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ORIGINAL CONTRIBUTION

Sensitivity to reward is associated with snack and sugar-sweetened beverage consumption in adolescents

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Abstract
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-year-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. 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 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 gender 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.

Keywords Sensitivity to reward · Adolescents · Snacking · sugar-sweetened beverages

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Introduction

Adolescence is characterized by higher demands for energy and nutrients due to rapid physiological, psychosocial and cognitive development [1, 2]. At the same time, adolescents are in the process of more autonomously developing their eating habits, which are likely to persist in adulthood [3, 4]. However, adolescents typically adopt unhealthy eating habits such as low fruit and vegetables consumption and high intake of energy-dense snacks and sugar-sweetened beverages (SSBs) [3, 4]. In Flanders, 27.0 % of the adolescents consume sweet snacks every day [5], and 43.8 and 32.8 % of the adolescent boys and girls consume SSBs on a daily basis, respectively, [6]. Snacks between meals accounted for 20.0–24.0 % of the total energy intake in adolescents [7]. Overconsumption of energy-dense snacks and SSBs in adolescents is on the rise [8, 9] and is known to be associated with obesity, and other health problems such as concentration problems, dental carries and other chronic diseases [10, 11].

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 [12–14]. The rewarding value, evaluated in terms of reinforcing value, of palatable foods is higher than that of bland foods [15–18]. 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 [12–14]. A theory frequently used to explain these differences is Gray's reinforcement sensitivity theory [19]. Gray describes a psychobiological trait, called sensitivity to reward (SR), which reflects the functional outcomes of the behavioral activation system (BAS) [19]. 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 [19–21]. BAS is typically measured with the BAS scales as developed by Carver and White [22] in adults and with the child version as developed by Franken et al. [23] in children and adolescents. These scales measure BAS through three activational factors [22]: 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 [22–26]. Previous research has also, however, shown that mainly BAS RR and DRV are associated with food intake and not BAS FS [21, 27, 28]. 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 of being overweight, experience more food cravings and episodes of emotional eating and have a higher activation of brain areas implicated in food reward [14, 20, 21, 28–30]. The few studies that addressed SR in adolescence concentrated mainly on dysfunctional eating [31, 32]. 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 [33].

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 [32, 34, 35]. Gender differences in SR and activation of brain reward circuits were also reported [21, 32, 36]. Although these few studies are inconclusive, it seems that boys have a higher SR and brain activation toward appetitive food pictures [21, 32, 36]. 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 [3, 4]. The influence of SR on these eating habits is expected to be considerable, as adolescents are characterized by a high vulnerability to rewarding processes [28, 33]. 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 gender 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.

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 [37].

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 dropout of 15 %. Taking into account the design of the study (design effect = 1.177), 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 five 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 [38], 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 third and fourth 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 third and fourth 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 min) on a pre-agreed date to complete the survey in the presence of the research staff.

Measures

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

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.

Sensitivity to reward

SR was assessed with the Dutch child version of the Carver and White BAS scales as developed by Franken et al. [23]. 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 the positive response toward a reward (BAS RR) [39]. All items are to be answered on a four-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 [21, 28]. The study by Voigt et al. [27] examined the associations of the different BAS subscales to risky health behaviors and found no association between BAS FS and diet. Convergent validity and internal consistency of these BAS scales in adolescents have been confirmed in previous studies [24–26]. In the present sample the Cronbach's Alphas were assessed as good for BAS DRV ($\alpha = 0.81$) and acceptable for BAS RR ($\alpha = 0.69$). BAS FS and therefore also BAS TOT was omitted, as its internal consistency is poor ($\alpha = 0.51$ in the present study) and is unlikely to be related to food intake.

Snack and sugar-sweetened beverage intake

Snack and SSB intake were assessed using a food frequency questionnaire (FFQ), based on earlier work by Huybrechts et al. [40]. 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 [40]. 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 1 month. The reliability and validity of this FFQ is reported elsewhere, and the FFQ was found valid and reliable on a group level [41]. 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 such as soft drinks and energy and sport drinks were used in accordance with the definition of Malik et al. [10]. Based on Rodriguez and Moreno [11], 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.

Snack classification

Snacks were classified as either healthy or unhealthy using the UK Ofcom nutrient profiling model [42]. 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), 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). The total score was calculated by subtracting the C subscore from the A subscore. The calculation method is detailed elsewhere [42]. Food items that scored more than four points were considered to be unhealthy [42]. 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.

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 expressed per 100 g [43]) of the most frequently consumed food items by adolescents within that category, as reported in the HELENA study [44]. 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 were expressed per g (the average values per 100 g divided by 100) [43]. 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.

Height and weight

Two trained research assistants measured body height and weight using a standardized protocol [45]. 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 [46]. According to the international obesity task force (IOTF) cutoff points, adolescents were classified as either non-overweight or overweight [47].

Statistical analyses

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

To assess the difference in BAS (DRV and RR) scores and SSB and snack intake, descriptive statistics and independent sample t tests were computed, and 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 gender on these associations. Separate analyses were performed for each of the two BAS scales, BAS DRV and BAS RR. Logarithmic transformations (log10) were applied to all outcome variables that were not normally distributed. Continuous explanatory variables were centered on the grand mean to ease the interpretation of interactions. The unstandardized (b's) coefficients were backtransformed and expressed as percentage differences (estimate-1 $\times$ 100). All analyses were adjusted for age, education type, gender 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 gender was assessed by adding interaction terms between gender and BAS DRV and BAS RR, respectively, in the different regression models.

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.

Results

Study characteristics

Of the 1210 selected adolescents, 106 adolescents were either absent due to illness, not allowed to participate by the parents or returned a questionnaire of unsatisfactory quality for further use (namely, a questionnaire in which less than one-third of the questionnaire was completed or the same answer was filled in for a full page or more). Thus, 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 1). 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 with 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 with boys ($t = -3.88$, $p < 0.001$).

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 2). BAS RR was positively associated with intake of unhealthy snacks, healthy snacks, fat from snacks and Na from snacks.

Moderation effect of gender

An interaction effect of gender and BAS RR (see Table 3) was found for the daily intake of SSBs, energy and sugar from SSBs and energy and fat from snacks. For the significant interaction effects, margin plots are shown in Fig. 1. Significant positive associations between BAS RR and the daily intake 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 gender. No interaction effects of gender and BAS DRV were found (see Table 3).

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 [3,

Table 1 Sample characteristics and mean BAS scores, snack and SSB intake

	Mean (SD)	
	Boys (50.87 %)[a]	Girls (49.13 %)[a]
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)***

BAS DRV behavioral activation system drive scores, *BAS RR* behavioral activation system reward responsiveness scores, *SSB* sugar-sweetened beverage, *SSBs* sugar-sweetened beverages

* 0.05 %, ** 0.01 %, *** 0.001 %

[a] Two sided *t* tests

Table 2 Associations BAS DRV and RR and SSB and snack intake

	SSBs			Snacks					
	Daily overall intake	Daily energy intake	Daily sugar intake	Daily healthy snack intake	Daily unhealthy snack intake	Daily energy intake	Daily sugar intake	Daily fat intake	Daily Na intake
	b% (CI%)[a]	b% (CI%)[a]	b% (CI%)[a]	b% (CI%)[a]	b% (CI%)[a]	b% (CI%)[a]	b% (CI%)[a]	b% (CI%)[a]	b% (CI%)[a]
BAS DRV	13.79 (5.37, 22.88)***	12.77 (5.08, 21.02)***	10.95 (4.45, 17.85)***	5.81 (0.28, 12.28)	5.42 (2.06, 8.88)***	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	1.92 (5.67, 10.12)	1.78 (−5.21, 9.28)	1.21 (−38.59, 7.56)	6.41 (0.27, 12.93)*	3.85 (0.53, 7.28)*	3.31 (−0.08, 6.81)	2.36 (−0.55, 5.36)	4.05 (1.03, 7.16)**	3.89 (0.20, 7.71)*

BAS DRV behavioral activation system drive scores, *BAS RR* behavioral activation system reward responsiveness scores, *SSBs* sugar-sweetened beverages

* 0.05 %, ** 0.01 %, *** 0.001 %

[a] Multilevel regression with gender, zBMI, type of education and age as control variables

Table 3 Moderation effect of gender on the BAS DRV/BAS RR-SSB/snack intake associations

	SSBs			Snacks					
	Daily overall intake	Daily energy intake	Daily sugar intake	Daily healthy snack intake	Daily unhealthy snack intake	Daily energy intake	Daily sugar intake	Daily fat intake	Daily Na intake
	b% (CI%)[a]	b% (CI%)[a]	b% (CI%)[a]	b% (CI%)[a]	b% (CI%)[a]	b% (CI%)[a]	b% (CI%)[a]	b% (CI%)[a]	b% (CI%)[a]
BAS DRV × gender	7.40 (−7.77, 25.06)	7.78 (−6.29, 23.97)	7.37 (−4.73, 21.01)	4.37 (−7.16, 17.34)	5.89 (−0.65, 12.86)	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 × gender	17.57 (0.77, 37.17)*	16.67 (1.26, 34.44)*	14.73 (1.64, 29.51)*	0.09 (11.10, 12.68)	6.06 (−0.58, 13.15)	6.90 (0.04, 14.23)*	4.58 (−1.27, 10.77)	6.64 (0.57, 13.08)*	7.12 (−0.30, 15.11)

BAS DRV behavioral activation system drive scores, *BAS RR* behavioral activation system reward responsiveness scores, *SSBs* sugar-sweetened beverages

* 0.05 %, ** 0.01 %, *** 0.001 %

[a] Multilevel regression with gender, zBMI, type of education and age as control variables

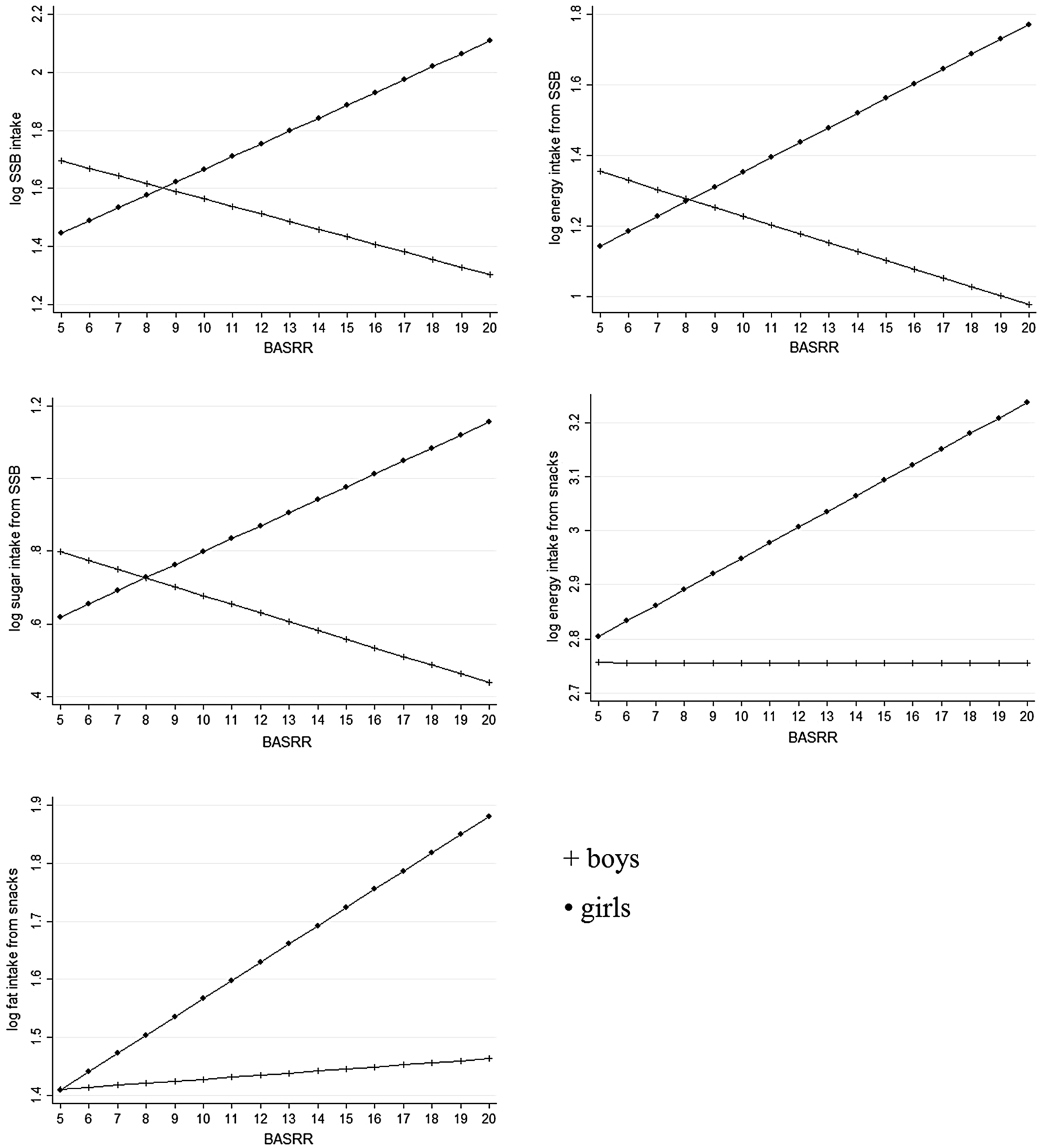

Fig. 1 Margin plots for the interaction of BAS RR and gender for snack and SSB intakes (boys *plus symbol*, girls *filled circle*)

9–11]. 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. Previous research in adults by Davis et al. [20] 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. 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 [13, 15–18]. However, this positive association can be explained as food itself (independent of its characteristics) is a natural reinforcer [13, 15–18]. BAS RR was not associated with SSB intake and was also not associated with 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 [21].

Second, we observed that the association between SR and snack and SSB consumption was moderated by gender, 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, 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 as BAS RR scores increased for both boys and girls. When the regression analyses were repeated for boys and girls separately, however, only significant associations were found for girls. No interaction effects of gender 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 gender 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 [32], 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. As "being hungry" is one of the main determinants of food choice reported by adolescents 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 [34, 48, 49]. Regarding the intake of SSBs, energy from SSBs and sugar from SSBs, the association between BAS RR and intake was even negative, 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 toward 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 gender.

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 [21, 32, 36]. 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 [50]. 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 (±75 min), 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. [51] has considerable advantages over adjusting for total energy intake. 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 [33, 52–54].

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).

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Conflict of interest The authors declare that there were no conflicts of interest.

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