the game and a short intro stating the main purpose of the app (tracking their snack intake) was given. A tutorial summarizing how to use the app was incorporated in the app. In the first four minutes of the app adolescents were informed about the main features such as the locker and the snack track tool by “Byte” one of the app’s characters. During the four weeks of the intervention however, the adolescents only received minimal guidance. Weekly process-evaluation (focus group discussions) was carried out in the intervention schools during the four-week intervention period to gather insights on the use of the app by the adolescents. Within these weekly process-evaluation moments also questions and/or problems could be asked or reported about the app to the researchers. The post survey took place in March and April 2016. Teachers and other school personnel were minimally involved in the implementation and evaluation of the intervention. After the intervention also focus group discussions were held with the teachers of the intervention schools.

7.2.4. Intervention

The intervention was developed according to the principles of the Intervention Mapping protocol [37], with the addition of an extensive participatory approach involving adolescents, teachers, principals and stakeholders from food industry, professional organizations active in health promotion, community members, umbrella school organizations. Adolescents were involved in both the conceptual (focus group research among 101 adolescents) as well as the pretesting phase of the intervention (small test groups to regularly gather feedback regarding feasibility, usability, and attractiveness of the app). Monthly teacher contacts (two per participating school) were also included during the process to ensure that the app format was fully compatible with existing pedagogic guidelines, expectations, and school programs. Other stakeholders (i.e., food industry, professional organizations active in health promotion, community members and umbrella school organizations) were frequently consulted through stakeholder meetings to ensure a culturally-, age- and community-relevant intervention.

An overview of targeted determinants, the corresponding behavior change techniques and intervention components is given in Figure 16. The intervention constituted of a four-week usage of the “Snack Track School” app. The app presented a virtual high school environment with typical school locations such as classrooms and a gym hall.

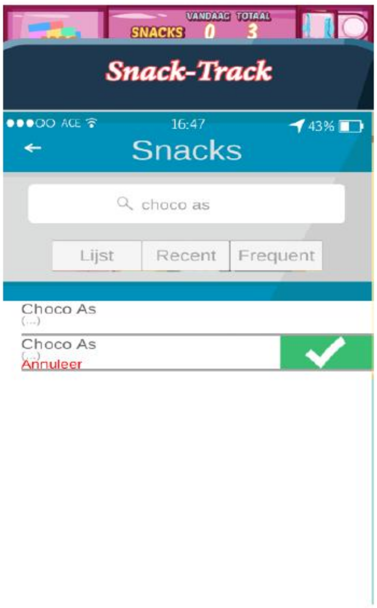
In the app each participant had his/her own “Snack Track Tool” (i.e., snack intake monitoring instrument in the virtual app environment). Participants could enter every consumed snack via this tool and could monitor their snack intake in a weekly report. Registration of the snacks also included a control check to avoid cheating. The snack database was constructed based on the Internubel Trade Name database [276] and contained over 3000 snack foods. The credit or points system of the app awarded points according to the UK Ofcom Nutrient Profile model [22] (see chapter 1). Points awarded ranged from 0 to 55, with zero being very unhealthy and 55 very healthy. In order to stimulate a balanced snacking pattern and not merely the tracking of as many snacks as possible, some gratuities and limitations were also built into the app. Participants could track as many snacks as they wanted, however they could only earn credits for the first 10 snacks. Three gratuities, based on the Flemish guidelines of recommended food and nutrient intakes for adolescents [277], were included: 1) a bonus for a snack intake ≤ 6 snacks per day, 2) a bonus for a snack intake of ≥2/3 healthy snacks per day, and 3) a bonus for adolescents that are involved in the app (logging in ≥3 times in the app per day) but do not snack. On top of the credit system with its gratuities and limitations, a goal setting booklet with a bonus system was also incorporated. Goal setting was applied from week 2 till week 4. Participants needed to select one of the four provided goal options, which they then needed to reach every day. In case of success, a bonus of 150 points was awarded at the end of the day. Screenshots of the “Snack Track Tool”, the credit system, the goal setting booklet and the report card are shown in Figure 17.

Every week had its own story line and challenges imbedded in a ‘game’ environment. Adolescents could progress through these weekly challenges (competition or cooperation) by their earned points**.** Week 1, 3 and 4 entailed a competition challenge and the winner would be the team that had collected the most points by healthy snack choices. Week 2 encompassed a cooperation assignment, all the points of all the players were counted to fill a good behavior thermometer to stop the school from closing. To further increase adolescents’ feelings of engagement and gamification, also an avatar and small assignments were incorporated. Upon completion of such assignments given by the app characters items to customize their avatar were awarded, for example new clothes, shoes and gadgets. The choice of the included game features (story, challenge, competition, cooperation and levelling up an avatar) as most appealing to adolescents was based on previous research [135, 252, 278, 279].

Dual Process Model

		Determinants	***Methods***	***Practical Application***
Snacking behaviour	Automatic Pathway	Habit	- Provision of rewards - Positive reinforcement	Use of in-game credits linked to the nutritional value of the chosen snack
	Reflective Pathway	Knowledge	- Active Learning - Advance organizers	Use of credit system, including a continuum from 0 (=unhealthy) -50 (=healthy); representation of chosen snacks with points/credits in a weekly in-game report; use of a bonus system for extra learning
		Attitude	- Mere exposure - Positive reinforcement	More exposure to healthy snacks as participants receive more credits for healthy snacks; more points (=more reinforcement) for the healthier option
		Self-efficacy	- Goal setting - Monitoring - Feedback	Personal goals can selected in the application per week, success will lead to extra credits; an in-game week report will represent the chosen snacks with their credits

Figure 16: Overview of the different intervention components



Snack Track Tool

Credit system

Report card with feedback on bonus system and achievement of chosen goal

Goal setting booklet

Figure 17: Screen shots intervention components

7.2.5. Measures

7.2.5.1. Outcome measures

7.2.5.1.1. Healthy snack ratio

Snack intake was assessed using the snack and beverage FFQ developed within this PhD thesis (see chapter 2) that probes for usual snack intake with a reference period of one month [183]. The intake of snacks was evaluated in terms of all food items consumed outside (>30 min) of breakfast, lunch and dinner [19]. Snacks were classified as either unhealthy or healthy using the UK Ofcom Nutrient Profiling model (see chapter 1), which provides a score that represents the 'unhealthiness' of a beverage or food product [22]. Following this scoring system snack items such as crisps, other salty snacks, sausage/cheese rolls and pizza, other fried snacks, fries, hamburgers, cheese or meat cubes, sandwich with sweet or savory spread, ice-cream, popsicles, breakfast cereals, pudding, mousses, chocolate, candy bars, candy, dry cookies, other cookies, breakfast rolls and pastries were considered to be unhealthy. Items such as water, fruit or vegetable juice, coffee/tea, milk, milk substitutes, unsweetened yoghurt, sweetened yoghurt, dried fruit, fruit, raw vegetables, nuts and seeds, kebab and pasta cups were considered as healthy. For each FFQ category the daily intake was calculated by multiplying the frequency of consumption with the quantity of consumption per week (g) divided by 7. These daily intakes were then summed to obtain the daily intake of healthy snacks (g) and unhealthy snacks (g). Subsequently a healthy snack ratio was also calculated. The higher this ratio, the more healthy the snack intake of the adolescents.

$$Healthy\ snack\ ratio = \left(\frac{daily\ intake\ of\ healthy\ snacks}{daily\ intake\ healthy\ and\ unhealthy\ snacks}\right) \times 100$$

7.2.5.1.2. Determinants

As reward-based strategies are combined with goal setting, self-monitoring, active learning, and advance organizers, effects on the following psychosocial variables could be expected [280-283]: awareness, intention, attitude, self-efficacy, habit and knowledge. All constructs, apart from habit and knowledge, were based on the reliable and valid healthy diet determinants of the HELENA study [234]. *Awareness* about the healthiness of the adolescents' snacking and intention to change the snacking behavior within the next six months were assessed using two one item questions with a five-point answer format [234]. *Attitude* was measured with five items in which adolescents' opinion will be asked on statements linking healthy snacks to taste and health (attitude regarding the taste of healthy snacks and attitude regarding overall health when eating healthy snacks) [234]. Self-efficacy was assessed via three items asking adolescents how hard it is to eat healthy snacks in general and in two specific situations (at home, and at school) [234].

Habit was measured with a four-item automaticity subscale (the 'Self-Report Behavioral Automaticity Index' [284]) based on the twelve-item Self-Report Habit Index [285]. This subscale was found to be reliable and sensitive to detect the habit-behavior association in energy balance-related behavior domains [284].

Knowledge about the healthiness of specific snacks (proxy) was assessed by means of a scoring test. Adolescents were to rate the healthiness of each FFQ item (28 in total) by giving it a score ranging from 0 to 100. Zero represents "very unhealthy" and 100 "very healthy". A mean health score for the unhealthy snack FFQ items and a mean health score for the healthy snack FFQ items was calculated. The higher the mean score for unhealthy snacks, the lower the knowledge of unhealthy snacks; the higher the mean score for healthy snacks, the higher the knowledge of healthy snacks.

7.2.5.2 Other measurements

7.2.5.2.1. Socio-demographics

Adolescents' sex was assessed with an one-item questions at baseline. The education type of the adolescents was obtained from the schools.

7.2.5.2.2. zBMI

Height and weight were measured at baseline and post intervention by two trained research assistants using a standardized protocol [185]. Body height was measured with a SECA Leicester Portable Stadiometer with an accuracy of 1 mm. Weight was measured with a calibrated electronic scale SECA 861 with an accuracy of 100 g. Age and sex-specific Body Mass Index z-scores (zBMI) were calculated using Flemish 2004 growth reference data [186]. The International Obesity Task Force cut-off points were used to determine normal or overweight individuals [187].

7.2.5.2.3. Total energy intake

Total energy intake of the adolescents was measured at baseline and post intervention with a FFQ that was adjusted to estimate total energy intake in adolescents [286]. The quantitative FFQ measured the average consumption of eighty-two food items during the past year. For each of these food groups, respondents were instructed to indicate the frequency and daily portion size categories that best fit their usual diet. The six frequency questions used were: never or less than once a month; 1-3 d/month; 1 d/week; 2-4 d/week; 5-6 d/week, and every day. Depending on the food group, 5-7 portion size categories are given, together with a list of common standard measures as examples. For some food groups, additional questions are asked regarding the type or preparation method, such as regular or decaffeinated coffee, and cooked or fried potatoes.

7.2.5.2.4. Sensitivity to reward

SR was measured with the Dutch version of the Carver and White BAS scales for children [93], consisting of three subscales, the BAS reward responsiveness (5 items), the BAS drive (4 items) and the BAS fun seeking subscale (4 items) and a composite scale, the BAS total (all 13 BAS items). All items are answered on a 4-point scale, ranging from totally disagree (1) to totally agree (4). Research in children, adolescents and adults indicates that mainly the BAS drive (DRV) subscale is associated with food intake and eating styles [87, 97, 199], so this subscale was therefore used in the analyses. In the present sample the Cronbach's Alpha's for BAS DRV at T0 was 0.80 and at T1 0.83. Scores BAS DRV items were added and presented as a score ranging from 4 until 16.

7.2.5.3. Process evaluation

Guided by previous process evaluations of mhealth interventions in children and adolescents, the process evaluation assessed reach and dose received (exposure and satisfaction) [130, 132, 287-289]. According to Saunders et al. (2005) reach refers to degree to which the intended priority audience participates in the intervention, exposure to the extent to which the participant use the intervention and satisfaction to the satisfaction of the participants with the program [290]. Within this intervention *reach* (or the participation rate) was translated to description of the drop-out, *exposure* to use of the app during the four-week intervention period and *satisfaction* to the amount of satisfaction/enjoyment the adolescents felt from using the app [274].

All actions that that participants performed in the app were logged and stored in a large log database containing per adolescents all actions that he or she performed within each login session such as entering a snack consumption (time, type and points) or opening his/her locker (process evaluation log data). *Exposure* was measured by counting the number of days that adolescents logged into the app was, ranging from 1 to 28. Based on this continuous variable, three equal app use categories (tertiles) were created: 1= non app users, 2=low users 3=high users. The control group was added as a fourth category eventually resulting in a categorical exposure variable with four groups: 0=control, 1= non app users, 2=low users 3=high users.

Adolescents' *satisfaction* with the app was measured after the intervention using the core module of the game experience questionnaire, a valid and reliable self-report instrument to comprehensively assess the multifaceted experience of playing a digital game [291]. This module comprises 33 items, which measure multiple components of gamers' experience via seven dimensions, namely competence, immersion, flow, annoyance, challenge, negative affect and positive affect. The items were presented as five-point Likert scale items: not at all, slightly, moderately, fairly and extremely. Mean scores were computed for each of the dimensions.

7.2.6. Statistical analyses

First, descriptive statistics were used to characterize both study groups at baseline (age, zBMI, sex, education type, healthy snack ratio, awareness, intention to eat healthy, attitude regarding the taste of healthy snacks (attitude taste), attitude regarding overall health when eating healthy snacks (attitude health), self-efficacy to eat healthy snacks, habit to eat healthy snacks, knowledge unhealthy snacks and knowledge healthy snacks), together with t and chi-square statistics to allow comparison of the intervention and control group. Chi-square tests and t-statistics were also used to evaluate whether participants characteristics were related to drop out during the study.

Second, to describe the exposure to the intervention, the number of participants that logged into the app each day of the intervention was computed. In addition non-users, high and low app users were compared on baseline characteristics by means of ANOVA and chi-square tests.

Third, to investigate satisfaction with the intervention, app satisfaction ratings (competence, immersion, flow, annoyance, challenge, positive and negative affect) were compared for the high and low *app user* groups by means of t-tests. App satisfaction ratings were 0 for the adolescents who did not use the app, therefore only the low and high users were compared.

Fourth, intervention effects were analyzed using multilevel linear regression modelling with three levels to account for the clustered design of the study (adolescents within classes and schools). A difference-in-difference approach and the intention-to-treat principles were used to assess the effect of the intervention. The dependent variables were the difference between post intervention (T1) and baseline (T0) in healthy snack ratio, awareness, intention to eat healthy snacks, attitude regarding the taste of healthy snacks (attitude taste), attitude regarding overall health when consuming healthy snacks (attitude health), self-efficacy to eat healthy snacks, habit to eat healthy snacks, knowledge unhealthy snacks and knowledge healthy snacks; and the independent variable a dichotomous variable indicating intervention (=1) or control (=0). All analyses were adjusted for age, zBMI, sex and education type of the adolescents, as these are known covariates in healthy eating interventions in children and adolescents. To assess the effect of the adjusting, we also analyzed the effect of the intervention using crude models. In addition two sensitivity analyses were executed: 1) adjustment for the outcome at baseline to account for the possibility of regression to mean [292] and 2) adjustment for total energy intake at baseline to account for possible differences in energy expenditure and body weight [192, 293]. The latter analysis could only be performed in a subsample of 310 adolescents that provided total energy intake data. In addition moderation by SR and sex was explored for all dependent variables, by adding respectively SR and the interaction terms SR x intervention, sex x intervention and sex x SR x intervention to the adjusted models from the above effect evaluation. If evidence of moderation was found, analyses were rerun for boys and girls separately.

Fifth, it was investigated if the intervention effects differed according to exposure by means of the same approach as stated above for the general intervention effects, but with a categorical exposure variable with four groups (0=control, 1= non app users, 2=low users 3=high users) as independent variable.

For all multilevel regression models, continuous parameters were mean centered and outliers were removed (±3SDs). Unstandardized coefficients and their standard errors were displayed and associations with p-values <0.05 were considered statistically significant.

All analyses were conducted using Stata version 13 SE (Stata Corporation, Texas, USA).

7.3. Results

7.3.1. Participants and dropout analysis (reach)

Of the 1463 adolescents selected to participate, 681 (46,5%) were allocated to the intervention group and 782 to the control group (see Figure 18). A total of 96 adolescents (14.1%) was not allowed by their parents to participate in the intervention, while in the control group only 32 (4.1%) were not allowed. In addition in the intervention group 49 adolescents (7.2%) were absent at the day of the baseline survey and 14 (2.1%) provided bad quality answers (defined as more than 33% of the questions not completed or straight-lining responses), in the control group this were respectively 49 (3.6%) and 11 (1.4%) adolescents. A total of 522 adolescents (76.7%) in the intervention group and 690 (88.2%) in the control group thus completed the baseline survey.

The post survey was completed by 416 and 572 adolescents in the intervention and control group respectively. A total of 106 and 118 adolescents dropped out (see Figure 18). The adolescents who dropped out were significantly more in technical or vocational education ($\chi 2=40.78$, $p<0.001$) older ($t=4.02$, $p<0.001$), had a lower score for attitude regarding overall health when eating healthy snacks ($t=-2.65$; $p<0.01$) and a lower knowledge of healthy snacks ($t=-3.46$, $p<0.001$). No significant differences between the adolescents that dropped out and those that did not were found for sex, zBMI, healthy snack ratio, awareness, intention to eat healthy, attitude regarding the taste of healthy snacks, self-efficacy to eat healthy, habit to eat healthy snacks and knowledge of unhealthy snacks.

Of the 1463 adolescents, 988 thus completed both the baseline and post survey and a participation rate of 67.5% was thus obtained for calculating the primary outcome measure (change in healthy snack ratio). No schools (clusters) were lost in the intervention or control group. The mean age of the 988 adolescents considered for analysis was 14.9±0.70 years, the mean zBMI 0.11±0.99, 59.4% were boys, 31.8% followed general education, 48.6% technical education and 18.4% vocational education.

Table 20 shows the mean healthy snack ratio and other characteristics at baseline of these 988 adolescents. The mean SR, healthy snack ratio and knowledge of unhealthy snacks; the mean scores for awareness, intention, attitude taste and self-efficacy; and the degree of education at baseline were significantly different between groups. The intervention group had a higher SR, a lower healthy snack ratio and knowledge of unhealthy snacks; lower scores for awareness, intention to eat healthy, attitude regarding the taste of healthy snacks and self-efficacy to eat healthy and less adolescents following general and technical education.

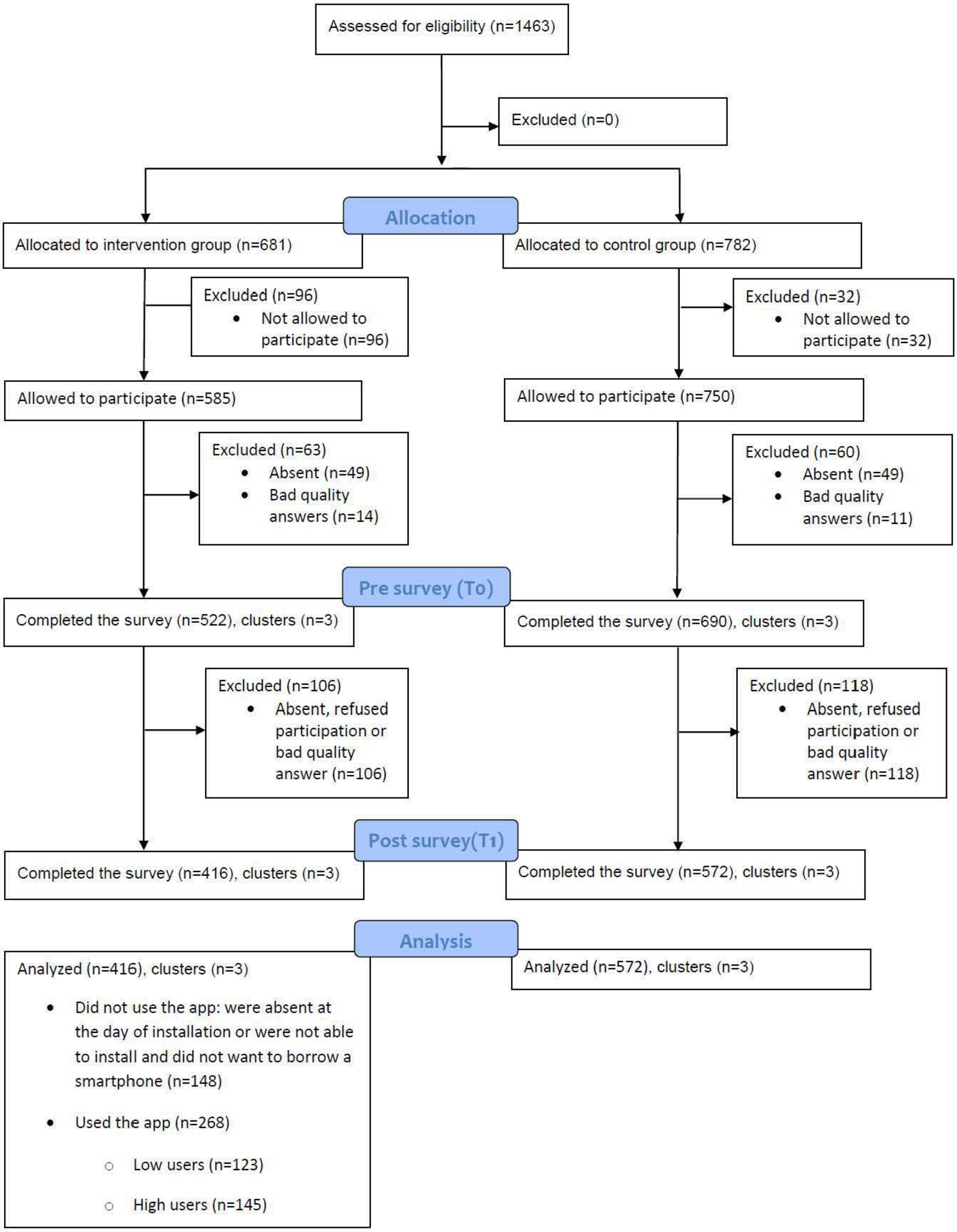


Figure 18: Flowchart of the "Snack Track School" intervention

Table 20: Sample characteristics

N=988	Intervention group (n=416) (Clusters=3)	Control group (n=572) (Clusters=3)	
	% or mean (SD)	% or mean (SD)	t or χ2
Age	14.96	14.91	-1.21
zBMI	0.08(0.98)	0.13(0.99)	0.86
SR	9.28(2.77)	8.65(2.68)	-3.61***
Boys	61.54%	57.87%	1.35
General education	30.77%	34.62%	22.34***
Technical education	43.99%	51.92%	
Vocational education	25.24%	13.46%	
Healthy snack ratio	39.88(26.46)	43.29(26.47)	2.00*
Awareness [0-4]	2.02(0.74)	2.10(0.77)	1.74*
Intention [1-5]	3.25(1.07)	3.43(1.08)	2.56**
Attitude taste [1-5]	2.99(1.08)	3.17(1.04)	2.57**
Attitude health [1-5]	3.64(0.82)	3.70(0.80)	1.14
Self-efficacy [1-5]	3.42(0.83)	3.56(0.85)	2.60**
Habit [1-5]	2.82(0.87)	2.89(0.83)	1.37
Mean health score (knowledge) unhealthy snacks [0-100]	34.37(16.01)	31.52(15.45)	-2.80**
Mean health score (knowledge) healthy snacks [0-100]	55.52(12.94)	55.26(13.24)	-0.30

* p<0.05, ** p<0.01, *** p<0.001

7.3.2. Exposure

7.3.2.1. Frequency of use of the intervention

In the intervention group, 268 adolescents (64.4%) started the intervention, 148 adolescents were either absent at the day of installation, did not want to participate anymore or could not download the app on their smartphone. These adolescents also did not want to borrow a smartphone with the app already installed on it. Of the 268 who started the intervention, 266 (99.2%) logged in at least once in week 1, 152 (56.7%) in week 2, 89 (33.2%) in week 3 and 55 (20.5%) in week 4. The percentage of the 268 adolescents who started the intervention that logged in at each day of the intervention is shown in Figure 19. The percentage adolescents that used the app decreased gradually from day 1 until day 28. Small increases around day 8, day 10, day 15 and day 22 coincided with the days of the focus group discussions organized as part of the process evaluation.

The mean exposure to the intervention, measured in the number of days that the adolescents logged in into the app, was 4.78±6.21 days for the full intervention group (n=416). When only the adolescents were considered who started the intervention (n=268) the mean exposure was 7.41±6.35 days.

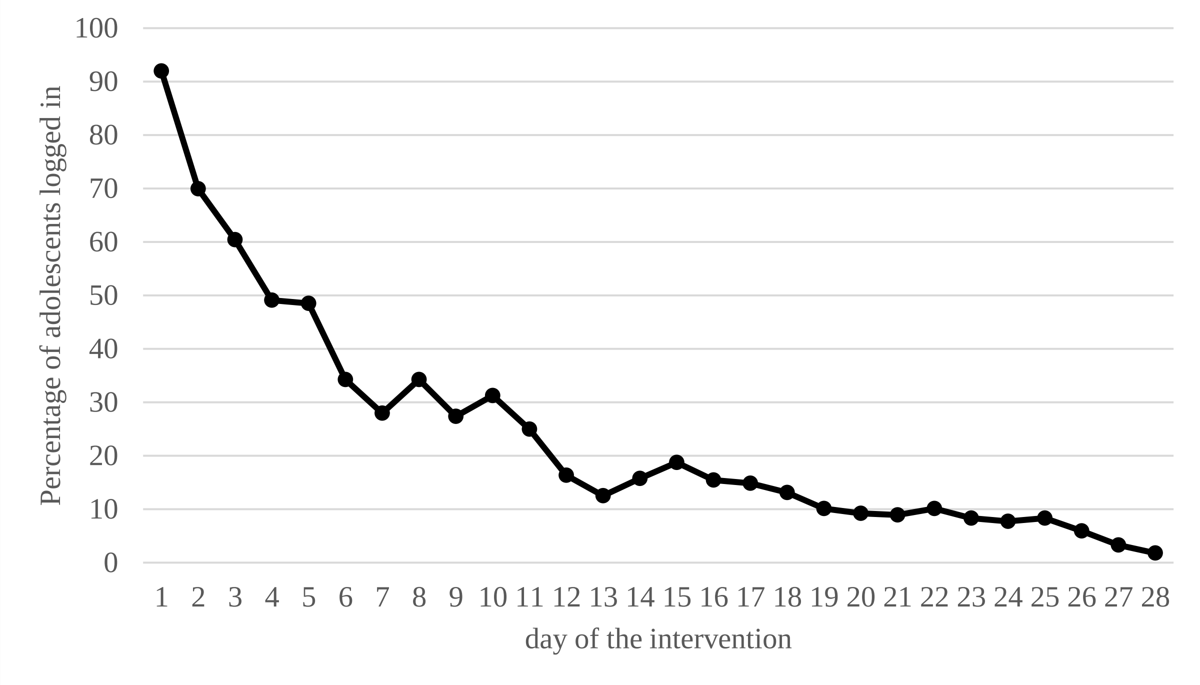


Figure 19: Percentage adolescents who logged in each day of the intervention

7.3.2.2. Differences between non-users, low and high app users

According to the number of days the adolescents logged into the app, adolescents were allocated to three groups i.e. non-users, low and high app users (see Table 21). The 3 groups differed at baseline in percentage boys, percentages following general, technical or vocational education, healthy snack ratio and attitude regarding overall health when eating healthy snacks. The high app users group consisted mostly of adolescents following general and technical education and more girls. Adolescents in this group also had the highest healthy snack ratio and the highest score for attitude regarding overall health when eating healthy at baseline. No significant differences between non, low and high app users could be observed for age, zBMI, SR, awareness, intention to eat healthy, attitude regarding the taste of healthy snacks, self-efficacy to eat healthy, habit to eat healthy and knowledge of unhealthy and healthy snacks.

Table 21: Baseline characteristics according to app user group (intervention group only)

N=416	Non app users (n=148)	Low app users (n=123)	High app users (n=145)	
	mean (SD) or percentage	mean (SD) or percentage	mean (SD) or percentage	F, t or χ2
Number of days logged in [0-28]	0(0)	2.38(1.13)	11.68(5.80)	-17.48***
Age	14.99(0.81)	14.85(0.73)	15.03(0.61)	2.09
zBMI	0.14(0.90)	-0.02(1.01)	0.09(1.03)	0.78
Boys	66.2%	65.9%	62.6%	6.69*
General education	11.5%	28.5%	52.4%	
Technical education	50.7%	44.7%	36.6%	64.54***
Vocational education	37.8%	26.8%	11.0%	
Healthy snack ratio	35.70(24.63)	38.85(26.85)	45.02(27.23)	4.77**
Awerness [0-4]	1.98(0.78)	2.02(0.71)	2.05(0.72)	0.34
Intention [1-5]	3.19(1.09)	3.13(1.13)	3.40(0.98)	2.49
Attitude taste [1-5]	3.01(1.18)	2.96(1.06)	3.00(0.99)	0.09
Attitude health [1-5]	3.5(0.89)	3.67(0.82)	3.73(0.71)	3.22*
Self-efficacy [1-5]	3.31(0.93)	3.45(0.75)	3.5(0.79)	2.05
Habit [1-5]	2.82(0.91)	2.84(0.86)	2.79(0.84)	0.11
Knowledge (mean health score) unhealthy snacks [0-100]	36.02(17.76)	34.85(17.01)	32.32(12.94)	2.02
Knowledge (mean health score) healthy snacks [0-100]	54.78(13.50)	54.31(13.43)	57.25(11.81)	2.06

* p<0.05, ** p<0.01, *** p<0.001

7.3.2.3. App satisfaction (high vs. low app users)

The high app users significantly rated the flow due to the app lower and felt more competent to use the app than the low app users (see Table 22). No significant differences between high and low app users were observed for immersion, annoyance, challenge, negative and positive affect.

Table 22: App satisfaction ratings for high and low app users (intervention group only)

N=416	Low app users (n=123)	High app users (n=145)	
	mean (SD) or percentage	mean (SD) or percentage	F, t or χ2
Competence [0-4]	0.72(0.87)	1.04(0.87)	-3.02**
Immersion [0-4]	0.46(0.71)	0.48(0.61)	-0.24
Flow [0-4]	0.36(0.70)	0.20(0.50)	2.13*
Annoyance [0-4]	0.96(1.02)	0.86(0.93)	0.90
Challenge [0-4]	0.63(0.74)	0.51(0.54)	1.63
Negative affect [0-4]	2.01(1.43)	1.99(1.22)	0.13
Positive affect [0-4]	0.62(0.82)	0.76(0.75)	-1.38

* p<0.05, ** p<0.01, *** p<0.001

7.3.3. Intervention effects

7.3.3.1. Main effects

No significant differences between the intervention and control group were observed for the healthy snack ratio, awareness, intention to eat healthy, attitude regarding the taste of healthy snacks, self-efficacy to eat healthy, habit to eat healthy snacks and knowledge unhealthy and healthy snacks (see Table 23). A significant difference between intervention and control was observed for attitude regarding overall health when eating healthy snacks. The score for attitude regarding overall health when eating healthy snacks decreased from T0 to T1 with 0.13 ±0.05 points more in the intervention group than in the control group.

Table 23: Effect of the intervention on the difference in outcomes between T0 and T1

		Difference		Unadjusted effects	Adjusted effects
Outcomes	**n[a]**	**ΔI (SD)[b]**	**ΔC (SD)[b]**	**Beta (SE)[c]**	**Beta (SE)[d]**
Healthy snack ratio	988	1.28(27.59)	3.38(24.43)	-2.27(1.80)	-3.52(1.82)
Awareness	866	0.04(0.87)	0.02(0.76)	0.02(0.06)	0.04(0.06)
Intention	1010	-0.23(1.14)	-.08(0.96)	**-0.15(0.07)***	-0.12(0.07)
Attitude taste	1005	-0.16(1.19)	-0.19(1.10)	0.04(0.07)	0.10(0.08)
Attitude health	1013	-0.32(0.87)	-0.17(0.76)	**-0.15(0.05)***	**-0.13(0.05)***
Self-efficacy	1009	-0.07(0.89)	-0.00(0.81)	-0.06(0.06)	-0.05(0.06)
Habit	1021	-0.00(0.86)	0.04(0.80)	-0.04(0.05)	0.00(0.06)
Mean health score (knowledge) unhealthy snacks	1001	2.70(16.71)	1.41(15.74)	1.32(1.11)	1.81(1.12)
Mean health score (knowledge) healthy snacks	1001	-3.84(15.88)	-1.91(14.79)	-1.90(1.04)	-1.62(1.02)

* p<0.05, ** p<0.01, *** p<0.00; [a] Total number of students; [b] Δ I: mean difference of the outcomes measured before and after the intervention in the intervention group, Δ C: mean difference of the outcomes measured before and after the intervention in the control group; [c] Crude multilevel models without covariates; [d] Multilevel models adjusted for age, BMI z-score, sex and education type

7.3.3.2. Sensitivity analyses

When the analyses were also controlled for the total energy intake at baseline the results remained in the same direction, except for the attitude regarding overall health when eating healthy snacks: the intervention effect became non-significant (b=-0.17±0.10, p=0.090).

When the analyses were adjusted for the baseline values of the healthy snack ratio and the determinants, results were similar except for the healthy snack ratio, intention to eat healthy and knowledge unhealthy snacks. The difference in healthy snack ratio from T0 to T1 was 4.60 (SD 1.63, p=0.005) percent lower in the intervention group compared to the control group. Also the decrease in intention from T0 to T1 was larger for the intervention group (b=-0.20±0.06, p=0.001), while the increase in mean health score and thus the decrease in knowledge of unhealthy snacks from T0 to T1 was smaller in the intervention group (b=-0.05±0.03, p<0.001) compared to the control group.

7.3.3.3. Moderation by SR

A significant three way interaction intervention x SR x sex was only found for difference in healthy snack ratio (b= -3.92±1.33, p<0.01). When analyses were ran separately for boys and girls, a significant intervention x SR interaction was found for both (boys: b= 1.92±0.81, p<0.05; girls: b= -2.28±1.02, p<0.05). Margin plots are shown in Figure 20. In boys of the intervention group the healthy snack ratio increases as SR increases (b=1.38±0.59, p<0.05), whereas in girls the opposite was observed (b=-1.90±0.94, p<0.05).

7.3.3.4. Differences between non-users, low and high app users

No significant differences between the different groups (control group, non app users, low users and high users) were observed, except for attitude regarding overall health when eating healthy snacks and the knowledge of unhealthy snacks (see Table 24). The low app users had a significantly lower decrease in attitude compared to the control group (b=-0.24±0.08, p<0.01) and a significant decrease in knowledge of unhealthy snacks (b=3.31±1.68, p<0.05).

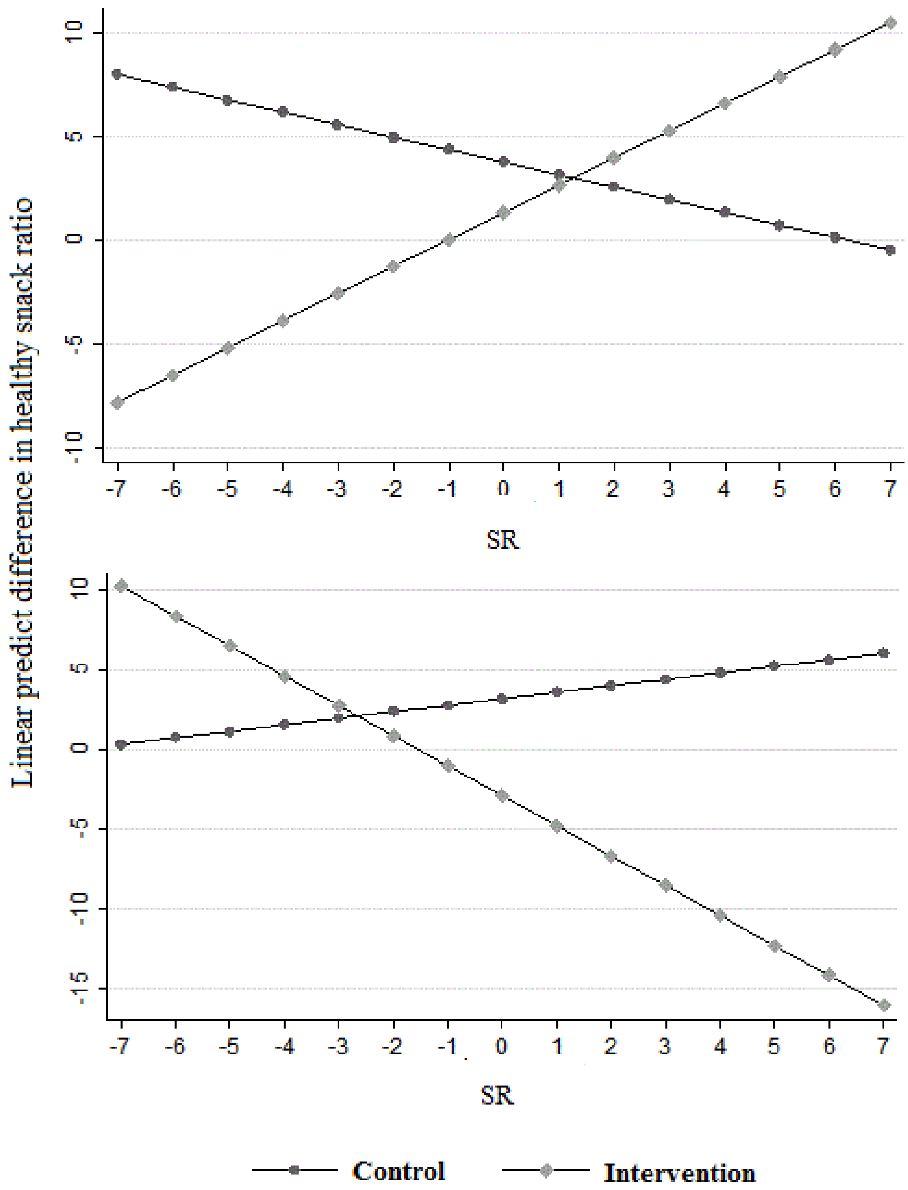


Figure 20: margin plots SR x condition for boys (above) and girls (below)
Analyses controlled for age, zBMI and education type

Table 24: Effect of the exposure on the difference in healthy snack ratio and the targeted determinants between T0 and T1

	Unadjusted effects[a]	Adjusted effects[b]
	b(SE)	b(SE)
	Healthy snack ratio	
Exposure[c]		
Did not use the app	-0.28(2.48)	-3.33(2.66)
Low users	-3.21(2.64)	-3.35(2.74)
High users	-3.42(2.50)	-3.80(2.54)
	Awareness	
Exposure[c]		
Did not use the app	-0.01(0.08)	-0.03(0.09)
Low users	0.10(0.08)	0.15(0.09)
High users	-0.01(0.04)	0.01(0.08)
	Intention	
Exposure[c]		
Did not use the app	-0.21(0.10)*	-0.16(0.11)
Low users	-0.16(0.10)	-0.08(0.11)
High users	-0.10(0.10)	-0.11(0.10)
	Attitude taste	
Exposure[c]		
Did not use the app	-0.06(0.10)	0.08(0.11)
Low users	0.01(0.11)	0.10(0.12)
High users	0.16(0.10)	0.12(0.11)
	Attitude health	
Exposure[c]		
Did not use the app	-0.16(0.07)*	-0.10(0.08)
Low users	-0.26(0.08)**	-0.24(0.08)**
High users	-0.05(0.07)	-0.07(0.07)
	Self-efficacy	
Exposure[c]		
Did not use the app	-0.10(0.08)	-0.09(0.09)
Low users	-0.12(0.09)	-0.10(0.09)
High users	0.04(0.08)	0.03(0.08)
	Habit	
Exposure[c]		
Did not use the app	-0.02(0.08)	0.05(0.08)
Low users	-0.13(0.08)	-0.08(0.08)
High users	0.02(0.08)	0.02(0.08)
	Mean health score(knowledge) unhealthy snacks	
Exposure[c]		
Did not use the app	1.63(1.66)	1.96(1.66)
Low users	2.11(1.72)	3.31(1.68)*
High users	0.01(1;66)	0.50(1.57)
	Mean health score(knowledge) healthy snacks	
Exposure[c]		
Did not use the app	-2.41(1.47)	-1.86(1.53)
Low users	-1.74(1.53)	-1.21(1.55)
High users	-1.54(1.46)	-1.75(1.43)

* p<0.05, ** p<0.01, *** p<0.001; [a] Crude multilevel models without covariates; [b] Multilevel models adjusted for age, BMI z-score, sex and education type; [c] Reference group= control group

7.4. Discussion

7.4.1. Main findings

The present study evaluated the feasibility and effect of a newly developed smartphone app "Snack Track School" on the healthy snack ratio and the targeted determinants of Flemish adolescents aged 14 to 16 years old. The intervention incorporated rewarding strategies together with reflective strategies delivered through a gamified application.

No significant positive differences between the intervention and control group in terms of changes in healthy snack ratio and targeted determinants could be observed. This was unexpected. A first possible factor that could explain the lack of effects is the large drop-out, 128 adolescents were not allowed to participate by the parents and 347 adolescents did not complete the baseline or post survey. Especially in the intervention group, attrition related to parental consent was large (96 adolescents vs. 32 in the control group). The unbalanced drop-out is most likely to be related to the intervention. Possibly parents believed their child to be distracted from their schoolwork, when enrolling in a four-week smartphone intervention program. Also adolescents are known to be a difficult group to engage in health promotion studies. As they are developing their own identity, opinions and ideas, they typically portray a strong negative response to the sense of being pushed in a certain direction [294].

Second, it was observed that adherence to the intervention was low. Only 64.4% of the adolescents were able to use the app. The installation of the app was time-consuming and required considerable smartphone memory. Most adolescents did not want to carry an additional smartphone just for the purpose of using our app. Of the 268 adolescents that actually used the app, only 20.5% had still logged in the fourth week of the intervention. This is similar to the retention rate mentioned by Spook et al. (2016) for the "Balance it" app intervention to promote healthy eating and higher physical activity in adolescents [288]. The study by Majumdar et al. (2003), which aimed to change energy balance-related behavior in adolescents with the use of a web-based game ("creature-101"), reported an intervention retention rate of 64% and was able to detect significant reductions in intake of sweetened beverages and processed snacks [132]. The used behavior change techniques were similar to the reflective strategies used within the current intervention, however "Creature-101" was web-based and implemented within the school curriculum, while our “Snack Track School” was a stand-alone intervention in which adolescents used the app with minimal external assistance or instructions during school breaks or at home. In line with Crutzen et al. (2013), who stated that apps are more effective when they are embedded in existing structures such as schools [295], intervention retention and effects could be improved by embedding our app within the school structure. In addition school teachers also mentioned during the focus group discussions that the app should have been better integrated within the school program and projects, that key teachers should have been more involved in following the intervention and that the app should be accompanied by changes in the school policy and school curriculum. (see box 1 below for a summary of the findings from the process evaluation focus groups with the teachers and appendix 5 for the full report). Reviews by DeSmet et al. (2014) and Schoeppe et al. (2016) also reported that intervention effects were higher for respectively serious games or apps incorporated within a multi-component intervention [133, 273]. In the future incorporating the “Snack Track School” app in a multicomponent intervention integrated within existing school programs seems advisable.

Third, actual engagement with the app is a precondition for retention of the intervention [133, 273]. Several web- and app-based interventions, targeting healthy eating or physical activity in adults, already showed that a higher usage of the websites or apps was related to increased intervention effects [296-298]. In the present study however, a higher intervention engagement was not related to a higher intervention efficacy. No significant positive differences between the high app users and the control group could be documented. The mean number of days that these high app users logged into the app was still only 12 days, which is less than half of the intervention period. It is possible that the use of the app even within this high app user group is inadequate to achieve the desired effects. Rahmani and Boren (2012) also report that insufficiently playing the game could explain the lack of intervention effects [299]. A decline in usage, enthusiasm and engagement with time, is an inherent challenge of interventions using websites, social media, apps or serious games [273, 289].

Fourth, mean ratings of app satisfaction were low in both the low and the high app users group. The adolescents reported to experience little flow, challenge and positive feelings when playing the app. In addition, adolescents also mentioned, during the focus group discussions, that the app was not attractive enough for their age, characters were too childish and that they lacked challenge and engagement (see box 1 below for a summary of the findings from the process evaluation focus groups with the adolescents and appendix 4 for the full report). The app contained several bugs, which could have led to frustration and might have also affected engagement [130, 300]. Despite our efforts to develop attractive game components in participation with the target population, we did not succeed in creating a gamified app that was sufficiently engaging and appealing for this age group. Only a few other studies also developed an app- or web-based game to improve adolescents' health [130, 132, 288]. "Creature 101" as already mentioned, was able to significantly reduce intake of sweetened beverages and processed snacks [132]. "Diabetic Mario" was only piloted tested in a sample of 12 adolescents, but preliminary results indicated positive effects on diabetes management [130]. These two studies not only used behavior change theories, but also extensively studied and used game theories [130, 132]. "Balance it" was not able to improve physical activity or dietary intake [288], despite their focus on both behavioral techniques and gaming techniques. As the reviews by DeSmet et al. (2014) and Schoeppe et al. (2016) indicate that serious games or apps were more effective when game theories were used to ensure flow and engagement [133, 273], efforts will thus be needed to increase flow, challenge and engagement to make the "Snack Track School" app more attractive for adolescents to improve intervention retention and effects.

Box 1: Summary of the topics covered in the focus group discussions (see appendix 4 and 5)

Each week of the intervention focus group discussions were held in each participating class of the three intervention schools for means of process evaluation. Focus group discussions were also held with a small group of teachers of each intervention school after the intervention took place. Questions related to the use of each component of the app were asked, along with general questions related to the amount of use of the app and encountered bugs, difficulties or unpleasant features. Results of these studies still need to be further researched via NVivo whether or not combined with the results of the users' statistics obtained from the logged data. Appendix 4 and 5 provide a descriptive report of reactions obtained in these focus group discussions.

In summary adolescents revealed that the design, characters and challenges presented in the app were too childish and too simple for their age group. They also felt that the app contained too little game-elements and suggested to incorporate a few mini-games and to make the week endings more interactive. In addition the storyline of the app was also unsatisfactory, the story was not clear and not enough integrated with the challenges presented. The adolescents also did not like that each week a new story with a new challenge was introduced, they prefer a game with a continuous flow with increasing levels of difficulty.

The school teachers highlighted some of the same points as the adolescents, based on their own observations but also based on what feedback they got from the adolescents. They also mentioned the childish design, the need for shorter and clearer storylines, more mini-games and better end-challenges. In addition they indicated the importance of mitering knowledge, they felt that the amount of knowledge given in the app was small and too implicit. For them more knowledge elements could have been presented, with also highlighting better wat is unhealthy and healthy. They also mentioned that intervention retention could be enlarged by improving the competition (only within class competition), the team spirit of the adolescents and by also coupling tangible rewards to the competition in the app. In addition they had several tips regarding implementation: better integration within the school curriculum, more guidance for the adolescents and teachers during the intervention and integration within a broader framework: peers, marketing, school policy.

Fifth, school teachers also highlighted during the focus group discussions (see box 1 and appendix 5) that the knowledge given in the app could be improved, that the competition could be boosted by keeping it within the classes, that peer influence should be acknowledged and integrated and that tangible rewards should be used in addition to the virtual points and competitions. The reviews by Dute et al. (2016) and Payne et al. (2015) also stated that apps features that foster social comparison and social support are well liked and might enhance intervention effects [272, 301]. Given the overall importance of peers and friends as influences on adolescents' snack intakes [43, 51, 67, 68], the class competition should be improved and incorporating app features that allow social comparison and social support should be explored.

Sixth, evidence of moderation of the intervention effects by sex x SR was found for the healthy snack ratio. Intervention effects slightly increased as SR increased in boys, one unit increase in SR was associated with a 1.38% increase in healthy snack ratio in boys of the intervention group. While for girls the opposite was observed, a one unit increase SR was associated with a 1.89% decrease in healthy snack ratio. The latter could be a consequence of the fact that girls already ate healthier at the start of the intervention (girls had a significant higher healthy snack ratio at baseline than boys, $t = -8.12$ and $p<0.001$) and rewarding strategies may have had a counterproductive effect. The use of rewards has been documented to have both positive as negative effects on the consumption of healthy foods, rewards can have a counterproductive effect when the food is already liked [114, 115]. However, when looking at the differences between the adolescents in the high app user group and the other adolescents in the intervention group, it was observed that the high app user group were more often female and following general education, felt more competent to use the app, had a higher attitude regarding overall health when eating healthy and had a higher healthy snack ratio at baseline. Previous studies also found that higher use of health-related apps is associated with being female and being higher educated [231, 302]. Female adolescents, following general education and who are more preoccupied with their health thus seemed more responsive to the app and the intervention. A further examination of the process evaluation log data will be needed to understand why the intervention did not lead to an increase in healthy snack ratio in girls, despite the fact that they used the app more. Possibly girls used and liked more the apps' reflective methods such as the goal setting booklet or the report card. Previous research also indicated that female children, adolescents and young adults have healthier food preferences, stronger beliefs in healthy eating and show more weight control involvement than male subjects [303, 304]. Different strategies might thus be needed to achieve healthier snacking habits depending on sex and SR. The reviews by DeSmet et al. (2014) and Schoeppe et al. (2016) also concluded that tailoring smartphone apps to specific populations or users characteristics might enhance intervention efficacy [133, 273].

7.4.2. Strengths and limitations

To date, only a few others studies have assessed the effectiveness of smartphone apps to change adolescents' or children's eating or physical activity behaviors [130, 132, 273, 288, 289]. To our knowledge, the present study is the only one to have considered both rewarding (targeting the implicit habits driven by the difference in RV between healthy and unhealthy snacks) and reflective strategies (targeting the explicit pathways) to improve adolescents' snack choices of healthy snacks. In addition, only a few other studies reported to log all actions of its intervention users [130, 288]. Schoeppe et al. (2016) stressed that more such objective app usage statistics should be collected to better understand levels of and reasons for participant (dis)engagement and intervention exposure [273]. Others strengths of this study were the elaborate intervention development process, that included a strong theoretical base, several preliminary studies and a participatory approach. Our study also had limitations. The intervention was not randomized and groups were thus not completely comparable at baseline. Randomization was not possible as school policy changes, regarding smartphone use at school, were needed to accommodate the intervention at schools. Intervention schools were thus selected early on in the project. In addition the data on snack intake and the determinants were self-reported and social desirable answers could have been given.

7.4.3. Conclusions and future research

First, the current app was not able to improve adolescents' snack choices and its determinants. The intervention retention and satisfaction were low for this purpose. The process evaluation raised several crucial points to improve intervention retention and effects. In addition to the practical problems faced, intervention effects could be improved by redesigning the app content and integrating the app better in the school context. The findings of the process evaluation will benefit future studies aiming to change adolescents' health behavior using smartphone apps.

Second, small positive intervention effects were observed within the subgroup of high SR adolescent boys, but not in girls. Tailoring the app depending on sex and SR might also be needed.

Chapter 8: General discussion

8.1. Main findings

Adolescents consume too many energy-dense snacks and beverages, leading to excess energy intake and possibly overweight and obesity [8-13]. When attempting to change behavior, it is recommended to follow a stepwise procedure, such as the intervention mapping protocol [37, 305].

The first step comprises a thorough problem analysis/needs assessment. As prevalence estimates of snack intakes in Flanders dates back 10 years an update of these estimates is warranted prior to examining the influencing factors [27-30]. Previous studies already reported that the reflective factors self-efficacy, attitudes and knowledge are related to adolescents' snack and beverages intakes [7, 39, 43, 46-49, 53]. However, in our current obesogenic environment, where energy dense snacks and beverages are omnipresent, intake of these foods is also increasingly driven by hedonic eating processes [73-75]. The latter processes are induced by the rewarding value of food and individual differences in SR. To date, little evidence exists on the influence of these hedonic eating processes in adolescents. This is unfortunate, as this population group is the most sensitive to rewarding processes and such processes might play a considerable role in influencing their eating behaviors [90, 91].

Once the influencing factors are identified, the intervention mapping protocol suggests selecting the appropriate theory-based intervention methods targeting the identified factors [37, 305]. To influence the implicit habitual processes (next to the reflective explicit processes) rewarding strategies could be employed, however, results on their effectiveness are mixed and mostly limited to children or adults [52, 110, 111, 114-116]. Before applying rewarding strategies in intervention studies, a proof of concept is thus advisable. Evidence on potential effectiveness could be gathered by means of behavioral choice experiments, which allow studying factors influencing snack choice and consumption based on the RV of food [76, 81, 82, 121, 122]. Once established that rewarding strategies may be used in adolescents, they can be integrated in an intervention study. Additional reflective strategies to target the explicit pathways should be added however, as eating is a dual process by nature [42]. Not only new theoretical insights to improve intervention effects in adolescents are warranted but also new intervention channels are needed [108]. Smartphone applications are an interesting medium, but little evidence on their use for behavior change in adolescents exists, including their use of commercial available fitness and nutrition apps.

This PhD thesis therefore performed four studies (see chapter 1 section 1.2.3.) and addressed the following research questions:

RQ1: Is our newly developed FFQ valid and reliable to estimate snack and beverage intakes in adolescents? (validation study, chapter 2)

RQ2: What is the total amount and amount of unhealthy and healthy snacks and SSBs consumed by Flemish adolescents? (cross-sectional study, chapter 3)

RQ3: Is a higher SR associated with a higher intake of snacks and SSBs in adolescents? (cross-sectional study, chapter 3)

RQ4: Do hedonic eating styles mediate the SR-unhealthy snack/beverage intake associations and is this mediation moderated by the availability of unhealthy snacks or SSBs at home or at school? (cross-sectional study, chapter 4)

RQ5: Is a higher use of fitness and nutrition apps use associated with healthier snack and beverage intakes and a lower BMI in adolescents and are these associations mediated by intermediate healthy diet determinants? (cross-sectional study, chapter 5)

RQ6: Can rewarding strategies increase the RV of fruit? (experimental study, chapter 6)

RQ7: Is a smartphone app that combines rewarding strategies with reflective methods to promote healthy snack choices in adolescents feasible and effective in increasing adolescents' healthy snack consumption? (intervention study, chapter 7)

8.1.1. Snack and beverage intake of Flemish adolescents

In chapter 2 a new quantitative FFQ was evaluated to measure snack and beverage intake in adolescents. Only the healthy snack and beverage ratios showed a good test-retest reliability and provided precise estimates of intakes on a group level (compared to the 24-hour recalls), and are thus appropriate to evaluate dietary change in intervention studies. For means of cross-sectional research mainly a moderate to good ranking ability [32, 33] is needed, which was achieved for all outcomes. Caution should however always be exercised when presenting absolute snack intakes, but could be improved in the future by grouping some snack options (see section 8.2.2.2).

In the cross-sectional study (see chapter 3), it was found that Flemish adolescent boys consumed on average 214 g of unhealthy snacks, 122 g of healthy snacks and 286 ml of sugar-sweetened beverages; girls respectively 162 g, 153 g and 182 ml. This is comparable with two to three portion of unhealthy snacks (average weight cookies or candy bar 50 g [306]), one portion of healthy snacks (average weight of an apple or yoghurt 125 g [306]) and one portion of SSBs per day (one glass can contain 150-250 ml fluid [306]). The energy intake from SSBs per day was 118 kcal for boys and 78 kcal for girls, while the energy intake from snacks was respectively 866 kcal and 688 kcal per day. However, the prevalence estimates for snack intakes should be interpreted with caution, as the validity study showed that our FFQ overestimate snack intakes (see section 2.3. and 2.4.). The Flemish institute for Health Promotion and Disease Prevention advises to not eat or drink more than 10% of one's total energy intake from products belonging the residual group. In general it is recommended to consume about 10% of one's daily energy needs from snacks [277]. Considering a mean energy need of 2600 kcal for 14-16-year-old adolescents boys and of 2100 kcal for 14-16-year-old adolescent girls [277], it thus is clear that Flemish adolescents do not comply with the recommendations and consume too much energy-dense snacks and beverages.

8.1.2. The importance of SR and the RV of food in explaining and understanding adolescents' snack and beverage intakes

Despite the abundance of rewarding unhealthy snacks and beverages, not everyone indulges in them [73-75]. Individual differences in susceptibility to hedonic eating processes driven by the reward value exist, SR has already shown to be related to food cravings, overeating and overweight in children and adults [75, 84, 86-89]. This PhD thesis reports an association between the intake of snacks and SSBs and SR in an adolescent population (see chapter 3). These results in adolescents confirm and expand on previous research in adults by Davis et al. (2007), who reported a positive relation between a high SR and increased sugar and fat preferences [86]. In addition it was observed that the associations between SR and snack and SSB consumption were moderated by sex. A high SR is thus a potential risk factor for high consumption of energy-dense snacks and SSB in adolescents, especially in girls. Magnitudes of the SR-snack/beverage intake associations and explained variances (chapters 3 and 4) however, were quite small. Consistent with the multicomponent etiology of overweight/obesity [189] and the biopsychosocial model of eating behaviors [43], SR is thus not the only factor influencing the snacking and drinking behavior of adolescents.

SR is typically measured with the BAS scales by Carver and White (1994) [92], which consists of three subscales (BAS FS, BAS DRV and BAS RR) and one composite scale BAS TOT (see chapter 1). BAS FS has been mainly considered in regard to smoking and alcohol abuse [94, 97] and was thus not considered, together with BAS TOT, within this PhD thesis. In chapter 3 it was shown that BAS DRV was associated with SSB and unhealthy snack intakes and nutrients derived from snacks and SSBs, while BAS RR was only associated to snack intake (both healthy and unhealthy). Earlier studies also showed that the relation of SR with unhealthy eating or weight related behaviors is mainly found in BAS DRV rather than in BAS RR [87], therefore in the forthcoming chapters of this PhD thesis only BAS DRV was used.

Chapter 4 further elaborated how SR influenced the intake of unhealthy snacks and beverages. In accordance with the hyper-responsiveness model [74, 75, 86], which depicts how a high SR is associated with hedonic eating (emotional and external eating) and could lead to habitual (over)eating, it was shown that external and emotional eating mediated the relation between SR and unhealthy snack intake. These results only explained a part of the association between SR and unhealthy snack intake. In addition none explained the SR-SSB intake association. Other mechanisms might thus also contribute to explaining how SR influence adolescents' eating and drinking habits. As SR individuals are more sensitivity to rewards [73, 74, 84], it is expected that an environment in which more of these cues are present might interact with SR and its related hedonic eating styles. However no such moderation could be observed within this PhD thesis. Other studies have shown relations between SR (adults) or impulsivity (children) and respectively fast food exposure or food variety [100, 307]. Impulsivity relates to insufficient thinking, controlling, planning and comprises a reward factor (reward related impulsivity) [307]. Based on the findings of this PhD thesis, it seems that availability of unhealthy snacks does not interact with external or emotional eating in promoting unhealthy snack intake in adolescents. More research is needed to clarify if the physical environment interacts with SR in adolescence. In absence of such evidence individual strategies will be needed to counter the influence of hedonic eating processes on obesity and overall health in adolescents.

8.1.3. (Reward-based) strategies to change adolescents' snacking behavior

New approaches to influence eating behaviors in adolescents are needed. Traditional effective behavior change strategies should be combined with recent theoretical insights from other research disciplines for this purpose. Eating behaviors are dual processes by nature, which implies that both the explicit reflective and the implicit habitual pathways should be targeted [42, 59]. Interventions targeting the reflective pathway are abundant and effective strategies to target this pathway are well established [109]. More research is however needed to understand what drives the formation of habits and to determine how to effectively inhibit/terminate unhealthy habits and promote/initiate healthy habits, especially in adolescents [56, 60].

Reward-based strategies derived from operant conditioning principles could be a promising strategy here [56].

As a higher RV of unhealthy snacks vs. healthy snacks might be one of the drivers of habitual intake of unhealthy snacks, a first step in determining the effectiveness of reward-based strategies in health promotion is to ascertain that the chosen rewarding strategies can effectively increase the RV of healthy snacks in adolescents. The present PhD thesis showed that by linking the choice for fruit to a reward, the RV of fruit could be increased to a comparable level as the RV of unhealthy snacks. Using rewards may thus increase liking, wanting and consumption of healthy foods in adolescents when used appropriately [115]. However, the RV of fruit + reward, fruit and unhealthy snacks were tested separately, it was not yet taken into account what would happen when an individual is presented with an actual choice between these snack options [259]. Choice experiments and field studies are thus needed to further confirm these findings and to conclude that increasing the RV of fruit by rewarding strategies can effectively change adolescents' snack choices.

Also the intervention channels used in behavior change interventions might have been ineffective, partly because they have not been applied adequately or were not sufficiently connected to adolescents' rapidly changing youth culture [108]. Mobile apps could provide an engaging way to involve children and adolescents in behavior change interventions [123]. Adolescents frequently use smartphones and apps and are highly skilled in using them [126-128]. In 2014, 86% of the adolescents in Flanders owned a smartphone and most had 10-20 apps on it [129]. The use of commercial fitness and/or nutrition apps was only weakly associated with healthier snacking and drinking habits in the present research (chapter 5). The overall weak associations could be a consequence of their limited theoretical basis. Several studies argue that commercial fitness and nutrition apps incorporate too little effective behavior change techniques and lack a thorough theory-driven approach [220, 221, 226, 230, 232]. Confirming this hypothesis, little evidence of mediation was found in our sample. The use of commercially available fitness and nutrition apps was associated to none or few key determinants (self-efficacy, attitude and social influence) of eating behaviors. As it is known that interventions that build upon theory are more effective [232], apps aimed to change behavior should focus more on targeting the key determinants identified in literature by incorporating the corresponding behavior change techniques in an effective manner [218, 230].

When evaluating the feasibility and effect of a gamified smartphone app “Snack track School” to improve adolescents’ snack choices no main effects were observed (chapter 7). Possible explanations are the large and unbalanced drop-out, the difficulties experienced at the implementation phase, the lack of integration in the school community and the age-appropriateness of the game features used. In a follow-up evaluation the app was also already tested for acceptability in a small group of 11 to 13-year old children. In this group the app was found to be “fun” and “appealing” and some promising effects on their snacking habits were observed by their teachers.

Moderation analyses of the intervention effects however, revealed that within boys the intervention effects on the healthy snack ratio slightly increased as SR increased in boys. While for girls the opposite was observed, which could be a consequence of the fact that girls already ate healthier at the start of the intervention and rewarding strategies may have had a counterproductive effect [114, 115]. A further evaluation of the process evaluation log data will be needed to understand why the intervention did not lead to an increase in healthy snack ratio girls, despite the fact that they used the app more. Possibly girls used more the apps’ reflective methods such as the goal setting booklet or the report card. Previous research also indicated that female children, adolescents and young adults have healthier food preferences, stronger beliefs in healthy eating and show more weight control involvement than male subjects [303, 304]. Different strategies might thus be needed to achieve healthier snacking habits depending on sex and SR.

8.2. Implications and recommendations for future research

The research conducted within this PhD thesis has theoretical and methodological implications and implications for health promotion and policy.

8.2.1. Theory

8.2.1.1. Implications

The findings presented within this PhD thesis highlight the importance of hedonic habitual eating processes and SR in understanding eating behavior in adolescents in obesogenic environments (see chapters 3 and 4). It is thus key to acknowledge SR and hedonic eating processes as drivers for unhealthy eating behaviors and to integrate these factors within the current models used to explain and understand eating behaviors.

The current research therefore attempted to provide a new theoretical approach to understand and change adolescents' snacking (and drinking) behaviors in which insights from different research disciplines were combined (see Figure 21). Insights from the theory of planned behavior [38, 39], the control theory [109, 110], behavioral choice theory [81, 121], learning theory [114, 117] and Gray's reinforcement sensitivity theory [86, 308] were combined into a dual process view [42] (see Figure 2 chapter 1). Dual system models imply that behavior is the result of a joint functioning of two systems: a reflective system including cognitive efforts to build beliefs and decisions (explicit processes) and an impulsive/automatic system (i.e., habits) in which certain stimuli or cues are linked to certain behaviors based on earlier learned associations (implicit processes) [42, 59]. At the explicit level it is generally accepted that eating behaviors of adolescents are driven by intention guided through the (pre-) motivational factors self-efficacy, attitudes and knowledge [42, 56, 60, 63, 64]. Despite the fact that the concept of habits is being adopted more and more into intervention research, little is still known on what drives the automatic habitual pathway and how to effectively inhibit/terminate unhealthy habits and promote/initiate healthy habits [56, 60]. Based on previous research it could be postulated that habits might originate (partially) from hedonic eating processes driven by taste, the rewarding value of food and individual differences in SR [56, 60, 63, 64]. Within this PhD thesis (chapter 3) it was shown that an increased SR was related to a higher intake of SSBs and unhealthy snacks in adolescents and that emotional and external eating styles partially mediated the SR-unhealthy snack intake relation in chapter 4. These latter eating styles could be related to habit formation by reacting to external environmental cues or by in eating response to moods [56, 60, 63, 64].

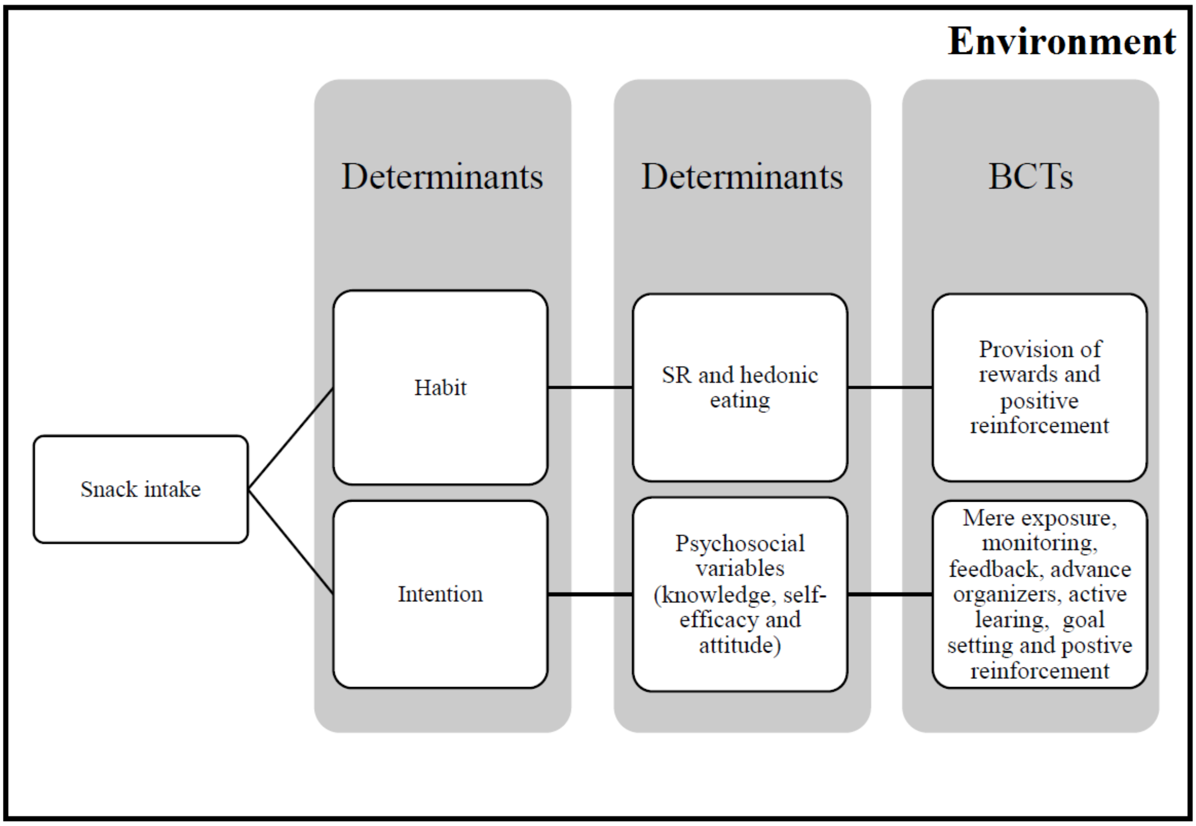


Figure 21: Proposed theoretical framework for understanding and changing adolescents' snack and/or beverage choices

This PhD thesis also showed that the association between SR and adolescents' snack and SSB intake is different according to the BAS subscales (BAS RR or DRV) used and sex (see chapter 3). BAS DRV was associated with both unhealthy snack and SSB intakes, whereas BAS RR was only associated to snack intake (both healthy and unhealthy). To our knowledge only two other studies, one in adults [97] and one in toddlers [96], also investigated both BAS RR and BAS DRV in relation to eating behaviors. Voigt et al. (2009) found no significant associations between BAS RR or BAS DRV and the intake of energy-dense foods [97]. Vandeweghe et al. (2016) found that BAS RR was associated with food enjoyment, food responsiveness and external eating, while BAS DRV was also associated with external eating and food responsiveness but not with food enjoyment [96]. Within this PhD moderation by sex was found for the BAS RR-snack or SSB intakes associations, but not for the BAS DRV- snack or SSB intakes associations (see chapter 3). It thus appears that boys and girls differ in their food reward responsiveness, but not in their motivation towards obtaining food or beverages. Given that several other studies also reported that BAS DRV was a stronger and more consistent predictor of food approach behavior, only BAS DRV was considered for the remainder chapters of this PhD thesis (chapter 4, 6 and 7*).* Further disentangling how BAS DRV and BAS RR relate to food intake in adolescents, whether or not in relation to sex, is however warranted.

In addition individual differences in SR exist also between boys and girls [87, 178], also within this PhD thesis (chapter 3) differences in BAS RR were found between boys and girls. In chapter 3 it was shown that girls had a significantly higher BAS RR score than boys. This finding is however in discordance with previous research in children where boys tended to have a higher BAS scores [87, 178, 180]. This discordance could be a consequence of the fact that girls of our age group (14-16 years old) may already have reached the typical peak of sensitivity to reward in adolescence [90], while boys have not. Not only individual differences in SR, but also in the SR-snack/SSB intake associations according to sex were observed (see chapter 3). Boys and girls were found to differ in their food reward responsiveness (BAS RR) but not in their motivation towards (BAS DRV) obtaining food or beverages. Other studies also reported sex differences in the relation between SR and BMI in children and adults [270, 309]. A positive association between SR and BMI was only found for women [270] and SR was found to predict fat accretion over the years only in girls and not in boys [309]. Future research on SR, eating behaviors and BMI should thus take into account sex differences in these relations.

As individual factors can interact with environmental factors, this PhD thesis also researched if the hedonic eating styles (external and emotional eating) showed an interaction with environment (availability of energy-dense snacks and beverages at home and school) in chapter 4. However, such interaction was not observed. The latter should be further investigated as variability in availability at school was low and exposure might be a better proxy to research how overabundance of energy-dense foods interacts with SR [100].

Given the importance of habits driven by SR and hedonic eating processes in adolescents' snacking behavior (see above), these hedonic processes should be taken into account when choosing an intervention approach to improve this snacking behavior. Focusing on reflective strategies alone to alter behavior might be insufficient. Several other researchers already stressed that relying on reflective strategies alone might only partially explain the small intervention effects reached so far [56, 60]. Therefore within this PhD it was proposed to incorporate both automatic (rewarding) and reflective strategies (goal setting, monitoring, feedback, active learning, advanced organizers and mere exposure) to improve the snacking behavior of adolescents (see Figure 20).

To influence the implicit habitual processes (next to the reflective explicit processes) rewarding strategies could be employed, however, results on their effectiveness are mixed and mostly limited to children or adults [52, 110, 111, 114-116]. Before applying rewarding strategies in intervention studies, a proof of concept was thus advisable. In chapter 6 it was shown that an intangible reward, under the form of a class competition, could increase the RV of fruit to comparable level as the RV of unhealthy snacks. This study thus added to previous research in children and indicates that rewarding strategies may thus also be used in adolescents to learn new healthy habits. It must however also be mentioned that this study did not consider what would happen when an individual is presented with an actual choice between healthy and unhealthy snacks [259]. Both relative choice experiments and field studies are still needed to further confirm these findings and to conclude that increasing the RV of fruit by rewarding strategies can effectively change adolescents' snack choices.

The proposed theoretical approach was developed within the PhD thesis for the purpose of understanding and changing adolescents' snack and beverage choice taking into account hedonic eating processes. However, it must be acknowledged that several other individual and environmental factors influence behavior through both the reflective as the habitual pathways. One such factor could be inhibitory control (IC), which was found to influence behavior through the reflective pathway in children, adults and adolescents [60, 63, 268, 310-314]. In addition physical, social and macro environmental factors are known to influence adolescents' snack intakes [43, 51, 66-68, 72] and should also be considered.

Individual characteristics, such as SR and sex, might also influence the effect of the behavior change strategies used [113, 115, 268, 269]. Individual differences in SR were shown to be associated with adolescents' snack intake [212]. Rewarding strategies were already found to work better in high SR vs. low SR toddlers in improving willingness to taste [115]. Within Chapter 6, it was expected that adolescents high in SR would be more motivated than low SR adolescents to work for fruit + reward. No evidence was found that SR moderated the difference in RV between fruit + reward and fruit or unhealthy snacks. This could possibly be explained by the low variability in SR scores of the adolescent sample. The mean SR scores of the sample for boys and girls were rather low compared to age and sex appropriate norms (T scores <40) determined within the REWARD project (Vervoort et al., 2016, unpublished data). Given that the relation between SR and adolescents' snack intake was moderated by sex in chapter 3 [115, 212] and also differences in SR between boys and girls exist [115, 270, 271], moderation of the intervention effects in chapter 7 according to SR and sex. Intervention effects on the healthy snack ratio were found to slightly increase as SR increased, but only in boys. Future intervention studies that apply reward strategies should take these differences in effects into account and should consider adapting interventions to individual child characteristics, such as sex and SR.

8.2.1.2. Future research

Several associations within the proposed theoretical framework are based on hypotheses by other research. These associations thus remain to be tested and provide subjects for future research (see associations with a question mark in Figure 22). Associations 1 and 2 in Figure 22 were researched in chapter 3 and 4, while associations with number 3 were already investigated by previous studies [62, 113, 315]. Related to association 1 in Figure 22 future research should further disentangle how the different BAS subscales (BAS DRV and BAS RR) relate to eating behaviors in adolescents (and other age groups) in general and separate for female and male subjects. In addition further research is also needed to determine how SR (and its different subscales) relates to individual differences in the RV of snacks [247, 316] and to differences in wanting and liking cfr. Berridge et al. (1996) [173], which was beyond the scope of the current PhD thesis.

In this PhD thesis the focus was on the role of SR at the individual level. Although the role of IC in this dual process view was briefly introduced, other factors could also influence the formation of habits or the strength of reflective functioning and should thus still be explored. Also the findings from this PhD thesis related to the associations between SR-availability of unhealthy rewarding foods at school and/or home need replication and future scrutiny. In addition, interactions of SR and hedonic eating processes with other aspects of the physical environment, the social environment, and macro system influences are yet to be explored.

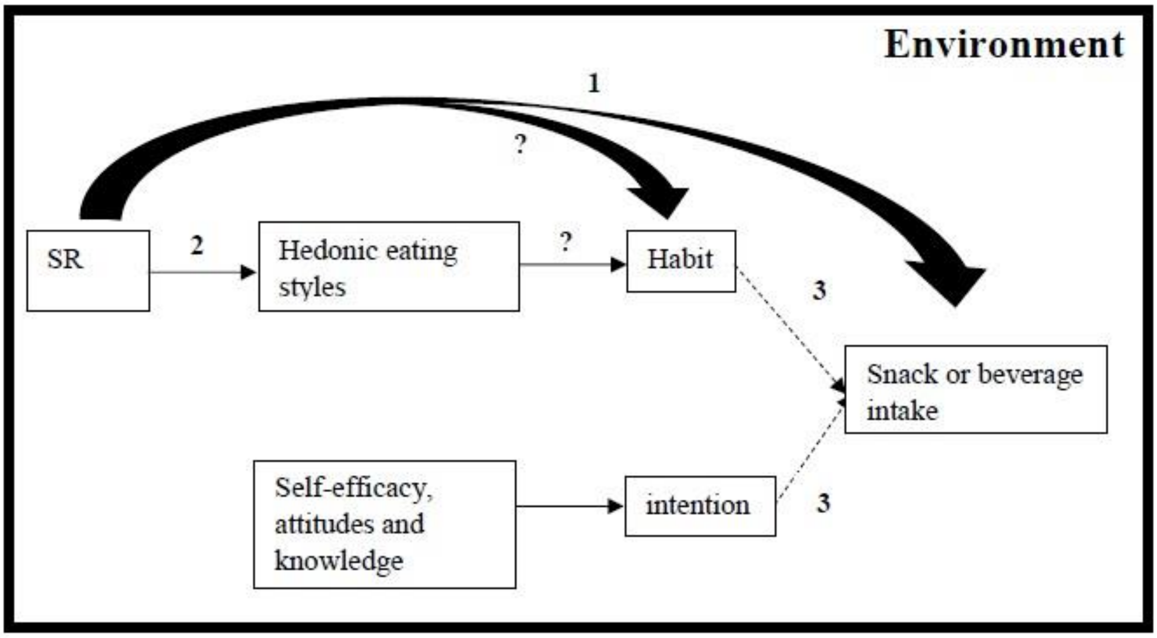


Figure 22: overview of the studied and unstudied associations of the proposed theoretical framework (see Figure 21)

Not only do several links within the individual level and between the individual level and the different environmental levels (social, physical and macro system) still remain to be tested, it is also imperative to evaluate the complete framework. The etiology of eating habits is multicomponent and no single factor determines behavior [43, 189]. Evaluating the complete framework will allow determining how SR relates to other individual factors and different environmental levels (social, physical and macro system) that influence snack and beverage intakes. Structural equation modelling (briefly used in chapter 4 and 5) provides an interesting technique for this purpose, as it allows assessing the relative importance of each factor and interdependencies between all possible influencing factors. Several previous studies already used structural equation modelling to validate theoretical models [86, 317].

Relations between SR and food cravings, unhealthy food preferences, food consumption and obesity in both children and adults are also reported [75, 84, 86, 98, 248, 268, 313]. The latter studies stress the importance of SR and hedonic eating in explaining eating behaviors across all population groups, not only in adolescents. The framework proposed within this PhD thesis could be extended to children and adults and to eating. However, the framework should still be validated in each group as levels of SR (and IC) differ between children, adolescents and adults [90, 91].

To date most evidence on SR and eating behavior and/or obesity is based on experimental or cross-sectional associations, no longitudinal evidence on the influence of rewarding processes on overweight and obesity exists. Some longitudinal evidence on SR exists, but it is limited to risk taking and fun seeking [318, 319]. Within the REWARD project (work package 2) causal relations between adiposity and SR in children were explored for the first time. This study was able to show that a higher SR was related to higher gain in adiposity over the years, but only in girls [309]. Further causal evidence should be gathered in relation to other nutritional parameters such as the intake of unhealthy foods or food preferences. As SR not only differs between individuals, but also between age groups [90, 91], findings should always be tested in each of these groups.

8.2.2. Methodology

8.2.2.1. Implications

In this PhD thesis a new quantitative FFQ to measure snack and beverage intake in adolescents was developed (see chapter 2). This FFQ can be used to assess diet-disease relationships and for evaluating interventions, limited to the healthy snack and beverage ratios. An additional feature of this FFQ that it not only allows measuring snack and beverage intake, but also allows distinguishing healthy and unhealthy snack and beverage intakes using a nutrient profiling approach (see chapter 2).

This PhD thesis was also the first to evaluate the RV of foods, in terms of the breakpoint by means of survival analysis. The RV is typically measured as either the breakpoint or the total number of responses made [76, 254]. The breakpoint refers to the progressive ratio schedule, where the participant decided to terminate the [76, 254]. Usually the mean schedule of terminating the task is compared across reinforcers [76, 320-322]. The present analysis however, is favorable over these traditional approaches as it allows assessing the chance (the risk) of terminating the FRT at each schedule. This analysis is of particular interest as chances to terminate the FRT are usually smaller for low PR schedules and higher for high PR schedules [76, 258].

8.2.2.2. Future research

The snack and beverage FFQ, which was developed within this PhD thesis, could be refined more to better estimate absolute snack intakes. It should be examined which snack items could be grouped in order to reduce the number of items and as such improve the validity to estimate absolute snack intakes. In addition future research should also focus on building a nutrient profile approaching, that is both continuous as classifying, specifically for snacks and/or beverages. In chapter 2 it was observed that currently used nutrient profile model [22] classified some snacks and beverages (beer, wine, pita and pasta cups) perceived as unhealthy to be healthy based on their nutritional composition per 100 gram. Future nutrient profile models for snacks and/or beverages should consider taking into account alcohol content and portion sizes consumed. Snacks that are eaten as such and have a typical portion size such as “one bar”, “one bag” or “one piece”. Some of these typical portion sizes are larger than 100 gram and this should contribute to the evaluation of the product as a healthy or unhealthy snack choice.

In Chapter 4 and 5 mediation analyses and moderated mediation analyses were applied using SEM according to principles described by Preacher, Zyphur and Zhang [203, 204, 210], Hayes [205] and Preacher, Rucker and Hayes [323] which are multilevel and SEM extensions to the mediation principles proposed by Baron and Kenny [324] and Mackinnon and colleagues [325, 326]. Mediation analyses are widely applied and provide an optimal way to test mechanisms based on theory, but are often criticized on their causal inference [326, 327]. Most difficulties arise from the assumption made regarding (unmeasured) confounding [327, 328]. The use of SEM already provides some benefits over classical regression based mediation approaches, including the simultaneous estimation of directs and indirect effects, the possibility for multiple mediation to determine the true mediator and the modelling of complex relations (including multilevel designs) [327, 328]. However the problems with the assumptions made regarding unmeasured confounding remain [329]. Additional challenges with SEM and mediation analyses arise when using cross-sectional data, temporal ordering and the direction of causality can never be ascertained with cross-sectional data [329]. In order to improve the causal inference of the mediation models state in chapter 4 and 5, future research could focus on improving the number of covariates and replication and cross-validation of the models [328, 329]. In addition currently already several techniques exist to determine confounder bias [327, 329]. However to ascertain the temporal order and to exclude bidirectionality, as expected in chapter 5, longitudinal data is needed.

8.2.3. Health promotion and policy

8.2.3.1. Implications

Chapter 5 of this PhD thesis showed weak associations between the use of fitness and nutrition apps and healthier snacking and drinking behaviors. This limited influence could be a consequence of their often limited theoretical basis. The mediation analyses presented within this chapter also showed that the use of commercially available fitness and nutrition apps was associated to none or few key determinants of eating behaviors. These apps might therefore not incorporate the corresponding behavior change techniques or use these techniques in an effective way. Our findings thereby add to those findings of several reviews and content analyses [220, 221, 226, 230, 232] that report that the beneficial influence of commercial fitness and nutrition apps on health is limited by their lack of (effective) behavior change techniques. This is unfortunate as the demand for apps that promote healthy habits is high and the potential for health promotion is large. 37% of the Flemish adolescents were found to use health apps (see chapter 5) and 58% of US adults [219]. However at the moment, there are only a few effective theory-based apps are on the market [218, 230, 232]. Public health professionals and app developers should thus join hands to design more theory-based apps to be used in health promotion and fulfill the needs of the population [218, 230, 232]. Effective behavior change techniques should be translated into mobile applications and intervention trials should be conducted to investigate their effectiveness on the behavior of interest and its related determinants [218, 230, 232].

The findings from this PhD thesis (chapter 3 and 4) show a positive association between SR and unhealthy eating behaviors, high SR adolescents might thus form a vulnerable group for eating and weight problems. Several other studies have also shown positive associations between SR and obesity, food cravings, food preferences and unhealthy food consumption in children and adults [74, 75, 86, 87, 248, 270, 330]. Recently also longitudinal evidence emerged that showed that SR explained 15% of the change in fat mass in children [309]. High SR girls showed a significant increase in fat mass over four years [309]. Specifically targeting these adolescents, children and adults high in SR, that are more vulnerable to the current obesogenic environment, might improve the effectiveness of obesity prevention programs. Future interventions would thus benefit from adopting the dual process approach, presented in section 8.2.1.1, that takes individual differences in SR into account to understand and change adolescents' eating behaviors.

Coefficients and explained variances within this PhD thesis (see chapter 3 and 4) were small, also in other studies SR explained no more than 15% of the variation BMI or eating behaviors [75, 248, 309]. SR is thus not the only factor associated with unhealthy eating behaviors and BMI. This is consistent with the multicomponent etiology of unhealthy eating behaviors and obesity [189]. Factors other than SR should thus also be considered. To date most studies have considered mainly the association of SR with health behavior, not many studies have looked at SR in relation to other factors. A study by Pacquet et al. (2010) found that SR moderated the association between the exposure to fast food and its intake in adults [100]. In chapter 4 of this PhD no interaction between SR and the availability of unhealthy snacks at home or at school was found. Further determining how SR relates to other influences on individuals food choice, see section 8.2.1.2., is crucial to determine its impact. In the regard of habits, Reinaerts et al. (2007) already found that habit explained an additional 13% of the variance in fruit consumption, while their full model (including psychosocial variables and social and physical environmental factors) explained 50% of the variance [112].

Other studies also emphasized the role of IC in eating behavior, more specifically the role of a low IC in relation to an increased SR is considered a risk for unhealthy eating habits and possibly overweight and obesity in adolescence [63, 268, 310, 312]. In adolescence IC is also generally lower than in adults [90, 91]. Adolescents, with their heightened SR and lower IC, compared to children and adults are thus an extra vulnerable group to develop unhealthy eating habits.

Offering rewards enhances children's willingness to taste and consume healthy food items such as fruit [115, 242-244]. However, to date little was known about using reward-based strategies to promote healthy food choices in adolescents. In chapter 6 it was shown that an intangible reward, under the form of a class competition, could increase the RV of fruit to comparable level as the RV of unhealthy snacks. This study thus added to previous research in children and indicates that rewarding strategies may thus also be used in adolescents to learn new healthy habits. It must however also be mentioned that this study did not consider what would happen when an individual is presented with an actual choice between healthy and unhealthy snacks [259]. Both relative choice experiments and field studies are still needed to further confirm these findings and to conclude that increasing the RV of fruit by rewarding strategies can effectively change adolescents' snack choices. As adolescents are highly susceptible to rewards and show higher activity in the reward related brain regions compared to children and adults [90, 91] the use of rewarding strategies might be especially interesting in adolescents to target the automatic/habitual influences on food choices in adolescents.

The intervention approach (see section 8.1.1.), incorporating such rewarding strategies in combination with known reflective strategies, was only effective in high SR boys. Chapter 7 showed no significant improvement in healthy snacking in the intervention group compared to the control group. The lack of main effects could however be attributed to implementation problems and the design of the app (intervention channel). Based on the results from the qualitative process evaluation (the focus group discussion held with the participants) and emerging literature on interventions using apps or serious games in adolescents and children [130-134, 272, 273, 301, 331] several suggestions for intervention implementation and developing apps for health promotion could be formulated (see the recommendations for future research in section 8.2.3.2.). Evidence of moderation of the intervention effects by sex x SR was however, found for the healthy snack ratio. Intervention effects slightly increased as SR increased in boys, one unit increase in SR was associated with a 1.38% increase in healthy snack ratio in boys of the intervention group. While for girls the opposite was observed, a one unit increase SR was associated with a 1.89% decrease in healthy snack ratio. Rewarding strategies may have had a counterproductive effect in girls, rewards can have a negative effect when the food is already liked [114, 115]. However, female adolescents seemed more responsive to the app and the intervention. A further evaluation of the process evaluation log data will be needed to understand why the intervention did not lead to an increase in healthy snack ratio girls, despite the fact that they used the app more. Possibly girls used more the apps' reflective methods such as the goal setting booklet or the report card. Previous research also indicated that female children, adolescents and young adults have healthier food preferences, stronger beliefs in healthy eating and show more weight control involvement than male subjects [303, 304]. It thus seems that different strategies might be needed to achieve healthier snacking habits depending on sex and SR.

Individual characteristics such as sex, SR (and IC) not only influence the formation of eating habits, they also influence the effect of behavior change strategies. Within this PhD thesis (see chapter 7) moderation of the intervention effects by SR and sex could be documented (see above). Several other studies also already reported differences between high and low SR individuals in the effectiveness of behavior change strategies [115, 332, 333]. To our knowledge no other studies have also considered exploring sex differences in this regard. Sex differences were however already found in acceptance and effects of nutrition or obesity interventions in children, adolescents and college students [334-336]. Research by Nederkoorn et al. (2006) also suggested that IC and SR not only influenced the development of obesity but also influenced its treatment [268]. Some strategies to change behavior might thus work also better in high SR individuals or high IC adolescents and their combinations [64, 314]. Not only sex, SR and IC, but also several other individual psychological and biological characteristics are related to food choice and might also influence intervention effects and should be researched. Intervention research would thus benefit from tailoring their intervention to subgroups depending on individual characteristics such as sex, IC and SR. Burgess et al. (2014) already attempted to develop a profiling questionnaire for the intake of palatable foods [337]. The latter study however, mainly focused on differentiating between several hedonic and habitual drivers and did not take into account the reflective drivers related to IC. The use of tailoring could be easily integrated in the recent emergence of apps as intervention channel. Apps are known to provide efficient opportunities for tailoring and personal feedback [123-125].

8.2.3.2. Future research

In chapter 6 of this PhD it was attempted to research strategies to increase the RV of healthy snacks such as fruit for the first time. A small increase could be documented, but not yet to an extent that its RV was higher than that of unhealthy snacks. These encouraging findings pave the way for future research to use the same approach to study other types of reward that are more potent to increase the RV of fruit or to test other strategies to increase the RV of healthy foods. These findings however always require confirmation in a situation where an individual is presented with an actual choice between these snack options by clinical (relative choice experiments) and/or field studies [259], as the approach presented in this PhD thesis tested the RV of the reinforcers as absolute. Other types of reward to explore could be derived from the study by McEvoy et al. (2014) [338]. This study showed that adolescent were in general positive towards reward-based interventions, but that preferences for the type rewards were influenced by geographical area (urban versus rural settings) [338]. Rewards such as leisure centre vouchers, home-work passes, free meal/drink items and stationary equipment were highlighted across groups [338]. Additionally pupils from rural and small urban-town schools preferred more group-based rewards such as house-points and class school trips, whereas pupils from urban-city schools liked more individualistic and immediate rewards, for example clothes vouchers, CDs, online music and mobile phone top-up vouchers. Other strategies to increase the RV of healthy snacks could be based on evaluative condition principles. Walsh et al. (2014) already showed that adults implicit affective associations about fruit could be altered using an implicit priming paradigm [261]. Another study in adults also found positive effects of evaluative conditioning principles, they found that a picture-picture evaluative conditioning procedure significantly increased negative implicit attitudes towards soda [339]. Epstein et al. (2007), Vervoort et al. (2016) and Jacques-Tiura and Greenwald (2016) also suggested that strategies to increase the RV of healthy foods should be combined with strategies to decrease the RV of unhealthy foods in order to maximize the chances that people would alter their food choice and consumption habits [76, 247, 262]. Known methods to decrease the consumption of unhealthy snacks are to increase the costs (for example food taxing), to decrease the variety of unhealthy snack options and to decrease the portion size; to increase the consumption of healthy snacks methods other than rewards include subsidies, increasing variety of healthy snack options and making healthy snacks the default option in restaurants and cafeterias [76, 247, 262, 263]. Food taxing has already been found to lower unhealthy snack and energy drink purchases in adolescents [340, 341]. Making healthy lunches the default option has also shown to increase the consumption of healthy foods in high school students [342]. Future studies should thus explore which combinations of the above mentioned strategies to decrease unhealthy food consumption and to increase healthy food consumption are promising in adolescents.

Future intervention research should acknowledge the dual process nature of eating behaviors and combine reflective strategies with implicit/automatic strategies, when attempting to change eating behaviors such as snacking. In addition to the strategies presented in this PhD thesis several other strategies to influence the reflective and automatic processes exist and could also be employed [56, 60]. The research by Rothman et al. (2009) provides a good overview of such reflective and automatic strategies [60]. To date little evidence exists on the use of both reflective and implicit strategies in adolescents to alter food choice, the few studies that researched the use of both types of strategies are limited to adults. Forman et al. (2016) already tested the combination of inhibitory control training and mindful decision making in adults to decrease salty snack consumption and found positive effects compared to control condition focusing on psychoeducation [343]. When attempting to extend evidence from adults to adolescence, one may not overlook the difference in SR and IC between adolescents and adults [90, 91].

Future interventions would also benefit from tailoring their intervention to subgroups, depending for instance on IC, SR and sex (chapter 7) [64, 115, 268, 314]. To identify such subgroups practices could be adopted from practices already long used in consumer research to identify population subgroups/clusters. In consumer research typically mapping or profiling approaches are used to identify subgroups of consumers [344, 345]. Apps provide opportunities for tailoring and personal feedback [123-125], a few short questions to measure for instance IC, SR and sex could be incorporated in future apps designed to change eating behavior. Several other individual psychological and biological characteristics are related to food choice and might also influence intervention effects, future research should focus on further exploring these characteristics.

Most of the intervention strategies proposed here are individual strategies as this was the focus of this PhD thesis. The influence of the environment on adolescents' food choices should not be overlooked however (see section 8.2.1.1. and 8.2.3.1), and strategies to change these environmental influences should also be explored in addition to individual strategies [43]. Examples of physical environmental and policy strategies were already given (see above) and include among other food taxes and nudging [76, 247, 262, 263]. Given also the importance of peer and friends on adolescents' food consumption [43, 51, 67, 68], strategies that foster social comparison and social support should also be considered.

Policy actions and interventions to the decrease the consumption of SSBs have been shown to be effective. Consumption of SSBs however, remains high across the globe and is undoubtedly connected to overweight and obesity [346]. Health promotion and policy should continue their efforts to reduce consumption of these beverages [346]. In this PhD thesis we documented that SR was also related to SSB consumption in adolescents (see chapters 2 and 3) health promotion actions should thus also take this influence into account. The proposed dual process theoretical framework could thus also possibly be applied to reduce to reduce the intake of SSBs.

The potential of apps for health promotion is generally acknowledged [123, 230]. Apps can reach a large number of users and provide new or more efficient opportunities for tailoring, multiple functionalities such as interactive possibilities and feedback opportunities and a more engaging way of behavior change [123-125]. However evidence on the effectiveness of such apps in health promotion interventions is still limited. Recently a review summarized the evidence of using apps in promotion of healthy eating, physical activity and decreasing sedentary activity [273]. This review reports that most studies using apps, newly developed or commercially available at least reported within group effects (low exposure vs. high exposure) and 8 of the 19 studies considered also reported significant between group effects (intervention vs. control). It also concluded that stronger effects were observed when apps were imbedded in a multi-component intervention. However not enough data was available to conclude what app features and/or behavior change techniques determined success. More intervention studies are needed to be able to determine what app features are successful and which factors drive user engagement [273]. Intervention studies are particularly needed in adolescents and children, as only four studies could be identified in the latter review. This PhD thesis already contributed by reporting on a stand-alone app intervention in adolescents and by providing users' statistics (log data). The log data however, still need to be further analyzed to determine what features of our app were more appealing and which were not. Many more studies studying health effects of apps and its specific features are still needed. Also research on the effective features of already existing commercial health apps and on the individual characteristics that are associated with higher use of such apps can help guide development of effective apps [124, 216, 273]. The study presented in chapter 5 was one of the first to document associations between commercial nutrition and fitness apps and eating habits and

BMI in adolescents. More research on associations with health behaviors along with research on the individual characteristics that determine the use of existing apps and its features is still needed in adolescents.

Based on the results from the intervention study (see chapter 7) and emerging literature on interventions using apps or serious games in adolescents and children [130-134, 273, 331] several recommendations could be given.

Regarding implementation of interventions:

- The downloading process of the app should be easy. For means of pilot testing and effect evaluations it would thus be better if adolescents could download the app already from the app store at home. Also it is important that the app does not take up too much memory, as adolescents preferred not having to remove any photos or other apps from their phone. A review on the effectiveness and acceptability of intervention using apps for health promotion by Payne et al. (2015) also stated that easiness of use was one of the most important factors that determined user retention and acceptability [301].
- Additional important factors for acceptability of an app identified in the review by Payne et al. (2015) were limited time needed to use the apps and apps that fitted in the daily routine of the users with appropriate and timely prompts [301]. Both factors were also recognized as important by the adolescents during the focus group discussions on evaluation of the "Snack Track School" app (see appendix 4 and box 1 in chapter 7).
- The app and the intervention in general should be fully accepted and adopted by the adolescents. Adolescents are a challenging group for health promotion, as they are developing their own identity, opinions and ideas and typically portray a strong negative response to the sense of being pushed in a certain direction [294]. Interventions have a higher chance to be adopted when 1) they are promoting healthy eating habits instead of discouraging unhealthy habits, 2) they are delivered by people that the adolescents are familiar with such as peers, teachers or parents instead of researchers and 3) they are using non-intrusive intervention strategies [294]. In future interventions it would thus

be better to involve the school and teachers even more in the development and implementation of the intervention and to possibly incorporate the intervention within the school activities, projects or curriculum. Also it is possible to deliver the intervention through peers and to increase the participatory part of the adolescents in intervention development. Several successful healthy eating or weight loss intervention in adolescents and children that use a peer-based approach already exist [347-349].

- The “Snack Track School” app entailed competition within classes and between classes and school groups (girls vs. boys), it is then imperative that all classes are actively involved in the intervention together with their teacher to make the competition truly vivid. This was unfortunately not reached in this intervention. Adolescents mentioned several times during the focus group discussions that they lacked a feeling of competition and group sense. Teachers mentioned during the focus group discussions (see appendix 5 and box 1 in chapter 7) that the competition could be improved by focusing on within class competition, using general leader boards, and by also including real-life tangible rewards.

Regarding development of apps and interventions:

- For a serious game or gamified app intervention to succeed, engagement and “fun” are crucial [108, 135, 331]. A state of immersion or transportation should be reached, a flow with a good balance between skills and challenge should be established and the players’ needs for mastery, autonomy, connectedness, arousal, diversion, fantasy, or challenge should be met [108, 133, 135, 279, 331]. In our app adolescents found the characters too childish and hence could not relate to the characters in the game. The adolescents also felt the app contained too little challenge and levels, nor was the story sufficiently attractive. Despite efforts made via user-group testing and preliminary research identifying interesting game components, we did not succeed in creating an engaging appealing gamified app. Combining game theories, focused on what drives engagement, with behavioral change theories could provide a solution here [133].

Baghaei et al. (2016) developed a set of game design strategies for mobile serious games to create and attain flow [130]. Also Baranowski et al. (2013), Spook et al. (2015) and Thompson et al. (2010) provide theory and guidance on how to create engagement in serious games, whether or not mobile [131, 331, 350].

- Such game theories [130, 131, 331, 350] could also help ensuring that the behavior change and the "fun" elements are appropriately intertwined with each other. As such, most adolescents experienced insufficient connection between the story line and the goal of the app.
- Creating a broader development team could also be useful to ensure that appropriate "fun" elements are present and are enough intertwined with the behavior change elements [331]. Not only should behavior change scientists and health professionals be included, but also an array professionals of dedicated to the element of "fun" should be part of development team [331].
- In addition it is imperative to focus on which game features are attractive specifically to the targeted group, as desired game features differ between children, adolescent and adults [351]. Our app was rated childish and not appropriate for their age by the adolescents, a later acceptability test then revealed that a younger age group (11-13 year olds) did find the app appealing.
- Our intervention only lasted four weeks, which is short in comparison to other interventions that used apps [272, 273] and school based health eating interventions in general [54, 107]. A longer intervention duration would increase intervention effects [273], the app developed within this PhD thesis was however designed as such to last only four weeks and should thus be altered for this purpose.
- The reviews by Payne et al. (2015) and Dute et al. (2016) found that monitoring was the most frequently used behavior change technique in apps that aimed at improving physical activity levels and the diet [272, 301]. Being able to track your personal progress and receiving feedback under the form of a record was also highly liked by

the users [301]. The review of Dute et al. (2016) also identified goal setting as an additional effective technique in apps [272]. In addition another behavior change technique that was found to frequently used, effective and liked by the users was the provision of social support [272, 301]. This technique was not incorporated in our app, but could be an additional beneficial feature. In this case, however acceptability by the adolescents should still be explored. Teachers also mentioned during the focus group discussions that the influence of peers on adolescents' food choices should not be overlooked. Future interventions aimed at adolescents should thus also explore strategies that allow for social comparison and social support, such as general leader boards and chat functions [272, 301]. As teachers also mentioned the importance of group dynamics, working with peer advocates [347-349] could also be considered in future studies.

- The interventions effect could also be increased by incorporating the developed app into a larger multicomponent intervention. Both Dute et. al. (2016) and Schoeppe et al. (2016) reported that multicomponent interventions were usually more effective than standalone app interventions [272, 273]. Multi-component interventions evaluated in the latter studies for instance combined an app with motivation emails, telephone monitoring sessions, text messages or imbedded the app in psychical education classes [272, 273].

8.3. General conclusion

This research showed that hedonic eating processes, driven by the rewarding value of food and an individuals' SR, are associated with unhealthy snack and SSB intakes in adolescents. Thereby adding to previous research in children and adults that high SR individuals are a risk group to develop unhealthy eating behaviors and/or overweight or obesity. It calls for health promotion to not overlook this potential influence and to take this into account when designing intervention programs. This PhD thesis incorporated these findings into a health promotion framework and proposed a new theoretical approach with a dual process nature to understand adolescents' eating behaviors. Based on the introduced theoretical model this PhD thesis also proposed a new intervention approach.

In addition it showed that rewarding strategies can increase the RV of fruits in adolescents. As such rewarding strategies might be effective in altering food choices of adolescents, this is however still to be further confirmed. The intervention study that incorporated both rewarding and reflective strategies was inconclusive, small positive effects were observed only for high SR boys. The feasibility study resulted in several interesting learning points to be addressed when using apps to improve eating behaviors in adolescents. Based on the lessons learned from the feasibility study and new literature, the app developed within this intervention study needs further refinement to reach its full potential in adolescents. Tailoring of the used strategies according to sex and SR should also be considered, however more research is needed to determine which features of the app appeal to each group. The app was also found to be appealing to younger children (11-13 year olds) and could thus be tested for efficacy within this age group.

Appendices

Appendix 1: Snack and Beverage FFQ

Beverages

Please fil in the table below how often you drink the following beverages, how much you then usually drink per day and what kind you usually drink. Column four provides a set of standard portions you can use to determine how much you usually drink.

	How often did you consume the following beverages?	**How much of these beverages do you then consume per day on average?**	**Examples of standard portions**	**Which kind do you usually consume?**
Water	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	149ml or less 150-299ml 300-449ml 450-599ml 600-749ml 750ml or more	*1 glass = 150ml* *1 can = 330ml* *1 plastic bottle = 500ml*	regular flavored (for example Vitalinea or Perrier with lemon)
Fruit juice	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	149ml or less 150-299ml 300-449ml 450-599ml 600-749ml 750ml or more	*1 glass = 150ml* *1 can = 330ml (for example V8)* *1 plastic bottle = 330ml* *1 carton = 200ml* *1 glass bottle = 200ml (for example. Looza)*	Fruit juice Vegetable juice Mixed juice Don't know
Sport drinks (for example Aquarius, Isostar or AA drink)	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	149ml or less 150-299ml 300-449ml 450-599ml 600-749ml 750ml or more	*1 can = 330ml* *1 plastic bottle = 500ml* *1 AA drink = 330ml*	Regular Light
Energy drinks (for example Redbull, Monster, Nalu or Tao energy)	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	149ml or less 150-299ml 300-449ml 450-599ml 600-749ml 750ml or more	*1 small can = 330ml* *1 large can = 500ml*	Regular Light
Soft drinks (for example cola, Lemonade or ice-tea)	Never or rarely 1-3 days per month 1 day per week	149ml or less 150-299ml 300-449ml 450-599ml 600-749ml	*1 glass = 150ml* *1 can= 330ml* *1 plastic bottle = 500ml* *1 glass bottle*	Regular Light

	2-4 days per week 5-6 days per week Daily	750ml or more	*= 200ml*	
Tea or coffee	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	149ml or less 150-299ml 300-449ml 450-599ml 600-749ml 750ml or more	*1 cup = 125ml* *1 mug = 225ml* *1 cup from the vending machine = 60ml*	Black With sugar With milk With milk and sugar With sweetener
Milk substitutes (for example soy drinks, rice drinks or oatmeal drinks)	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	149ml or less 150-299ml 300-449ml 450-599ml 600-749ml 750ml or more	*1 glass = 150ml* *1 cup = 125ml* *1 mug = 225ml* *1 soy drink = 250ml*	Regular Light
Sweetened milk beverages (for example chocolate milk)	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	149ml or less 150-299ml 300-449ml 450-599ml 600-749ml 750ml or more	*1 glass = 150ml* *1 cup = 125ml* *1 mug = 225ml* *1 small carton = 200ml*	Regular Light
Milk	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	149ml or less 150-299ml 300-449ml 450-599ml 600-749ml 750ml or more	*1 glass = 150ml* *1 cup = 125ml* *1 mug = 225ml* *1 small plastic bottle = 500ml*	buttermilk skimmed milk semi skimmed milk full fat milk
Beer	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	149ml or less 150-299ml 300-449ml 450-599ml 600-749ml 750ml or more	*1 bottle/1 glass = 250 or 330ml* *1 can = 330 of 500ml*	Zero-Alcohol beer Heavy bear (for example Duvel or Trappist) Other beer (for example Jupiler, Palm or cherry beer)
Cocktails (for example mojito, Bacardi Breezer or cocktails with fruit juice)	Never or rarely 1-3 days per month 1 day per week	149ml or less 150-299ml 300-449ml 450-599ml 600-749ml	*1 bottle Ready-to-drink cocktail = 275ml* *1 longdrink glass = 220 ml*	Cocktail with beer (bv. mazout, shandy) Ready-to-drink cocktail

	2-4 days per week 5-6 days per week Daily	750ml or more		(bv. Bacardi Breezer) Cocktail (bv. mojito, pisang met fruitsap)
Aperitif (for example Porto, Pinea or Martini)	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	149ml or less 150-299ml 300-449ml 450-599ml 600-749ml 750ml or more	*1 glass = 75ml*	
Wine or sparkling wine	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	149ml or less 150-299ml 300-449ml 450-599ml 600-749ml 750ml or more	*1 glass = 100ml (sparkling wine)* *1 glass = 125ml (red, rosé or white wine)*	
Liquor	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	149ml or less 150-299ml 300-449ml 450-599ml 600-749ml 750ml or more	*1 glass = 35ml*	

Snacks

Please fil in the table below how often you eat the following foods as a snack, how much you then usually consume per day and what kind you usually eat. Column four provides a set of standard portions you can use to determine how much you usually eat. A snack is defined as any food consumed in between or after the three main meals (breakfast, lunch and dinner). Any food consumed within 30 minutes before or after the main meal is still considered part of the meal and not as a snack.

	How often did you consume the following food items?	**How much of these items do you then consume per day on average?**	**Examples of standard portions**	**Which kind do you usually consume?**
Chocolate and pralines AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	9g or less 10-24g 25-39g 40-54g 55-69g 70g or more	*1 individually wrapped bar = 47g* *1 bar of a large tablet (200g) = 25g* *1 bouchée = 25g* *1 praline = 15g*	
Candybars (for example Balisto, Mars, Snickers, Twix or Lion) AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	24g or less 25-49g 50-74g 75-99g 100-124g 125g or more	*1 large candybar (for example Mars, Snickers, Twix, Bounty) = 50g* *1 medium candyabar (for example Milkiway, Cha-cha, Balisto) = 25g* *1 mini candybar (bv. Mars mini, Twix mini) = 20g*	
Candy (for example M&M's, Chokotoff or lolly) AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	9g or less 10-34g 35-59g 60-84g 85-109g 110g or more	*1 small bag of M&M's = 45g* *1 chokotoff = 9g* *1 Fruit-tella, winegum, gummibear or cola bottle shaped candy = 4g*	

Dry cookies (for example petit beurre cookies, Sultana or gingerbread) AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	14g or less 15-49g 50-84g 85-119g 120-154g 155g or more	*1 petit beurre cookie = 8.5g* *1 slice of gingerbread = 23g* *1 wrap of Sultana Cookies (=2 cookies) = 43g*	
Other cookies (for example prince cookies, sprits, Pick up!, speculaas or Leo) AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	14g or less 15-49g 50-84g 85-119g 120-154g 155g or more	*1 prince cookie = 22g* *1 speculaas = 7g* *1 cereal bar = 23g* *1 boudoir = 5.5g* *1 Pick up! = 28g*	
Breakfast rolls (for example croissant) AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	74g or less 75-149g 150-224g 225-299g 300-374g 375g or more	*1 butter roll/croissant = 50g* *1 roll with custard or chocolate = 80g*	
Pastry (for example waffles, pancakes, apple pie or chocolate cake) AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	74g or less 75-149g 150-224g 225-299g 300-374g 375g or more	*1 piece of pie = 130 g* *1 slice of cake = 30g* *1 pancake = 70g* *1 frangipane = 70g*	
Breakfast cereal (for example Frosties, Honeypops, Cocopops, Smacks, muesli) AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	24g or less 25-49g 50-74g 75-99g 100-124g 125g or more	*1 small box of cereals = 26g*	
Natural unsweetened yoghurt or cottage cheese AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	74g or less 75-149g 150-224g 225-299g 300-374g 375g or more	*1 Petit Suisse = 60g* *1 Danone cottage cheese = 200g* *1 plastic cup of yoghurt = 125g*	Skimmed yoghurt or cottage cheese Semi skimmed yoghurt or cottage cheese full fat yoghurt or cottage cheese

Sweetened Yoghurt or cottage cheese with or without flavors (for example Danio, Vitalinea, Activia or Petit Gervais) AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	74g or less 75-149g 150-224g 225-299g 300-374g 375g or more	*1 large Petit Gervais = 100g* *1 Danio = 180g* *1 plastic cup of yoghurt = 125g*	Skimmed yoghurt or cottage cheese Semi skimmed yoghurt or cottage cheese full fat yoghurt or cottage cheese sweetened with: sugar or syrup sweetener don't know
Pudding, milk- or soy-based (for example chocolate pudding, rice pudding) AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	74g or less 75-149g 150-224g 225-299g 300-374g 375g or more	*1 pudding or soy dessert = 125g* *1 rice pudding = 100g*	Regular Light
Mousses (for example chocolate mousse, bavarois or tiramisu) AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	74g or less 75-149g 150-224g 225-299g 300-374g 375g or more	*1 chocolate mousse = 70g* *1 tiramisu or bavarois = 80g*	
Ice cream AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	54ml or less 55-89ml 90-124ml 125-159ml 160-194ml 195ml or more	*1 scoop of ice cream = 60ml* *1 ice Mars = 60ml* *1 magnum = 110ml* *1 cornetto = 120ml*	
Popsicles (for example Calipo) AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	54 ml or less 55-89ml 90-124ml 125-159ml 160-194ml 195ml or more	*1 calipo = 105ml* *1 mini-calipo = 60ml*	
Dried fruit (for example raisins, prunes, apricots , dates, figs) AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	14g or less 15-24g 25-34g 35-44g 45-54g 55g or more	*1 dried apricot = 8g* *1 dried fig = 20g* *1 hand of raisins = 20g*	

Fruit AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	99g or less 100-199g 200-299g 300-399g 400-499g 500g or more	*1 mandarin medium size = 90g* *1 pear medium size = 170g* *1 apple medium size =155g* *1 Banana medium size = 200g* *1 hand of grapes = 125g*	
Raw vegetables AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	39g or less 40-79g 80-119g 120-159g 160-199g 200g or more	*1 tomato = 150g* *1 cherry tomato = 12g* *1 raw carrot = 100g* *1 radish = 6g*	
Nuts and seeds (for example peanuts, walnuts cashew nuts or sunflower seeds) AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	14g or less 15-29g 30-44g 45-59g 60-74g 75g or more	*1 hand of pealed almonds = 25g* *1 hand of salted peanuts = 30g*	
Sandwich with sweet or savory spread AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	39g or less 40-79g 80-119g 120g or more	*1 small slice of bread = 20g* *1 regular slice of bread = 27g*	With sweet spread (for example hazelnut paste) With savory spread (for example cheese)
Salami or cheese cubes AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	19g or less 20-39g 40-59g 60g or more	*1 Babybel = 22g* *1 BIFI = 23g* *1 knack sausage = 8g* *1 cube of cheese = 5g* *1 triangle of Cheese spread = 20g*	
Crips or similar products (for example Lays, Doritos or Grills) AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	44g or less 45-69g 70-94g 95-119g 120-144g 145g or more	*1 small bag of crisps = 45g* *1 medium bag of crisps = 150g* *1 large bag of crisps = 225g*	Regular Light (for example Lays baked)

Other salty snacks (for example Tuc , cheese or bacon cookies) AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	29g or less 30-49g 50-69g 70-89g 90-109g 110g or more	*1 Tuc = 3.5g* *1 bag of prawn crackers = 80g* *1 cheese crispie = 3g*	
Sausage rolls, pizza, cheese rolls, panini,… AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	99g or less 100-149g 150-199g 200-249g 250-299g 300g or more	*1 sausage roll = 150g* *1 ham and cheese roll =130g* *1 hot-dog = 125g* *1 pizza baguette = 150g*	
Other fried snacks (for example fried meat ball cheese croquet or loempia) AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	99g or less 100-149g 150-199g 200-249g 250-299g 300g or more	*1 medium meat ball= 65g* *1 chicken nugget = 20g* *1 medium loempia = 105g* *1 cheese or shrimp croquette = 45g*	With mayonnaise or other fries sauces With ketchup No sauce
Fries AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	149g or less 150-199g 200-249g 250-299g 300-349g 350g or more	*1 average portion of fries at home or in the restaurant = 225g* *1 medium portion of fries at McDonald's or Quick = 127g*	
Hamburgers (for example cheese Burger or big Mac) AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	149g or less 150-199g 200-249g 250-299g 300-349g 350g or more	*1 Big Mac/Giant = 200g* *1 hamburger Mora = 110g* *1 cheeseburger = 120g*	
Pitta/durum AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	149g or less 150-199g 200-249g 250-299g 300-349g 350g or more	*1 pitta = 275g*	

Pastacups AS A SNACK	Never or rarely 1-3 days per month 1 day per week 2-4 days per week 5-6 days per week Daily	149g or less 150-199g 200-249g 250-299g 300-349g 350g or more	*1 portion of prepared noodles = 285g* *1 pastacup (for example Panzacup) = 270g*	Pasta Noodles

Appendix 2: Bland Altman plots for the reliability study

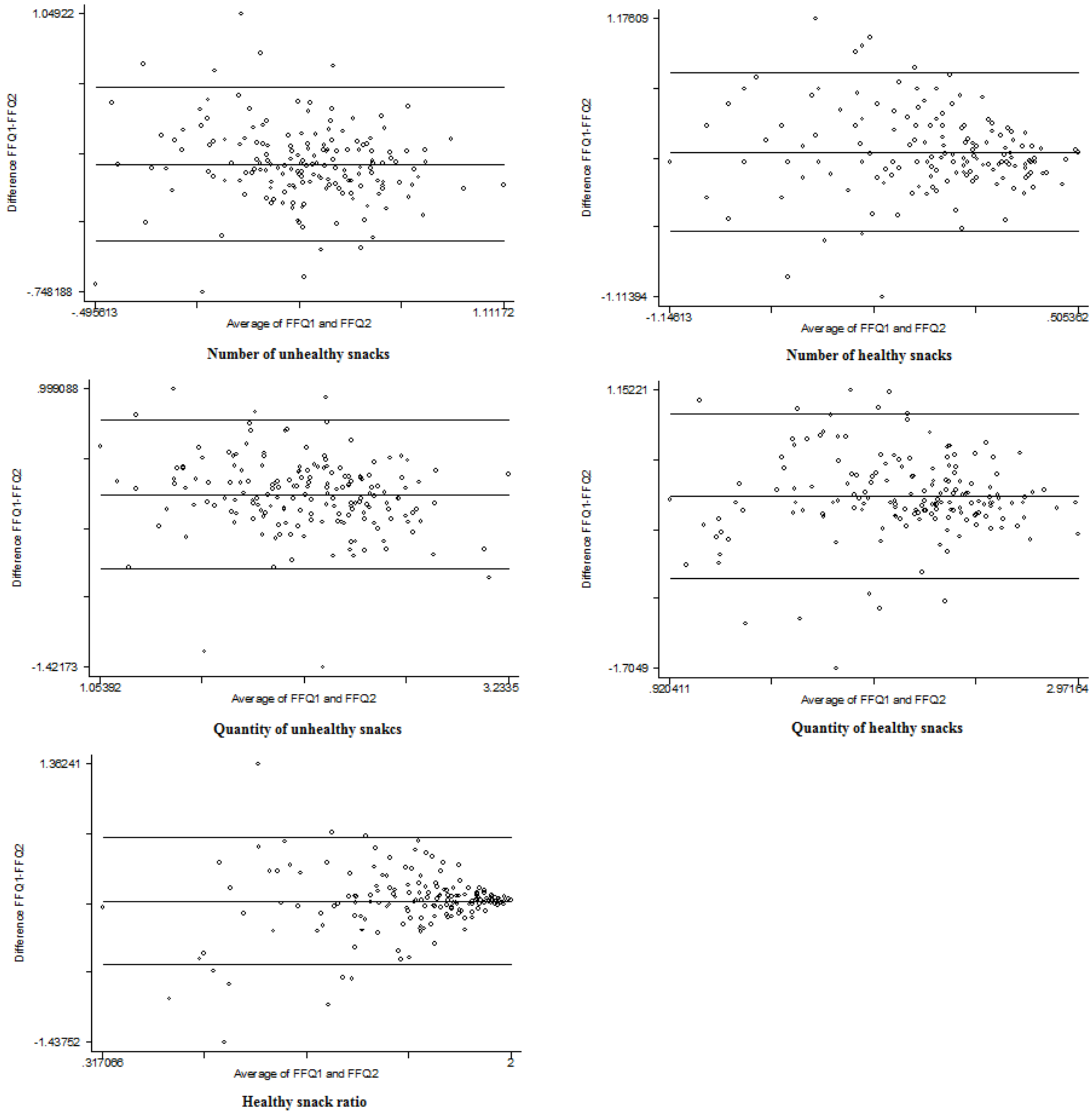


Figure 23: Bland Altman plots for the reliability study (n=179)

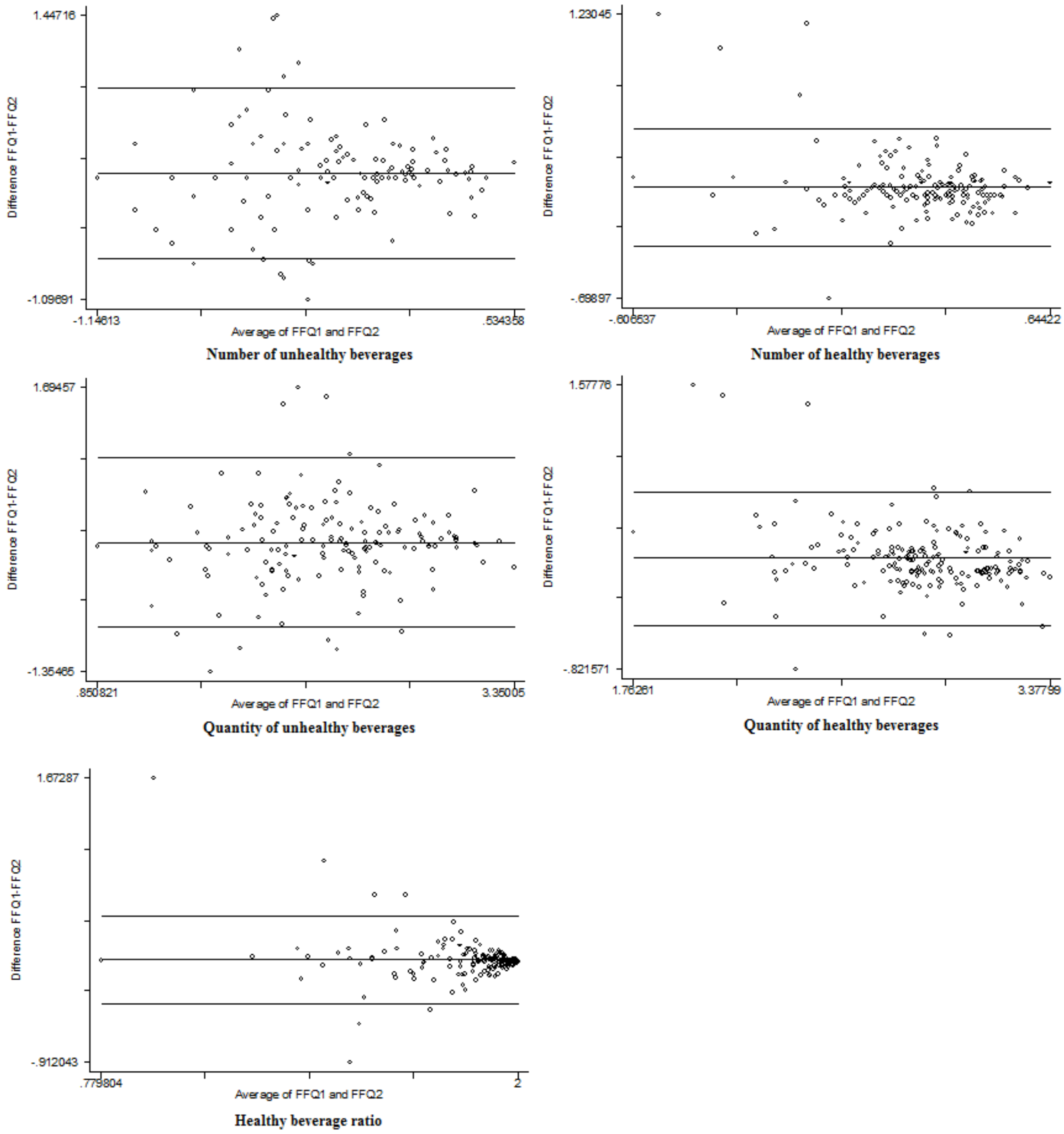


Figure 24: Bland Altman plots for the reliability study (n=179) (continued)

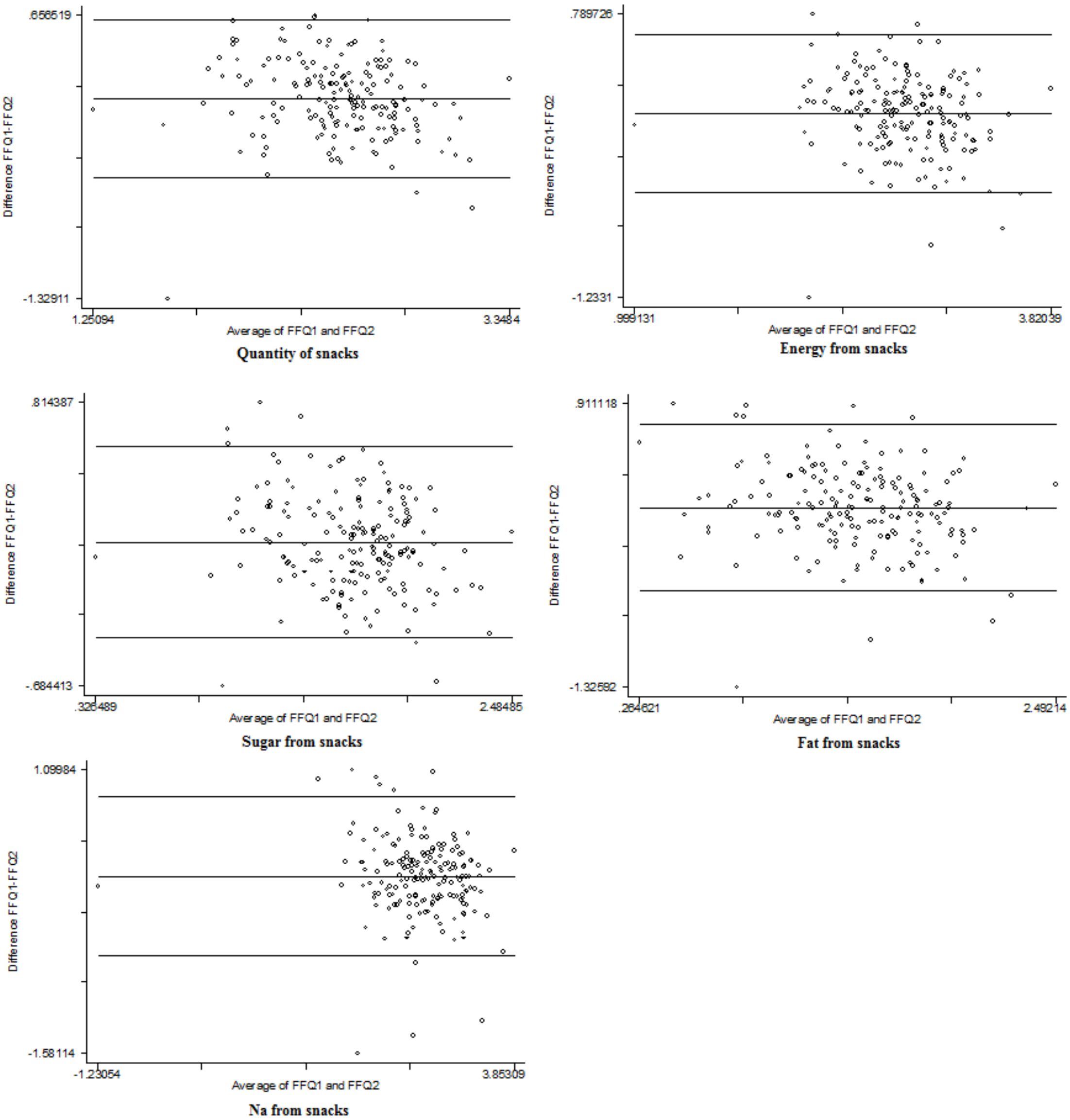


Figure 25: Bland Altman plots for the reliability study (n=179) (continued)

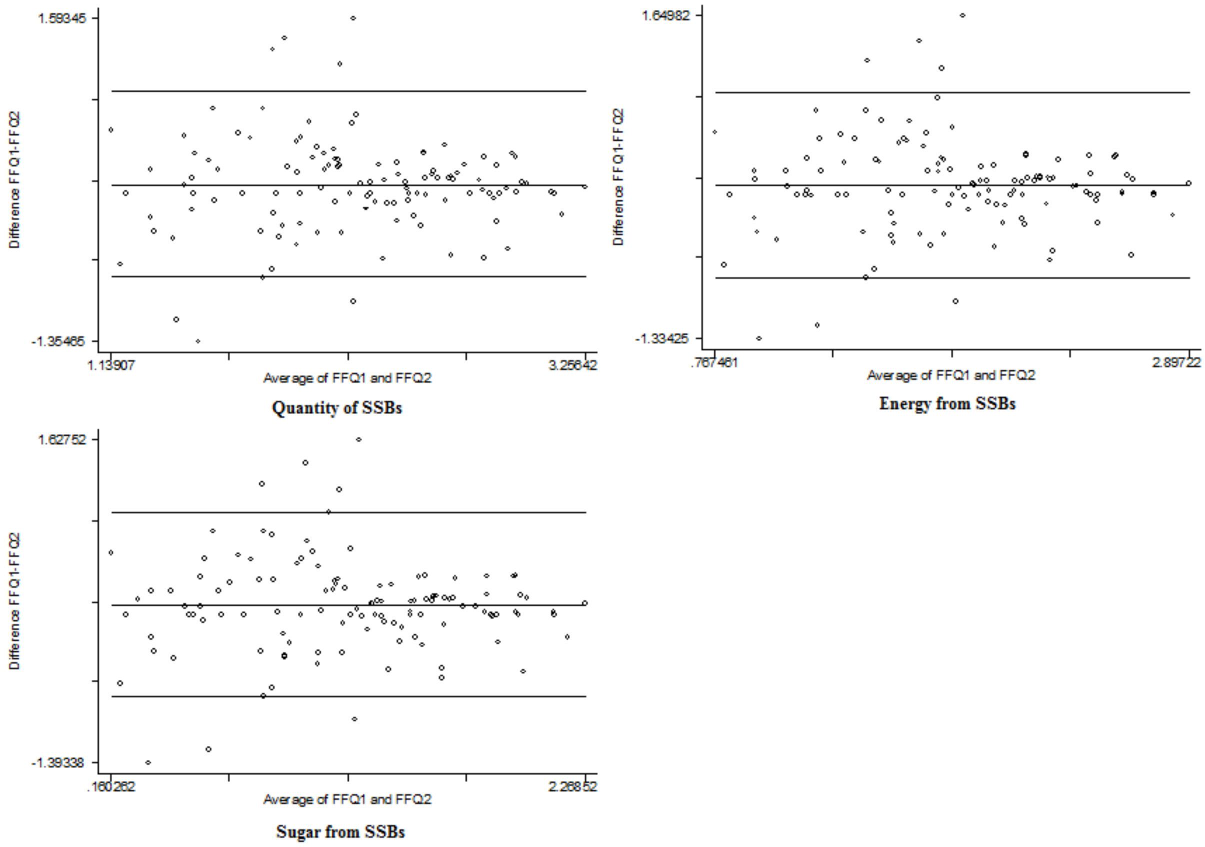


Figure 26: Bland Altman plots for the reliability study (n=179) (continued)

Appendix 3: Bland Altman plots for the validation study

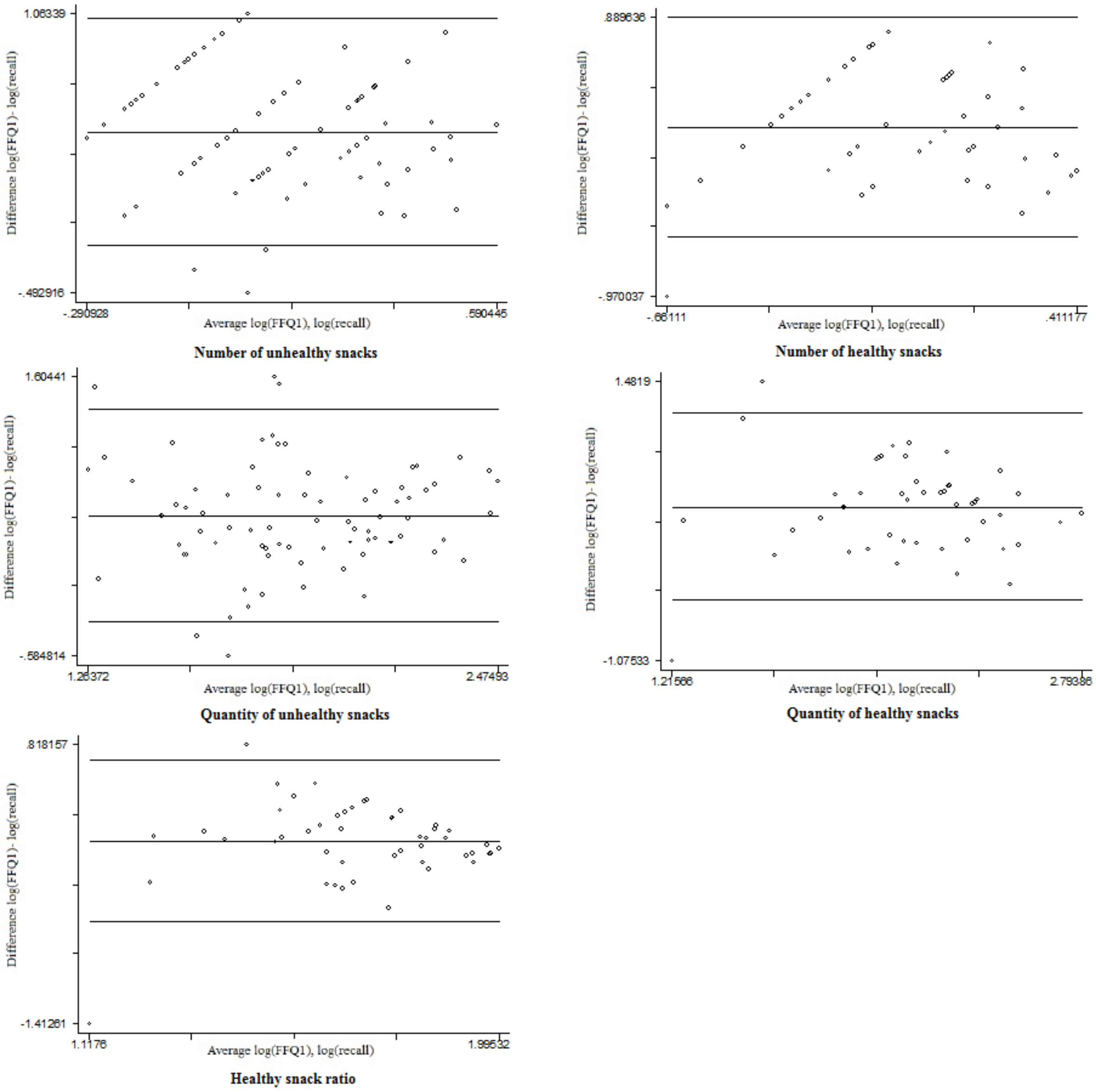


Figure 27: Bland Altman plots for the validation study (n=99)

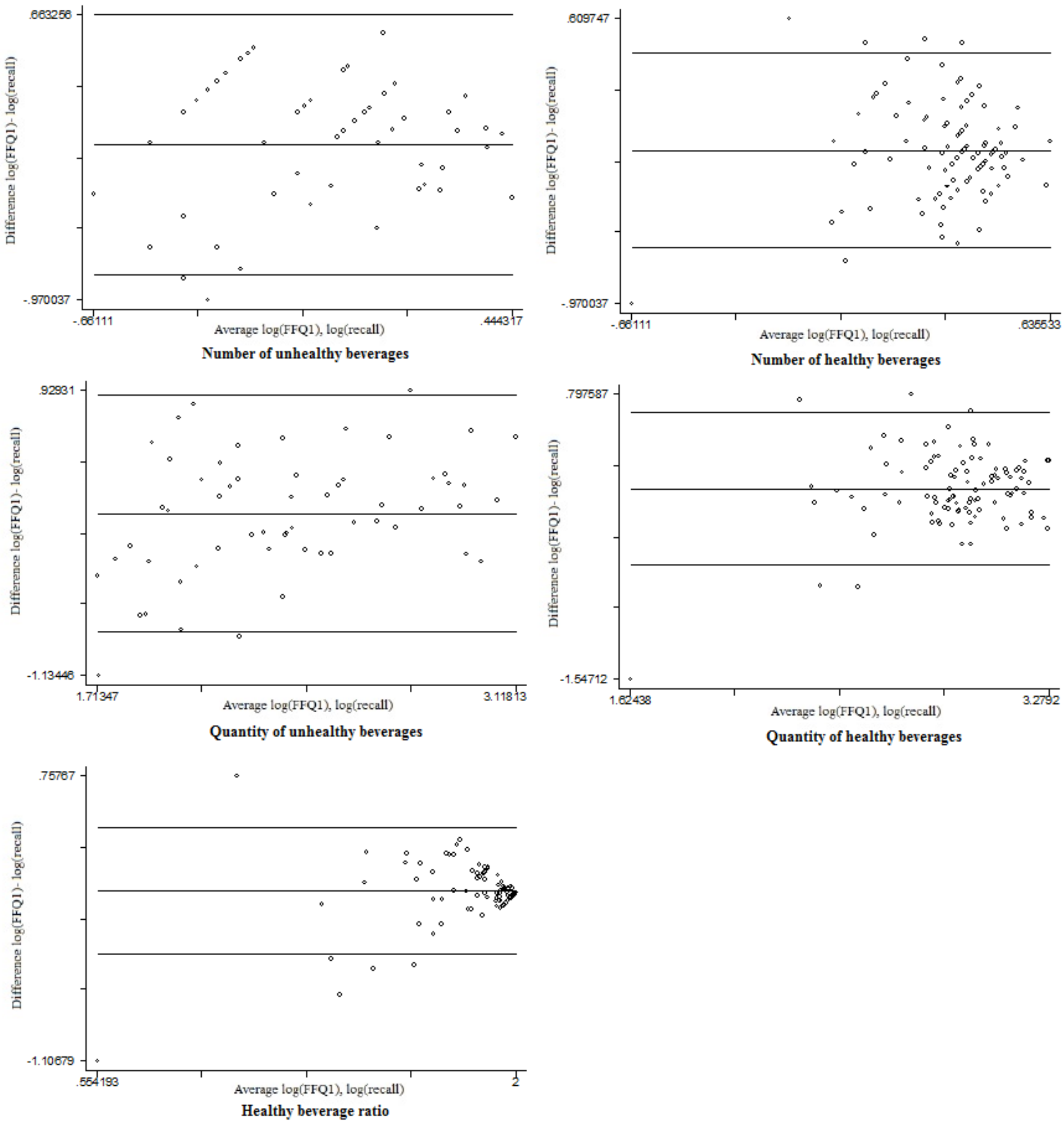


Figure 28: Bland Altman plots for the validation study (n=99) (continued)

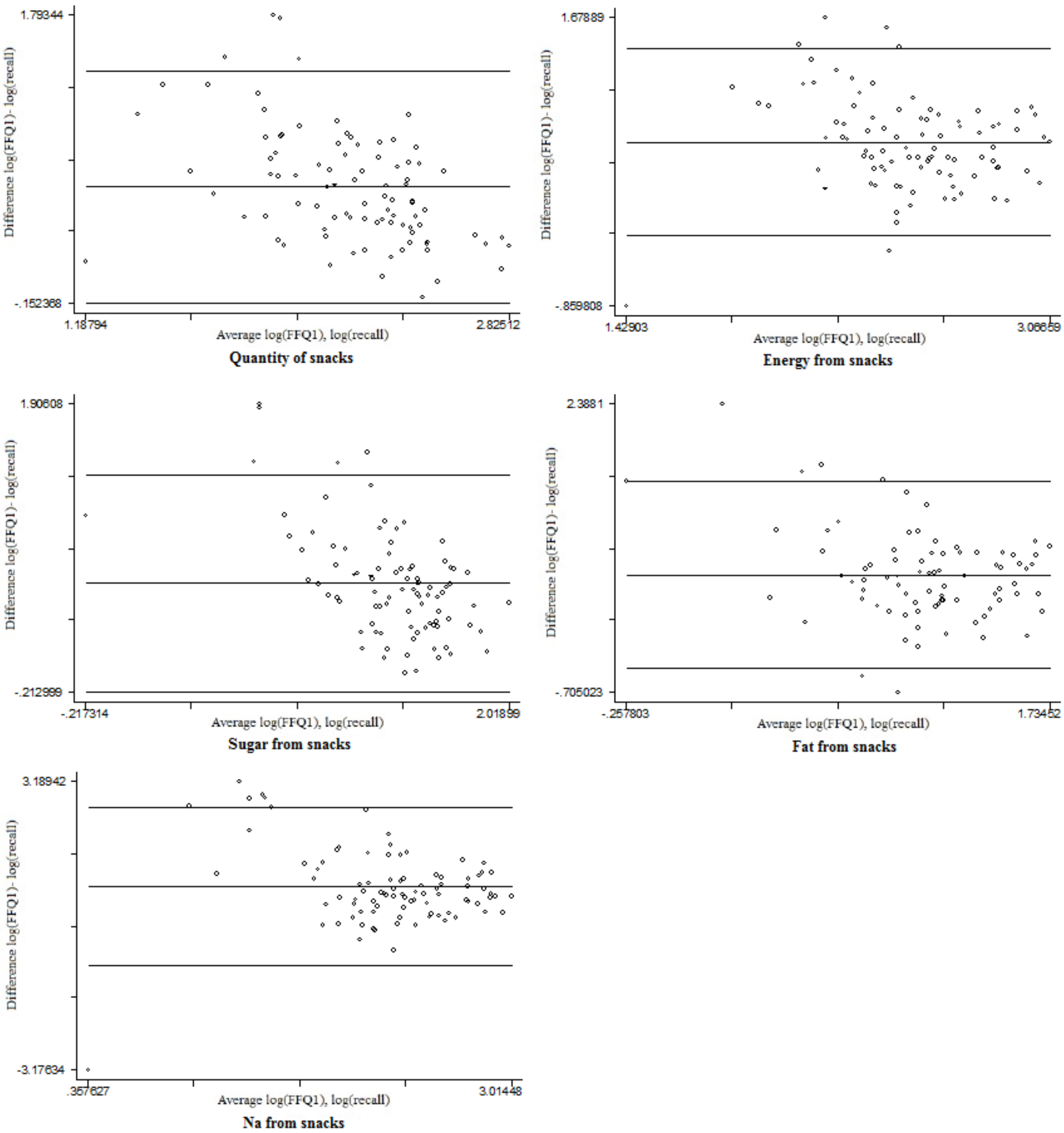


Figure 29: Bland Altman plots for the validation study (n=99) (continued)

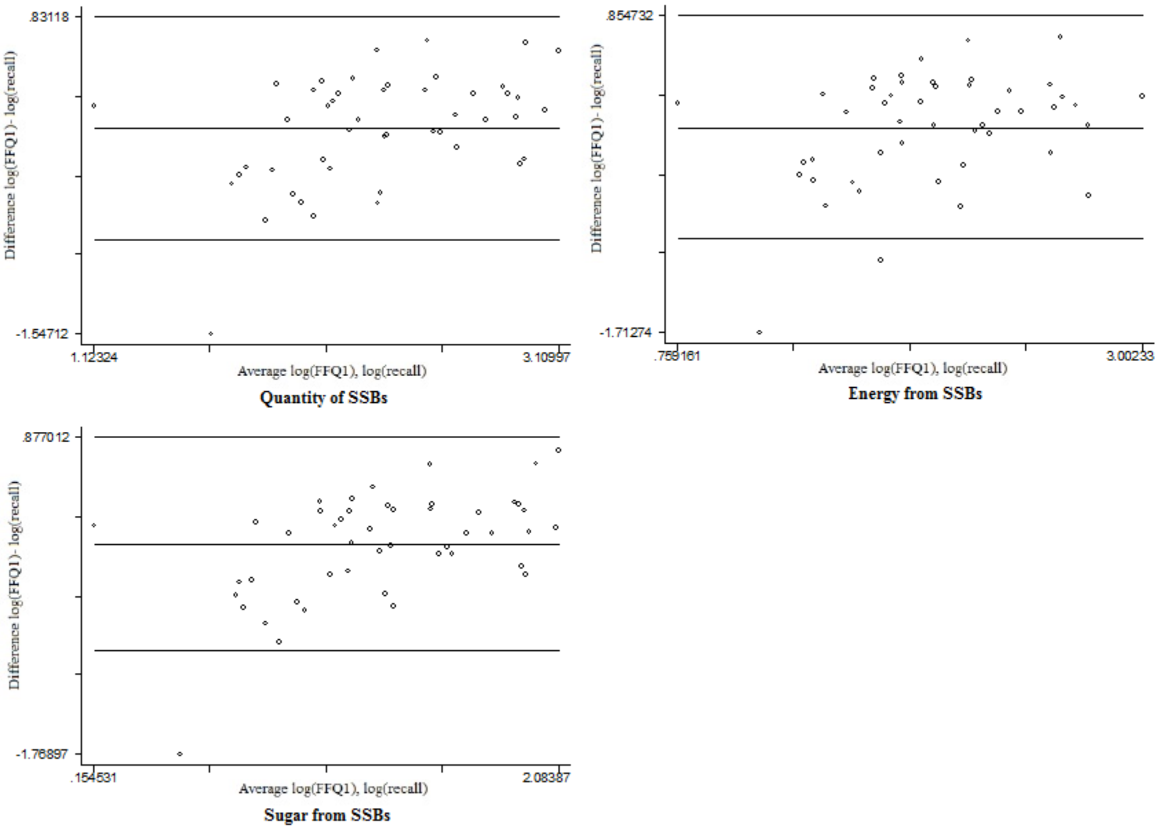


Figure 30: Bland Altman plots for the validation study (n=99) (continued)

Appendix 4: Report of the focus group discussions with the adolescents (qualitative process-evaluation)

1. Design

Comments given

- The adolescents found the overall design of the app too childish, especially the avatars and the layout of the school.
- The background music of the app was too boring for young people. They immediately turned it off.
- Some actions in the app required too much work, to locate and view the team overview four actions were needed. They first had to go to the main hall, then click on the locker, next on the post it and then they finally saw the team list.

Suggestions given

- The app is probably more suitable for younger people, such as 5th – 6th grade and 1st secondary.
- Add more sounds and fun music to make the app more attractive.

2. Challenge and competition

Comments given

- The game loop of the app was unclear, adolescents did not always understand what was the main goal of the app (i.e. collecting points to win the week challenge).
- Adolescents found that there was not enough action going on in the app. When they started playing the app, they would click continuously on locations of the school but there was nothing to do.
- Adolescents found some of the assignments/challenges in the app too easy and childish, for example cleaning up the playground.
- The activities for collecting avatar items were too simple and not challenging enough.
- As a monitoring application, adolescents found the app too complicated, while as a game they found that the app lacked enough challenge.
- There was no sense of competition between the teams. The app and its story was too little focused on this. Furthermore, as mentioned before it was difficult to find back their own team overview and adolescents therefore did not consult

this on a frequent basis. Also the score of the other team was not shown, which resulted in a lower competition feeling. During the first week a balance between the amount of healthy and unhealthy snacks eaten by the other team was shown, but this was not clear. Adolescents would rather have a true leaderboard.

- At the start of the intervention the division of the teams was not always successful. Some adolescents were in a very small team, while others were in a big team. Also it they did not like that the teams changed every week and they would be in teams with adolescents from other classes.

Suggestions given

- When we want to present the app as a game to them, More gamifications should be incorporated in the application. There should be activities in all classrooms. Ideas given: be able to move your avatar from one location to another, be able to play basketball with your avatar or shop in a grocery store with the avatar, etc.
- It would be nice if the app incorporated some mini-games.
- The activities to earn the avatar items need to be more difficult and diversified.
- The scores of their own team and the other team should be shown on a daily basis to enhance the competitive feeling, for instance with a leader board that is easily accessible.
- The teams should be composed within their own class group. They find it more fun and motivating if they know their teammates.

3. Storylines

Comments given

- Most adolescents did not understand the story lines, mainly because they did not read the texts.
- The final animation at the end of each week was passive and not engaging enough. For example, In the first week there was a passive food fight. The adolescents were disappointed that they could not do anything during the final animation. They just got a message with the winner or loser, they would like to be able to throw food themselves.

Suggestions given

- The animations should be much more challenging. They would like to participate in the animations in an active way.

4. Flow

Comments given

- They were not motivated to play app for 4 weeks, because every week there was a new story and the points were reset.
- The adolescents indicated that there was a lot of text to read. Usually they would not read the texts and just click the text balloons away.

Suggestions given

- Incorporate levels in the game, so that the winning team can move to a higher level. This would be more motivating for the participants to play the game during four weeks. In addition they find it important that they can try to reach a climax with a big reward at the end.
- Delete the text in the app. It is important to limit the text.

5. Scanning snacks and reward system

Comments given

- The adolescents sometimes forgot to scan their snacks. If they then would scan their snack later that day, they couldn't anymore take the selfie when needed. They found this annoying as they could be considered cheating, when they just wanted to scan a snack they ate earlier that day.
- School breaks are sometimes rather short, sometimes they do not have enough time to scan their snacks. They would like the possibility to also indicate their eaten snacks in the evening at home.
- Some adolescents also said they were just too lazy to scan their snacks.
- A part of the adolescents did not understand the usefulness of the application. They did not understand why they needed to track their snack intake.
- Despite the long detailed snack list, some of their favorite snacks were not in the list, such as Kinder Bueno, Pickup, Oreo-cookie, etc.
- Some students did not understand why they did not have to scan sweetened beverages as chocolate milk.
- After scanning two snacks at one moment, following message appears: 'It is not healthy to eat more snacks after each other' and participants had to wait two minutes to scan a next snack. Adolescents indicated that often they would consume two snacks at the same time (for example a yoghurt and a piece of fruit) and did not understand the usefulness of this rule.

- The reminders given by the app were annoying to the adolescents as they appeared at the wrong times for them. Sometimes they would appear when they were in class and were thus not able to consume any snacks.
- The adolescents felt motivated when they could earn points. They understood the points system of the app quickly, if they ate more healthy snacks, they could collect more points.
- However the gratuities and limitations build in the app were not confusing and unclear. They did not understand well how they could earn the daily and weekly bonuses is confusing and unclear. Some adolescents even thought they could earn the most points if they just ate a lot of snacks.
- It wasn't clear for cheaters how many points they had lost.

Suggestions given

- It would be easier if they could enter all snacks of one day in the evening.
- Adding brand names of snacks to the database. Many students search their snacks on the basis of the brand name.
- Some adolescents wanted to enter quantities of their snacks. They indicated that this would be better, because they wanted to be able to discriminate between eating a small piece of chocolate or a whole chocolate bar.
- The adolescents want like to choose the time slots and frequency of the reminders sent during the day.
- A clear overview of the points and bonus points given is needed.
- It would be better to get some feedback each time they receive bonus points or lose points for the gratuities, limitations, cheating and goals achieved.

6. Selfies and validation

Comments given

- Some adolescents liked to take selfies but others did not. Some indicated that it is not cool when others see a photo of them with food, as screenshots could be taken by other adolescents using the app.
- The frequency of taking the selfies did not feel random them, they even felt that not much selfies needed to be taken. As a result they could only validate a small number of selfies of others.
- The validation system did work at some smartphones. They saw checkered pictures and black screens. Sometimes a good picture was rejected because it was probably a black screen at the other team's smartphone. As a result sometimes points were lost unjustified and they had to clean up the playground.

- If students cheated, they had to clean up the playground. They found this punishment childish and not fun.

Suggestions given

- The adolescents suggested to only having to take a photo of the snack, but not of their own face. The app should then also allow to use the back camera, now only the front camera of the smartphone could be used.
- Another punishment for cheaters with serious consequences in the app would be better. For example, the players lose more points or they cannot participate in the game for some time (i.e. get a time-out).

7. Avatar

Comments given

- The adolescents liked the personal avatar in the app. It was fun to change the clothes of the avatar. The animal heads and items that they could earn, were sometimes childish.
- They also often received the same clothes when complementing an assignment.
- The adolescents could only see their own avatar a few times in the app, they would like if their avatar would be playable character.

Suggestions given

- The avatar should have more human characteristics so that the students can identify themselves better with their own avatar. The difference between male and female avatars should also be better visible.
- The items should be more cool and more fun. For example a football jersey of F.C. Barcelona.
- Adolescents also recommended to change the avatar depending on the snack choice, as such receive feedback about their snack choice in a fun way. If they eat unhealthy the avatar could look bad, while when they eat healthy the avatar would look beautiful and attractive.

8. General remarks

- There is a lot of peer pressure of friends to play or not play the app. The adolescents influenced another. It is important that playing the app becomes an accepted social activity within the classroom and that their teachers would also be involved.
- The adolescents, who quit playing the game shortly after release, said they had no interest in playing the game. They prefer doing something else in their spare time.
- The application takes a large part of the memory space of the smartphone. As a result, their smartphones would slow down.
- Adolescents, who borrowed a smartphone, found it unpractical to use two mobile phones at the same time. They forgot to bring the borrowed smartphone with them and as a result they did not register their snacks. Furthermore, the given Windows Phones were rather slow and blocked once in a while.

Appendix 5: Report of the focus group discussions with the teachers (qualitative process-evaluation)

1. Design

Comments given

- The teachers found the design of the app to be too childish for 14 to 16-year old adolescents. A virtual school environment is not attractive to the adolescents.
- Changing clothes of the avatar is mainly attractive for female adolescents.
- The app would be better suited for children of the first grade of high school.

Suggestions given

- The teachers suggested that a virtual town, in which the adolescents could walk around and buy healthy snacks for their avatar would be more fun. The example of "the Sims" was given.

2. Knowledge around healthy eating

Comments given

- The teachers were not certain the adolescents truly understood the goal of the intervention. The motivation to eat healthy is limited among certain groups of adolescents, they do understand the benefits of eating healthy. Girls tend to discuss their eating behaviors, but boys do not.
- The teachers felt that too much attention was given to the game elements and too little to awareness and consciously monitoring their snacks.

Suggestions given

- More attention should be given to the advantages of making healthy snacks: feeling more energetic, better for health, etc.
- It is important to provide the adolescents with knowledge why it is important to eat healthy, also when they are not overweight and sport regularly. In addition they usually do not know very well what is a healthy snack and what is not. It would be interesting to provide the adolescents with small quizzes in the app, in which they could earn points for good answers.

3. Scanning snacks, selfies and validation

Comments given

- Looking for their snack in a large database of 3000 snacks is not appealing to the adolescents. It would be better if there could be worked with bar code scanning or photo recognition.
- Giving in their snack into the app was sometimes difficult for the adolescents, the school breaks are very short and they did not always have the time.
- The validation system with the selfies also hindered the adolescents to register their snacks later that day. Even with the validation system they could still cheat anyway, by taking a photo of the same apple, etc.
- The punishment of cleaning the playground was not always liked by the adolescents.

4. Points and competition

Comments given

- The teachers liked the point system and the competition. Adolescents always like competition and leaderboards.

Suggestions given

- A overall leaderboard in which they could see everyone's point could further enlarge the competition feeling.
- More integration of the storyline, the avatar and the point system is needed.
- It would be better to keep the competition within the class to keep the team spirit high and to get adolescents to motivate each other to eat more healthy.
- Now the adolescents have to understand solely from the difference in points what is healthy and what is not, it would be better to also let them know more consciously what is healthy and what is not. For instance by putting healthy snacks in red in the report card, by providing a schematic overview during the app what is healthy, letting an alarm bell ring if they consume too many unhealthy snacks, etc.

5. Storyline

Comments given

- The storylines should be simple and clear. Adolescents do not like too much texts. Some teachers even felt that a storyline might not be necessary.

Suggestions given

- A game consisting with different levels might be enough.
- Storyline could also be told out loud by the characters.

6. Additional game elements

Comments given

- The challenges at each end of the week should be more fun and rewarding, a food fight or closing of the school is not appealing enough for this age group.

Suggestions given

- For 14 to 16-year old adolescents the interaction with peers is important, incorporating a chat function or linking the app to Facebook might be interesting.
- Mini-games should be added, for instance a virtual visit to the supermarket.
- It might be good to also give the adolescents some tangible rewards (cinema tickets, etc.), making a game that can keep the adolescents engaged for four weeks is difficult.

7. Implementation of the intervention

Comments given

- The adolescents needed more guidance at the start of the intervention, more attention needs to be given to what is expected from them and it needs to be emphasized more that it is a class challenge.

Suggestions given

- More promotion of the app should take place, for instance get a famous person to make promotion for the app.
- Adolescents are greatly influenced by their peers, more attention needs to be payed to this aspect. The group and class dynamics should be emphasized more.
- The intervention needs to be incorporated more within the school and the class happenings.
- More tangible elements should be included to get and keep the intervention running.
- Teachers should be more involved to guide and motivate the adolescents. Addressing a few key teachers to do this could help.
- It could be interesting to couple such an app to changes in the school policy, such as removing the vending machines.
- Incorporating the app into a school project around healthy eating could also be stimulating.

- Combining healthy nutrition with physical activity might also be interesting.
- Integrating the app within healthy education lessons could be a good idea as well, than teachers could give some more information on healthy nutrition.
- Follow-up is also important to keep the adolescents to eat healthy, why not do the intervention once every semester?

References

1. Adolescent development [http://www.who.int/maternal_child_adolescent/topics/adolescence/dev/en/]
2. Spear BA: Adolescent growth and development. *J Am Diet Assoc* 2002, 102:S23-S29.
3. Cusatis DC, Shannon BM: Influences on adolescent eating behavior. *J Adolesc Health* 1996, 18:27-34.
4. Davis M, Gance-Cleveland B, Hassink S, Johnson R, Paradis G, Resnicow K: Recommendations for prevention of childhood obesity. *Pediatrics* 2007, 120:S229-S253.
5. Phillips SM, Bandini LG, Naumova EN, Cyr H, Colclough S, Dietz WH, Must A: Energy-dense snack food intake in adolescence: Longitudinal relationship to weight and fatness. *Obes Res* 2004, 12:461-472.
6. Lien N, Lytle LA, Klepp KI: Stability in consumption of fruit, vegetables, and sugary foods in a cohort from age 14 to age 21. *Prev Med* 2001, 33:217-226.
7. Martens MK, Van Assema P, Brug J: Why do adolescents eat what they eat? Personal and social environmental predictors of fruit, snack and breakfast consumption among 12–14-year-old Dutch students. *Public Health Nutr* 2005, 8:1258-1265.
8. Nielsen SJ, Popkin BM: Changes in beverage intake between 1977 and 2001. *Am J Prev Med* 2004, 27:205-210.
9. Ng SW, Mhurchu CN, Jebb SA, Popkin BM: Patterns and trends of beverage consumption among children and adults in Great Britain, 1986-2009. *Br J Nutr* 2012, 108:536-551.
10. Duffey KJ, Huybrechts I, Mouratidou T, Libuda L, Kersting M, De Vriendt T, Gottrand F, Widhalm K, Dallongeville J, Hallstrom L, et al: Beverage consumption among European adolescents in the HELENA study. *Eur J Clin Nutr* 2012, 66:244-252.
11. Chapelot D: The Role of Snacking in Energy Balance: a Biobehavioral Approach. *J Nutr* 2011, 141:158-162.
12. Hess JM, Jonnalagadda SS, Slavin JL: What Is a Snack, Why Do We Snack, and How Can We Choose Better Snacks? A Review of the Definitions of Snacking, Motivations to Snack, Contributions to Dietary Intake, and Recommendations for Improvement. *Adv Nutr* 2016, 7:466-475.
13. Bellisle F: Meals and snacking, diet quality and energy balance. *Physiol Behav* 2014, 134:38-43.
14. Kerr MA, Rennie KL, McCaffrey TA, Wallace JMW, Hannon-Fletcher MP, Livingstone MBE: Snacking patterns among adolescents: a comparison of type, frequency and portion size between Britain in 1997 and Northern Ireland in 2005. *Br J Nutr* 2009, 101:122-131.
15. Keast DR, Nicklas TA, O'Neil CE: Snacking is associated with reduced risk of overweight and reduced abdominal obesity in adolescents: National Health and Nutrition Examination Survey (NHANES) 1999-2004. *Am J Clin Nutr* 2010, 92:428-435.
16. Nicklas TA, O'Neil CE, Fulgoni VL: Relationship between snacking patterns, diet quality and risk of overweight and abdominal obesity in children. *International Journal of Child Health and Nutrition* 2013, 2:189-200.
17. Phillips SM, Bandini LG, Naumova EN, Cyr H, Colclough S, Dietz WH: Energy-dense snack food intake in adolescence: Longitudinal relationship to weight and fatness. *Obes Res* 2004, 12.
18. Sebastian RS, Cleveland LE, Goldman JD: Effect of snacking frequency on adolescents' dietary intakes and meeting national recommendations. *J adolescent health* 2008, 42:503-511.
19. Rodriguez G, Moreno LA: Is dietary intake able to explain differences in body fatness in children and adolescents? *Nutr Metab Cardiovas* 2006, 16:294-301.
20. Scarborough P, Boxer A, Rayner M, Stockley L: Testing nutrient profile models using data from a survey of nutrition professionals. *Public Health Nutr* 2007, 10:337-345.

21. Garsetti M, de Vries J, Smith M, Amosse A, Rolf-Pedersen N: Nutrient profiling schemes: overview and comparative analysis. *Eur J Nutr* 2007, 46:15-28.
22. Nutrient Profiling Technical Guidance [http://multimedia.food.gov.uk/multimedia/pdfs/techguidenutprofiling.pdf]
23. Malik VS, Schulze MB, Hu FB: Intake of sugar-sweetened beverages and weight gain: a systematic review. *Am J Clin Nutr* 2006, 84:274-288.
24. Mathias KC, Slining MM, Popkin BM: Foods and Beverages Associated with Higher Intake of Sugar-Sweetened Beverages. *Am J Prev Med* 2013, 44:351-357.
25. Bleich SN, Wolfson JA: US adults and child snacking patterns among sugar-sweetened beverage drinkers and non-drinkers. *Prev Med* 2015, 72:8-14.
26. Bucher T, Collins C, Diem S, Siegrist M: Adolescents' perception of the healthiness of snacks. *Food Qual Prefer* 2016, 50:94-101.
27. Matthys C, De Henauw S, Devos C, De Backer G: Estimated energy intake, macronutrient intake and meal pattern of Flemish adolescents. *Eur J Clin Nutr* 2003, 57:366-375.
28. Vereecken CA, Maes L: Television viewing and food consumption in Flemish adolescents in Belgium. *Sozial-Und Praventivmedizin* 2006, 51:311-317.
29. Vereecken CA, De Henauw S, Maes L: Adolescents' food habits: Results of the health behaviour in school-aged children survey. *Brit J Nutr* 2005, 94:423-431.
30. Van den Bulck J, Van Mierlo J: Energy intake associated with television viewing in adolescents, a cross sectional study. *Appetite* 2004, 43:181-184.
31. Larson N, Story M, Eisenberg ME, Neumark-Sztainer D: Secular Trends in Meal and Snack Patterns among Adolescents from 1999 to 2010. *J Acad Nutr Diet* 2016, 116:240-+.
32. Cade J, Thompson R, Burley V, Warm D: Development, validation and utilisation of food-frequency questionnaires–a review. *Public Health Nutr* 2002, 5:567-587.
33. Thompson FE, Subar AF: Dietary assessment methodology. *Nutrition in the Prevention and Treatment of Disease* 2008, 2:3-39.
34. Neuhouser ML, Lilley S, Lund A, Johnson DB: Development and Validation of a Beverage and Snack Questionnaire for Use in Evaluation of School Nutrition Policies. *J Am Diet Assoc* 2009, 109:1587-1592.
35. Hedrick VE, Savla J, Comber DL, Flack KD, Estabrooks PA, Nsiah-Kumi PA, Ortmeier S, Davy BM: Development of a Brief Questionnaire to Assess Habitual Beverage Intake (BEVQ-15): Sugar-Sweetened Beverages and Total Beverage Energy Intake. *J Acad Nutr Diet* 2012, 112:840-849.
36. Kremers SP: Theory and practice in the study of influences on energy balance-related behaviors. *Patient Educ Couns* 2010, 79:291-298.
37. Bartholomew LK, Parcel GS, Kok G, Gottlieb NH: *Planning health promotion programs: an intervention mapping approach.* John Wiley & Sons; 2011.
38. Ajzen I: The theory of planned behavior. *Organ Behav Hum Decis Process* 1991, 50:179-211.
39. de Vries H, Dijkstra M, Kuhlman P: Self-efficacy: the third factor besides attitude and subjective norm as a predictor of behavioural intentions. *Health Educ Res* 1988, 3:273-282.
40. Prochaska JO, DiClemente CC, Velicer WF, Rossi JS: Criticisms and concerns of the transtheoretical model in light of recent research. *Br J Addict* 1992, 87:825-828.
41. de Vries H, Mudde A, Leijs I, Charlton A, Vartiainen E, Buijs G, Clemente MP, Storm H, Gonzalez Navarro A, Nebot M, et al: The European Smoking Prevention Framework Approach (EFSA): an example of integral prevention. *Health Educ Res* 2003, 18:611-626.
42. Kremers SP, de Bruijn GJ, Visscher TL, van Mechelen W, de Vries NK, Brug J: Environmental influences on energy balance-related behaviors: a dual-process view. *Int J Behav Nutr Phys Act* 2006, 3:9.
43. Story M, Neumark-Sztainer D, French S: Individual and environmental influences on adolescent eating behaviors. *J Am Diet Assoc* 2002, 102:S40-S51.

44. de Bruijn G-J, Kremers SPJ, de Vries H, van Mechelen W, Brug J: Associations of social-environmental and individual-level factors with adolescent soft drink consumption: results from the SMILE study. *Health Educ Res* 2007, 22:227-237.
45. Brug J, Lechner L, De Vries H: Psychosocial determinants of fruit and vegetable consumption. *Appetite* 1995, 25:285-296.
46. Pearson N, Ball K, Crawford D: Predictors of changes in adolescents' consumption of fruits, vegetables and energy-dense snacks. *Br J Nutr* 2011, 105:795-803.
47. O'Dea JA: Why do kids eat healthful food? Perceived benefits of and barriers to healthful eating and physical activity among children and adolescents. *J Am Diet Assoc* 2003, 103:497-501.
48. Vereecken CA, De Bourdeaudhuij I, Maes L: The HELENA online food frequency questionnaire: reproducibility and comparison with four 24-h recalls in Belgian-Flemish adolescents. *Eur J Clin Nutr* 2010, 64:541-548.
49. McClain AD, Chappuis C, Nguyen-Rodriguez ST, Yaroch AL, Spruijt-Metz D: Psychosocial correlates of eating behavior in children and adolescents: a review. *International Journal of Behavioral Nutrition and Physical Activity* 2009, 6:20.
50. Fitzgerald A, Heary C, Kelly C, Nixon E, Shevlin M: Self-efficacy for healthy eating and peer support for unhealthy eating are associated with adolescents' food intake patterns. *Appetite* 2013, 63:48-58.
51. Kümpel Nørgaard M, Nørgaard Hansen K, Grunert KG: Peer influence on adolescent snacking. *Journal of Social Marketing* 2013, 3:176-194.
52. Hartmann C, Siegrist M, van der Horst K: Snack frequency: associations with healthy and unhealthy food choices. *Public Health Nutr* 2013, 16:1487-1496.
53. De Bourdeaudhuij I, Velde ST, Brug J, Due P, Wind M, Sandvik C, Maes L, Wolf A, Perez Rodrigo C, Yngve A, et al: Personal, social and environmental predictors of daily fruit and vegetable intake in 11-year-old children in nine European countries. *Eur J Clin Nutr* 2008, 62:834-841.
54. De Bourdeaudhuij I, Van Cauwenberghe E, Spittaels H, Oppert JM, Rostami C, Brug J, Van Lenthe F, Lobstein T, Maes L: School-based interventions promoting both physical activity and healthy eating in Europe: a systematic review within the HOPE project. *Obes Rev* 2011, 12:205-216.
55. Doak CM, Visscher TLS, Renders CM, Seidell JC: The prevention of overweight and obesity in children and adolescents: a review of interventions and programmes. *Obes Rev* 2006, 7:111-136.
56. van't Riet J, Sijtsema SJ, Dagevos H, De Bruijn GJ: The importance of habits in eating behaviour. An overview and recommendations for future research. *Appetite* 2011, 57:585-596.
57. Brug J: Determinants of healthy eating: motivation, abilities and environmental opportunities. *Fam Pract* 2008, 25 Suppl 1:i50-55.
58. Fitzgerald A, Heary C, Nixon E, Kelly C: Factors influencing the food choices of Irish children and adolescents: a qualitative investigation. *Health Promot Int* 2010, 25:289-298.
59. Deutsch R, Strack F: Duality models in social psychology: From dual processes to interacting systems. *Psychol Inq* 2006, 17:166-172.
60. Rothman AJ, Sheeran P, Wood W: Reflective and automatic processes in the initiation and maintenance of dietary change. *Ann Behav Med* 2009, 38.
61. De Vet E, Stok FM, De Wit JBF, De Ridder DTD: The habitual nature of unhealthy snacking: How powerful are habits in adolescence? *Appetite* 2015, 95:182-187.
62. de Vries H, Eggers SM, Lechner L, van Osch L, van Stralen MM: Predicting fruit consumption: the role of habits, previous behavior and mediation effects. *BMC Public Health* 2014, 14:1-11.
63. Ames SL, Kisbu-Sakarya Y, Reynolds KD, Boyle S, Cappelli C, Cox MG, Dust M, Grenard JL, Mackinnon DP, Stacy AW: Inhibitory control effects in adolescent binge eating and consumption of sugar-sweetened beverages and snacks. *Appetite* 2014, 81:180-192.

64. Horstmann A, Dietrich A, Mathar D, Possel M, Villringer A, Neumann J: Slave to habit? Obesity is associated with decreased behavioural sensitivity to reward devaluation. *Appetite* 2015, 87:175-183.
65. Kubik MY, Lytle LA, Hannan PJ, Perry CL, Story M: The association of the school food environment with dietary behaviors of young adolescents. *Am J Public Health* 2003, 93:1168-1173.
66. Larson N, Eisenberg ME, Berge JM, Arcan C, Neumark-Sztainer D: Ethnic/racial disparities in adolescents' home food environments and linkages to dietary intake and weight status. *Eating Behaviors* 2015, 16:43-46.
67. Wouters EJ, Larsen JK, Kremers SP, Dagnelie PC, Geenen R: Peer influence on snacking behavior in adolescence. *Appetite* 2010, 55:11-17.
68. van Ansem WJC, Schrijvers CTM, Rodenburg G, van de Mheen D: Children's snack consumption: role of parents, peers and child snack-purchasing behaviour. Results from the INPACT study. *Eur J Public Health* 2015, 25:1006-1011.
69. Lally P, Bartle N, Wardle J: Social norms and diet in adolescents. *Appetite* 2011, 57:623-627.
70. Norgaard MK, Sorensen BT, Grunert KG: Social and individual determinants of adolescents' acceptance of novel healthy and cool snack products. *Appetite* 2014, 83:226-235.
71. van der Horst K, Timperio A, Crawford D, Roberts R, Brug J, Oenema A: The school food environment - Associations with adolescent soft drink and snack consumption. *Am J Prev Med* 2008, 35:217-223.
72. Gevers DWM, Kremers SPJ, de Vries NK, van Assema P: Patterns of Food Parenting Practices and Children's Intake of Energy-Dense Snack Foods. *Nutrients* 2015, 7:4093-4106.
73. Hennegan JM, Loxton NJ, Mattar A: Great expectations. Eating expectancies as mediators of reinforcement sensitivity and eating. *Appetite* 2013, 71:81-88.
74. Davis C, Fox J: Sensitivity to reward and body mass index (BMI): Evidence for a non-linear relationship. *Appetite* 2008, 50:43-49.
75. Davis C, Strachan S, Berkson M: Sensitivity to reward: implications for overeating and overweight. *Appetite* 2004, 42:131-138.
76. Epstein LH, Leddy JJ, Temple JL, Faith MS: Food reinforcement and eating: A multilevel analysis. *Psychol Bull* 2007, 133:884-906.
77. Giesen JC, Havermans RC, Douven A, Tekelenburg M, Jansen A: Will work for snack food: the association of BMI and snack reinforcement. *Obesity (Silver Spring)* 2010, 18:966-970.
78. Epstein LH, Yokum S, Feda DM, Stice E: Food reinforcement and parental obesity predict future weight gain in non-obese adolescents. *Appetite* 2014, 82:138-142.
79. Epstein LH, Carr KA, Lin H, Fletcher KD: Food reinforcement, energy intake, and macronutrient choice. *Am J Clin Nutr* 2011, 94:12-18.
80. Temple JL, Legierski CM, Giacomelli AM, Salvy S-J, Epstein LH: Overweight children find food more reinforcing and consume more energy than do nonoverweight children. *Am J Clin Nutr* 2008, 87:1121-1127.
81. Goldfield GS, Epstein LH: Can fruits and vegetables and activities substitute for snack foods? *Health Psychol* 2002, 21:299-303.
82. Giesen JC, Havermans RC, Jansen A: Substituting snacks with strawberries and Sudokus: does restraint matter? *Health Psychol* 2010, 29:222-226.
83. Temple JL: Factors that influence the reinforcing value of foods and beverages. *Physiol Behav* 2014, 136:97-103.
84. Franken IHA, Muris P: Individual differences in reward sensitivity are related to food craving and relative body weight in healthy women. *Appetite* 2005, 45:198-201.
85. Gray JA: Three fundamental emotion systems. In *The nature of emotion: fundamental questions* Edited by Ekman P, J. R, Davidson: New York: Oxford University Press; 1994: 243-247

86. Davis C, Patte K, Levitan R, Reid C, Tweed S, Curtis C: From motivation to behaviour: A model of reward sensitivity, overeating, and food preferences in the risk profile for obesity. *Appetite* 2007, 48:12-19.
87. Verbeken S, Braet C, Lammertyn J, Goossens L, Moens E: How is reward sensitivity related to bodyweight in children? *Appetite* 2012, 58:478-483.
88. Beaver JD, Lawrence AD, Van Ditzhuijzen J, Davis MH, Woods A, Calder AJ: Individual differences in reward drive predict neural responses to images of food. *J Neurosci* 2006, 26:5160-5166.
89. Stice E, Yokum S, Burger KS, Epstein LH, Small DM: Youth at Risk for Obesity Show Greater Activation of Striatal and Somatosensory Regions to Food. *J Neurosci* 2011, 31:4360-4366.
90. Hardin MG, Ernst M: Functional Brain Imaging of Development-Related Risk and Vulnerability for Substance Use in Adolescents. *J Addict Med* 2009, 3:47-54.
91. Galvan A: The Teenage Brain: Sensitivity to Rewards. *Curr Dir Psychol Sci* 2013, 22:88-93.
92. Carver CS, White TL: Behavioral-inhibition, behavioral activation, and affective responses to impending reward and punishment - the bis bas scales. *J Pers Soc Psychol* 1994, 67:319-333.
93. Muris P, Meesters C, De Kanter E, Timmerman E: Behavioural inhibition and behavioural activation system scales for children: relationships with Eysenck's personality traits and psychopathological symptoms. *Personality and Individual Differences* 2005, 38:103-113.
94. Tapper K, Baker L, Jiga-Boy G, Haddock G, Maio GR: Sensitivity to reward and punishment: Associations with diet, alcohol consumption, and smoking. *Pers Indiv Differ* 2015, 72:79-84.
95. Tapper K, Pothos EM, Lawrence AD: Feast your eyes: hunger and trait reward drive predict attentional bias for food cues. *Emotion* 2010, 10:949-954.
96. Vandeweghe L, Vervoort L, Verbeken S, Moens E, Braet C: Food Approach and Food Avoidance in Young Children: Relation with Reward Sensitivity and Punishment Sensitivity. *Front Psychol* 2016, 7.
97. Voigt DC, Dillard JP, Braddock KH, Anderson JW, Sopory P, Stephenson MT: Carver and White's (1994) BIS/BAS scales and their relationship to risky health behaviours. *Pers Individ Dif* 2009, 47:89-93.
98. Loxton NJ, Dawe S: Alcohol abuse and dysfunctional eating in adolescent girls: The influence of individual differences in sensitivity to reward and punishment. *Int J Eat Disorder* 2001, 29:455-462.
99. Snoek HM, Van Strien T, Janssens J, Engels R: Emotional, external, restrained eating and overweight in Dutch adolescents. *Scand J Psychol* 2007, 48:23-32.
100. Paquet C, Daniel M, Knaeuper B, Gauvin L, Kestens Y, Dube L: Interactive effects of reward sensitivity and residential fast-food restaurant exposure on fast-food consumption. *Am J Clin Nutr* 2010, 91:771-776.
101. Hu FB: Resolved: there is sufficient scientific evidence that decreasing sugar-sweetened beverage consumption will reduce the prevalence of obesity and obesity-related diseases. *Obes Rev* 2013, 14:606-619.
102. Moreno LA, Rodriguez G: Dietary risk factors for development of childhood obesity. *Curr Opin Clin Nutr* 2007, 10:336-341.
103. Bjelland M, Brantsaeter AL, Haugen M, Meltzer HM, Nystad W, Andersen LF: Changes and tracking of fruit, vegetables and sugar-sweetened beverages intake from 18 months to 7 years in the Norwegian mother and child cohort study. *BMC Public Health* 2013, 13:11.
104. Ames SL, Wurpts IC, Pike JR, MacKinnon DP, Reynolds KR, Stacy AW: Self-regulation interventions to reduce consumption of sugar-sweetened beverages in adolescents. *Appetite* 2016, 105:652-662.

105. Lane H, Porter K, Estabrooks P, Zoellner J: A Systematic Review to Assess Sugar-Sweetened Beverage Interventions for Children and Adolescents across the Socioecological Model. *J Acad Nutr Diet* 2016, 116:1295-1307.e1296.
106. Larson N, Story M: A Review of Snacking Patterns among Children and Adolescents: What Are the Implications of Snacking for Weight Status? *Childhood Obesity* 2013, 9:104-115.
107. Stice E, Shaw H, Marti CN: A meta-analytic review of obesity prevention programs for children and adolescents: The skinny on interventions that work. *Psychol Bull* 2006, 132:667-691.
108. Lu AS, Baranowski J, Cullen KW, Jago R, Thompson D, Baranowski T: Interactive Media for Childhood Obesity Prevention. *Health Communication* 2010, 25:581-582.
109. Carver CS, Scheier MF: Control theory: a useful conceptual framework for personality-social, clinical, and health psychology. *Psychol Bull* 1982, 92:111-135.
110. Michie S, Abraham C, Whittington C, McAteer J, Gupta S: Effective Techniques in Healthy Eating and Physical Activity Interventions: A Meta-Regression. *Health Psychol* 2009, 28:690-701.
111. Michie S, Hardeman W, Fanshawe T, Prevost AT, Taylor L, Kinmonth AL: Investigating theoretical explanations for behaviour change: the case study of ProActive. *Psychol Health* 2008, 23:25-39.
112. Reinaerts E, de Nooijer J, Candel M, de Vries N: Explaining school children’s fruit and vegetable consumption: the contributions of availability, accessibility, exposure, parental consumption and habit in addition to psychosocial factors. *Appetite* 2007, 48.
113. De Vet E, Stok FM, De Wit JB, De Ridder DT: The habitual nature of unhealthy snacking: How powerful are habits in adolescence? *Appetite* 2015, 95:182-187.
114. Cooke LJ, Chambers LC, Anez EV, Wardle J: Facilitating or undermining? The effect of reward on food acceptance. A narrative review. *Appetite* 2011, 57:493-497.
115. Vandeweghe L, Verbeken S, Moens E, Vervoort L, Braet C: Strategies to improve the Willingness to Taste: The moderating role of children's Reward Sensitivity. *Appetite* 2016, 103:344-352.
116. Wardle J, Herrera ML, Cooke L, Gibson EL: Modifying children's food preferences: the effects of exposure and reward on acceptance of an unfamiliar vegetable. *Eur J Clin Nutr* 2003, 57:341-348.
117. Gulliksen H: A rational equation of the learning curve based on Thorndike's law of effect. *The Journal of General Psychology* 1934, 11:395-434.
118. Lowe CF, Horne PJ, Hardman CA, Tapper K: A peer-modeling and rewards-based intervention is effective in increasing fruit and vegetable consumption in children. *Prev Med* 2006, 43:351-351.
119. Just DR, Price J: Using Incentives to Encourage Healthy Eating in Children. *J Hum Resour* 2013, 48:855-872.
120. Horne PJ, Tapper K, Lowe CF, Hardman CA, Jackson MC, Woolner J: Increasing children's fruit and vegetable consumption: a peer-modelling and rewards-based intervention. *Eur J Clin Nutr* 2004, 58:1649-1660.
121. Salvy S-J, Nitecki LA, Epstein LH: Do Social Activities Substitute for Food in Youth? *Ann Behav Med* 2009, 38:205-212.
122. Smith JA, Epstein LH: Behavioral economic-analysis of food choice in obese children. *Appetite* 1991, 17:91-95.
123. Schoffman DE, Turner-McGrievy G, Jones SJ, Wilcox S: Mobile apps for pediatric obesity prevention and treatment, healthy eating, and physical activity promotion: just fun and games? *Transl Behav Med* 2013, 3:320-325.
124. Dallinga JM, Mennes M, Alpay L, Bijwaard H, de la Faille-Deutekom MB: App use, physical activity and healthy lifestyle: a cross sectional study. *BMC Public Health* 2015, 15.
125. McNaughton SA: Advancing nutrition promotion research and practice. *Nutr Diet* 2015, 72:305-308.

126. Direito A, Jiang Y, Whittaker R, Maddison R: Apps for IMproving FITness and Increasing Physical Activity Among Young People: The AIMFIT Pragmatic Randomized Controlled Trial. *J Med Internet Res* 2015, 17.
127. Kontos E, Blake KD, Chou WY, Prestin A: Predictors of eHealth usage: insights on the digital divide from the Health Information National Trends Survey 2012. *J Med Internet Res* 2014, 16:e172.
128. Eshet-Alkalai Y, Chajut E: Changes over time in digital literacy. *Cyberpsychol Behav* 2009, 12:713-715.
129. apestaartjaren: onderzoeksrapport apestaartjaren 6. 2016.
130. Baghaei N, Nandigam D, Casey J, Direito A, Maddison R: Diabetic Mario: Designing and Evaluating Mobile Games for Diabetes Education. *Games Health J* 2016.
131. Spook JE, Paulussen T, Paulissen R, Visschedijk G, Kok G, van Empelen P: Design Rationale Behind the Serious Self-Regulation Game Intervention "Balance It": Overweight Prevention Among Secondary Vocational Education Students in The Netherlands. *Games for Health Journal* 2015, 4:387-400.
132. Majumdar D, Koch PA, Lee H, Contento IR, Islas-Ramos AD, Fu D: "Creature-101": A Serious Game to Promote Energy Balance-Related Behaviors Among Middle School Adolescents. *Games Health J* 2013, 2:280-290.
133. DeSmet A, Van Ryckeghem D, Compernolle S, Baranowski T, Thompson D, Crombez G, Poels K, Van Lippevelde W, Bastiaensens S, Van Cleemput K, et al: A meta-analysis of serious digital games for healthy lifestyle promotion. *Prev Med* 2014, 69:95-107.
134. Hieftje K, Edelman EJ, Camenga DR, Fiellin LE: Electronic media-based health interventions promoting behavior change in youth: a systematic review. *JAMA Pediatr* 2013, 167:574-580.
135. Baranowski T, Buday R, Thompson DI, Baranowski J: Playing for real - Video games and stories for health-related behavior change. *Am J Prev Med* 2008, 34:74-82.
136. Lasater G, Piernas C, Popkin BM: Beverage patterns and trends among school-aged children in the US, 1989-2008. *Nutr J* 2011, 10.
137. Sebastian RS, Cleveland LE, Goldman JD: Effect of snacking frequency on adolescents' dietary intakes and meeting national recommendations. *J adolescent health* 2008, 42.
138. Bertoli S, Petroni ML, Pagliato E, Mora S, Weber G, Chiumello G, Testolin G: Validation of food frequency questionnaire for assessing dietary macronutrients and calcium intake in Italian children and adolescents. *J Pediatr Gastroenterol Nutr* 2005, 40:555-560.
139. Nelson M, Black AE, Morris JA, Cole TJ: Between-subject and within-subject variation in nutrient intake from infancy to old-age - estimating the number of days required to rank dietary intakes with desired precision. *Am J Clin Nutr* 1989, 50:155-167.
140. Cade J, Thompson R, Burley V, Warm D: Development, validation and utilisation of food-frequency questionnaires - a review. *Public Health Nutr* 2002, 5:567-587.
141. Huybrechts I, Vereecken C, De Bacquer D, Vandevijvere S, Van Oyen H, Maes L, Vanhauwaert E, Temme L, De Backer G, De Henauw S: Reproducibility and validity of a diet quality index for children assessed using a FFQ. *Brit J Nutr* 2010, 104:135-144.
142. Vereecken CA, Maes L: A Belgian study on the reliability and relative validity of the Health Behaviour in School-Aged Children food-frequency questionnaire. *Public Health Nutr* 2003, 6:581-588.
143. Huybrechts I, De Bacquer D, Matthys C, De Backer G, De Henauw S: Validity and reproducibility of a semi-quantitative food-frequency questionnaire for estimating calcium intake in Belgian preschool children. *Br J Nutr* 2006, 95:802-816.
144. Diethelm K, Jankovic N, Moreno LA, Huybrechts I, De Henauw S, De Vriendt T, Gonzalez-Gross M, Leclercq C, Gottrand F, Gilbert CC, et al: Food intake of European adolescents in the light of different food-based dietary guidelines: results of

the HELENA (Healthy Lifestyle in Europe by Nutrition in Adolescence) Study. *Public Health Nutr* 2012, 15:386-398.
145. Vereecken CA, De Bourdeaudhuij I, Maes L, Grp HS: The HELENA online food frequency questionnaire: reproducibility and comparison with four 24-h recalls in Belgian-Flemish adolescents. *Eur J Clin Nutr* 2010, 64:541-548.
146. Haftenberger M, Heuer T, Heidemann C, Kube F, Krems C, Mensink GBM: Relative validation of a food frequency questionnaire for national health and nutrition monitoring. *Nutr J* 2010, 9.
147. Slater B, Philippi ST, Fisberg RM, Latorre M: Validation of a semi-quantitative adolescent food frequency questionnaire applied at a public school in Sao Paulo, Brazil. *Eur J Clin Nutr* 2003, 57:629-635.
148. da Silva IT, Timm AdS, Damasceno NRT: Influence of obesity and cardiometabolic makers on lipoprotein-associated phospholipase A(2) (Lp-PLA(2)) activity in adolescents: the healthy young cross-sectional study. *Lipids Health Dis* 2013, 12.
149. Eaton DK, Olsen EOM, Brener ND, Scanlon KS, Kim SA, Demissie Z, Yaroch AL: A Comparison of Fruit and Vegetable Intake Estimates from Three Survey Question Sets to Estimates from 24-Hour Dietary Recall Interviews. *J Acad Nutr Diet* 2013, 113:1165-1174.
150. Powell LM, Nguyen BT: Fast-Food and Full-Service Restaurant Consumption Among Children and Adolescents Effect on Energy, Beverage, and Nutrient Intake. *Jama Pediatrics* 2013, 167:14-20.
151. Huybrechts I, Vereecken C, De Bacquer D, Vandevijvere S, Van Oyen H, Maes L, Vanhauwaert E, Temme L, De Backer G, De Henauw S: Reproducibility and validity of a diet quality index for children assessed using a FFQ. *Br J Nutr* 2010, 104:135-144.
152. Conway JM, Ingwersen LA, Moshfegh AJ: Accuracy of dietary recall using the USDA five-step multiple-pass method in men: an observational validation study. *J Am Diet Assoc* 2004, 104:595-603.
153. NUBEL: *the Belgian Food composition table, 5th edition.* 2009.
154. Lachat C: Lucille: software to process your food intake data. 2010.
155. Hebert JR, Miller DR: The inappropriateness of conventional use of the correlation-coefficient in assessing validity and reliability of dietary assessment methods. *Eur J Epidemiol* 1991, 7:339-343.
156. Ambrosini GL, Mackerras D, de Klerk NH, Musk AW: Comparison of an Australian food-frequency questionnaire with diet records: implications for nutrition surveillance. *Public Health Nutr* 2003, 6:415-422.
157. Mukaka M: A guide to appropriate use of Correlation coefficient in medical research. *Malawi Med J* 2012, 24:69-71.
158. Bland JM, Altman DG: Measuring agreement in method comparison studies. *Stat Methods Med Res* 1999, 8:135-160.
159. Ambrosini GL, de Klerk NH, O'Sullivan TA, Beilin LJ, Oddy WH: The reliability of a food frequency questionnaire for use among adolescents. *Eur J Clin Nutr* 2009, 63:1251-1259.
160. Verstraeten R, Lachat C, Ochoa-Aviles A, Hagstromer M, Huybregts L, Andrade S, Donoso S, Van Camp J, Maes L, Kolsteren P: Predictors of validity and reliability of a physical activity record in adolescents. *BMC Public Health* 2013, 13:11.
161. Landis JR, Koch GG: Measurement of observer agreement for categorical data. *Biometrics* 1977, 33:159-174.
162. Sim J, Wright CC: The kappa statistic in reliability studies: Use, interpretation, and sample size requirements. *Phys Ther* 2005, 85:257-268.
163. Watson JF, Collins CE, Sibbritt DW, Dibley MJ, Garg ML: Reproducibility and comparative validity of a food frequency questionnaire for Australian children and adolescents. *International Journal of Behavioral Nutrition and Physical Activity* 2009, 6.

164. Banwell C, Hinde S, Dixon J, Sibthorpe B: Reflections on expert consensus: a case study of the social trends contributing to obesity. *Eur J Public Health* 2005, 15:564-568.
165. Frank GC, Nicklas TA, Webber LS, Major C, Miller JF, Berenson GS: A food frequency questionnaire for adolescents - defining eating patterns. *J Am Diet Assoc* 1992, 92:313-318.
166. Magarey A, Watson J, Golley RK, Burrows T, Sutherland R, McNaughton SA, Denney-Wilson E, Campbell K, Collins C: Assessing dietary intake in children and adolescents: Considerations and recommendations for obesity research. *Int J Pediatr Obes* 2011, 6:2-11.
167. Livingstone MBE, Robson PJ, Wallace JMW: Issues in dietary intake assessment of children and adolescents. *Brit J Nutr* 2004, 92:S213-S222.
168. Markovits H, Benenson JF, Kramer DL: Children and Adolescents' Internal Models of Food-Sharing Behavior Include Complex Evaluations of Contextual Factors. *Child Dev* 2003, 74:1697-1708.
169. Tabacchi G, Amodio E, Di Pasquale M, Bianco A, Jemni M, Mammina C: Validation and reproducibility of dietary assessment methods in adolescents: a systematic literature review. *Public Health Nutr* 2014, 17:2700-2714.
170. Studie jongeren en gezondheid Intern rapport, vakgroep Maantschappelijke Gezondheidskunde [http://www.jongeren-en-gezondheid.ugent.be]
171. Appelhans BM, Woolf K, Pagoto SL, Schneider KL, Whited MC, Liebman R: Inhibiting Food Reward: Delay Discounting, Food Reward Sensitivity, and Palatable Food Intake in Overweight and Obese Women. *Obesity* 2011, 19:2175-2182.
172. Goldfield GS, Lumb AB, Colapinto CK: Relative Reinforcing Value of Energy-dense Snack Foods In Overweight and Obese Adults. *Can J Diet Pract Res* 2011, 72:170-174.
173. Berridge KC: Food reward: Brain substrates of wanting and liking. *Neurosci Biobehav R* 1996, 20:1-25.
174. Franken IHA, Muris P, Rassin E: Psychometric properties of the Dutch BIS/BAS Scales. *Journal of Psychopathology and Behavioral Assessment* 2005, 27:25-30.
175. Muris P, Meesters C, de Kanter E, Timmerman PE: Behavioural inhibition and behavioural activation system scales for children: relationships with Eysenck's personality traits and psychopathological symptoms. *Pers Indiv Differ* 2005, 38:831-841.
176. Yu R, Branje SJT, Keijsers L, Meeus WHJ: Psychometric Characteristics of Carver and White's BIS/BAS Scales in Dutch Adolescents and Their Mothers. *J Pers Assess* 2011, 93:500-507.
177. Cooper A, Gomez R, Aucote H: The Behavioural Inhibition System and Behavioural Approach System (BIS/BAS) Scales: Measurement and structural invariance across adults and adolescents. *Pers Indiv Differ* 2007, 43:295-305.
178. Matton A, Goossens L, Braet C, Vervaet M: Punishment and Reward Sensitivity: Are Naturally Occurring Clusters in These Traits Related to Eating and Weight Problems in Adolescents? *Eur Eat Disord Rev* 2013, 21:184-194.
179. Cuzzocrea F, Larcan R, Lanzarone C: Gender differences, personality and eating behaviors in non-clinical adolescents. *Eat Weight Disord-St* 2012, 17:E282-E289.
180. Vervoort L, Vandeweghe L, Vandewalle J, Van Durme K, Vandevivere E, Wante L, McIntosh K, Verbeken S, Moens E, Goossens L, Braet C: Measuring punishment and reward sensitivity with a parent-report version of the bis/bas-scales. 2014.
181. Roberts C, Currie C, Samdal O, Currie D, Smith R, Maes L: Measuring the health and health behaviours of adolescents through cross-national survey research: recent developments in the Health Behaviour in School-aged Children (HBSC) study. *J Public Health* 2007, 15:179-186.
182. Franken IHA, Muris P, Georgieva I: Gray's model of personality and addiction. *Addict Behav* 2006, 31:399-403.

183. Nathalie De Cock JVC, Patrick Kolsteren, Carl Lachat, Lieven Huybregts, Lea Maes, Benedicte Deforche, Roosmarijn Verstraeten, Jolien Vangeel, Kathleen Beullens, Steven Eggermont and Wendy Van Lippevelde: Development and validation of a quantitative snack and beverage FFQ for adolescents *J Hum Nutr Diet* 2016.
184. [http://www.helenastudy.com/.]
185. van Stralen MM, Velde SJt, Singh AS, De Bourdeaudhuij I, Martens MK, van der Sluis M, Manios Y, Grammatikaki E, Chinapaw MJM, Maes L, et al: EuropeaN Energy balance Research to prevent excessive weight Gain among Youth (ENERGY) project: Design and methodology of the ENERGY cross-sectional survey. *BMC Public Health* 2011, 11.
186. Roelants M, Hauspie R, Hoppenbrouwers K: References for growth and pubertal development from birth to 21 years in Flanders, Belgium. *Ann Hum Bio* 2009, 36:680-694.
187. Cole TJ, Lobstein T: Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity. *Int J Pediatr Obes* 2012, 7:284-294.
188. Ochoa-Aviles A, Verstraeten R, Lachat C, Andrade S, Van Camp J, Donoso S, Kolsteren P: Dietary intake practices associated with cardiovascular risk in urban and rural Ecuadorian adolescents: a cross-sectional study. *BMC Public Health* 2014, 14.
189. Davison KK, Birch LL: Weight status, parent reaction, and self-concept in five-year-old girls. *Pediatrics* 2001, 107:46-53.
190. French SA, Jeffery RW, Story M, Breitlow KK, Baxter JS, Hannan P, Snyder MP: Pricing and promotion effects on low-fat vending snack purchases: The CHIPS study. *Am J Public Health* 2001, 91:112-117.
191. Voedingstips voor jongeren tussen 12 en 18 jaar [http://vig.kanker.be/content/category/categorycontent.aspx?CategoryGUID=7ee8037c-a892-4345-9063-026b3815dc47]
192. Jakes RW, Day NE, Luben R, Welch A, Bingham S, Mitchell J, Hennings S, Rennie K, Wareham NJ: Adjusting for energy intake - what measure to use in nutritional epidemiological studies? *Int J Epidemiol* 2004, 33:1382-1386.
193. Shomaker LB, Tanofsky-Kraff M, Savastano DM, Kozlosky M, Columbo KM, Wolkoff LE, Zocca JM, Brady SM, Yanovski SZ, Crocker MK, et al: Puberty and observed energy intake: boy, can they eat! *Am J Clin Nutr* 2010, 92:123-129.
194. Dreher JC, Schmidt PJ, Kohn P, Furman D, Rubinow D, Berman KF: Menstrual cycle phase modulates reward-related neural function in women. *Proc Natl Acad Sci U S A* 2007, 104:2465-2470.
195. Davidsen L, Vistisen B, Astrup A: Impact of the menstrual cycle on determinants of energy balance: a putative role in weight loss attempts. *Int J Obes* 2007, 31:1777-1785.
196. Lasater G, Piernas C, Popkin BM: Beverage patterns and trends among school-aged children in the US, 1989-2008. *Nutr J* 2011, 10:103-103.
197. Martin-Calvo N, Martinez-Gonzalez MA, Bes-Rastrollo M, Gea A, Ochoa MC, Marti A, Memberst G: Sugar-sweetened carbonated beverage consumption and childhood/adolescent besity: a case-control study. *Public Health Nutr* 2014, 17:2185-2193.
198. Sebastian R, Cleveland L, Goldman J, Moshfegh A: Impact of eating frequency by adolescents on food intake and meeting MyPyramid recommendations. *FASEB J* 2007, 21:A710-A711.
199. De Cock N, Van Lippevelde W, Vervoort L, Vangeel J, Maes L, Eggermont S, Braet C, Lachat C, Huybregts L, Goossens L, et al: Sensitivity to reward is associated with snack and sugar sweetened beverage consumption in adolescents. *Eur J Nutr* 2015.
200. van Strien T, Frijters JER, Bergers GPA, Defares PB: The Dutch Eating Behavior Questionnaire (DEBQ) for assessment of restrained, emotional, and external eating behavior. *Int J Eat Disord* 1986, 5:295-315.
201. Schlundt DG: Assessment of specific eating behaviors and eating style. In *Handbook of assessment methods for eating behaviors and weight-related problems: Measures,*

theory, and research. Thousand Oaks, CA, US: Sage Publications, Inc; 1995: 241-302
202. Lien N, van Stralen MM, Androutsos O, Bere E, Fernandez-Alvira JM, Jan N, Kovacs E, van Lippevelde W, Manios Y, te Velde SJ, Brug J: The school nutrition environment and its association with soft drink intakes in seven countries across Europe - the ENERGY project. *Health & Place* 2014, 30:28-35.
203. Preacher KJ: Multilevel SEM Strategies for Evaluating Mediation in Three-Level Data. *Multivariate Behavioral Research* 2011, 46:691-731.
204. Preacher KJ, Zyphur MJ, Zhang Z: A General Multilevel SEM Framework for Assessing Multilevel Mediation. *Psychol Methods* 2010, 15:209-233.
205. Hayes AF: *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach.* Guilford Press; 2013.
206. Drieskens S: Voedingsstatus. In

In: Gisle L, Demarest S (ed.). Gezondheidsenquête 2013. Rapport 2: Gezondheidsgedrag en leefstijl. WIV-ISP, Brussel, 2014.
207. Vlaams onderwijs in cijfers 2014-2015 [http://www.vlaanderen.be/nl/publicaties/detail/vlaams-onderwijs-in-cijfers-2014-2015]
208. Klein DA, Walsh BT: Eating disorders. *Int Rev Psychiatry* 2003, 15:205-216.
209. Cullen KW, Baranowski T, Owens E, Marsh T, Rittenberry L, de Moor C: Availability, accessibility, and preferences for fruit, 100% fruit juice, and vegetables influence children's dietary behavior. *Health Educ Behav* 2003, 30:615-626.
210. Preacher KJ, Zhang Z, Zyphur MJ: Alternative Methods for Assessing Mediation in Multilevel Data: The Advantages of Multilevel SEM. *Structural Equation Modeling-a Multidisciplinary Journal* 2011, 18:161-182.
211. Galesic M, Bosnjak M: Effects of Questionnaire Length on Participation and Indicators of Response Quality in a Web Survey. *Public Opin Q* 2009, 73:349-360.
212. De Cock N, Van Lippevelde W, Vervoort L, Vangeel J, Maes L, Eggermont S, Braet C, Lachat C, Huybregts L, Goossens L, et al: Sensitivity to reward is associated with snack and sugar-sweetened beverage consumption in adolescents. *Eur J Nutr* 2016, 55:1623-1632.
213. Kushner RF, Choi SW: Prevalence of Unhealthy Lifestyle Patterns Among Overweight and Obese Adults. *Obesity* 2010, 18:1160-1167.
214. Must A, Tybor DJ: Physical activity and sedentary behavior: a review of longitudinal studies of weight and adiposity in youth. *Int J Obes* 2005, 29:S84-S96.
215. Berkey CS, Rockett HRH, Field AE, Gillman MW, Frazier AL, Camargo CA, Colditz GA: Activity, dietary intake, and weight changes in a longitudinal study of preadolescent and adolescent boys and girls. *Pediatrics* 2000, 105.
216. Gowin M, Cheney M, Gwin S, Wann TF: Health and Fitness App Use in College Students: A Qualitative Study. *American Journal of Health Education* 2015, 46:223-230.
217. Burrows TL, Khambalia AZ, Perry R, Carty D, Hendrie GA, Allman-Farinelli MA, Garnett SP, McNaughton SA, Rangan AM, Truby H: Great ‘app-eal’but not there yet: A review of iPhone nutrition applications relevant to child weight management. *Nutr Diet* 2015, 72:363-367.
218. Brannon EE, Cushing CC: A Systematic Review: Is There an App for That? Translational Science of Pediatric Behavior Change for Physical Activity and Dietary Interventions. *J Pediatr Psychol* 2015, 40:373-384.
219. Krebs P, Duncan DT: Health App Use Among US Mobile Phone Owners: A National Survey. *Jmir Mhealth and Uhealth* 2015, 3:107-119.
220. Middelweerd A, Mollee JS, van der Wal CN, Brug J, te Velde SJ: Apps to promote physical activity among adults: a review and content analysis. *International Journal of Behavioral Nutrition and Physical Activity* 2014, 11.

221. Azar KMJ, Lesser LI, Laing BY, Stephens J, Aurora MS, Burke LE, Palaniappan LP: Mobile Applications for Weight Management Theory-Based Content Analysis. *Am J Prev Med* 2013, 45:583-589.
222. [http://www.appbrain.com/stats/android-market-app-categories]
223. [http://www.pocketgamer.biz/metrics/app-store/categories/]
224. Litman L, Rosen Z, Spierer D, Weinberger-Litman S, Goldschein A, Robinson J: Mobile Exercise Apps and Increased Leisure Time Exercise Activity: A Moderated Mediation Analysis of the Role of Self-Efficacy and Barriers. *J Med Internet Res* 2015, 17.
225. Bert F, Giacometti M, Gualano MR, Siliquini R: Smartphones and health promotion: a review of the evidence. *J Med Syst* 2014, 38:9995.
226. Direito A, Dale LP, Shields E, Dobson R, Whittaker R, Maddison R: Do physical activity and dietary smartphone applications incorporate evidence-based behaviour change techniques? *BMC Public Health* 2014, 14.
227. Wang Q, Egelandsdal B, Amdam GV, Almli VL, Oostindjer M: Diet and Physical Activity Apps: Perceived Effectiveness by App Users. *Jmir Mhealth and Uhealth* 2016, 4:202-215.
228. DiFilippo KN, Huang W-H, Andrade JE, Chapman-Novakofski KM: The use of mobile apps to improve nutrition outcomes: A systematic literature review. *J Telemed Telecare* 2015, 21:243-253.
229. Johnston C, Thompson-Felty C: Adherence to Daily Diet Monitoring using One of Three Commercial Diet Apps via Smart Phones was Associated with Significant Weight Loss in Healthy Overweight Adults Irrespective of the Diet App. *FASEB J* 2015, 29:1.
230. Pagoto S, Schneider K, Jojic M, DeBiasse M, Mann D: Evidence-Based Strategies in Weight-Loss Mobile Apps. *Am J Prev Med* 2013, 45:576-582.
231. Wiederhold BK: Behavioral Health Apps Abundant, but Evidence-Based Research Nearly Nonexistent. *Cyberpsychology Behavior and Social Networking* 2015, 18:309-310.
232. West JH, Hall PC, Hanson CL, Barnes MD, Giraud-Carrier C, Barrett J: There's an App for That: Content Analysis of Paid Health and Fitness Apps. *J Med Internet Res* 2012, 14:184-195.
233. Scaglioni S, Arrizza C, Vecchi F, Tedeschi S: Determinants of children's eating behavior. *Am J Clin Nutr* 2011, 94:2006S-2011S.
234. Vereecken C, De Henauw S, Maes L, Moreno L, Manios Y, Phillipp K, Plada M, De Bourdeaudhuij I, Grp HS: Reliability and validity of a healthy diet determinants questionnaire for adolescents. *Public Health Nutr* 2009, 12:1830-1838.
235. Eggermont S: Developmental Changes in Adolescents' Television Viewing Habits: Longitudinal Trajectories in a Three-Wave Panel Study. *Journal of Broadcasting & Electronic Media* 2006, 50:742-761.
236. Kenny R, Dooley B, Fitzgerald A: Developing mental health mobile apps: Exploring adolescents' perspectives. *Health Informatics J* 2016, 22:265-275.
237. Schnall R, Okoniewski A, Tiase V, Low A, Rodriguez M, Kaplan S: Using text messaging to assess adolescents' health information needs: an ecological momentary assessment. *J Med Internet Res* 2013, 15:e54.
238. https://ec.europa.eu/digital-single-market/en/mhealth
239. Serrano KJ, Yu M, Coa KI, Collins LM, Atienza AA: Mining Health App Data to Find More and Less Successful Weight Loss Subgroups. *J Med Internet Res* 2016, 18:e154.
240. Moreno LA, Rodriguez G: Dietary risk factors for development of childhood obesity. *Curr Opin Clin Nutr* 2007, 10.
241. Epstein LH, Leddy JJ: Food reinforcement. *Appetite* 2006, 46:22-25.
242. Wardle J, Herrera ML, Cooke L, Gibson EL: Modifying children's food preferences: the effects of exposure and reward on acceptance of an unfamiliar vegetable. *European Journal of Clinical Nutrition* 2003, 57:341-348.

243. Lowe CF, Horne PJ, Tapper K, Bowdery M, Egerton C: Effects of a peer modelling and rewards-based intervention to increase fruit and vegetable consumption in children. *European Journal of Clinical Nutrition* 2004, 58:510-522.
244. Cooke LJ, Chambers LC, Anez EV, Croker HA, Boniface D, Yeomans MR, Wardle J: Eating for Pleasure or Profit: The Effect of Incentives on Children's Enjoyment of Vegetables. *Psychological Science* 2011, 22:190-196.
245. Temple JL, Bulkley AM, Briatico L, Dewey AM: Sex differences in reinforcing value of caffeinated beverages in adolescents. *Behav Pharmacol* 2009, 20:731-741.
246. Clark EN, Dewey AM, Temple JL: Effects of daily snack food intake on food reinforcement depend on body mass index and energy density. *Am J Clin Nutr* 2010, 91:300-308.
247. Vervoort L, Clauwaert A, Vandeweghe L, Vangeel J, Van Lippevelde W, Goossens L, Huybregts L, Lachat C, Eggermont S, Beullens K, et al: Factors influencing the reinforcing value of fruit and unhealthy snacks. *Eur J Nutr* 2016:1-10.
248. De Decker A, Sioen I, Verbeken S, Braet C, Michels N, De Henauw S: Associations of reward sensitivity with food consumption, activity pattern, and BMI in children. *Appetite* 2016, 100:189-196.
249. Gevers DWM, Kremers SPJ, de Vries NK, van Assema P: Intake of energy-dense snack foods and drinks among Dutch children aged 7-12 years: how many, how much, when, where and which? *Public Health Nutr* 2016, 19:83-92.
250. Reiss S, Havercamp S: Sensitivity theory of motivation: Implications for psychopathology. *Behav Res Ther* 1996, 34:621-632.
251. Cameron J, Banko KM, Pierce WD: Pervasive negative effects of rewards on intrinsic motivation: The myth continues. *Behavior Analyst* 2001, 24:1-44.
252. Dickey MD: Engaging by design: How engagement strategies in popular computer and video games can inform instructional design. *Etr&D-Educational Technology Research and Development* 2005, 53:67-83.
253. Vervoort L, Wolters LH, Hogendoorn SM, de Haan E, Boer F, Prins PJM: Sensitivity of Gray's Behavioral Inhibition System in clinically anxious and non-anxious children and adolescents. *Personality and Individual Differences* 2010, 48:629-633.
254. Roane HS: On the applied use of progressive-ratio schedules of reinforcement. *J Appl Behav Anal* 2008, 41:155-161.
255. Grambsch PM, Therneau TM: Proportional hazards tests and diagnostics based on weighted residuals. *Biometrika* 1994, 81:515-526.
256. Bickel WK, Marsch LA, Carroll ME: Deconstructing relative reinforcing efficacy and situating the measures of pharmacological reinforcement with behavioral economics: a theoretical proposal. *Psychopharmacology* 2000, 153:44-56.
257. Bickel WK, Madden GJ: A comparison of measures of relative reinforcing efficacy and behavioral economics: cigarettes and money in smokers. *Behav Pharmacol* 1999, 10:627-637.
258. Hosmer DW, Lemeshow S, May S: Model development. *Applied Survival Analysis: Regression Modeling of Time-to-Event Data, Second Edition* 2008:132-168.
259. Salvy SJ, Coelho JS, Kieffer E, Epstein LH: Effects of social contexts on overweight and normal-weight children's food intake. *Physiol Behav* 2007, 92:840-846.
260. Bedard PL, Krzyzanowska MK, Pintilie M, Tannock IF: Statistical power of negative randomized controlled trials presented at American Society for Clinical Oncology annual meetings. *J Clin Oncol* 2007, 25:3482-3487.
261. Walsh EM, Kiviniemi MT: Changing how I feel about the food: experimentally manipulated affective associations with fruits change fruit choice behaviors. *J Behav Med* 2014, 37:322-331.
262. Jacques-Tiura AJ, Greenwald MK: Behavioral Economic Factors Related to Pediatric Obesity. *Pediatr Clin North Am* 2016, 63:425-446.
263. Huyghe E, Van Kerckhove A: Can fat taxes and package size restrictions stimulate healthy food choices? *International Journal of Research in Marketing* 2013, 30:421-423.

264. Epstein LH, Lin H, Carr KA, Fletcher KD: Food reinforcement and obesity. Psychological moderators. *Appetite* 2012, 58:157-162.
265. Epstein LH, Temple JL, Neaderhiser BJ, Salis RJ, Erbe RW, Leddy JJ: Food reinforcement, the dopamine D2 receptor genotype, and energy intake in obese and nonobese humans. *Behav Neurosci* 2007, 121:877-886.
266. Epstein LH, Wright SM, Paluch RA, Leddy JJ, Hawk LW, Jr., Jaroni JL, Saad FG, Crystal-Mansour S, Shields PG, Lerman C: Relation between food reinforcement and dopamine genotypes and its effect on food intake in smokers. *Am J Clin Nutr* 2004, 80:82-88.
267. De Cock N, Van Lippevelde W, Goossens L, De Clercq B, Vangeel J, Lachat C, Beullens K, Huybregts L, Vervoort L, Eggermont S, et al: Sensitivity to reward and adolescents' unhealthy snacking and drinking behavior: the role of hedonic eating styles and availability. *Int J Behav Nutr Phys Act* 2016, 13:17.
268. Nederkoorn C, Braet C, Van Eijs Y, Tanghe A, Jansen A: Why obese children cannot resist food: the role of impulsivity. *Eat Behav* 2006, 7:315-322.
269. Blissett J, Bennett C, Fogel A, Harris G, Higgs S: Parental modelling and prompting effects on acceptance of a novel fruit in 2-4-year-old children are dependent on children's food responsiveness. *Br J Nutr* 2016, 115:554-564.
270. Dietrich A, Federbusch M, Grellmann C, Villringer A, Horstmann A: Body weight status, eating behavior, sensitivity to reward/punishment, and gender: relationships and interdependencies. *Front Psychol* 2014, 5:1073.
271. Verbeken S, Braet C, Lammertyn J, Goossens L, Moens E: How is reward sensitivity related to bodyweight in children? *Appetite* 2012, 58.
272. Dute DJ, Bemelmans WJ, Breda J: Using Mobile Apps to Promote a Healthy Lifestyle Among Adolescents and Students: A Review of the Theoretical Basis and Lessons Learned. *JMIR Mhealth Uhealth* 2016, 4:e39.
273. Schoeppe S, Alley S, Van Lippevelde W, Bray NA, Williams SL, Duncan MJ, Vandelanotte C: Efficacy of interventions that use apps to improve diet, physical activity and sedentary behaviour: a systematic review. *Int J Behav Nutr Phys Act* 2016, 13:127.
274. Van Lippevelde W, Vangeel J, De Cock N, Lachat C, Goossens L, Beullens K, Vervoort L, Braet C, Maes L, Eggermont S, et al: Using a gamified monitoring app to change adolescents' snack intake: the development of the REWARD app and evaluation design. *BMC Public Health* 2016, 16:725.
275. Konstantopoulos S: The Power of the Test for Treatment Effects in Three-Level Cluster Randomized Designs. *Journal of Research on Educational Effectiveness* 2008, 1:66-88.
276. Nubel vzw: database of tradenames. Brussels, Belgium: Nubel v.z.w.; 2015.
277. Aanbevelingen voor voeding voor jongeren [http://www.vigez.be/themas/voeding-en-beweging/aanbevelingen/aanbevelingen-voor-voeding/jongeren]
278. Peng W, Lin J-H, Pfeiffer KA, Winn B: Need Satisfaction Supportive Game Features as Motivational Determinants: An Experimental Study of a Self-Determination Theory Guided Exergame. *Media Psychol* 2012, 15:175-196.
279. Annetta LA: The "I's" Have It: A Framework for Serious Educational Game Design. *Rev Gen Psychol* 2010, 14:105-112.
280. Zajonc RB: Mere exposure: A gateway to the subliminal. *Curr Dir Psychol Sci* 2001, 10:224-228.
281. Fazio RH: On the automatic activation of associated evaluations: An overview. *Cogn Emot* 2001, 15:115-141.
282. Latham GP, Locke EA: New developments in and directions for goal-setting research. *Eur Psychol* 2007, 12:290-300.
283. Bandura A: Human agency in social cognitive theory. *Am Psychol* 1989, 44:1175-1184.

284. Gardner B: Habit as automaticity, not frequency. *European Health Psychologist* 2012, 14:32-36.
285. Verplanken B, Orbell S: Reflections on past behavior: A self-report index of habit strength. *J Appl Soc Psychol* 2003, 33:1313-1330.
286. Braet C, Tanghe A, Bode PD, Franckx H, Winckel MV: Inpatient treatment of obese children: a multicomponent programme without stringent calorie restriction. *Eur J Pediatr* 2003, 162:391-396.
287. Blackman KCA, Zoellner J, Kadir A, Dockery B, Johnson SB, Almeida FA, McCrickard DS, Hill JL, You W, Estabrooks PA: Examining the Feasibility of Smartphone Game Applications for Physical Activity Promotion in Middle School Students. *Games for Health Journal* 2015, 4:409-419.
288. Spook J, Paulussen T, Kok G, van Empelen P: Evaluation of a Serious Self-Regulation Game Intervention for Overweight-Related Behaviors ("Balance It"): A Pilot Study. *J Med Internet Res* 2016, 18:169-182.
289. Garde A, Umedaly A, Abulnaga SM, Robertson L, Junker A, Chanoine JP, Ansermino JM, Dumont GA: Assessment of a Mobile Game ("MobileKids Monster Manor") to Promote Physical Activity Among Children. *Games for Health Journal* 2015, 4:149-158.
290. Saunders RP, Evans MH, Joshi P: Developing a process-evaluation plan for assessing health promotion program implementation: a how-to guide. *Health Promot Pract* 2005, 6:134-147.
291. Poels K, de Kort Y, Ijsselsteijn W: It is always a lot of fun!: exploring dimensions of digital game experience using focus group methodology. In *Proceedings of the 2007 conference on Future Play*. ACM; 2007: 83-89.
292. Barnett AG, van der Pols JC, Dobson AJ: Regression to the mean: what it is and how to deal with it. *Int J Epidemiol* 2005, 34:215-220.
293. Willett WC, Howe GR, Kushi LH: Adjustment for total energy intake in epidemiologic studies. *Am J Clin Nutr* 1997, 65:1220S-1228S; discussion 1229S-1231S.
294. Stok FM, de Ridder DT, de Vet E, Nureeva L, Luszczynska A, Wardle J, Gaspar T, de Wit JB: Hungry for an intervention? Adolescents' ratings of acceptability of eating-related intervention strategies. *BMC Public Health* 2016, 16:5.
295. Crutzen R, Kohl L, de Vries N: *Kennissynthese online preventie.* Universitaire Pers Maastricht; 2012.
296. Gilliland J, Sadler R, Clark A, O'Connor C, Milczarek M, Doherty S: Using a Smartphone Application to Promote Healthy Dietary Behaviours and Local Food Consumption. *Biomed Research International* 2015:11.
297. Wang JB, Cadmus-Bertram LA, Natarajan L, White MM, Madanat H, Nichols JF, Ayala GX, Pierce JP: Wearable Sensor/Device (Fitbit One) and SMS Text-Messaging Prompts to Increase Physical Activity in Overweight and Obese Adults: A Randomized Controlled Trial. *Telemedicine and E-Health* 2015, 21:782-792.
298. Kirwan M, Duncan MJ, Vandelanotte C, Mummery WK: Using Smartphone Technology to Monitor Physical Activity in the 10,000 Steps Program: A Matched Case-Control Trial. *J Med Internet Res* 2012, 14.
299. Rahmani E, Boren SA: Videogames and Health Improvement: A Literature Review of Randomized Controlled Trials. *Games Health J* 2012, 1:331-341.
300. Carter MC, Burley VJ, Nykjaer C, Cade JE: Adherence to a Smartphone Application for Weight Loss Compared to Website and Paper Diary: Pilot Randomized Controlled Trial. *J Med Internet Res* 2013, 15:17.
301. Payne HE, Lister C, West JH, Bernhardt JM: Behavioral functionality of mobile apps in health interventions: a systematic review of the literature. *JMIR Mhealth Uhealth* 2015, 3:e20.
302. Sandholzer M, Deutsch T, Frese T, Winter A: Predictors of students' self-reported adoption of a smartphone application for medical education in general practice. *BMC Med Educ* 2015, 15:1.

303. Wardle J, Haase AM, Steptoe A, Nillapun M, Jonwutiwes K, Bellisle F: Gender differences in food choice: the contribution of health beliefs and dieting. *Ann Behav Med* 2004, 27:107-116.
304. Cooke LJ, Wardle J: Age and gender differences in children's food preferences. *Br J Nutr* 2005, 93:741-746.
305. Eldredge LKB, Parcel GS, Kok G, Gottlieb NH: *Planning health promotion programs: an intervention mapping approach.* John Wiley & Sons; 2011.
306. gezondheidsraad H: MATEN EN GEWICHTEN: Handleiding voor een gestandaardiseerde kwantificering van voedingsmiddelen. 2005.
307. Guerrieri R, Nederkoorn C, Jansen A: The interaction between impulsivity and a varied food environment: its influence on food intake and overweight. *Int J Obesity* 2008, 32:708-714.
308. Gray JA: Three fundamental emotion systems. In *The nature of emotion: fundamental questions.* Edited by Ekman P, Davidson JR. New York: Oxford University Press; 1994
309. De Decker A, De Clercq B, Verbeken S, Wells JC, Braet C, Michels N, De Henauw S, Sioen I: Fat and lean tissue accretion in relation to reward motivation in children. *Appetite* 2017, 108:317-325.
310. Fino E, Melogno S, Iliceto P, D'Aliesio S, Pinto MA, Candilera G, Sabatello U: Executive functions, impulsivity, and inhibitory control in adolescents: A structural equation model. *Adv Cogn Psychol* 2014, 10:32-38.
311. Jasinska AJ, Yasuda M, Burant CF, Gregor N, Khatri S, Sweet M, Falk EB: Impulsivity and inhibitory control deficits are associated with unhealthy eating in young adults. *Appetite* 2012, 59:738-747.
312. Reyes S, Peirano P, Luna B, Lozoff B, Algarin C: Potential effects of reward and loss avoidance in overweight adolescents. *Pediatr Res* 2015, 78:152-157.
313. Kakoschke N, Kemps E, Tiggemann M: Combined effects of cognitive bias for food cues and poor inhibitory control on unhealthy food intake. *Appetite* 2015, 87:358-364.
314. Haynes A, Kemps E, Moffitt R: Inhibitory self-control moderates the effect of changed implicit food evaluations on snack food consumption. *Appetite* 2015, 90:114-122.
315. Brug J, de Vet E, de Nooijer J, Verplanken B: Predicting fruit consumption: cognitions, intention, and habits. *J Nutr Educ Behav* 2006, 38.
316. Rollins BY, Loken E, Savage JS, Birch LL: Measurement of food reinforcement in preschool children. Associations with food intake, BMI, and reward sensitivity. *Appetite* 2014, 72:21-27.
317. Verstraeten R, Leroy JL, Pieniak Z, Ochoa-Aviles A, Holdsworth M, Verbeke W, Maes L, Kolsteren P: Individual and Environmental Factors Influencing Adolescents' Dietary Behavior in Low- and Middle-Income Settings. *PLoS One* 2016, 11:e0157744.
318. van Duijvenvoorde AC, Op de Macks ZA, Overgaauw S, Gunther Moor B, Dahl RE, Crone EA: A cross-sectional and longitudinal analysis of reward-related brain activation: effects of age, pubertal stage, and reward sensitivity. *Brain Cogn* 2014, 89:3-14.
319. Braams BR, van Duijvenvoorde AC, Peper JS, Crone EA: Longitudinal changes in adolescent risk-taking: a comprehensive study of neural responses to rewards, pubertal development, and risk-taking behavior. *J Neurosci* 2015, 35:7226-7238.
320. Epstein LH, Carr KA, Lin H, Fletcher KD: Food reinforcement, energy intake, and macronutrient choice. *Am J Clin Nutr* 2011, 94:12-18.
321. Epstein LH, Carr KA, Lin H, Fletcher KD, Roemmich JN: Usual Energy Intake Mediates the Relationship Between Food Reinforcement and BMI. *Obesity* 2012, 20:1815-1819.
322. Rollins BY, Dearing KK, Epstein LH: Delay discounting moderates the effect of food reinforcement on energy intake among non-obese women. *Appetite* 2010, 55:420-425.

323. Preacher KJ, Rucker DD, Hayes AF: Addressing moderated mediation hypotheses: Theory, methods, and prescriptions. *Multivariate behavioral research* 2007, 42:185-227.
324. Baron RM, Kenny DA: The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *J Pers Soc Psychol* 1986, 51:1173.
325. MacKinnon DP: *Introduction to Statistical Mediation Analysis.* New York: Erlbaum and Taylor Francis Group; 2008.
326. MacKinnon DP, Fairchild AJ, Fritz MS: Mediation analysis. In *Annu Rev Psychol. Volume* 58. Palo Alto: Annual Reviews; 2007: 593-614: *Annual Review of Psychology*].
327. MacKinnon DP, Pirlott AG: Statistical approaches for enhancing causal interpretation of the M to Y relation in mediation analysis. *Pers Soc Psychol Rev* 2015, 19:30-43.
328. Bullock HE, Harlow LL, Mulaik SA: Causation issues in structural equation modeling research. *Structural Equation Modeling: A Multidisciplinary Journal* 1994, 1:253-267.
329. VanderWeele TJ: Invited commentary: structural equation models and epidemiologic analysis. *Am J Epidemiol* 2012, 176:608-612.
330. Beaver JD, Lawrence AD, Ditzhuijzen J, Davis MH, Woods A, Calder AJ: Individual differences in reward drive predict neural responses to images of food. *J Neurosci* 2006, 26.
331. Baranowski T, Buday R, Thompson D, Lyons EJ, Lu AS, Baranowski J: Developing Games for Health Behavior Change: Getting Started. *Games Health J* 2013, 2:183-190.
332. Covey J: The role of dispositional factors in moderating message framing effects. *Health Psychol* 2014, 33:52.
333. Forman EM, Hoffman KL, McGrath KB, Herbert JD, Brandsma LL, Lowe MR: A comparison of acceptance-and control-based strategies for coping with food cravings: An analog study. *Behav Res Ther* 2007, 45:2372-2386.
334. Whittemore R, Chao A, Jang M, Jeon S, Liptak T, Popick R, Grey M: Implementation of a school-based internet obesity prevention program for adolescents. *J Nutr Educ Behav* 2013, 45:586-594.
335. Greve J, Heinesen E: Evaluating the impact of a school-based health intervention using a randomized field experiment. *Econ Hum Biol* 2015, 18:41-56.
336. Rausch Herscovici C, Kovalskys I, De Gregorio MJ: Gender differences and a school-based obesity prevention program in Argentina: a randomized trial. *Rev Panam Salud Publica* 2013, 34:75-82.
337. Burgess EE, Turan B, Lokken KL, Morse A, Boggiano MM: Profiling motives behind hedonic eating. Preliminary validation of the Palatable Eating Motives Scale. *Appetite* 2014, 72:66-72.
338. McEvoy CT, Lawton J, Kee F, Young IS, Woodside JV, McBratney J, McKinley MC: Adolescents' views about a proposed rewards intervention to promote healthy food choice in secondary school canteens. *Health Educ Res* 2014, 29:799-811.
339. Shaw JA, Forman EM, Espel HM, Butryn ML, Herbert JD, Lowe MR, Nederkoorn C: Can evaluative conditioning decrease soft drink consumption? *Appetite* 2016, 105:60-70.
340. Salvy SJ, Kluczynski MA, Nitecki LA, O'Connor BC: Peer influence on youth's snack purchases: A laboratory analog of convenience store shopping. *Eating Behaviors* 2012, 13:233-239.
341. Temple JL, Ziegler AM, Epstein LH: Influence of Price and Labeling on Energy Drink Purchasing in an Experimental Convenience Store. *J Nutr Educ Behav* 2016, 48:54-+.
342. Hanks AS, Just DR, Smith LE, Wansink B: Healthy convenience: nudging students toward healthier choices in the lunchroom. *Journal of Public Health* 2012:fds003.

343. Forman EM, Shaw JA, Goldstein SP, Butryn ML, Martin LM, Meiran N, Crosby RD, Manasse SM: Mindful decision making and inhibitory control training as complementary means to decrease snack consumption. *Appetite* 2016, 103:176-183.
344. Almli VL, Van Wezemael L, Verbeke W, Ueland O: One technology does not fit all: profiling consumers of tender and tenderised beef steaks. *Meat Sci* 2013, 93:361-370.
345. Ares G, Deliza R, Barreiro C, Giménez A, Gámbaro A: Comparison of two sensory profiling techniques based on consumer perception. *Food Qual Prefer* 2010, 21:417-426.
346. Popkin BM, Hawkes C: Sweetening of the global diet, particularly beverages: patterns, trends, and policy responses. *Lancet Diabetes Endocrinol* 2016, 4:174-186.
347. Santos RG, Durksen A, Rabbanni R, Chanoine JP, Lamboo Miln A, Mayer T, McGavock JM: Effectiveness of peer-based healthy living lesson plans on anthropometric measures and physical activity in elementary school students: a cluster randomized trial. *JAMA Pediatr* 2014, 168:330-337.
348. Bogart LM, Cowgill BO, Elliott MN, Klein DJ, Hawes-Dawson J, Uyeda K, Elijah J, Binkle DG, Schuster MA: A randomized controlled trial of students for nutrition and eXercise: a community-based participatory research study. *J Adolesc Health* 2014, 55:415-422.
349. Bogart LM, Elliott MN, Uyeda K, Hawes-Dawson J, Klein DJ, Schuster MA: Preliminary healthy eating outcomes of SNaX, a pilot community-based intervention for adolescents. *J Adolesc Health* 2011, 48:196-202.
350. Thompson D, Baranowski T, Buday R, Baranowski J, Thompson V, Jago R, Griffith MJ: Serious Video Games for Health How Behavioral Science Guided the Development of a Serious Video Game. *Simulation & gaming* 2010, 41:587-606.
351. Bardus M, van Beurden SB, Smith JR, Abraham C: A review and content analysis of engagement, functionality, aesthetics, information quality, and change techniques in the most popular commercial apps for weight management. *Int J Behav Nutr Phys Act* 2016, 13:35.

Curriculum Vitae

Personal information

Name: De Cock

First name: Nathalie

Address: Ketelpoort 38, 9000 Gent

Telephone: (0032) 478333577

Date of Birth: December 21, 1988

Nationality: Belgian

E-mail: nathaliel.decock@ugent.be

Education

2013-	PhD in Applied Biological Sciences at Ghent University, Department of Food Quality and Food Safety, Ghent University, PhD thesis: the role of hedonic motives in explaining and changing adolescents' snacking and drinking behaviors
2011-2012	Master of Science in Nutrition and Rural Development: Human Nutrition, Ghent University, master dissertation: A comparative overview of commonly used Food security indicators in Limpopo, South Africa
2009-2011	Master of Science in Bioscience Engineering: Food Science and Nutrition, Ghent University, master dissertation: Structure development in confectionary products: the importance of triglyceride composition
2006-2009	Bachelor of Science in Bioscience Engineering: Chemistry and Food technology, Ghent University
2000-2006	Secondary school Latin and mathematics (8 hours per week), Sint-Vincentius instituut Dendermonde

Additional training

2015 Serious Health Games & Apps Conference

2015 Impact & Research Communication skills

2014 Advanced course on using Mplus

2014 Advanced Academic English: Writing Skills ((Bioscience) Engineering)

2013 Basic training for teaching assistants

2013 Multilevel Analysis for Grouped and Longitudinal Data

Professional experience

2013- PhD in Applied Biological Sciences at Ghent University, Department of Food Quality and Food Safety, Ghent University

2012 Internship, INCAP, Guatemala

2011 Student collaborator, household food security evaluation in the Limpopo province, South Africa

Scientific contributions

International A1 publications

De Cock N, Vervoort L, Kolsteren P, Van Lippevelde W, Huybrechts L, Vangeel J, Notebaert M, Beullens K, Goossens L, Maes L, Deforche B, Braet C, Eggermont S, Van Camp J and Lachat C. A reward increases the reinforcing value of fruit. *British Journal of Nutrition*. In revision. 2017*.*

De Cock N, Vangeel J, Lachat C, Beullens K, Vervoort L, Goossens L, Maes L, Deforche B, De Henauw S, Braet C, Kolsteren P, Eggermont S, Van Camp J and Van Lippevelde W. Use of fitness and nutrition apps and adolescents' BMI, snacking and drinking habits: multilevel associations and mediation models. *Journal of Medical Internet Research.* In revision. 2017*.*

Jebena M. G., Lindstrom D., Belachew T., Hadley C. , Lachat C., Verstraeten R., De Cock N. and Kolsteren P. Food Insecurity and Common Mental Disorders among Ethiopian Youth: Structural Equation Modeling. *PloS one*. 11(11). 2016.

De Cock N. ,Van Camp J., Kolsteren P., Lachat C., Huybregts L., Maes L., Deforche B., Verstraeten R., Vangeel J., Beullens K., Eggermont S. and Van Lippevelde W. Development and validation of a quantitative snack and beverage FFQ for adolescents . *Journal of Human Nutritition and Dietetics*. 2016.

Vangeel J, De Cock N, Beullens K, Vervoort L, Van Lippevelde W, Goossens L, Van Camp J, Lachat C, Eggermont S. Exploring game engagement and behavioral activation and inhibition as moderators of the association between game use and unhealthy snack intake. *Poetics*. In revision. 2016.

Vervoort L, Clauwaert A, Vandeweghe L, Vangeel J, Van Lippevelde W, Goossens L, Huybregts L, Lachat C, Eggermont S, Beullens K, Braet C and De Cock N. Factors influencing the reinforcing value of fruit and unhealthy snacks. *European Journal of Nutrition*. 1-10. 2016.

Van Lippevelde W, Vangeel J, De Cock N, Lachat C, Goossens L, Beullens K, Vervoort L, Braet C, Maes L, Eggermont S, Deforche B and Van Camp J. Using a gamified monitoring app to change adolescents' snack intake: the development of the REWARD app and evaluation design. *BMC Public Health*. 16:725. 2016.

Vangeel J , Beullens K, Vervoort L, De Cock N, Van Lippevelde W, Goossens L, Eggermont S. The Role of Behavioral Activation and Inhibition in explaining adolescents' game use and game engagement levels. *Media Psychology*. 2016.

Vangeel, J., Beullens, K., Goossens, L., Vervoort, L., De Cock, N., Van Lippevelde, W., & Eggermont, S. A reinforcement sensitivity perspective on adolescents' susceptibility to the influence of soap opera viewing on alcohol attitudes. *Mass Communication and Society*. 1-24. 2016.

De Cock N, Van Lippevelde W, Vervoort L, Vangeel J, Maes L, Eggermont S, Braet C, Lachat C, Huybregts L, Goossens L, Beullens K, Kolsteren P and Van Camp J. Sensitivity to reward is associated with snack and sugar sweetened beverage consumption in adolescents. *European Journal Of Nutrition.* 55(4). p.1623-1632. 2016.

De Cock N, Van Lippevelde W, Goossens L, De Clercq B, Vangeel J, Lachat C, Beullens K, Huybregts L,Vervoort L, Eggermont S, Maes L, Braet C, Deforche B, Kolsteren P and Van Camp J. Sensitivity to reward and adolescents' unhealthy snacking and drinking behavior: the role of hedonic eating styles and availability. International Journal of Behavioral Nutrition and Physical Activity. 13(1):1-11. 2016.

De Cock, N., D'Haese, M., Vink, N., Van Rooyen, C. J., Staelens, L., Schönfeldt, H. C., & D'Haese, L. Food security in rural areas of Limpopo province, South Africa. *Food Security*.*5*(2), 269-282. 2013.

Oral and poster presentations at international conferences

"REWARD serious game: intervention in adolescents. Presentation of the results and discussion". Reward Symposium. October 2016, Brussels, Belgium. Oral presentation.

"The Snack Track app: a healthy snacking intervention". Serious Health games and apps conference. December 2015, Ghent, Belgium. Oral presentation.

"External eating mediates the influence of sensitivity to reward on the unhealthy snack pattern of adolescents independent of food availability at home or at school. International Society for Behavioral Nutrition and Physical Activity (ISBNPA) Annual Meeting. May 2015, Edinburgh, UK. Oral presentation.

"Reward sensitivity is associated with snack and sugar sweetened beverage consumption in adolescents". International Society for Behavioral Nutrition and Physical Activity (ISBNPA) Annual Meeting. May 2015, Edinburgh, UK. Oral presentation.

“Reliability and validity of a food frequency questionnaire to evaluate snack and drink intake in Flemish adolescents”. Belgian Nutrition Society (BNS) Annual Meeting. April 2015, Brussels, Belgium. Poster.

“Reward Sensitivity (RS) is associated with snack and sugar-sweetened beverage (SSB) intake in Flemish adolescents”. International Society for Behavioral Nutrition and Physical Activity (ISBNPA) Annual Meeting. May 2014, San Diego, USA. Poster.

“Reward sensitivity is related to snack consumption in adolescents”. Belgian Nutrition Society (BNS) Annual Meeting. April 2014, Brussels, Belgium. Oral presentation.