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ORIGINAL CONTRIBUTION

Factors influencing the reinforcing value of fruit and unhealthy snacks

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Abstract
Objective The present study investigated the reinforcing value of healthy and unhealthy snack food in adolescents ($n = 108$, aged 14–16 years). Moderation by access to different foods, sex and the personality trait reward sensitivity is tested.
Methods In a computerized Food Reinforcement Task, adolescents could earn portions of a healthy and an unhealthy snack following an identical progressive reinforcement schedule for both food types. Reinforcing value of food was indexed by the number of button presses for each food type. Participants were allocated randomly to two-order condition: fruit–snack versus snack–fruit. Reward sensitivity was assessed with the Dutch age-downward version of Carver and White's BIS/BAS scale.
Results Results showed that the reinforcing value of an unhealthy snack is higher than that of fruit, with participants making more button presses for unhealthy snacks, $M = 1280.40$, $SD = 1203.53$, than for fruit, $M = 488.04$, $SD = 401.45$, $F(1,48) = 25.37$, $p < 0.001$. This effect is stronger in boys ($\beta = -1367.67$) than in girls ($\beta = -548.61$). The effect is only present in the snack–fruit condition, not in the fruit–snack condition, indicating that access to food moderates the effect of food type. There is no evidence for moderation by reward sensitivity.
Conclusions Results point to the importance of simultaneously increasing barriers to obtain unhealthy food and promoting access to healthy food in order to facilitate healthy food choices.

Keywords Reward sensitivity · Adolescents · Reinforcing value of food · Food reward

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Introduction

Food intake is regulated not only by homeostatic signals or habits but also by hedonic influences (e.g., liking of and preference for a certain taste) and by the reinforcing value of food items (e.g., being motivated or wanting to eat a certain food item). The reinforcing value of food reflects its motivational capacities and incentive quality and is conceptualized as the amount of effort an individual is willing to make to obtain it [1–3]. Food hedonics and food reinforcement are closely connected: Foods that are highly liked are often considered to be highly reinforcing as well [4–6]. However, according to the incentive sensitization theory [7–9] both concepts refer to separate processes, each originating in different brain regions [2, 10, 11]. This distinction is empirically validated by several studies showing that liking and wanting not always operate

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in conjunction and that they might be influenced differently by contextual and individual factors, like food deprivation or satiety [12–15] or weight [4, 16]. Because the reinforcing value of food (wanting) is a stronger determinant of food intake than the hedonic value (liking) [17–21], insight on the determining factors of this reinforcing value of food might be of crucial interest for interventions aiming to improve eating behavior and diet quality [4, 21–23].

One important determinant of the reinforcing value of food is the type of food, with high energy, less healthy foods being more rewarding than low energy, healthier foods [4, 17, 21, 23–25]. However, most studies to date focused on the reinforcing value of unhealthy foods, while less is known on the reinforcing value of more healthy foods [4]. In the present study, we will investigate the reinforcing value of both unhealthy and healthy snacks. To realize this, we adapted existing food reinforcing value paradigms [24] to allow for a clear comparison between both food types. Most studies investigate the motivation to obtain foods by answering the question how much effort individuals are willing to do for a certain food item, before they switch to an alternative for which they have to do less effort (substitution) [21, 26]. As such, the reinforcing value of a certain food type is often conceptualized relative to the reinforcing value of another reward (relative reinforcing value, RRV) and assessed with a laboratory-based computerized choice task with a progressive ratio schedule of reinforcement for one food type and a fixed reinforcement schedule for the alternative [3, 27]. Such experiments provide insights on the amount of work individuals are willing to do for an unhealthy food item when a more easily obtainable alternative is present. This knowledge is undoubtedly informative when one is trying to find foods or activities that might be as rewarding as unhealthy food in an effort to improve eating habits by suggesting attractive alternatives to eating unhealthy food. Yet, in real life, people are often convinced that eating healthy food is more cumbersome and requires more effort than eating less healthy convenience food. Therefore, the main aim of the present study is to directly compare the amount of effort individuals want to do for healthy versus unhealthy food as indices for the reinforcing value of both food types. For that reason, we evaluate the reinforcing value (RV) of healthy versus unhealthy food separately, following a progressive ratio schedule of reinforcement for each food type.

Another important determinant of the reinforcing value of food is an individual's level of deprivation or satiety [12, 13, 28]. Satiety to a certain type of food, however, does not eliminate the motivation to obtain or eat another food completely [29, 30]. Actually even *mere exposure* to palatable food (without consumption) can reduce the reinforcing value of healthy food [31]. Therefore, it can be assumed that access to unhealthy foods diminishes the motivation to obtain more healthy foods. Assessing if access to one type of food influences the reinforcing value of the other type by manipulating the order of the exposure (healthy–unhealthy vs. unhealthy–healthy) sheds light on whether or not people are motivated to 'compensate' their intake of unhealthy food with increased efforts to obtain healthy food or whether access to healthy food minimizes the motivation to work for unhealthy food.

Apart from the influences of food characteristics, the reinforcing value of food is also determined by individual factors, like sex [4], weight [3, 20, 27, 32–35], hunger [36] and reward sensitivity (RS) [19]. RS is a psychobiological personality trait, related to activity in the brain's reward regions and referring to an individual's ability to experience pleasure or reward on exposure to appetitive stimuli (i.e., palatable foods). This personality trait is thought to be particularly interesting in the understanding of eating behavior [37, 38]. Consistent with this assumption, empirical studies link RS to food preferences and intake [38–44]. Furthermore, performance on a Food Reinforcement Task is moderated by the participants' RS [19]. In the present study, we will therefore investigate whether RS moderates the reinforcing value of healthy and unhealthy food and whether it moderates the influence of acquiring one food type on the motivation to obtain the other type. Several studies report sex differences in the reinforcing value of food [25, 45] and in the associations of RS with food-related outcomes, but the exact nature of these effects remains unclear [41, 42, 44]. Therefore, we also explore sex effects. Studies investigating the reinforcing value of food are done in different age groups [e.g., 17, 19, 46]; however only a minority of these studies address adolescence [e.g., 35]. Nevertheless, adolescence might be a particular relevant period to study food reward, because during this period consumption of energy-dense, unhealthy snacks is highly prevalent [47] and activity in reward-related brain regions is increased compared to younger and older age [48].

Methods

The present study is part of the Reward: Rewarding Healthy Food Choices project. The overall aim of the Reward: Rewarding Healthy Food Choices project is to provide evidence for a new public health framework to improve the eating patterns of children and adolescents focusing on reward strategies, the rewarding value of food and individual differences in reward sensitivity.

Participants and procedure

A convenience sample of 110 adolescents (age 14–16 years) was recruited via secondary schools in Flanders, Belgium, with a cover story that the study intended to examine the participants abilities to concentrate on a monotonous task. Two adolescents were not allowed to participate due to allergies to the experimental food. Final sample size was 108, sufficient to detect medium-sized main and interaction effects with power ≥.80.

The experiment was conducted in small groups by a trained researcher within the first hours after school, as this is a typical time for adolescents to consume high-calorie snacks. Participants were asked to eat normally on the day of the test, but to refrain from eating or drinking (except water) for at least 2 h prior to the test session. Before testing, participants were provided with a choice of two isocaloric preloads (sandwich with ham or cheese, about 210–250 kcal), since consumption of a standard preload minimizes the effects of hunger on food reinforcement and increases the ability of detecting individual differences in food reinforcement [36]. While eating the preload, participants completed a self-report questionnaire measuring RS and reported their height and weight which were used to calculate zBMI [49]. Finally, participants rated their hunger level on a 7-point Likert scale (1="not hungry at all" to 7="extremely hungry") and completed a computerized food reinforcement task.

Active informed consent of both parents and adolescents was obtained. The study protocol was approved by the Ethics Committee of the Ghent University Hospital and was performed in accordance with the ethical standards laid down in national laws and Declaration of Helsinki.

Measures

BIS/BAS scale

Reward sensitivity (RS) was indexed by the BAS scale of a Dutch age-downward version of Carver and White's BIS/BAS scale [50]. Thirteen items are scored on a 4-point scale (1 = not at all true, 2 = somewhat not true, 3 = somewhat true, and 4 = all true) and summed to obtain BAS_Total scores with higher scores indicating more RS (range 13–52). The scale is a valid measurement of RS in children and adolescents [50, 51]. Normative data for a Flemish youth population are available [52]. If one or two items of the questionnaire were missing, the missing was replaced by the mean of the scale. If more than two items were missing, data for that subject on that questionnaire were not included in the analyses. Internal consistency of BAS_Total score in the present sample was acceptable (Cronbach's $\alpha = 0.74$).

Reinforcing value of food: food reinforcement task

The food reinforcement task (FRT) is a computerized paradigm measuring the reinforcing value (RV) of food by assessing how hard participants are willing to work (i.e., the amount of button presses they are willing to make) for access to healthy and unhealthy food [3, 27]. Prior to the start of the FRT, participants could choose the healthy (i.e., fruit: apple, pear, grape, plum, or tangerine; kilocalories per 100 g ranging between 45 and 54 kcal) and unhealthy (i.e., unhealthy snack: chocolate bar, chocolate, marshmallows, cookies or potato crisps; kilocalories per 100 g ranging between 344 and 534 kcal) food item they wanted to work for from a buffet. Participants could win portions (in grams) of a healthy food item in one block and of an unhealthy food item in the other block by mouse button presses. The order of the two blocks was randomized for each participant: 60 participants were in the fruit–snack condition, 48 in the snack–fruit condition. The number of button presses on each food item before participants stopped responding for that item was a measure of the RV for that particular food item. The more button presses, the more points and thus the more food they gained. 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) twice as many points were needed to obtain the same amount of unhealthy snacks as fruit (1 point = 10 g healthy snack, 1 point = 5 g unhealthy snack). Not every button press equaled one point. Participants were told that, throughout the course of the experiment, it would get increasingly difficult to obtain the food item: Further down the experiment, more button presses were needed to gain an extra point. More specifically, participants earned points for each food item according to an identical progressive reinforcement schedule that began at FR2 and progressed through FR4, FR8, FR16, FR32, FR64, FR128, FR256, FR512. During the course of the experiment, a picture of the food item participants were working for and the amount of points won was displayed on the screen. There was no maximum amount of food, and participants were told to continue pressing the button as long as they were motivated. Progression to the next reinforcement level was done after earning 20 points. When participants were no longer motivated to work for the first food item, they could start working for the second one by pressing the space bar. To avoid satiation or habituation, participants were not allowed to eat the food items until the computer task was completed: They received the food at the end of the experimental session.

Analyses

Simple *t* tests or Chi-square tests were used to test whether participants in each block order group (fruit–snack vs. snack–fruit) differed on several baseline characteristics.

The reinforcing value of both food types (indexed by the total number of responses made for each food type) was

Table 1 Parameter estimates for model 1 and the subsequent analysis stratified for block order

	b	SE	CI
Model 1			
Intercept	1280.40***	128.33	[1026.02, 1534.77]
Stimulus	−792.35***	128.33	[−1038.60, −546.11]
Block order	−609.48	124.23	[−950.76, −268.20]
Stimulus × block order	903.99***	166.67	[573.62, 1234,35]
Fruit–snack			
Intercept	670.92***	69.32	[532.26, 809.57]
Stimulus	111.63	79.89	[−48.18, 271.442]
Snack–fruit			
Intercept	1280.40***	171.90	[934.78, 1626.02]
Stimulus	−792.35***	157.32	[−1108.67, −476.04]

*** $p < 0.001$; reference category stimulus: fruit; reference category block order: fruit–snack

tested using multilevel modeling, taking into account the clustering of the data within individuals (repeated measures)[1] [53, 54]. The reinforcing value of both food types (RVsnack vs. RVfruit) and the effect of exposure to the different food types were assessed using a linear random intercept (mixed) model (model 1) with stimulus (fruit vs. snack) as within-subjects factor, block order (fruit–snack vs. snack–fruit) as between-subjects factor and the stimulus x block order interaction. It was opted to work with a repeated-measures mixed model with an unstructured covariance structure, as we suspected that the variance in the number of clicks would be depended on the stimulus presented. Model 1 showed that this was justified as the variance indices were different for RVsnack, var = 594,618.36, SD = 107,580.35, Wald $Z = 5.53$, $p < 0.001$, and RVfruit, var = 65,349.55, SD = 35,555.99, Wald $Z = 1.84$, $p = 0.066$.

The moderating effects of sex and RS were assessed with the same repeated-measures mixed model by adding either sex and the stimulus × block order × sex (model 2) or RS and the stimulus × block order × RS (model 3) interaction terms along with all possible two-way interaction effects. The continuous variable RS was mean-centered to allow for a convenient interpretation of the interaction terms [53, 55]. If a significant interaction effect with either sex or RS was found, analyses were stratified by these factors. Estimates were obtained using the maximum likelihood estimation method. All statistical analyses were performed with IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp 2013, Armonk, NY). Statistical significance was set at 5 %, and all tests were two-sided.

[1] We tested whether the RV of food was dependent on hunger resp. zBMI by using a linear random intercept (mixed) model (model 1) with hunger resp. zBMI and stimulus (fruit vs. snack) as within-subjects factors, block order (fruit–snack vs. snack–fruit) as between-subjects. However, because the main and interaction effects of hunger resp. zBMI did not reach significance, we choose not to report these analyses. Results of these analyses are available on request from the first author.

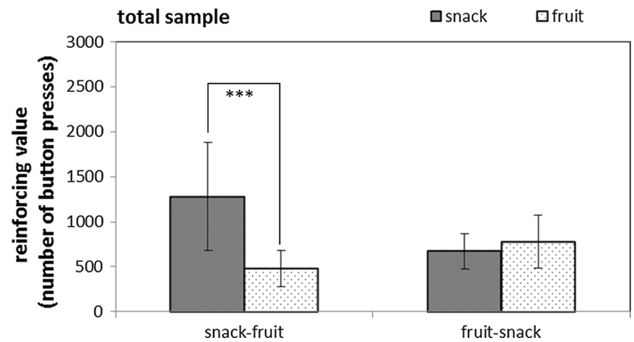

Fig. 1 Mean reinforcing value (and SD *error bars*) for each food item per block order group; note ***$p < 001$

Results

Descriptives

The mean age of the present sample was 14.44 years (SD = 0.68), 27.2 % of the participants were boys, and sex information was missing for three participants. Mean BAS_total score was low compared to normative data for a Flemish adolescent population: $M = 35.30$, SD = 5.36 (T score = 39.93) for boys, $M = 33.33$, SD = 5.26 (T score = 36.46) for girls [52]. There were no significant differences between conditions on age, $t(210) = 1.61$, $p = 0.11$, sex, $\chi^2(1) = 1.31$, $p = 0.25$, or BAS_total, $t(210) = 0.47$, $p = 0.64$.

Reinforcing value of fruit and snack

Model 1 (Table 1) with block order as between-subjects factor and stimulus as within-subjects factor (−2 LL 3413.33) showed no significant main effect of block order, $F(1108) = 1.94$, $p = 0.17$, and a significant effect of stimulus, $F(1,108) = 16.68$, $p < 0.001$, with $M = 941.80$, SD = 943.66 for RVsnack and $M = 651.66$, SD = 534.16 for RVfruit. This main effect of stimulus was qualified by a significant stimulus × block order interaction, $F(1,108) = 29.42$, $p < 0.001$ (Fig. 1).

The main effect of stimulus was only significant in the snack–fruit group with a higher RV for snacks, $M = 1280.40$, SD = 1203.53, than for fruit, $M = 488.04$,

Table 2 Parameter estimates for model 2 and the subsequent analysis stratified for sex

	b	SE	CI
Model 2			
Intercept	1019.35***	151.42	[719.11, 1319.60]
Stimulus	−548.61***	148.99	[−844.03, −253.20]
Block order	−401.65	197.70	[−793.65, 9.65]
Sex	910.51**	265.17	[384.72, 1436.30]
Stimulus × block order	640.52***	194.52	[254.83, 1026.21]
Sex × stimulus	−819.05**	260.91	[−1336.39, 301,72]
Sex × block order	−679.75	365.87	[−1405.20, 45.70]
Sex × block order × stimulus	921.94*	359.98	[208.16, 1635.72]
Split file: boys			
Intercept	1929.87***	307.59	[1301.69, 2558.05]
Stimulus	−1367.67***	293.49	[−1967.06, −768.28]
Block order	−1081.40*	435.00	[−1969.78, −193.02]
Stimulus × block order	1562.47***	415.06	[714.80, 2410.13]
Split file girls			
Intercept	1019.35***	117.43	[785.43, 1253.28]
Stimulus	−548.61***	120.02	[−787.71, −309.52]
Block order snack	−401.65*	153.31	[−707.06, −96.24]
Stimulus × block order	640.52***	156.70	[328.36, 952.68]

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; reference category stimulus: fruit; reference category block order: fruit–snack; reference category sex: boys

Table 3 Parameter estimates for the subsequent analysis stratified for sex and block order group

	b	SE	CI
Boys: fruit–snack			
Intercept	848.47***	172.80	[480.16, 1216.77]
Stimulus	194.80	216.55	[−266.77, 656.37]
Boys: snack–fruit			
Intercept	1929.87***	399.11	[1079.25, 2780.48]
Stimulus	−1367.67**	354.02	[−2122.19, −613.14]
Girls: fruit–snack			
Intercept	617.70***	71.43	[473.74, 761.67]
Stimulus	91.91	79.26	[−67.83, 251.64]
Girls: snack–fruit			
Intercept	1019.35***	151.79	[709.81, 1328.90]
Stimulus	−584.61***	148.85	[−852.16, −245.07]

** $p < 0.01$; *** $p < 0.001$

SD = 401.45, F(1,48) = 25.37, $p < 0.001$. In the fruit–snack group, there was no main effect of stimulus, F(1,60) = 1.95, $p = 0.17$, RV(snack): M = 670.91, SD = 541.47, RV(fruit): M = 782.55, SD = 591.49 (Table 1; Fig. 1).

Moderating effect of sex

Adding sex to the model (model 2, Table 2) (–2 LL 3303.97), there was no significant main effect of block order, F(1,105) = 2.51, $p = 0.117$, but a significant main effect of stimulus, F(1,105) = 20.49, $p < 0.001$, and a significant main effect of sex, F(1,105) = 10.57, $p < 0.01$, with boys making more button presses, M = 1096.0, SD = 1112.9, than girls, M = 697.3, SD = 570.5. The three-way interaction stimulus × block order × sex was significant F(1,105) = 656, $p < 0.05$. The −2 LL of model 2 is lower than the one of model 1, $\chi^2(4) = 109.36$, $p < 0.001$, indicating that model 2 provided the better fit for the data.

Stratifying this three-way interaction for boys and girls (Table 2) revealed that the stimulus × block order interaction was significant in both boys, F(1,30) = 14.71, $p < 0.001$, and girls, F(1,75) = 16.71, $p < 0.001$ (Table 2). Stratifying these two-way interactions (Table 3) showed that in boys, the main effect of stimulus was only significant in the snack–fruit group, F(1,15) = 14.93, $p < 0.01$, RV(fruit): M = 562.20, SD = 551.56, RV(snack): M = 1929.87, SD = 1600.37, but not in the fruit–snack group, F(1,15) = 0.81, $p = 0.383$, RV(fruit): M = 1043.27, SD = 869.17, RV(snack): M = 848.47, SD = 692.70. In girls, the same pattern of results was found with a significant main effect of stimulus only in the snack–fruit group, F(1,31) = 13.58, $p < 0.001$, RV(fruit): M = 470.74, SD = 317.71, RV(snack): M = 1019.35, SD = 859.88, but not in the fruit–snack group, F(1,44) = 1.35, $p = 0.26$, RV(fruit): M = 709.61, SD = 439.86, RV(snack): M = 617.70, SD = 479.31. The stimulus effect in the snack–fruit condition was bigger in boys, $\beta = -1367.67$, SD = 354.02, $p < 0.01$, than in girls, $\beta = -548.61$, SD = 148.85, $p < 0.001$ (Fig. 2).

Moderating effect of reward sensitivity

Adding RS to the model (model 3, Table 4) (−2LL 3381.36), there was no significant main effect of block order, F(1,107) = 2.34, $p = 0.129$, but the main effect of stimulus, F(1,107) = 17.19, $p < 0.001$, and the stimulus x block order two-way interaction, F(1,107) = 29.91, $p < 0.001$, remained significant as in model 1. The effects involving RS were not significant: no significant main effect, F(1,107) = 0.06, $p = 0.814$, no significant two-way interactions, stimulus × RS, F(1,107) = 0.36, $p = 0.550$ and block order x RS, F(1,107) = 0.12, $p = 0.736$, and no significant three-way interaction stimulus × block order × RS, F(1,107) = 0.08, $p = 0.782$. The −2 LL of model 3 is lower than the one of model 1 $\chi^2(4) = 31.97$,

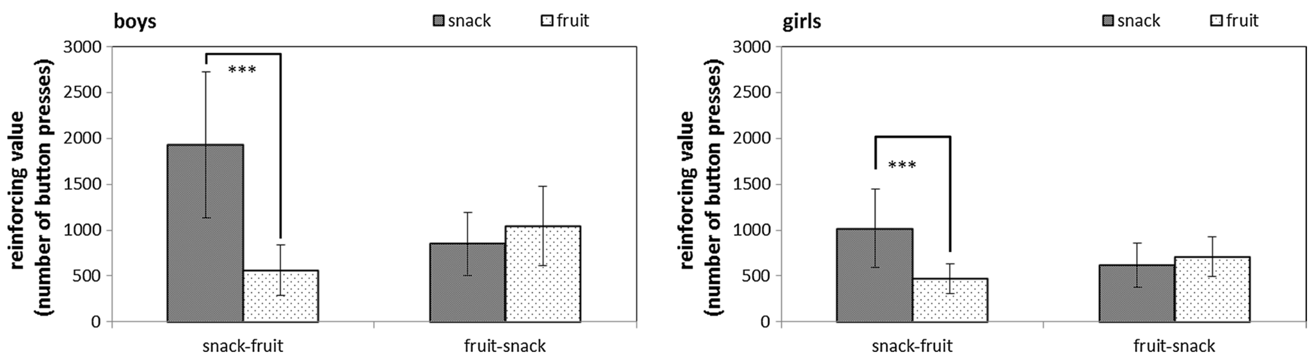

Fig. 2 Mean reinforcing value (and SD *error bars*) for each food item per block order group, separately for boys and girls; note ***$p < 001$;**$p < 01$

Table 4 Parameter estimates for model 3

Model 3	*b*	SE	CI
Intercept	1302.79***	129.17	[1046.73, 1558.85]
Stimulus	−805.87***	125.54	[−1054.74, −557.00]
Block order	−631.65	172.46	[−973.53, −289.77]
RS	−13.19	26.41	[−65.54, 39.16]
Stimulus × block order	916.71***	167.62	[584.43, 1248.99]
RS × stimulus	14.00	25.66	[−36.88, 64.87]
RS × block order	11.73	32.88	[−53.46, 76.92]
RS × block order × stimulus	−8.85	31.96	[−72.20, 54.51]

*** $p < 0.001$

$p < 0.001$, indicating a better fit. However, the difference in the −2 LL between model 3 and model 1 is smaller than the difference between model 2 and model 1, indicating that model 2 provided the best fit for the data.

Conclusion and discussion

The results of the present study confirm earlier statements that people are motivated more to obtain unhealthy energy-dense food items than healthy food items [4, 17, 21, 23–25], and extend the evidence for these statements to adolescents. The significant main effect of stimulus type indeed shows that the reinforcing value of unhealthy snacks is higher than that of fruit. However, the significant interactions with block order call for a more subtle and balanced assertion. Obtaining a food item decreases the motivation to obtain a second one, and this decrease depends on the type of food. When adolescents initially had to work for a healthy fruit item, they were still motivated to work equally hard for an unhealthy, energy-dense snack afterward. However, when they initially had to work for a snack, their motivation to work for fruit diminished. As such, the data do not indicate that access to healthy food fully protects from wanting unhealthy food. On the other hand, access to unhealthy snacks does decrease the motivation for healthy food. Translated to a real-life example, this means that, unfortunately, having a lavish basket of fruit in the kitchen does not safeguard kids from wanting to eat that delicious chocolate mousse as dessert. After they get an apple, they still might want to eat chocolate mousse. On the contrary, knowing that this chocolate mousse is in the fridge will diminish their motivation to grab and bite an apple. Nonetheless, when adolescents have obtained fruit, their motivation to further work for snack is lower than their initial motivation to work for snacks. This finding is consistent with earlier evidence that intake of or exposure to healthy (diet-congruent) food items diminishes intake, at least in adult dieters [56, 57]. As such, availability of healthy food can be a valuable tool to enhance dietary quality. However, the present study and its results deviate from previous studies suggesting that healthy snacks might be potential substitutes for unhealthy snacks [3, 22, 23, 58]. Such substitution can indeed be found when response requirements for unhealthy food increase while those for healthy foods remain constant and minimal. In the present study, however, where response requirements increase for both unhealthy and healthy food, findings show that adolescents are willing to do more persisting effort for unhealthy food than for healthy food.

Data of the present study show a high level of interindividual variability, as indicated by the large standard deviations (SDs between 401.5 and 1203.5) and the significant variance at subject level. Such variable results suggest that the reinforcing value of food might depend on individual difference factors [4, 19]. The significant interactions involving sex indeed confirm that the reinforcing value of food differs between adolescent boys and girls. Boys seem more motivated to work for food than girls, whether it is healthy or unhealthy. Since hunger is found to influence the reinforcement value of food, and since energy requirements (and thus hunger) is greater in boys, it might be assumed that this sex difference can be related to hunger. However, in the present study, hunger ratings were not significantly different for boys and girls and they were not significant predictors of reinforcing value of food, making the assumption unlikely. The higher reinforcing value of unhealthy foods compared to healthy foods is more pronounced in boys than in girls. This sex effect dovetails with previous studies describing sex differences in the intake of unhealthy and healthy snacks with boys consuming more unhealthy and girls consuming more healthy snacks [44]. Previous studies also describe how reward sensitivity (RS) is implicated in eating behavior. For example, higher RS is found to be predictive for higher preference for unhealthy foods, higher intake of snacks (both healthy and unhealthy) and more episodes of overeating [37, 38, 43, 44]. RS is also found to impact preschool children's performance (response speed) in a Food Reinforcement Task [19]. However, the present study provided no evidence for the moderation of food reinforcement by reward sensitivity. This unexpected null finding might be attributed to the low and rather homogeneous levels of RS in the present study sample compared to age and sex appropriate norms (*T* scores <40) [52]. To fully understand the implications of the reinforcement value of food, more research on its determinants and moderators (e.g., weight, restraint, satiety vs. hunger) is needed.

Most studies to date investigate the reinforcing value of one food type relative to that of another food type as an index of substitutability. In the present study, we tested the reinforcing value of healthy versus unhealthy food separately, allowing for clear comparisons between both food types, and reflecting the real-world situation in which individuals consider eating healthy more cumbersome and requiring more effort than eating unhealthy convenience food. Nonetheless, future research might further increase this ecological validity, by studying the reinforcing value of different food types concurrently. This can be accomplished by running independent, progressive ratio schedules of reinforcement for each food type on two different computers [59, 60].

In the present study, we used an experimental design to test the reinforcing value of unhealthy and healthy food items. By using this approach, we maximized the likelihood that the difference between the reinforcing value of the two foods is caused by the difference in food type, allowing for causal inferences. However, the experimental approach constraints the ecological validity of the present results given the large discrepancies between the experimental setting and naturalistic eating environments. Additionally, research participation effects (i.e., Hawthorne effect) might partly account for the observed behavior with participants persevering in responding longer than they normally would [61], and even possibly affecting different food types differently. Nonetheless, responses to experimental reinforcing schedules are considered useful indices of reinforcing value of food, and they do have predictive validity for intake and eating behavior [3, 19].

Although food wanting and food liking refer to distinct processes [1, 8, 23, 62], they are often related and sometimes hard to disentangle [4–6]. We did not explicitly assess how much the adolescents liked the food they had to work for, but to avoid them having to work for a food item they disliked, we offered them to choose the snack and fruit they preferred out of five energy-dense snacks and five fruits. Nevertheless, there might be inter- and intraindividual differences in liking of the food items that constrain variability in motivation to obtain the food, thereby limiting the interpretation of the reinforcing value of unhealthy snacks and fruits in the present study. Future research might aim to investigate reinforcing value of different food types with matched levels of liking. Presenting a wider range of healthy snack items might increase the chances that participants can choose a healthy food item they like as much as their unhealthy food item of choice, enabling a controlled test of the reinforcing value of both food types. Offering a wider range of healthy snacks could also broaden the taste spectrum of the healthy snacks from which participants can choose. In the present study, only sweet healthy foods were presented, while there were sweet and savory unhealthy snacks. However, since wanting for sweet versus savory foods depends on motivational state and individual preferences [17], future research might aim to take taste into account.

Understanding the exact nature of the reinforcing value of food and its determinants provides essential information in the understanding of eating behavior and food intake. The present study showed that the reinforcing value of food depends on an individual's sex. The differences in food reward between unhealthy snacks and healthy snacks are higher in adolescent boys than in adolescent girls: Boys are motivated more than girls to obtain food. This increased food reward in boys is consistent with brain studies documenting sex differences in reward-related brain circuits [63]. Studies investigating brain development also reveal higher activity in reward-related regions during adolescence compared to younger and older age [48, 64, 65], making the adolescents in the present study a particularly interesting target group to study food reward. Consequently, adopting a developmental approach and studying food reward in different age groups is critical to understand the role of food reinforcement in the development of eating behavior.

The reinforcing value of food is often studied in the context of interventions aimed at reducing the consumption of energy-dense snacks [4, 21–23]. Increasing the response requirements to obtain unhealthy foods decreases the motivation to obtain them when healthier alternatives that require less effort are available. This behavioral economics approach provides an experimental analog of real-life policy actions like sugar or fat taxes whether or not combined with the subsidizing of healthy foods. It supports the idea that hampering access to unhealthy food while simultaneously facilitating access to healthy food might have positive health benefits [22, 23, 66]. An alternative to increasing the effort needed to obtain an unhealthy snack is to manipulate the reinforcing value of healthy food to that extent that this will be able to compete with highly rewarding unhealthy food. Evaluative conditioning procedures show that repeatedly pairing fruit with positive stimuli increases the chances that people make the healthy choice when offered a healthy and an unhealthy snack [67]. Furthermore, offering rewards or praise enhances children's tasting, consumption and liking of previously dislike food items [68–72]. However, the impact of combining healthy food with positive stimuli or rewards on their reinforcing value is not yet tested. Future research should explore the possibility of increasing reinforcing value of healthy food by coupling it with reward and evaluate the implications for interventions aimed at improving eating behaviors.

In summary, the present study shows that adolescents are willing to make more effort for an energy-dense snack than for a healthy snack, with the difference being larger in boys than in girls. Having access to one type of food does not prevent wanting a second one. On the contrary, access to unhealthy snacks decreases the motivation to work for healthy food, while having obtained a healthy snack does not eliminate the motivation to work for an unhealthy snack. This finding stresses the importance of simultaneously increasing costs for unhealthy food and facilitating access to healthy food. Although the high variability in responses suggests an influence of individual difference factors, we did not find support for moderation of reinforcing value of food by an individual's reward sensitivity. Future research should investigate the impact of other individual characteristics like weight, satiety or restraint [4].

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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