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An associative account of how the obesogenic environment biases adolescents' food choices

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ABSTRACT

Adolescents and children are the targets of much food advertising, the majority of which is for unhealthy snacks. Although the effects of advertising on food preferences and consummatory behavior are well documented, our understanding of the underlying mechanisms is still limited. The present study investigates an associative (ideomotor) mechanism by which exposure to rewarding (snack) outcomes may activate behavior that previously resulted in these rewards. Specifically, we used a computerized task to investigate whether exposing adolescents to food pictures directly, or to Pavlovian cues predictive of those food pictures, would bias their subsequent responses towards the presented/signaled food. Furthermore, we assessed whether this effect was particularly pronounced with palatable, high-calorie snacks (crisps and chocolate) relative to low-calorie snacks (tomatoes and cucumber). In two experiments, adolescents learnt that certain key presses would yield particular food pictures – some high calorie and others low calorie – before learning Pavlovian associations between cues (cartoon monsters) and these same food pictures. Subsequently, in a response-priming test, we examined the extent to which the food pictures and Pavlovian cues spontaneously primed the previously associated response. The results show that we replicated, in adolescents, previous demonstrations of ideomotor response priming in adults: food pictures biased responding towards the response that previously yielded them, and this effect transferred to the Pavlovian cues. Furthermore, the priming effect was significantly stronger for high-calorie rewards than for low-calorie. These findings indicate that the ideomotor mechanism plays an important role in the detrimental effect of our obesogenic environment, with its plethora of unhealthy food reminders, on adolescents' food-related choices.

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1. General introduction

Obesity is on the rise amongst children and adolescents with one in five children under 15 being overweight or obese across member states of the Organisation for Economic Co-operation and Development(OECD, 2014). The food choices made by children and adolescents are thought to be biased by the obesogenic environment that constantly exposes them to palatable, unhealthy food and targeted advertisements (Cairns, Angus, Hastings, & Caraher, 2013; Livingstone, 2005; Lobstein & Dibb, 2005). Indeed, the

majority of advertisements aimed at children and adolescents are for unhealthy foods high in sugar and/or fat (Boyland, Harrold, Kirkham, & Halford, 2011; Powell, Szczypka, Chaloupka, & Braunschweig, 2007). Although the detrimental effect of advertising on food-related behavior of children and adolescents is well documented (see e.g. Harris, Pomeranz, Lobstein, & Brownell, 2009 for review), little is known about the mechanisms of food-marketing effects (Harris, Bargh, & Brownell, 2009; Harris, Pomeranz, et al., 2009). In the current study we investigated a possible mechanism that may underlie the effect of advertising and food exposure on adolescents' food-related choices.

A number of studies have investigated the effect that external food cues have on children's food preferences and food consumption (Folkvord, Anschütz, Wiers, & Buijzen, 2015; Halford,

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Gillespie, Brown, Pontin, & Dovey, 2004; Harris, Bargh et al., 2009; Robinson, Borzekowski, Matheson, & Kraemer, 2007). Pavlovian conditioning (learning the predictive associations between cues and outcomes) plays an important role in building brand awareness and preference at a young age. In two studies, children preferred food wrapped in fast food restaurant wrappers or affixed with a well-known cartoon character (Roberto, Baik, Harris, & Brownell, 2010; Robinson et al., 2007). It has also been demonstrated that viewing unhealthy food advertisements either during TV commercials or in computer games led children to consume more unhealthy food relative to a control group (Halford et al., 2004; Harris, Bargh, et al., 2009; Harris, Pomeranz, et al., 2009; Folkvord et al., 2015). A possible mechanism for these detrimental effects is provided by ideomotor theory as well as certain associative theories (Asratyan, 1974; Gormezano & Tait, 1976; Hommel, 2009; Hommel, Müsseler, Aschersleben, & Prinz, 2001; James, 1890; Lotze, 1852; Pavlov, 1927; see for review de Wit & Dickinson, 2009).

Ideomotor theory proposes that exposure to a certain outcome can activate the behavior that previously yielded this outcome. For example, seeing someone enjoying candy may initiate a trip to the nearest candy dispenser. Bi-directional associations between responses (R) and outcomes (O) are argued to underlie this O–R priming effect (as shown in Fig. 1). Researchers in the field of human psychology have shown that images of chocolate will lead participants to preferentially respond on keys previously associated with chocolate (Hogarth, 2012; Hogarth & Chase, 2011). However, as advertisers are well aware, stimuli (S) in our environment can also indirectly influence behavior, argued by these associative theories to be via a S–O–R associative pathway. Consider how candy brands use popular cartoon characters to market their products. Following exposure to advertisements in which cartoon characters are associated with candy, one can be reminded of candy merely by seeing the cartoon character (S–O), which in turn can activate the associated response (O–R; to head to the nearest candy dispenser; see Fig. 1). The latter indirect S–O–R priming effect has been studied using food rewards in several experimental 'Pavlovian-to-instrumental transfer' (PIT) studies (in adults) in recent years (Bray, Rangel, Shimojo, Balleine, & O'Doherty, 2008; Prévost, Liljeholm, Tyszka, & O'Doherty, 2012; Watson, Wiers, Hommel, & de Wit, 2014).

To study indirect S–O–R priming Watson et al. (2014) first instructed participants during an instrumental training phase that one key would yield popcorn and the other chocolate Smarties. Subsequently, in a Pavlovian training stage, the participants learnt the relationships between two black and white patterns and popcorn and Smarties. Finally, in the critical test, participants were able to press on either of the keys to gain popcorn and chocolate Smarties for later consumption. Occasionally the Pavlovian cues were presented. In line with the predictions of ideomotor theory, participants pressed more for chocolate Smarties when the pattern associated with Smarties was on screen and pressed more for popcorn during the popcorn pattern. Crucially the cues had never been trained with an instrumental response − participants were indirectly primed to perform the instrumental response that was associated with the signaled food reward.

In the present study, we investigated direct O–R and indirect S–O–R priming with food rewards in adolescents, and we addressed for the first time the question whether these effects are more potent with palatable, high-calorie food outcomes than with bland, low-calorie outcomes. Adolescents were trained to respond for both high and low-calorie food outcomes (instrumental training phase) and then in a Pavlovian training phase they learnt the relationships between Pavlovian stimuli (cartoon monsters) and these same food outcomes. Subsequently, in a (nominal extinction) test, we examined the extent to which the food-outcome pictures spontaneously primed the response that had previously yielded that food picture during instrumental training (direct O–R priming). We also measured the extent to which the Pavlovian stimuli would spontaneously prime the instrumental response for the outcome that they predicted (indirect S–O–R priming). We expected that the palatable, high-calorie food pictures would be more motivating for the adolescents than the bland, low-calorie food pictures, and that this motivational difference would lead to relatively strong response-priming rates for the high-calorie outcomes.

We also examined whether adolescent boys and girls would show differential rates of learning and/or response priming as a function of calorie content. A number of studies in adults report that men and women differ in their behavioral and neuronal responses towards food images (Cornier, Salzberg, Endly, Bessesen, & Tregellas, 2010; Houben & Jansen, 2011; Wang et al., 2009) although the evidence for these gender differences in children and adolescents is less clear (Folkvord et al., 2015; Nederkoorn, Coelho, Guerrieri, Houben, & Jansen, 2012; Snoek, van Strien, Janssens, & Engels, 2006). Finally we included measures of impulsivity in our study to assess whether impulsivity would be related to the priming effects. Individuals with higher levels of trait impulsivity are argued to be more sensitive to cues that predict rewards (Carver & White, 1994; Stanford et al., 2009). One previous study investigating O–R priming with financial rewards reports a stronger priming effect in individuals scoring higher on a measure of reward sensitivity (Muhle-Karbe & Krebs, 2012). In addition, children and adolescents who are overweight score higher on various measures of impulsivity − both self-report measures (Van den Berg et al., 2011) and response inhibition tasks (Batterink, Yokum, & Stice, 2010; Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006) suggesting a link between conditioned food-seeking behaviors and impulsivity. Therefore, we hypothesized that those adolescents scoring higher on impulsivity would show stronger priming effects for high-calorie food outcomes.
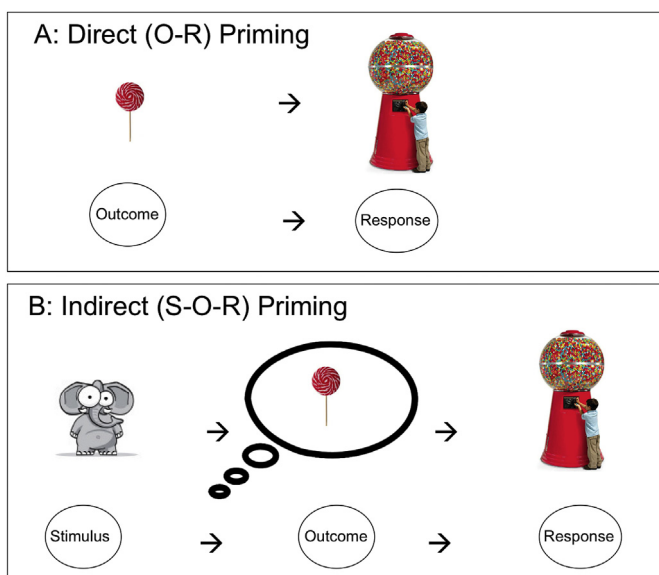
Fig. 1. A) Direct response priming − the sight of candy triggers a trip to the candy dispenser. B) Indirect response priming − following advertising associating a cartoon character with candy, seeing the cartoon character reminds one of candy and triggers a trip to the candy dispenser.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Following study approval by the Psychology Ethics Committee of the University of Amsterdam, letters were sent to the parents of students attending a secondary school in Amsterdam, The Netherlands. Parents could refuse inclusion of their child in the study by returning the opt-out form (a passive informed consent procedure approved by the Ethics Committee). Subsequently, a total of 103 adolescents took part in the study and testing was carried out during 5 days at the school, during school hours. Unfortunately, data from two days of testing (32 participants) could not be included in our analyses as participants on the first day completed longer training blocks than subsequent days and original data files from another day were inadvertently deleted. Of the remaining 71 participants, four were excluded from the study because of a corrupt data file and four were excluded because they had more than 15 response omissions or alternate instrumental key presses in any one phase of the task (assumed to be an indication that they were not taking the task seriously). One participant was excluded for scoring no higher than 50% (chance level) in the final block of instrumental training. The final participant group consisted, therefore, of 62 adolescents (25 males) between the ages of 12—15 years. Demographic information stratified by gender can be seen in Table 1. When using the standard Dutch growth charts to assess BMI (Talma, Schonbeck, Bakker, HiraSing, & van Buuren, 2010), 12 participants (5 males) were classed as overweight for their gender and age.

2.1.2. Stimuli and materials

A computerized task similar to that used by de Wit and colleagues (de Wit, Ridderinkhof, Fletcher, & Dickinson, 2013; Experiment 2) was programmed in visual basic. The task consisted of an instrumental training phase and subsequent test of instrumental R—O knowledge. This was followed by a Pavlovian training phase and then both direct and indirect response priming were examined in the test phase. The task design is depicted in Fig. 2 and described in the procedure section. Four cartoon monsters were used as discriminative cues during instrumental training and four different cartoon monsters were used as Pavlovian cues (measuring approximately 150 x 130 pixels). All eight monster images were used in the response-priming test. Photographs measuring 260 x 160 pixels of potato crisps, chocolate, cucumber and tomatoes were used in both training phases and during the priming test (see Fig. 2).

Food Desire and Hunger Questionnaire. Participants were asked to rate their hunger and their desire for each of the four foods on 7-point Likert scales marked with the anchors: not at all (1), a little bit (4) and very much (7).

Table 1
Demographic information stratified by gender for Experiments 1 and 2.

	Girls	Boys
Experiment 1		
Participants = 62	n = 37	n = 25
Mean age (SD)	13.2 yrs (0.9 yrs)	13.5 yrs (0.5 yrs)
Mean BMI (SD)	20.4 (2.7)	20.3 (4.6)
Experiment 2		
Participants = 111[a]	n = 49	n = 60
Mean age (SD)	13.8 yrs (0.7 yrs)	14.0 yrs (0.8 yrs)
Mean BMI (SD)	21.1 (3.8)	20.5 (3.2)

[a] =Gender of two participants was not recorded.
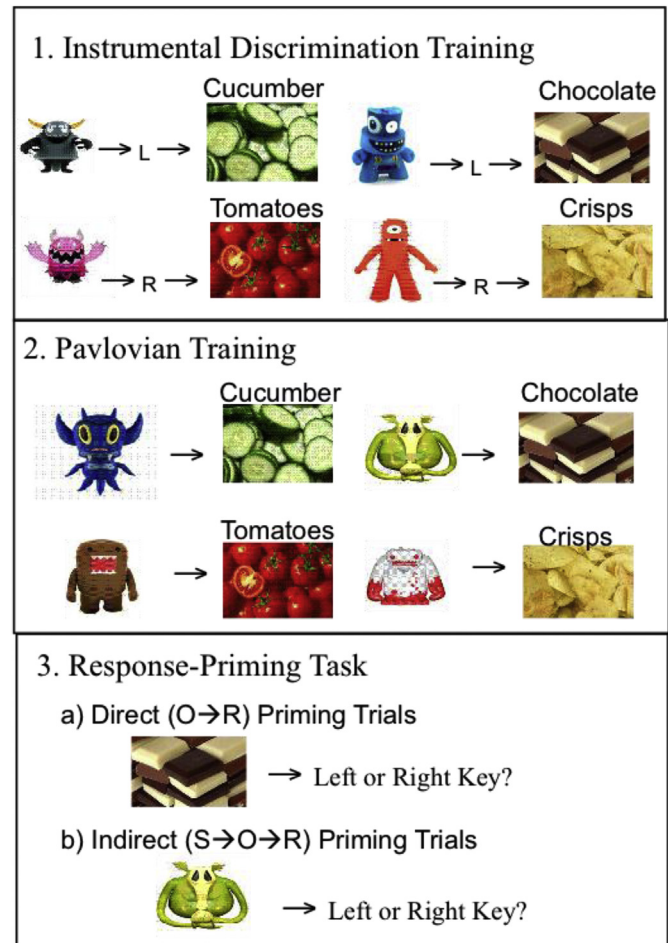
Fig. 2. Task design. In the presence of discriminative stimuli participants first learnt the relationship between instrumental responses and food pictures. They then learnt the relationships between four Pavlovian monsters and these same food pictures. In the test phase the food and Pavlovian monster pictures were presented to examine whether responses would be biased towards the presented/signaled food.

Substance Use Risk Profile Scale. Impulsivity and sensation seeking were measured using the substance use risk profile scale (SURPS; Woicik, Stewart, Pihl, & Conrod, 2009). The SURPS consists of 23 items scored on a 4 point Likert-scale. The SURPS contains in total four subscales but only data from the impulsivity and sensation seeking subscales were analyzed. The SURPS has good internal consistency and reasonable test—retest reliability in adolescent populations (Malmberg et al., 2010).

2.1.3. Procedure

Participants were tested in groups of four, during school hours. Each participant sat behind a laptop, wearing headphones, with a wooden partition preventing them from seeing any of the other participants. Participants were told that they were going to play the "Delicious Snack Game" in which they would earn points for chocolate, crisps, cucumber and tomatoes by slaying monsters. They were told to do their best and try and win as many points as possible because at the end they would be able to win a tasty food reward.

The task began with the _instrumental training phase._ Participants were told that every time they successfully defeated a monster they would earn points which would go towards a tasty food reward. They could defeat monsters by pushing on either the left or right key, every time that they saw a monster appear on the screen. If

that key was the correct key to defeat the monster then they would see a food picture appear and they would win one point. If it was the wrong key to defeat that monster then they would see the words "incorrect" and they would not earn any points. Each monster was defending a particular food (chocolate, potato crisps, cucumber or tomatoes) and had a specific key press that was needed to defeat it. Participants were told that in the beginning they would have to guess which key to press but that they would gradually learn through their incorrect responses which key was the correct one. The test leader then checked that the instructions were clear and showed the participants an example from a booklet using a cartoon monster and a food picture that was were not used in the task.

Each trial began with the presentation of a monster, which would stay on the screen for 2 s, or until a response on either the left (z) or right (m) key was made. The monster functioned as a discriminative stimulus signaling which response would be correct. Correct responses were followed by a picture of one of the four food outcomes presented in the middle of the screen along with the number of points earned and a cash register sound. Incorrect responses were followed by a game show "losing" sound and the presentation of a "0" in the middle of the screen. If no response was recorded the words "too late" were presented. All feedback was presented for 1 s and the ITI varied randomly between 1 and 2 s. For each participant, both response keys were paired with one high calorie and one low-calorie outcome. The relationships between the correct response and the outcome pictures were counterbalanced across participants ensuring that each outcome was paired equally often with the left and right keys (across participants). Furthermore, the relationships between the four discriminative monster stimuli and the four outcome pictures were permutated across participants. The instrumental training phase consisted of ten blocks in which the four different monster stimuli were each presented twice, in random order (amounting to 80 trials in total).

Following the instrumental training phase, participants were tested on their knowledge of the O−R relationships during the *Instrumental Query Phase*. On each query trial, two of the outcome pictures (either both low calorie or both high calorie) were presented, one above the other. During training, a left key press had yielded one of these outcomes whilst a right key press had yielded the other outcome. One of these two outcomes was now presented with a red cross overlaid and participants were instructed that this outcome was no longer worth any points. Their task was to press the key belonging to the food outcome that did not have a cross through it. Each outcome pair was presented eight times, with each outcome being presented four times as devalued (with the cross through it). A given picture appeared above the other on half the trials. The response window was 2 s and no feedback was given during these query trials. The ITI was random between 1 and 2 s.

Participants then completed the *Pavlovian training* phase. Pavlovian training consisted of both a short passive phase and a longer active phase. Before the passive phase began, participants were told that a new series of monsters would be shown and that each monster would be followed by a food picture. These were the same food pictures as used during instrumental training. They were told to look closely and try to remember which monster defended which food. On each trial a monster appeared at the top of the screen. After 2 s one of the four food pictures would then be shown underneath the monster and both would remain on the screen together for 1 s. The relationships between the monsters and the food pictures were counterbalanced across participants. The passive training consisted of one block in which each of the four monster-food pictures couplings were presented twice in random

order. Before the active Pavlovian phase began, participants were told that they would be tested on what they had just learnt − about which monster was defending which food. They were told that every time they saw a monster appear they had to select with the mouse the correct food picture, from the four food pictures that would be displayed at the bottom of the screen. For every correct answer they would receive one point and in the beginning they might make mistakes but that would help them learn.

During the active training a monster was presented at the top of the screen and smaller versions of the four food pictures were presented underneath in a 2 x 2 matrix (the location of the food pictures within this matrix was randomly determined on each trial). These images remained on screen for 3 s or until a response was made with the mouse. Correct answers were followed by a "1" (indicating one point) appearing at the top of the screen and the full size image of the correct food picture. Incorrect responses were followed by the full size image of the correct food picture and a "0" at the top of the screen. If no response was recorded the words "too late" were presented. All feedback was presented for 1 s and the ITI varied randomly between 1 and 2 s. The active Pavlovian training phase consisted of six blocks in which the four different monster stimuli were each presented twice, in random order (amounting to 48 trials in total).

Participants then performed the *response-priming test*. They were told that they would now be shown, one by one, all of the pictures of the monsters and the foods that had been used in the game. They were told that for every picture they had to select either the left or the right key as quickly as possible. Sometimes they would know which was the correct key to press (namely in the case of the discriminative stimuli), but for some pictures they would not. If they were not sure they were told to not think too hard about the correct response but to just spontaneously select a key in a nonsystematic order. They were told that they would not receive any feedback on whether their responses were correct or not, but that they were still earning points for correct responses. On each trial, one of the 12 pictures that had been used in the task was presented (the four food pictures to assess direct response priming, the four Pavlovian monster stimuli to assess indirect response priming and the four instrumental monster stimuli as a control condition). Presentation time was 2 s or until a response was made. No feedback was given. The test consisted of 2 blocks in which each of the twelve pictures was presented twice, in random order (48 trials in total).

Participants were then asked to rate on the Likert scales how much they desired each food and they completed the SURPS questionnaire (paper versions). Weight and height were measured and BMI (kg/m^2) calculated. Finally, participants were given a paper bag with their "reward" which contained a plain wheat biscuit and either two cherry tomatoes or a piece of cucumber.

All procedures were approved by the local Ethics committee, and complied with relevant laws and institutional guidelines.

2.2. Results

For all tests using ANOVA in this and the following experiment, calorie (high/low) was always entered as a within-subjects variable and where relevant, block is also entered as a within-subjects variable (training phases only). Greenhouse-Geisser p values are reported with the original degrees of freedom. A significance criterion of $p = 0.05$ was adopted and all reported t-tests were two-tailed.

2.2.1. Instrumental training phase

Participants learnt across the instrumental training blocks to select the correct key for each monster stimulus, as can be seen in
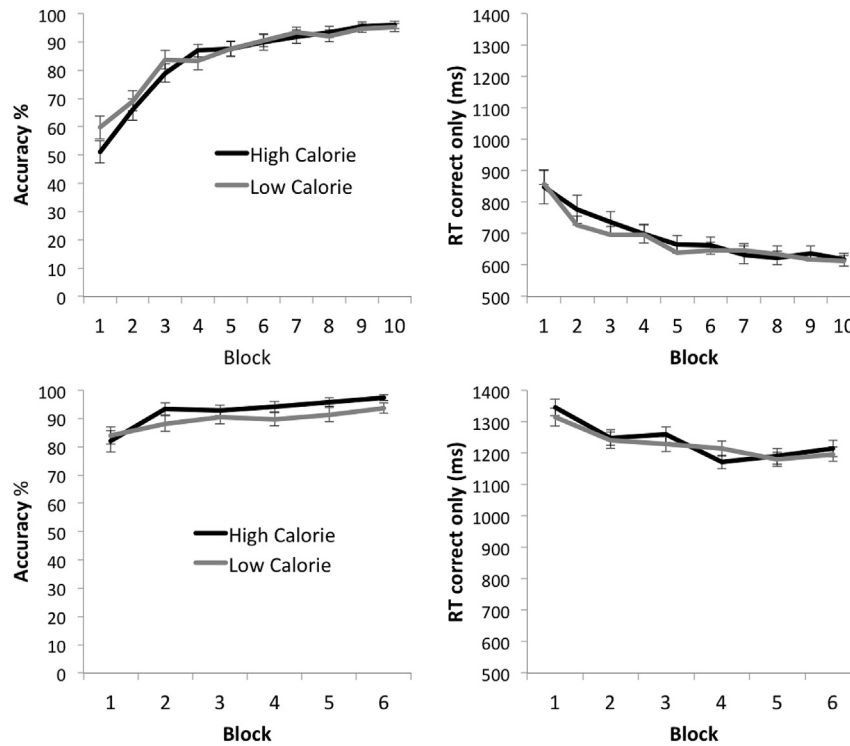
Fig. 3. Experiment 1: Top Row: Accuracy (left panel) and RT (right panel) over the 10 blocks of the Instrumental Training phase. Bottom Row: Accuracy and RT over the 6 blocks of the Pavlovian Training phase. Error bars represent standard error of the mean.

Fig. 3 (top row, left panel). The repeated measures ANOVA showed a main effect of block, F (9, 549) = 54.6 $p < 0.0001$, but no effect of calorie content, F (1,61) = 1.12, $p = 0.30$. As can be seen in Fig. 3 (top row, right panel), this same pattern was observed for RTs. When examining correct RTs only, participants became faster over the course of training, as reflected in a main effect of block F (9, 378) = 15.5, $p < 0.0001$, but there was no significant effect of calorie content, $F < 1$, $p = 0.42$.

2.2.2. Instrumental R–O query phase

Participants were able to correctly select the response leading to the signaled outcome with a mean accuracy of 74%, significantly better than chance level of 50%, t (61) = 9.3, $p < 0.0001$, confirming that participants had encoded the R–O relationships during the instrumental training phase. Calorie content of the outcome pictures did not modulate accuracy on the query trials as evidenced by a non-significant effect of calorie content, t (61) = 0.76, $p = 0.46$. However, this same analysis of the RT data (correct trials only) revealed that participants responded faster (mean: 1131 ms, SD: 399 ms) for high-calorie relative to low-calorie trials (mean: 1271 ms, SD: 640 ms); t (61) = 2.0, $p = 0.05$.

2.2.3. Pavlovian Training phase

Participants learnt the relationships between the cues and food outcomes across the Pavlovian training blocks, as can be seen in Fig. 3 (bottom row). Participants became more accurate over time as indicated by a main effect of block, F (5, 305) = 10.4, $p < 0.0001$, and also tended to perform better on the high-calorie trials as indicated by a marginally significant effect of calorie content, F (1, 61) = 3.7, $p = 0.06$. Analysis of the RT data showed that participants became faster over the course of training, as reflected by a main effect of block F (5, 275) = 14.5, $p < 0.0001$. This time there was no effect of calorie content of the outcome picture, $F < 1$, $p = 0.68$ (see Fig. 3: bottom row, right panel).

2.2.4. Test phase – direct & indirect response priming

Participants demonstrated that the discriminative associations from the instrumental training phase were still intact with mean accuracy of 93% (SD: 14%) on trials in which the discriminative stimuli were presented. The data of interest, however, were response-priming rates on trials where either the food pictures (direct response priming) or Pavlovian monsters (indirect response priming) were presented. Trials were considered accurate (and priming successful) when participants selected the response that during instrumental training had yielded the outcome currently being presented/signaled. The mean priming rate was 68%, significantly higher than the chance level of 50%, t (61) = 7.2, $p < 0.0001$. To compare the effect of calorie on both direct and indirect priming, cue type was added to the repeated measures ANOVA. This revealed an interaction between cue type and calorie, F (1,61) = 6.0, $p = 0.02$ so in the next step we compared high and low-calorie priming rates separately for the two cue types. As can be seen in Fig. 4 (left panel), the direct O–R priming effect was stronger for the high-calorie outcomes than the low-calorie outcomes, t (61) = 3.5, $p = 001$, meaning that participants' choices were more strongly biased by pictures of crisps and chocolate than by pictures of cucumber and tomatoes. In contrast, in the case of indirect S–O–R priming – when they were merely reminded of these food outcomes by the Pavlovian monster stimuli – there was no significant modulation by the calorie content of the outcome cue, t (61) = 0.77, $p = 0.45$.

This analysis was repeated with RT for correctly primed responses as the dependent variable. Participants reacted faster to the outcomes than to the Pavlovian cues (main effect of cue type: F (1, 56) = 10.8 $p = 0.002$), and were faster overall —across the direct and indirect priming trials – to respond to the high-calorie cues than to the low-calorie cues as indicated by a main effect of calorie: F (1, 56) = 8.4, $p = 0.005$ (see right panel of Fig. 4).

2.2.5. Hunger and desire ratings

Participants reported mean hunger ratings of 3.7 points (SD:
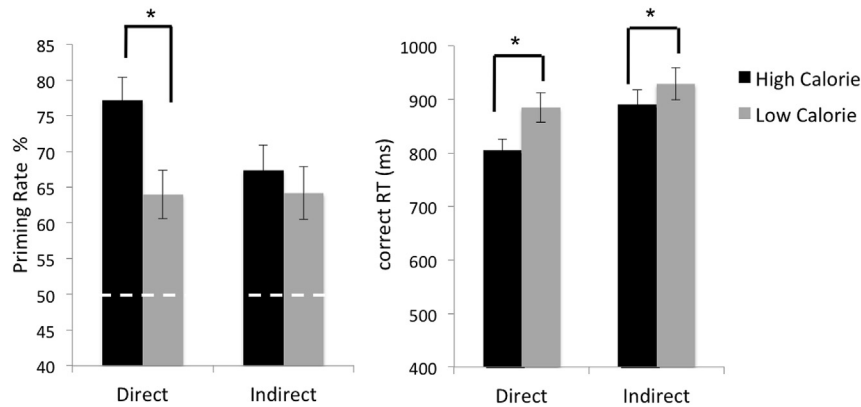
Fig. 4. Experiment 1: Left Panel: Direct (O-R) and indirect (S-O-R) priming rates for high- and low-calorie outcome pictures. The white dotted line represents 50% chance level. Priming rates were greater for high-calorie versus low-calorie outcomes, but only on direct priming trials (*$p = 0.001$). Right Panel: Participants were faster overall for the high-calorie outcomes (main effect of calorie: *$p = 0.006$). Error bars represent standard error of the mean.

1.6). There was no significant difference between their reported desire to eat high-calorie foods (mean rating: 3.5 points, SD: 1.5) compared to low-calorie food (mean rating: 3.3 points, SD: 1.5; $t(61) = 0.72$, $p = 0.48$).

2.2.6. Correlational analyses

To see whether impulsivity or sensation seeking scores were related to individual differences in performance on the priming task we correlated scores on these subscales of the SURPS to both indirect and direct priming rates (%) for high-calorie food outcomes. However, neither impulsivity nor sensation seeking were significantly correlated with these variables (all $ps > 0.20$).

2.2.7. Gender analyses

In order to examine whether boys and girls would perform any different on any phase of the task, we repeated all of the above analyses with gender as a between-subjects factor. The only significant main or interaction effects involving gender were observed during the action-outcome query trials and the Pavlovian training trials. During the query trials boys responded faster overall (mean: 1062 ms, SD: 229 ms) relative to girls (mean: 1296 ms, 547 ms; $F(1, 60) = 4.1$, $p = 0.05$). When examining accuracy during the Pavlovian training phase we observed an interaction between calorie and gender, $F(1, 60) = 5.5$, $p = 0.02$. Whereas boys' performance did not differ on high-relative to low-calorie trials (mean: 95%, SD: 7% vs. mean: 94%, SD: 12%; $t(24) = 0.6$, $p = 0.59$), girls performed better on the high-calorie trials (mean: 93%, SD: 11% vs. mean: 90%, SD: 12%; $t(36) = 3.1$, $p = 0.004$).

2.3. Discussion

In Experiment 1, we examined ideomotor response-priming effects in adolescents with high-versus low-calorie food outcomes. As expected, we found that when participants were presented with food outcome pictures and asked to select a response as fast and spontaneously as possible, their choices were biased towards the response that had previously yielded these food outcomes (direct priming). Importantly, they were significantly more accurate and quick to respond when the food picture depicted a high-calorie food (although response priming for low-calorie food was still observed). We also replicated previous demonstrations of indirect cue-elicited response priming by demonstrating that when participants were shown cues that had been paired with food pictures, they selected the key that had

previously been associated with the signaled food picture more frequently than the alternative key (Bray et al., 2008; Prévost et al., 2012; Watson et al., 2014). Although the strength of this indirect priming effect was not modulated by the calorie content of the signaled food picture, there was a significant effect in the reaction times, with participants responding faster for Pavlovian stimuli previously associated with high-calorie food outcomes. We found very limited evidence for gender differences. Importantly, during the priming test, boys and girls showed the same pattern of results. Finally we found no evidence to suggest that impulsivity or sensation seeking (as measured with the SURPS) are related to (S)-O−R priming.

It is surprising that the adolescents did not rate the high-calorie food (crisps and chocolate) as being more desirable than the low-calorie food (cucumbers and tomatoes). The behavioral data suggests that in fact the high-calorie food was more motivating for the participants. The lack of a difference in the self-report desire ratings may reflect a social desirability effect, such that the adolescents were trying to appear to be making healthy choices. The response-priming task, therefore, may be a better (albeit indirect) measure of snack preference than self-report.

To summarize, the results of Experiment 1 suggest that: (1) in adolescents, instrumental responding can be biased both directly and indirectly by external food-related stimuli, and (2) that this effect tends to be particularly pronounced with high-calorie food rewards. However, there were some limitations to the study design of Experiment 1 that may offer a possible explanation for the finding that in the case of indirect S−O−R priming, calorie content modulated only RT and not response-priming rates. Although the adolescents were told that they were earning points towards a tasty snack, they did not directly experience the different food outcomes during the training phases and this may have reduced the sensitivity to the type of food outcome (chocolate and crisps versus cucumber and tomatoes). In Experiment 2, therefore, we sought to replicate these data in another group of adolescents with a number of improvements to the study design. Specifically, we decided to have the adolescents sample the food before beginning the game and we also allowed them to win the food rewards during the training phases of the game (for later consumption). In addition, given the lack of a relationship in Experiment 1 between the SURPS measure and the behavioral data, we chose to focus instead on an alternative measure of impulsivity (reward responsiveness; Carver & White, 1994).

3. Experiment 2

3.1. Methods

3.1.1. Participants

Participants were recruited (as in Experiment 1) from a different secondary school. A total of 138 adolescents took part in the study and testing was carried out at the school, during school hours. 27 participants were excluded − eight because they scored no higher than 50% (chance level) in the final block of instrumental training and 19 as they had more than 15 response omissions or alternate instrumental key presses in any one phase of the task. The final participant group consisted, therefore, of 111 adolescents (60 males) between the ages of 12−16 years. Demographic information stratified by gender can be seen in Table 1 (although note that for two participants their gender data was not recorded). When using the standard Dutch growth charts to assess BMI (Talma et al., 2010), 20 participants (11 males) were classed as overweight for their gender and age.

3.1.2. Stimuli and materials

The same stimuli and computerized task used in Experiment 1 were used and any changes are outlined below (see Procedure). The questionnaires were modified in the following way.

Food Desire and Hunger Questionnaire: The questionnaire was programmed in Inquisit and participants slid a mouse along a visual analogue scale with the anchors: "not at all", "neutral" and "maximum". Participants first rated their hunger using this scale and then were asked to taste each of the four foods (in random order) before rating their desire to eat them.

Behavioral Inhibition System/Behavioral Activation System (BIS/BAS) Scales: The BIS/BAS scales measure individual differences in general aversive and appetitive motivation (Carver & White, 1994). The BAS (13 questions rated on 4-point Likert scales) consists of three subscales. For the current study, only data pertaining to items on the reward responsiveness subscale were analyzed. This scale measures positive anticipation of reward and has good internal consistency in an adolescent sample (Cooper, Gomez, & Aucote, 2007).

3.1.3. Procedure

Participants were tested in groups of seven, during school hours. Participants sat one behind the other with headphones on and were prevented from turning around or interacting with the person in front or behind them. To the left of their laptop participants now had four small bowls filled with the four food outcomes (tomatoes, cucumber, crisps and chocolates). They also had a small plastic plate that was theirs to place any rewards on that were won during the task.

Participants first completed the food desire and hunger questionnaire before continuing with the *Delicious Snack Game*. Participants were given the same instructions as in Experiment 1, although they were now told that the three participants at the end of the experiment who earned the most points in the game would be rewarded with two cinema passes. In addition they were also told that during the game, every time they heard a cash register sound at the same time that they saw a food picture − they could take one piece of that food and place it on their personal rewards plate to eat later.

The task began as in Experiment 1, with the *instrumental training phase*. However, participants did not receive auditory feedback on every trial (although they did still receive visual performance-based feedback -"incorrect" and "correct"). Instead, every fourth time that the correct response was performed for a particular monster stimulus, the cash register sound was heard indicating that participants were able to take one piece of that reward and move it onto their own plate. The ITI on these "reward" trials was extended to 3 s. The instrumental training phase consisted of nine blocks in which the four different monster stimuli were each presented twice, in random order (72 trials in total).

The *Pavlovian training* phase followed immediately after the instrumental training phase and consisted of 1 block of passive and 9 blocks of active training (72 active trials in total). Again, participants did not hear the buzzer or cash register sounds on every trial. Instead every fourth pairing of a particular monster stimulus and food outcome was accompanied by the cash register sound indicating that the participant was able to move one piece of that reward from the small bowl onto their plastic plate. The ITI on these trials was extended to 3 s.

Participants then performed the *direct and indirect response-priming test* (as Experiment 1). The food bowls were cleared away from the tables beforehand (the individual reward plates were left by the participants but moved to the edge of the table out of reach). Participants were told that they would not receive feedback on their responses in this stage but that they were still winning points.

At the end of the experiment, participants were encouraged to eat their food rewards from the training phases while they filled in the BIS/BAS questionnaire. Weight and height were measured and BMI was calculated.

3.2. Results

3.2.1. Hunger and desire ratings

The adolescents' mean hunger rating was 44% (SD: 27%). In contrast to Experiment 1, participants indicated that they had more desire to eat the high-calorie foods (mean rating of 58%, SD: 25%) compared to the low-calorie foods (mean 40%, SD: 24%, t (110) = 5.95, $p <$ 0001).
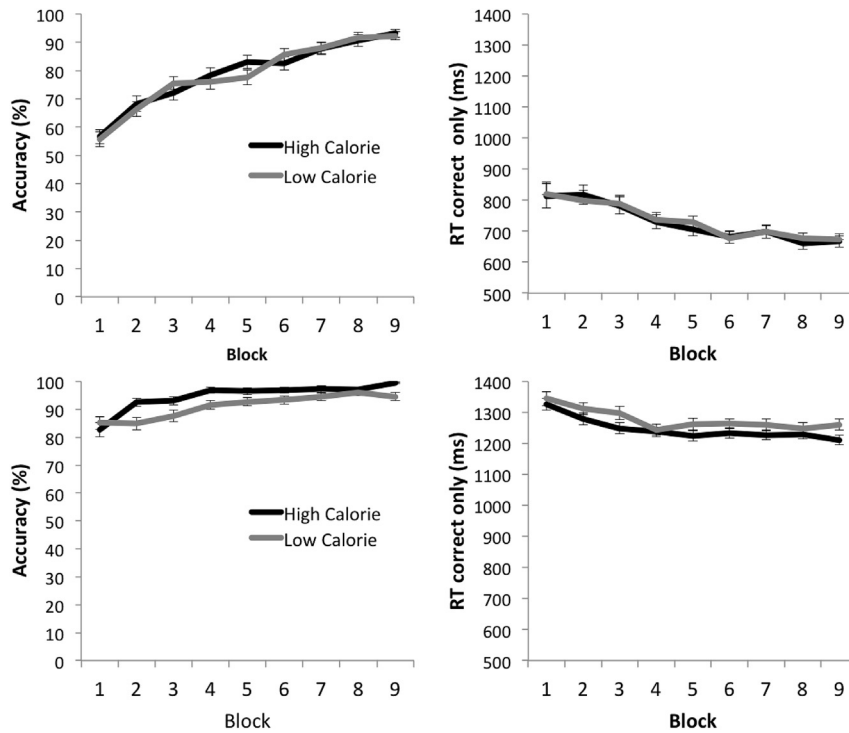
3.2.2. Instrumental training phase

As can be seen in Fig. 5 (top row, left panel), participants learned across the instrumental training blocks to select the correct key for each monster stimulus. Replicating the accuracy results of Experiment 1, the analysis showed a main effect of block, F (8,864) = 66.5, $p <$ 0.0001, but no effect of calorie content, $F < 1$, $p =$ 0.73. As can be seen in the top row, right side panel of Fig. 5, this same pattern was observed for correct RTs (main effect of block F(8, 560) = 11.8 $p <$ 0.0001 but no effect of calorie content, $F < 1$, $p =$ 0.71).

3.2.3. Pavlovian Training phase

Participants successfully learned the relationships between the cues and food outcomes across the Pavlovian training blocks. The analysis revealed an interaction between block and calorie, F (8,856) = 2.8, $p =$ 0.01. Similarly to Experiment 1, the rate of learning appeared to be faster for high-calorie outcomes (see bottom row, left panel of Fig. 5). Accuracy between the two conditions was not significantly different at block 1, t (108) = 0.88, $p =$ 0.38, although differences in performance did emerge and accuracy was significantly higher for high-calorie outcomes during the final block, t (109) = 2.8, $p =$ 0.05. As can be seen in the bottom row, right panel of Fig. 5 and in contrast to the results of Experiment 1, calorie content also impacted on RTs − participants were relatively fast on high-calorie trials as indicated by a main effect of calorie content, F (1,97) = 4.7, $p =$ 0.03. Finally, they also became generally faster over the course of the training as indicated by a main effect of block, F(8, 776) = 10.4, $p <$ 0.0001.

3.2.4. Test phase − direct & indirect response priming

Participants' performance on the discriminative stimuli trials of the test phase was still good (mean: 78%, SD: 21%). We followed

Fig. 5. Experiment 2: Top Row: Accuracy (left panel) and RT (right panel) over the 9 blocks of the Instrumental Training phase. Bottom Row: Accuracy and RT over the 9 blocks of the Pavlovian Training phase. Error bars represent standard error of the mean.

the same procedure outlined in Experiment 1 to calculate accuracy on trials during the priming test where either the food pictures (direct priming) or Pavlovian monsters (indirect priming) had been presented. The mean priming rate was 54%, significantly higher than chance level of 50%, $t(110) = 2.9$, $p = 0.005$. Cue type (2 levels) was added to the repeated measures ANOVA to compare both direct- and indirect-response priming. As can be seen in Fig. 6 (left panel), priming rates were higher overall for the high-calorie outcomes as indicated by a main effect of calorie, $F(1,110) = 5.0$, $p = 0.03$. In contrast to Experiment 1, there was no significant difference between the cue types, $F(1,110) = 2.4$, $p = 0.13$, nor interaction between these two variables, $F < 1$, $p = 0.36$. In regards to the main effect of calorie, it is clear from Fig. 6 that priming rates for low-calorie outcomes are extremely low. In fact, one-sample t-test revealed that the mean priming effect for low-calorie outcomes did not differ significantly from

chance level of 50%, $t(110) = 0.83$, $p = 0.41$.

This analysis was repeated with RT for correctly primed responses as the dependent variable which yielded an interaction between cue type and calorie, $F(1,99) = 7.2$, $p = 0.009$. In the next step, we compared high- and low-calorie priming rates, separately for the two cue types. As in Experiment 1, during direct-priming trials participants reacted significantly faster for the high-calorie outcomes compared to the low-calorie outcomes, $t(105) = 2.69$, $p = 0.08$. For indirect priming, surprisingly, participants responded faster on low-calorie trials relative to the high-calorie trials, $t(103) = 2.2$, $p = 0.04$ (see Fig. 6, right panel). In order to see whether this could be due to a speed-accuracy trade-off on the indirect-priming trials, for both high- and low-calorie outcomes we correlated the mean RTs during indirect priming with the mean accuracy. However, this was not significant for either high- or low-calorie indirect priming trials ($ps > 0.58$).
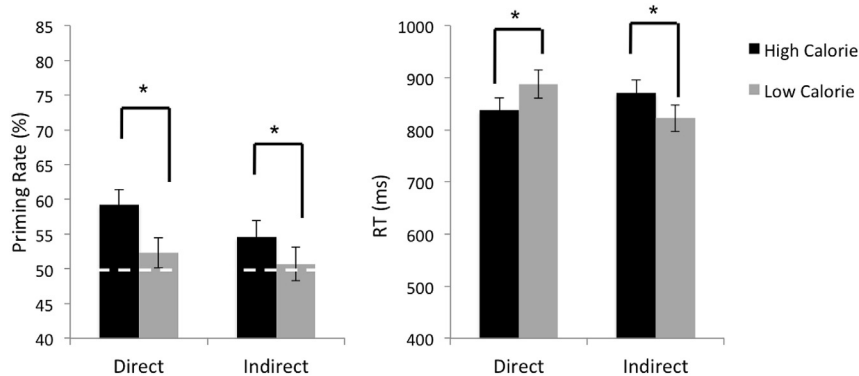
Fig. 6. Experiment 2: Left Panel: Direct (O-R) and indirect (S-O-R) priming rates. The white dotted line represents 50% chance level. Priming rates were higher overall for high-calorie outcomes (* main effect of calorie $p = 0.024$). Right Panel: RTs on correct (primed) trials for direct and indirect priming and high- and low-calorie outcome pictures. * $ps < 0.042$. Error bars represent standard error of the mean.

3.2.5. Correlational analyses

In order to investigate how individual differences in sensitivity to reward would relate to performance on the response-priming task we correlated scores on the sensitivity to reward subscale of the BISBAS with indirect and direct priming rates (%) for high-calorie food outcomes. Reward responsiveness did not correlate with either of the outcome measures ($ps > 0.38$).

Given that participants rated the high-calorie foods as more desirable and also showed stronger priming rates for high-calorie foods we investigated a possible correlational relationship between desire ratings and priming rates (collapsed across both cue types). There was no significant correlation found between desire and priming rates for either the high-calorie foods, $r(109) = 0.09$, $p = 0.34$, or the low-calorie foods, $r(109) = 0.06$, $p = 0.56$. Furthermore, the high-low difference scores for desire and priming also didn't correlate significantly with each other, $r(109) = -0.046$, $p = 0.63$.

3.2.6. Gender analyses

We again repeated all of the above analyses with gender as a between-subjects factor. The only significant main or interaction effects involving gender were observed during the instrumental training phase. Boys responded faster overall (mean: 692 ms, SD: 114 ms) compared to girls (mean: 774 ms, SD: 114 ms) as indicated by a main effect of gender, $F(1, 68) = 8.9$, $p = 0.004$.

3.3. Discussion

In Experiment 2 we broadly replicated the results of Experiment 1 with a new adolescent sample and with a slightly modified task design in which the food rewards were directly delivered contingent upon performance during the training phases. As expected, and in contrast to Experiment 1, participants did rate the high-calorie food as being more desirable than the low-calorie food. This may be because participants were asked to taste the food before rating it in Experiment 2 and also because this was done at the beginning of the experiment (rather than at the end as in Experiment 1). In Experiment 2, our main hypothesis was again confirmed and response priming was found to be stronger for high-calorie relative to low-calorie cues. Contrary to Experiment 1 in which this effect was only observed on the direct-priming trials (where the outcome was presented) in Experiment 2 we also saw the modulating effect of calorie content on indirect-priming trials. When crisps or chocolate were signaled by the Pavlovian cues, participants also responded more frequently and faster on the associated key, relative to the trials in which tomatoes and cucumber were signaled. The fact that we observed modulation of the indirect-priming effect by calorie content in Experiment 2 only, may be because of increased power due to the larger sample size. In line with this idea, the RT data from Experiment 1 show that although we did not see a difference in response-priming rates participants *did* respond faster to Pavlovian stimuli predictive of high-versus low-calorie outcomes. Alternatively, the procedural differences in Experiment 2 may have led to this different result. The fact that the adolescents experienced the food rewards during the training phases in Experiment 2, might have led to stronger associative learning (particularly for the more desirable high-calorie foods) which in turn led to calorie-sensitive indirect S−O−R priming. However, the overall low rates of response priming in Experiment 2 relative to Experiment 1 speak against this. It is impossible to qualify whether stronger associative learning occurred in one experiment relative to the other, as accuracy during the training phases was very high leading to possible ceiling effects. However, we did not expect that the response-priming rates would be lower in Experiment 2 relative to Experiment 1. It is possible that

the modifications made to the procedure meant that adolescents were not as engaged during the response-priming test as they had been in Experiment 1. For example, in Experiment 2 the adolescents had already "won" their food rewards during the training phases and (although not explicitly told) nonetheless knew that they would not win any more food (only points) during the test phase.

Analyses of the reaction times revealed a surprising finding. In contrast to Experiment 1, participants were slower to respond for Pavlovian stimuli that signaled high-calorie outcome pictures during the indirect priming trials. This may have been because participants, on the relatively complex indirect-priming trials, tried harder to be accurate (at the expense of their reaction times). It is possible that exposure to the tasty high-calorie snacks led participants to engage in such a strategy and would mean that explicit processes are also contributing to these effects, as has been suggested by other researchers using the Pavlovian-to-instrumental transfer paradigm (Hogarth, Maynard, & Munafò, 2014; Hogarth, Retzler, et al., 2014; Hogarth, Dickinson, Hutton, Elbers, & Duka, 2006). Although traditionally ideomotor (or more broadly associative) response priming has been conceived as representing behavior that is unconscious and automatic (see for review: Ridderinkhof, 2014), there is no conclusive evidence on this issue (Hommel, 2013). Recent theorizing suggests that this is not important for understanding ideomotor response priming − the underlying mechanism is the same and can still lead to maladaptive behaviors, regardless of whether it is accompanied or not by explicit awareness (Hogarth, Maynard, et al., 2014; Hogarth, Retzler, et al., 2014; Hommel, in press, 2013; Ridderinkhof, 2014). Interestingly, from a cognitive viewpoint, there is no advantage to being more accurate on the high-relative to the low-calorie trials, as participants were informed before the priming test that each correct response would be rewarded with one point and, therefore, the calorie content of the pictures was in this regard irrelevant. This interesting result provides further evidence that the adolescents found the high-calorie outcomes particularly motivating.

We again found very limited evidence for gender differences in Experiment 2. Crucially, both boys and girls had an equivalent pattern of response priming with higher rates in the presence of high-calorie food cues.

4. General discussion

Across two different experiments we have shown that in adolescents, food-related choices can be biased both directly and indirectly by external food-related stimuli. This study is the first to demonstrate these response-priming effects in adolescents, replicating previous demonstrations of direct response priming by food pictures in adult samples (Hogarth, 2012; Hogarth & Chase, 2011) and indirect response priming with cues previously associated with food rewards (Bray et al., 2008; Prévost et al., 2012; Watson et al., 2014). Moreover, we show that this ideomotor response-priming effect is particularly pronounced in the context of palatable high-calorie snacks relative to low-calorie food. These findings contribute to previous demonstrations of the role of external food cues on children's food preferences and consumption (Halford et al., 2004; Harris, Bargh, et al., 2009; Harris, Pomeranz, et al., 2009; Robinson et al., 2007), by providing support for the idea that the fundamental ideomotor mechanism may contribute to the promotion of unhealthy food choices by snack advertisements.

This study raises a number of important questions in regards to ideomotor response priming and the role of motivation. We found that response priming was sensitive to the motivational relevance of the food outcomes (i.e. calorie content and/or palatability modulated the response priming rates). In Experiment 2, we even

failed to find evidence for response priming with low-calorie outcomes at all. In contrast to the current study, others that have investigated these priming effects using food rewards (in adults) have found that the motivational relevance of the food pictures does *not* affect the priming rates (Hogarth, 2012; Hogarth & Chase, 2011; Watson et al., 2014). These studies have previously reported that cues associated with food outcomes triggered responding for those outcomes regardless of whether the food was currently desired or not. There is, however, a crucial difference in study design. In the aforementioned studies the motivational value of the food outcomes was manipulated *after* the training phases. For example, participants in the Watson et al. (2014) study rated popcorn and chocolate Smarties as equally desirable at the beginning of the experiment, but after the training phases one of these food outcomes was devalued (through consumption). By contrast, in the current experiments there was already a motivational difference between the high- and low-calorie foods during training. Indeed, participants reported a preference for the high-calorie foods. This likely led to the formation of stronger O–R and S–O associations during training, which in turn meant stronger response priming during the test phase. Although we deem it likely that the palatability of the high-calorie foods is driving this motivational effect on priming, we should point out that we failed to observe a correlational relationship between self-report desire and priming rates in Experiment 2. Furthermore, there is evidence to suggest that actual calorie density rather than self-reported palatability may determine the incentive value of food outcomes (Tang, Fellows, & Dagher, 2014). The current study was not designed to discriminate between these factors, but this is an intriguing avenue for future research. This issue may also have practical application because if children and adolescents' preferences for healthy food can be made more positive at an early stage this may in turn weaken the biasing effects of high-calorie food cues on choice behavior relative to low-calorie food. It has been suggested that, theoretically, the effects of advertising could be utilized for good i.e. by promoting healthy food to children (Livingstone, 2005) and in line with this, children's explicit attitudes towards healthy food were seen to become more positive following such an intervention (Dixon, Scully, Wakefield, White, & Crawford, 2007). Future studies could investigate whether in addition to changes in explicit preferences, such interventions do lead to stronger response priming for healthy low-calorie foods relative to unhealthy high-calorie foods. Alternatively, if calorie density *per se* is driving these effects, then preference would presumably not be a useful target for intervention.

There are of course a number of other differences between the current paradigm and others that have assessed either direct- or indirect-response priming by food cues (e.g. Bray et al., 2008; Hogarth & Chase, 2011; Watson et al., 2014). The current paradigm includes some novel features so that we could examine for the first time interesting questions relating to the comparison of direct O–R and indirect S–O–R priming as well as the effect of calorie content on both these types of response priming. In order to ensure that the response keys were equally often assigned with high- and low-calorie food outcomes (and prevent a response bias), it was necessary to assign each response key to two different outcomes. Discriminative stimuli during the instrumental training phase thus supported learning these multiple associations and we then included these stimuli in the priming test as an extra control condition. We also used active Pavlovian training rather than the more traditional passive Pavlovian training where the participant just views stimuli on a screen. The advantage of the active Pavlovian training is that we could examine the rate of learning of the relationships between stimuli and their associated outcomes whereas passive training, by its nature, does not involve the

gathering of any data. We were able to observe during the Pavlovian learning phase higher performance on high-calorie trials. It should be noted that the core features of the Pavlovian-to-instrumental paradigm were upheld (for example we used separate instrumental and Pavlovian training phases and, crucially, Pavlovian stimuli were never trained with an instrumental response). Although the test phase was conducted in nominal extinction, with participants being told that they would receive no feedback but were still winning points, one limitation of the procedure of Experiment 2 was that the food was still visible to participants during the test phase. However, given that all participants had earned a similar number of each of the four food rewards this would have been unlikely to bias their responding.

Further research should examine whether highly controlled laboratory tasks such as the present task do translate to complex food-choice behavior in the real world. It has been suggested that the biasing effect of environmental cues on choice behavior may be important for understanding maladaptive or addictive behavior (Colagiuri & Lovibond, 2015; Hogarth, 2012; Hogarth, Retzler, et al., 2014; Hogarth & Chase, 2011; Hogarth, Maynard, et al., 2014; Lovibond & Colagiuri, 2013; Watson et al., 2014) and the current data contribute to this, by showing that response priming by external food cues was more pronounced in the context of palatable, high-calorie snack foods. The fact that mere exposure to the sight of food can bias instrumental responding highlights the validity of concerns about the obesogenic environment and food marketing directed towards children and adolescents that have previously been raised (Harris, Bargh, et al., 2009; Harris, Pomeranz, et al., 2009). Furthermore, we also show that these biasing effects readily generalize to any (neutral) stimulus that become associated with these foods, such that these Pavlovian stimuli will indirectly influence instrumental choice behavior (even though they themselves have never been trained directly with a response). This points to the pervasiveness of these cueing effects in our daily environment and suggests that merely reminding children of unhealthy palatable foods, either when watching TV or playing video games, for example, can be enough to trigger response behavior directed towards gaining those foods.

Of interest is whether some individuals are more sensitive than others to the biasing effects of external stimuli on instrumental responding. The sample used in the current study was relatively homogenous in regards to BMI, but future studies should investigate the relationship between BMI and ideomotor response priming by (high-calorie) food outcomes to shed more light on the role of the ideomotor mechanism in external stimulus control over food-related responses. We did investigate whether adolescents scoring higher on impulsivity and reward responsiveness would show a stronger response-priming effect (e.g. Muhle-Karbe & Krebs, 2012) particularly for high-calorie food outcomes. However, we did not find evidence for a relationship between response priming for high-calorie snacks and a self-report measure of impulsivity (Experiment 1) or reward responsiveness (Experiment 2). This lack of an effect could mean that the general self-report measures of impulsivity and reward responsiveness used in this study were not sensitive enough. It has recently been argued, for example, that overeating is related to deficits in food-related inhibitory control rather than general response inhibition (Houben, Nederkoorn, & Jansen, 2014). Likewise, a relationship may exist between instrumental response priming by food cues and food-related inhibitory control (rather than general impulsivity or response inhibition).

In summary, this study provides an associative account of how the obesogenic environment biases adolescents' food-related choices. These results highlight the ease at which associations between rewarding outcomes, responses and predictive stimuli are

acquired and can affect behavior, even after very limited exposure to these relationships. As adolescents were found to be more sensitive to the biasing effect of high versus low-calorie food outcomes, efforts should be made to curtail targeted advertising of unhealthy foods to adolescents.

Acknowledgments

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