



Where is the chocolate? Rapid spatial orienting toward stimuli associated with primary rewards [☆]



Eva Pool ^{*}, Tobias Brosch, Sylvain Delplanque, David Sander

Swiss Center for Affective Sciences, University of Geneva-CISA, Geneva, Switzerland

Laboratory for the Study of Emotion Elicitation and Expression, Department of Psychology, FPSE, University of Geneva, Geneva, Switzerland

ARTICLE INFO

Article history:

Received 8 August 2012

Revised 13 November 2013

Accepted 4 December 2013

Keywords:

Affective relevance
Initial rapid orienting
Chocolate odor
Incentive salience
Reward devaluation

ABSTRACT

Some stimuli can orient attentional resources and access awareness even if they appear outside the focus of voluntary attention. Stimuli with low-level perceptual salience and stimuli with an emotional content can modulate attention independently of voluntary processes. In Experiment 1, we used a spatial cuing task to investigate whether stimuli that are controlled for their perceptual salience can modulate the rapid orienting of attention based exclusively on their affective relevance. Affective relevance was manipulated through a Pavlovian conditioning paradigm in which an arbitrary and affectively neutral perceptual stimulus was associated with a primary reward (i.e., a chocolate odor). Results revealed that, after conditioning, attentional resources were rapidly oriented toward the stimulus that was previously associated with the reward. In Experiment 2, we used the very same conditioning procedure, but we devaluated the reward after conditioning for half of the participants through a sensory-specific satiation procedure. Strikingly, when the reward was devaluated, attention was no longer oriented toward reward-associated stimuli. Our findings therefore suggest that reward associations rapidly modulate visual processing independently of both voluntary processing and the perceptual salience of the stimulus. This supports the notion that stimuli associated with primary rewards modulate rapid attention orienting on the basis of the affective relevance of the stimulus.

© 2013 Elsevier B.V. All rights reserved.

1. Introduction

When we concentrate on a task, we are still able to process information appearing outside our voluntary attentional focus. For instance, when we read a book in a noisy cafeteria, we do not process all the chatter of the people sitting around us; however, if a baby starts crying, we stop reading and reallocate our attentional resources

toward the baby's location. This kind of stimuli can involuntarily orient our attentional resources because (a) they have low-level perceptual properties that are salient (e.g., [Theeuwes, 1991](#)) and (b) they have emotional content (e.g., [Vuilleumier, 2005](#)).

Despite a large amount of evidence (see, e.g., [Yiend, 2009](#), for a review) consistently demonstrating that attention is involuntarily orientated toward emotional stimuli, to date there has been little agreement on which properties allow emotional stimuli to have this privileged attentional status ([Brosch, Pourtois, & Sander, 2010](#)). Some authors claim that emotional stimuli can orient attentional resources if they have intrinsic properties that represent a threat to the organism survival ([Flykt, 2006](#)). Appraisal theories propose an alternative explanation. According to these theories, it is not the intrinsic property of the stimulus itself that matters, but rather the interaction between

[☆] This research was supported by the National Center of Competence in Research (NCCR) for the Affective Sciences, financed by a grant from the Swiss National Science Foundation (51NF40-104897), hosted by the University of Geneva, and was also supported by a research grant from Firmenich, SA, to David Sander and Patrik Vuilleumier.

^{*} Corresponding author. Address: Swiss Center for Affective Sciences, University of Geneva, Campus Biotech, Uni Dufour, Rue Général Dufour 24, 1211 Geneva 4. Tel.: +41 (0)22 741 51 62.

E-mail address: eva.pool@unige.ch (E. Pool).

the stimulus and the concerns of the individual perceiving it (e.g., Sander, Grandjean, & Scherer, 2005). If a stimulus is appraised as relevant to an important current concern of the individual, the individual's attention is rapidly and involuntarily oriented toward it (Brosch, Sander, Pourtois, & Scherer, 2008). Therefore, according to appraisal theories, not only should threatening stimuli orient attention, but also positive stimuli because they are affectively relevant.

Consistent with this proposal, several experiments have demonstrated that attentional resources are rapidly oriented toward positive emotional stimuli as well as negative stimuli (e.g., Brosch et al., 2008; Öhman, Flykt, & Esteves, 2001). However, these experiments typically used emotional stimuli that are perceptually salient (e.g., pictures of spiders, pictures of baby faces), thereby rendering it virtually impossible to dissociate influences caused by affective relevance from those caused by low-level perceptual characteristics. One way to behaviorally dissociate these two types of influences is to demonstrate that (a) initially neutral stimuli that do not influence the involuntary orienting of attention may become modulators of attention once they acquire affective relevance, and (b) that they would lose their capacity to orient attention once they lost their affective relevance. Neutral, perceptually common, stimuli that are systematically associated with a reward can acquire positive affective relevance. Theories in the neuroscience of motivation have proposed that attention is automatically oriented toward reward-associated stimuli (e.g., Bromberg-Martin, Matsumoto, & Hikosaka, 2010). According to the incentive salience hypothesis (Berridge & Robinson, 1998), the organism attributes incentive salience to stimuli associated with the reward through learning. During this process, previously neutral stimuli may acquire the ability to modulate attention independently of voluntary attention, even if they do not have any particular low-level perceptual salience.

This hypothesis has recently been tested in humans (Anderson, Laurent, & Yantis, 2011a, 2011b; Hickey, Chelazzi, & Theeuwes, 2010a, 2010b, 2011). In Anderson et al. (2011a), (2011b), a simple visual stimulus (i.e., a one-color shape) was associated with a secondary reward (i.e., a visual monetary symbol). Subsequently, the same shape was used as a distractor in trials of a visual search paradigm: if the reward-associated shape was present between the distractors, then voluntary target detection was delayed. This task interference shows that attention is oriented toward reward-associated stimuli even when participants are asked to orient their attention toward a different target. Hickey et al., 2010a, 2010b, 2011 demonstrated that attention is oriented toward a feature associated with secondary reward even when it is counterproductive for the current participants performance, therefore providing empirical evidence suggesting that attention is orientated toward reward-associated stimuli independently of voluntary controlled processes. If this is the case, then attentional modulation of the reward-associated stimuli should rapidly occur at early stages of information processing. Electrophysiological results reported by Hickey et al. (2010a) suggest that this is indeed the case. They showed that reward-associated features

lead to enhanced brain activity during early stages of visual processing. However, the rapidity of this attentional modulation remains underinvestigated. To the best of our knowledge, all experiments testing the attentional modulation of reward-associated stimuli in humans used paradigms with a relatively long exposure time (i.e., more than 600 ms), thus preventing to know whether the early modulation of the brain activity is translated in a likewise rapid modulation of involuntary attentional orienting which would influence behavior.

Here we directly investigated this question by testing whether reward-associated stimuli influence involuntary orienting of covert attention after 100 ms. In this context, involuntary modulation of spatial attention orienting can be driven by two mechanisms: (a) initial orienting toward the emotional stimulus, or (b) difficulty in disengaging attention from the emotional stimulus and reallocating it toward another target (e.g., Posner, Inhoff, Friedrich, & Cohen, 1987). Research conducted in animals supports the hypothesis of initial orienting by showing an attentional bias generated by faster eye movements toward reward-associated stimuli (Matsumoto & Hikosaka, 2009). Recent studies showed similar results in humans, by demonstrating that reward associated stimuli were more likely to draw initial gaze than neutral stimuli (Anderson and Yantis, 2012a; Hickey & van Zoest, 2012; Theeuwes & Belopolsky, 2012), but the gaze is not maintained at that location for a longer period (Theeuwes & Belopolsky, 2012). In the present study, we further investigated the role of initial orienting and disengagement in attentional orienting toward reward-associated stimuli, by using an attentional paradigm that has been specifically designed to investigate this issue (i.e., spatial cuing task; Posner & Cohen, 1984).

Moreover, in the present study neutral stimuli were associated with a primary reward, in this case a chocolate odor. This is different from all previous studies investigating human attention toward reward-associated stimuli, because other studies only used a secondary reward, namely, a visual symbol representing monetary gain. The typical distinction between primary and secondary rewards is that whereas secondary rewards like money or power acquire value or significance only through experiences and associative learning, primary rewards like food and odors have an innate value and biological significance (Gottfried, 2011). Although several studies revealed that primary rewards modify human's perceptual processes (e.g., Seitz, Kim, & Watanabe, 2009) they have never been used, to the best of our knowledge, to investigate attention toward reward-associated stimuli. There are two main advantages in using a primary reward in this particular context. First, it is possible to test whether results found with secondary rewards can be replicated by using primary rewards. Second, and more importantly, the rewarding properties of primary reward such as odor can easily be manipulated. It has been shown that the reward value of a food odor decreases when related food has been eaten to satiety, an effect termed sensory-specific satiation (O'Doherty et al., 2000; Rolls & Rolls, 1997). Moreover, it has also been demonstrated that sensory-specific satiation does not only influence the processing of the rewarding

odor itself, but also of neutral stimuli associated with it (Gottfried, O'Doherty, & Dolan, 2003). Here we investigated whether the attentional orientation toward reward-associated stimuli can be manipulated by devaluating the reward through a sensory-specific satiation.

More precisely, we designed two experiments to test: (a) whether attention is rapidly oriented toward stimuli associated with a primary reward, (b) whether this attentional modulation is driven by a rapid initial orienting or a difficulty in disengaging attention (Experiment 1) and (c) whether reward devaluation influences the rapid attentional orienting toward reward-associated stimuli (Experiment 2). Such data will be key in order to test our general hypothesis that affective relevance, rather than perceptual saliency, can explain attentional orienting towards emotional stimuli.

2. Experiment 1

In Experiment 1, we investigated the rapid orienting of attention by using visual stimuli associated with a primary reward, namely, chocolate odor. We used a Pavlovian conditioning task in which a geometric figure (positive conditioned stimulus: CS+) is associated with a chocolate odor (unconditioned stimulus: US), and another geometric figure (negative conditioned stimulus: CS–) is not associated with any odor. To measure attentional orienting, we adapted a spatial cuing task (e.g., Posner & Cohen, 1984), in which a non-predictable cue was presented for 100 ms prior to a target. The cue could be either the image used as CS+ or the image used as CS– during the prior conditioning phase. For valid trials, the target appeared in the same location as the cue, and faster reaction times in trials with CS+, as compared with CS–, cues were taken to reflect an initial orienting toward the preceding cue. For invalid trials, the target appeared in the opposite location to the cue, and slower reaction times were taken to reflect difficulty in disengaging attention from the cue. Our prediction was that, if Pavlovian associative learning was successful, then spatial attention would be rapidly oriented toward the image that was neutral but associated with the chocolate odor during the conditioning phase, reflected in faster responses in CS+ valid trials compared with CS– valid trials.

3. Method

3.1. Participants

Fifty undergraduate psychology students participated for course credits. Ten participants were later excluded: two for not following the instructions, two for not meeting the inclusion criteria (trouble in odor perception and eye problems that interfered with proper vision), and one for showing reaction times more than 3 standard deviation from the mean in the spatial cuing task. Five more participants were excluded for disliking the chocolate: they did not perceive the odor as rewarding. The 40 remaining participants (3 male, 23.95 ± 7.06 years old) had normal or corrected-to-normal vision, no history of psychiatric or

neurological diseases, no trouble with odor perception, and no smoking habits.

3.2. Materials and procedure

Participants completed the spatial cuing task before and after the Pavlovian conditioning and they answered questions concerning the manipulation check at the end of the experiment.

3.2.1. Pavlovian conditioning

The Pavlovian conditioning paradigm created by Talmi, Seymour, Dayan, and Dolan (2008) was adapted to our research question. Three neutral images were attributed to the Pavlovian roles of “baseline,” “CS+,” or “CS–” and were counterbalanced across participants.

There were 36 “task-on” periods of 12 s during which the CS+ or the CS– was displayed on a computer screen, followed by a “task-off” period of 12 s during which a baseline screen was displayed. All images were presented at the center of the screen (8° visual angle).

During the task-on periods, a target (a black asterisk; 2° visual angle) appeared every 4 s at the center of the CS– image three times per period. The onset time of the first target was randomized between 0 and 2 s. Participants had to press the “A” key with their non-dominant index finger as fast as possible after the perception of the target that was presented for a maximum of 1 s. They were informed that by pressing the key, they would trigger an odor's release, and they were asked to discover whether a particular image could predict the type of odor that was released. Each time the CS+ image was displayed and the participant pressed the key, a chocolate odor (Firmenich, SA, Geneva, Switzerland) was released using a computer-controlled olfactometer; when the CS– image was displayed, odorless air was released (see Fig. 1). To underline that the kind of odor released depended on the CS images and not on the key-pressing action, participants were told that the key-pressing task was a measure of their sustained attention independent of the odor-image contingencies (Talmi et al., 2008). They were also informed that not responding during the 1-s interval after target onset would release the odor anyway. In the task-off periods, the baseline image was displayed without any target, and no odor was released.

After the conditioning task, participants evaluated the pleasantness of the images used as CS+, CS–, and baseline on a visual analogue scale. Subsequently, six pairs of all possible combinations of CS+, CS–, and baseline were randomly presented and participants chose which one they preferred. A preference score for each stimulus was computed from the number of times that the stimulus was chosen.

3.2.2. Spatial cuing task

The spatial cuing task was adapted from other studies investigating attentional orienting toward emotional stimuli (e.g., Fox, Russo, Bowles, & Dutton, 2001; Vogt, De Hower, Koster, Van Damme, & Crombez, 2008). Each trial began with a fixation cross presented randomly for between 250 and 750 ms in the center of the screen with a

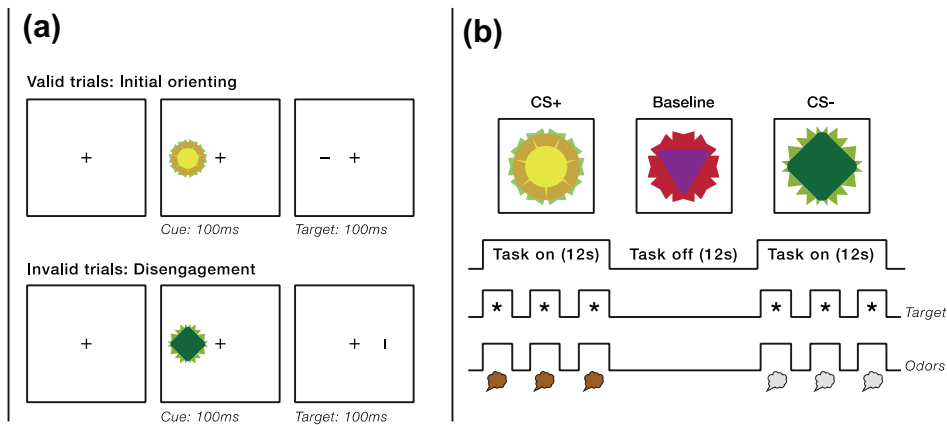


Fig. 1. Paradigm used in the present experiment. (a) The spatial cuing task: In the valid trial, the target appeared in the same location as the cue; in the invalid trial, the target appeared in the opposite location to the cue. The cue could be either the image used as CS+ or the image used as CS-. Participants were requested to detect the orientation (horizontal vs. vertical) of the target. (b) The human Pavlovian paradigm adapted from Talmi et al. (2008): We selected three geometric complex figures typically used in human conditioning paradigms (Gottfried et al., 2003; O'Doherty et al., 2004; Valentin, Dickinson, & O'Doherty, 2007) that in a pilot study ($n = 26$) were rated as equally neutral on a pleasantness scale. During “task-on” periods, the CS+ or CS- was displayed, a target appeared at the center of the image, and participants had to press a keyboard that triggers odor release. During the “task-off” period, the baseline was displayed without any target, and no odor was released.

white background. A cue was subsequently presented either on the left or on the right side of the fixation cross for 100 ms. The cue was either the CS+ image or the CS- image displayed with a visual angle of 8° . A black bar (2° visual angle) was then presented for 100 ms. Participants were requested to press the “B” key when the target was displayed horizontally and the “N” key when it was displayed vertically. The target appeared either at the same location as the cue (valid trial) or in the opposite location (invalid trial; see Fig. 1). Participants had a maximum of 1300 ms to respond until the next trial started. Participants were asked to look at the central fixation cross during the entire task.

A training session of 12 trials was repeated until the participants reached an accuracy of 75%, after which the experimental task began. It consisted of 128 trials in which the valid and invalid trials were equally presented and the left or right position of the cue and the target were counterbalanced.

3.2.3. Manipulation check

Participants evaluated, on a visual analogue scale presented on the screen, the pleasantness (from “extremely unpleasant” to “extremely pleasant”), familiarity (from “not familiar at all” to “extremely familiar”), edibility (from “not edible” to “extremely edible”), and intensity (from “not perceived” to “extremely strong”) of the chocolate odor and of the odorless air (e.g., Delplanque et al., 2008; Khan et al., 2007). Subsequently, they answered questions about chocolate (back translated to French from Rolls & McCabe, 2007) that allowed investigation of whether participants associated chocolate with the two components of reward (Berridge & Robinson, 2003): motivation (i.e., “On a scale from 1 to 10, how much would you say that you sometimes crave chocolate?”) and hedonic pleasure (i.e., “On a scale from 1 to 10, how much would you say that you like chocolate?”).

4. Results

4.1. Manipulation check

Wilcoxon tests revealed that the chocolate odor was evaluated as more edible ($z = 5.01$, $p < .001$, $r = .79$), more intense ($z = 5.49$, $p < .001$, $r = .86$), more familiar ($z = 4.99$, $p < .001$, $r = .78$), and more pleasant ($z = 2.03$, $p = .042$, $r = .32$) than the odorless air. Participants reported a mean of 7.65 ($SD = 1.9$) out of 10 for the craving item and a mean of 8.62 ($SD = 1.4$) out of 10 for the likeability item, showing that they typically associated chocolate with both components of reward: hedonic pleasure and motivation (Berridge & Robinson, 2003).

4.2. Pavlovian conditioning

Successful Pavlovian conditioning was revealed by both the reaction times of the key-pressing task and the pleasantness rating of the CSs.

For the key-pressing task, we analyzed reaction times on the first target of the on-task period. All responses that were shorter than 200 ms (<3% of the trials), more than 3 standard deviations from the mean (<1% of the trials), or absent (<3% of the trials) were removed. A paired t -test showed that participants were faster when the CS+ was displayed ($M = 431.61$, $SD = 72.46$) than when the CS- was displayed ($M = 446.63$, $SD = 82.20$), $t(39) = 2.55$, $p = .014$, $d = .25$.

Correlational analysis showed that pleasantness and preference for the CS+ varied according to evaluation of the chocolate odor. The more the participants judged the chocolate odor as pleasant ($r = .57$, $p > .001$) and familiar ($r = .35$, $p = .023$), the more they liked the CS+. Similarly, the more they judged the chocolate odor as pleasant ($r = .64$, $p < .001$), the more they preferred the CS+ compared with the CS- and the baseline.

From these results, an index of conditioning was computed to establish the success of the conditioning procedure for each participant individually. More precisely, to determine whether a participant was conditioned, we used two indicators: the reaction time during the key-pressing task (implicit indicator) and the pleasantness rating of the CSs and the odors (explicit indicator). These two indicators were chosen based on previous work by Talmi et al. (2008), which reported the original conditioning paradigm that we adapted to odors. For reaction times, the participant was considered as successfully conditioned, if the mean reaction time to detect the first target during the key-pressing task was shorter when the CS+ was displayed than when the CS– was displayed. For pleasantness rating: first, the difference between pleasantness ratings of the two CSs (CS+ minus CS–) was computed; only the signs were considered (positive or negative); then, the same was done for the pleasantness rating of the odors (chocolate odor minus control odor). The two signs were then compared: If they had the same sign (e.g., if the chocolate odor was rated as more likeable than the odorless air, and the CS+ was also rated as more likeable than the CS–), the participant was considered as successfully conditioned according to this indicator. A participant was considered as successfully conditioned if he/she showed conditioning effects on both indicators: reaction times and pleasantness ratings.

Based on this index, participants were apportioned into the conditioned group ($n = 18$) or the non-conditioned group ($n = 22$).

4.3. Spatial cuing task

For reaction time analysis, all responses that were shorter than 200 ms (<0.01% of the trials), more than 3 standard deviations from the mean (<2% of the trials), or incorrect (<6% of the trials) were removed.

To test the sensitivity of our task to the attentional orienting, a 2 (validity: valid or invalid trials) \times 2 (image: CS+ or CS–) \times 2 (session: pre- or post-conditioning) repeated measures analysis of variance (ANOVA) was applied on reaction times. A main effect of validity $F(1, 39) = 52.97$, $p < .001$, $\eta^2 = .57$, confirmed that participants were faster to detect the target in valid trials ($M = 560.07$, $SD = 77.32$) compared to invalid trials ($M = 582.99$, $SD = 82.62$). Moreover, the analysis revealed a main effect of session $F(1, 39) = 18.89$, $p < .001$, $\eta^2 = .20$ showing that participants became globally faster the second time they accomplished the spatial cuing task ($M = 556.83$, $SD = 57.80$) compared to the first time ($M = 586.83$, $SD = 66.28$).

To test our main hypothesis, a 2 (session: pre- or post) \times 2 (image: CS+ or CS–) \times 2 (validity: valid or invalid) repeated measures ANOVA was applied to the reaction times obtained from the conditioned group. It revealed a significant three-way interaction, $F(1, 17) = 5.81$, $p = .035$, $\eta^2 = .23$ (see Fig. 2), reflecting that participants who successfully associated the CS+ with the chocolate odor were significantly faster in detecting the probe when it was validly cued with the CS+ compared to the CS–, $t(17) = 2.69$, $p = .010$, $d = .30$ (see Table 1), however, they were not significantly slower in detecting the probe when it was

invalidly cued by the CS+ compared to the CS–, $t(17) = 0.8$, $p = .930$. This result suggests that the initial orienting phase was more affected by the conditioning than the disengagement. The same analysis applied to error rates only revealed a main effect of validity, $F(1, 17) = 6.61$, $p = .024$, $\eta^2 = .26$, showing that participants were globally more precise in the valid trials ($M = 96.44$, $SD = 2.29$) compared to the invalid trials ($M = 95.57$, $SD = 2.80$).

To compare the initial orienting in conditioned and non-conditioned participants, a 2 (session: pre- or post-conditioning) \times 2 (image: CS+ or CS–) \times 2 (group: conditioned or non-conditioned) mixed repeated measures ANOVA was applied to the reaction times obtained in the valid trials. It revealed a significant three-way interaction, $F(1, 38) = 4.31$, $p = .044$, $\eta^2 = .10$. As previously mentioned, participants who successfully associated the CS+ with the chocolate odor were significantly faster in detecting the probe when it was cued by the CS+ than when it was cued by the CS–, $t(17) = 2.69$, $p = .010$, $d = .30$. This difference was not present before conditioning, $t(17) = -1.29$, $p = .201$, in participants who showed successful conditioning, and it was not present in participants who did not show successful conditioning before, $t(21) = -0.98$, $p = .332$, or after conditioning, $t(21) = -0.82$, $p = .416$. The same analysis applied to error rates did not reveal any significant effect.

A 2 (session: pre- or post-conditioning) \times 2 (image: CS+ or CS–) \times 2 (group: conditioned or non-conditioned) mixed repeated measures ANOVA applied to reaction times obtained in invalid trials did not reveal the three way interaction ($F < 1$).

5. Discussion

In this experiment, we aimed to show that two stimuli that do not differ in perceptual salience may still differentially modulate spatial attention when they differ in affective relevance. More precisely, we investigated whether the rapid orienting of spatial attention is influenced by a neutral stimulus associated with a primary reward, in this case a chocolate odor. Results revealed that when an initially neutral image is successfully associated with a rewarding outcome, this image modulates attention.

To the best of our knowledge, this is the first demonstration that an initially neutral stimulus associated with a primary reward modulates rapid involuntary orienting of covert attention after 100 ms. Nonetheless, the present experiment has an important limitation preventing the conclusion that this attentional modulation is solely due to the rewarding properties of the chocolate odor. During the Pavlovian conditioning, one stimulus has been associated with the chocolate odor, whereas the other has been associated with odorless air. The chocolate odor is different from the odorless air in several aspects not related to its rewarding nature, but to its perceptual characteristics, more particularly it is a richer and a more interesting sensorial experience. These perceptual differences may have increased the participants' interest in the stimulus associated with the chocolate odor, which may have then been

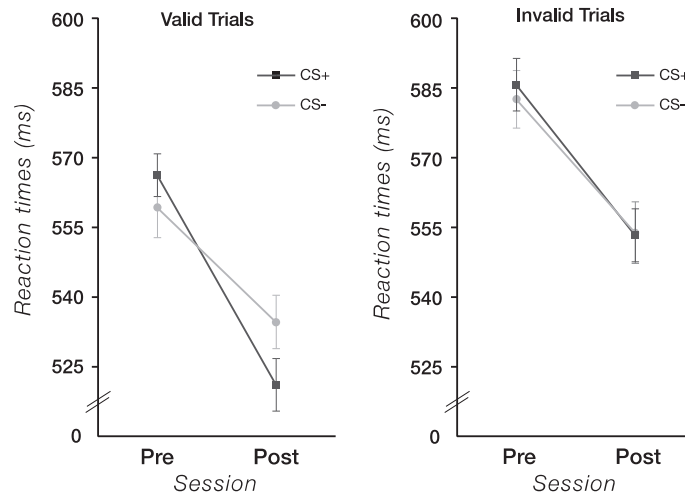


Fig. 2. Results for the attentional task. Mean reaction times of the target detection in the spatial cuing task when the target was correctly cued by the CS+ and CS–, before and after conditioning, for the valid and the invalid trials in the conditioned group. Error bars indicate within participant 95% confidence intervals (Cousineau, 2005).

Table 1

Mean response times (ms) and standard error of the spatial cuing task.

Condition	Pre-conditioning				Post-conditioning			
	Valid		Invalid		Valid		Invalid	
	CS+	CS–	CS+	CS–	CS+	CS–	CS+	CS–
Non-conditioned	586.91 (14.27)	582.15 (13.96)	613.86 (15.17)	606.07 (14.82)	561.71 (12.13)	557.99 (11.90)	582.01 (13.24)	580.07 (13.24)
Conditioned	566.17 (15.78)	559.21 (15.44)	584.40 (16.77)	581.07 (16.39)	521.09 (13.41)	534.56 (13.16)	552.25 (14.64)	552.82 (14.64)

Note: Conditioned group ($n = 18$); non-conditioned group ($n = 22$).

better attended during the attentional task regardless of reward. One way to tackle this issue would be to present another odor that would be neutral enough not to constitute a primary reward but would be similarly rich to the chocolate in term perceptual characteristic. However, given the vast interindividual variability in hedonic odor perception (e.g., Delplanque et al., 2008; Distel et al., 1999; Ferdenzi et al., 2013), it appears very difficult to find a consensual neutral odor. Moreover, the learning process to associate two neutral stimuli is different from the one to associate an emotional stimulus with a neutral one. Indeed, it might be possible that the reward-associated stimulus modulates attention because it has been better encoded during the associative learning, and not because it evokes a representation of the associated reward. As this question seems to be very difficult to settle empirically, a more promising approach would be to specifically decrease the reward properties of the chocolate, without changing its perceptual characteristics. As mentioned in the introduction, eating a target food to satiety decreases the reward value of the food as well as the food odor (O'Doherty et al., 2000; Rolls & Rolls, 1997). This odor devaluation procedure can be administrated after the associative learning, thereby avoiding learning confounds and allowing isolating the selective effects of the reward representation.

6. Experiment 2

In Experiment 2, we investigated whether attentional orientation toward reward-associated stimuli can be modulated by devaluating the reward through a sensory-specific satiation. The conditioning procedure was exactly the same as Experiment 1: in a Pavlovian conditioning task a geometric figure (CS+) was associated with a chocolate odor (US) while another geometric figure (CS–) was associated with odorless air. Again, attentional orienting was measured through the spatial cuing task in which a non-predictive cue (the image used as CS+ or the image used as CS–) was presented for 100 ms prior to target presentation. Two main aspects have been modified in the general procedure. First, participants were asked not to eat four hours before the experimental session to control that the motivation to eat chocolate was high. Second, after the Pavlovian conditioning, but before the second administration of the spatial cuing task, the rewarding chocolate odor was devaluated through a sensory-specific satiation procedure (Gottfried, O'Doherty, & Dolan, 2003). Half of the participants were asked to eat chocolate to satiety, whereas another half was asked to simply wait without particular task. Previous research has demonstrated that sensory-specific satiation decreases two rewarding properties of

food related odor: motivation and hedonic pleasure (Gottfried, O'Doherty, & Dolan, 2003; O'Doherty et al., 2000; Rolls & Rolls, 1997). The reward devaluation procedure was performed just after the Pavlovian conditioning because several experiments showed that the reward representation evoked by the cue perception is flexible and sensitive to devaluation procedures (e.g., Wellman, Gale, & Malkova, 2005). Thanks to this methodological choice, during the Pavlovian conditioning the two groups were in similar conditions. This allows to avoid possible confounds of associative learning processes on the interpretation of the effect of the reward devaluation on the attentional orienting. Our prediction was that the rewarding properties of the odor is a determining factor for the rapid attentional orienting toward stimuli associated with chocolate odor. More precisely, we predicted that, for successfully conditioned non-satiated participants, the initial orienting toward the neutral image that is now associated with the chocolate odor would be stronger than for successfully conditioned satiated participants.

7. Method

7.1. Participants

Seventy-four participants who liked chocolate and were not dieting were recruited on the premises of the University of Geneva. They received 15.- Swiss francs for their participation. One participant was later excluded due to a technical problem during the Pavlovian conditioning procedure. 37 participants (10 male, 23.56 ± 5.51 years old) were assigned to the sensory-specific satiation group, whereas 36 participants (10 male, 22.83 ± 7.3 years old) were assigned to the control group. All participants had normal or corrected-to-normal vision, no psychiatric or neurological diseases and no trouble with odor perception.

7.2. Materials and procedure

Participants completed the spatial cuing task before and after the Pavlovian conditioning. After the Pavlovian conditioning, but before the second spatial cuing task, a group of participants underwent a sensory-specific procedure, whereas another group of participants was asked to wait without performing any particular task. At the end of the experiment, they answered questions concerning the manipulation check.

7.2.1. Pavlovian conditioning

The procedure was identical to Experiment 1, except for the scent of the chocolate odor. In Experiment 1, five participants disliked the chocolate odor, thus to select the most pleasant chocolate odor we ran a pilot study ($n = 127$) in which participants evaluated the pleasantness of three different odors: chocolate powder (used in Experiment 1), cacao, and chocolate malt. We selected the odor of the chocolate malt ($M = 6.9$, $SD = 2.23$), since it was rated as significantly more pleasant than the chocolate powder ($t(126) = 12.3$, $p < .001$, $d = 1.30$), and the cacao odors ($t(126) = 9.49$, $p < .001$, $d = .94$).

7.2.2. Spatial cuing task

The procedure was identical to Experiment 1.

7.2.3. Sensory-specific satiation

Participants in the sensory-specific satiation group were asked to eat as much chocolate (pieces of dark and milk chocolate bars) as they wanted until they found the target food no longer palatable and were completely full. The amount of eaten chocolate was discreetly weighted with a precision scale (precision $\pm .001$ g). The level of hunger, food pleasantness and odor pleasantness was measured through a visual analogue scale before and after the selective satiation procedure (Gottfried, O'Doherty, & Dolan, 2003). Participants in the control group were asked to take a 5 min break.

7.2.4. Manipulation check

The procedure was identical to Experiment 1.

8. Results

8.1. Manipulation check

Paired *t*-tests revealed that the chocolate odor was evaluated as more edible ($t(72) = 13.09$, $p < .001$, $d = 2.30$), more intense ($t(72) = 14.62$, $p < .001$, $d = 2.10$), more familiar ($t(72) = 9.53$, $p < .001$, $d = 1.48$) and more pleasant ($t(72) = 5.11$, $p < .001$, $d = .80$) than the odorless air. Participants reported a mean of 8.14 ($SD = 2.08$) out of 10 for the craving item and a mean of 8.87 ($SD = 1.41$) out of 10 for the likeability item, showing that they typically associated chocolate with both components of reward: hedonic pleasure and motivation (Berridge & Robinson, 2003).

8.2. Pavlovian conditioning

Successful Pavlovian conditioning was revealed by both the reaction times of the key-pressing task, and the pleasantness ratings of the CSs.

For the key-pressing task, we analyzed reaction times on the first target of the on-task period. All responses that were shorter than 200 ms (<2% of the trials), more than 3 standard deviations from the mean (<1.5% of the trials), or absent (<5% of the trials) were removed. A paired *t*-test showed that participants were faster when the CS+ was displayed ($M = 411.84$, $SD = 69.79$) than when the CS- was displayed ($M = 427.38$, $SD = 73.04$), $t(72) = 3.03$, $p = .001$, $d = .24$.

Correlational analysis showed that pleasantness and preference for the CS+ varied according to the evaluation of the chocolate odor. The more the participants judged the chocolate odor as pleasant ($r = .53$, $p > .001$) and intense ($r = .27$, $p = .017$), the more they liked the CS+. From these results, a conditioning index was computed to establish the success of the conditioning procedure for each participant individually (see Experiment 1). From this index, participants were apportioned into the conditioned group ($n = 16$ for the control group; $n = 19$ for the sensory-specific satiation group) or the non-conditioned group

($n = 20$ for the control group; $n = 18$ for the sensory-specific satiation group).

8.3. Sensory-specific satiation

Participants ate on average 62.5 g (± 39.9) of chocolate during the sensory-specific satiation procedure. Paired t -tests showed that hunger ($t(36) = 7.02$, $p < .001$, $d = 1.26$), pleasantness of the chocolate taste ($t(36) = 7.09$, $p < .001$, $d = 1.49$) and pleasantness of the chocolate odor ($t(36) = 7.31$, $p < .001$, $d = .81$) decreased after the sensory-specific satiation compared to before (see Fig. 3a).

8.4. Spatial cuing task

For reaction time analysis, all responses that were shorter than 200 ms ($< 0.1\%$ of the trials), more than 3 standard deviations from the mean ($< 2\%$ of the trials), or incorrect ($< 5\%$ of the trials) were removed.

To test the sensitivity of the task to attentional orienting, a 2 (validity: valid or invalid trials) \times 2 (image: CS+ or CS-) \times 2 (session: pre- or post- conditioning) repeated measures ANOVA was applied to the reaction time. A main effect of validity $F(1, 72) = 78.15$, $p < .001$, $\eta^2 = .52$, confirmed that participants were faster to detect the target in valid trials ($M = 571.00$, $SD = 71.72$) compared to invalid trials ($M = 591.40$, $SD = 71.02$). Moreover, the analysis revealed a main effect of session $F(1, 72) = 18.13$, $p < .001$, $\eta^2 = .32$, showing that participants became globally faster the second time they accomplished the spatial cuing task ($M = 565.95$, $SD = 84.84$) compared to the first time ($M = 596.43$, $SD = 70.30$).

We then tested whether the results for the participants of the control group showed the same pattern we obtained in Experiment 1. A 2 (session: pre- or post-conditioning) \times 2 (image: CS+ or CS-) \times 2 (validity: valid or invalid) repeated measures ANOVA was applied to the reaction times obtained from the conditioned group. It revealed a

significant three way interaction $F(1, 15) = 15.80$, $p = .005$, $\eta^2 = .51$. After conditioning, participants who successfully associated the CS+ with the chocolate odor were significantly faster in detecting the probe when it was cued with the CS+ $t(15) = 3.08$, $p = .011$, $d = .35$ (see Table 2); they were not significantly slower in detecting the probe when it was invalidly cued with the CS+ $t(15) = 0.96$, $p = .350$ (see Table 2). The same analysis applied to the error rates did not reveal any significant effect.

To compare the initial orienting in conditioned and non-conditioned participants, a 2 (session: pre- or post-conditioning) \times 2 (image: CS+ or CS-) \times 2 (group: conditioned or non-conditioned) mixed repeated measures ANOVA was applied to the reaction times obtained in the valid trials of the control group. It revealed a significant three-way interaction, $F(1, 34) = 5.92$, $p = .027$, $\eta^2 = .10$. As previously mentioned, after conditioning, participants who successfully associated the CS+ with the chocolate odor were significantly faster in detecting the probe when it was cued by the CS+ than when it was cued by the CS-, $t(15) = 3.08$, $p = .011$, $d = .35$. This difference was not present before conditioning, $t(15) = -0.99$, $p = .326$, in participants who showed successful conditioning, and was also absent in participants who failed to condition both before and after conditioning (respectively, $t_s(19) = -0.19$, -0.35 , $p_s = .84$, $.72$). The same analysis applied to error rates revealed a main effect of session $F(1, 34) = 8.55$, $p = .006$, $\eta^2 = .20$, showing that participants became more precise in the second session. Moreover, the analysis showed a significant interaction between the image and the session $F(1, 34) = 4.51$, $p = .041$, $\eta^2 = .11$. A planned contrast revealed that after conditioning, conditioned participants were marginally more accurate in detecting the target when it was cued with the CS+ compared to the CS-, $t(15) = 1.96$, $p = .057$, $d = .48$.

Second, we tested whether participants in the sensory-specific satiation group showed the same attentional pattern. A 2 (session: pre- or post-conditioning) \times 2 (image:

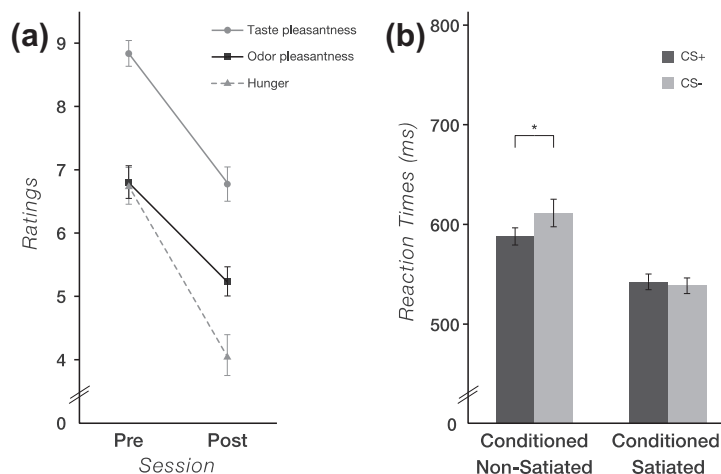


Fig. 3. Results of Experiment 2. (a) Results of the sensory-specific satiation procedure. Mean ratings of odors pleasantness, taste pleasantness and hunger before and after sensory-specific satiation. (b) Results for the attentional task. Mean reaction times of the target detection in the spatial cuing task when the target was correctly cued by the CS+ and CS-, after conditioning, for the conditioned participant of the sensory-specific satiation group and the control group. Error bars indicate within participant 95% confidence intervals (Cousineau, 2005).

CS+ or CS-) \times 2 (validity: valid or invalid) repeated measures ANOVA was applied to the reaction times obtained from the conditioned participants of the sensory-specific satiation group: the three-way interaction was not significant, $F(1, 18) = 0.28, p = .602, \eta^2 = .01$ (see Table 3). To compare the initial orienting in the conditioned and non-conditioned participants, a 2 (session: pre- or post-conditioning) \times 2 (image: CS+ or CS-) \times 2 (group: conditioned or non-conditioned) mixed repeated measures ANOVA was applied to the reaction times obtained in the valid trials: the three-way interaction was not significant, $F(1, 35) = 1.55, p = .221$.

Finally, to test our main hypothesis, we directly compared the participants of the sensory-specific satiation group and the control group that were successfully conditioned. A 2 (session: pre- or post-conditioning) \times 2 (image: CS+ or CS-) \times 2 (validity: valid or invalid) \times 2 (condition: control or sensory-specific satiation) mixed repeated measures ANOVA was applied to the reaction times obtained in the valid trials. The analysis revealed a main effect of condition, showing that globally participants in the control group ($M = 614.86, SD = 117.96$) were slower than participants in the sensory-specific group ($M = 547.92, SD = 18.56$). More interestingly for our hypothesis, the analysis showed a significant four way interaction $F(1, 33) = 4.35, p = .044, \eta^2 = .11$. To further investigate this effect in relation with our main hypothesis, a 2 (image: CS+ or CS-) \times 2 (condition: control or sensory-specific satiation) \times 2 (validity: valid or invalid) mixed repeated measures ANOVA was applied to the reaction times obtained during the second session. This analysis revealed a significant three way interaction $F(1, 33) = 6.74, p = .013, \eta^2 = .17$. In the valid trials, participants who were not satiated with chocolate were significantly faster in detecting the probe when it was cued by the CS+ than when it was cued by the CS-, whereas this difference was not significant in participants that who satiated with the chocolate (respectively, $t_s(15, 18) = 3.08, -0.56, p_s = .011, .577$; see Fig. 3b); there were no significant differences for the invalid trials neither in participants who were not satiated with chocolate, nor in participants who were satiated (respectively, $t_s(15, 18) = -0.98, 1.10, p_s = .332, .276$, see Tables 2 and 3). The same analysis applied to error rate did not reveal any significant effect.

8.5. Additional analysis

One may object to the main finding on the attentional orienting to the reward associated stimulus depending on the criteria that have been used to classify toward participants as being successfully conditioned or not. To rule out this potential issue we ran an additional analysis collapsing participants of Experiment 1 and participants of the control group of Experiment 2, since the two procedures were identical. A 2 (session: pre- or post-conditioning) \times 2 (image: CS+ or CS-) \times 2 (validity: valid or invalid) repeated measure ANOVA was applied to the reaction time during the spatial cuing task obtained from all participants, independently if they were classified as successfully conditioned or not. It revealed a marginal three way interaction $F(1, 74) = 2.51, p = .110, \eta^2 = .03$. We confirmed that

participants were significantly faster in detecting the probe when it was cued by the CS+ ($M = 553.64, SD = 63.69$) than when it was cued by the CS- ($M = 560.02, SD = 67.31$) after conditioning $t(74) = 1.99, p = .049, d = .14$; and that they were not significantly influenced by the kind of CS before conditioning nor for the invalid trials (all $p_s > .3$).

9. Discussion

Experiment 2 replicated the main finding of Experiment 1 by showing that attention is rapidly oriented toward perceptually neutral stimuli associated with a primary reward, in this case a chocolate odor. Moreover, Experiment 2 aimed to demonstrate that the rapid modulation of stimuli associated with a chocolate odor on spatial orienting critically depends on the rewarding properties of the chocolate odor. To manipulate the rewarding properties of the chocolate odor, we administered a sensory-specific satiation procedure after the Pavlovian conditioning (Gottfried, O'Doherty, & Dolan, 2003). After this procedure, participants were less hungry and reported less pleasure during the perception of the chocolate odor. The sensory-specific satiation thereby decreased two fundamental rewarding properties of the chocolate odor: its motivational salience and its hedonic pleasure (Berridge & Robinson, 2003). Results showed that initially neutral stimuli successfully associated with a chocolate odor modulate rapid orienting of spatial attention but only if the rewarding properties of chocolate odor have not been devaluated through sensory-specific satiation.

To the best of our knowledge, this is the first demonstration that the modulation of reward-associated stimuli on attention depends on the properties of the reward, more specifically on its hedonic pleasure or its motivational salience. These findings also rule out the alternative explanation that rewarded stimuli would capture attention because of a mere associative learning that caused a transfer of non-affective properties of the rewarding stimulus to the initially irrelevant stimulus. It provides therefore direct evidence supporting the hypothesis that initially neutral stimuli orient the involuntary orienting of attention because of their acquired affective relevance.

10. General discussion

In two experiments, we provide evidence that stimuli that do not differ in perceptual salience can modulate the involuntary orienting of attention if they differ in affective relevance. More specifically, we demonstrated that stimuli associated with primary reward can involuntarily orient spatial attention and that this modulation critically depends on the properties of the primary reward. These results are consistent with recent experiments testing the incentive salience hypothesis in humans, and showing involuntary attentional interference effects by reward-associated cue (Anderson et al., 2011a, 2011b; Hickey & van Zoest, 2012; Hickey et al., 2010a, 2010b, 2011). Critically, our results also revealed that this attentional capture is independent of the stimuli's low-level perceptual characteristics. The attentional bias toward CS+ compared with

Table 2

Mean response times (ms) and standard error of the spatial cuing task of the control group.

Condition	Pre-conditioning				Post-conditioning			
	Valid		Invalid		Valid		Invalid	
	CS+	CS–	CS+	CS–	CS+	CS–	CS+	CS–
Non-conditioned	585.31 (14.79)	583.81 (16.02)	603.86 (15.82)	607.67 (15.35)	548.18 (12.23)	545.82 (13.58)	567.33 (13.38)	567.29 (13.50)
Conditioned	643.49 (36.10)	626.03 (16.03)	629.40 (28.06)	638.90 (30.60)	587.84 (13.56)	611.08 (22.18)	621.89 (23.82)	613.42 (21.55)

Note: Conditioned group ($n = 16$); non-conditioned group ($n = 20$).**Table 3**

Mean response times (ms) and standard error of the spatial cuing task of the sensory-specific satiation group.

Condition	Pre-conditioning				Post-conditioning			
	Valid		Invalid		Valid		Invalid	
	CS+	CS–	CS+	CS–	CS+	CS–	CS+	CS–
Non-conditioned	580.54 (17.56)	591.43 (17.41)	601.47 (16.61)	606.08 (19.77)	536.87 (14.38)	539.85 (15.24)	560.84 (15.58)	565.81 (16.51)
Conditioned	561.26 (15.42)	549.41 (14.43)	578.35 (15.77)	587.06 (18.01)	542.44 (14.55)	538.55 (15.08)	562.53 (14.71)	571.29 (16.84)

Note: Conditioned group ($n = 19$); non-conditioned group ($n = 18$).

CS– was present in the same participants only after—not before—conditioning. Our findings are not consistent with studies showing that neutral stimuli that acquired emotional value through associative learning did not capture attention at early stages of visual processing (Batty, Cave, & Pauli, 2005; Rutherford, O'Brien, & Raymond, 2010). However, these studies used complex stimuli (e.g., abstract stimuli and faces) whereas our experiment used stimuli that were easy to discriminate and that were very different in basic perceptual features: (i.e., each stimulus had a distinct different color: yellow, red and green). It has been demonstrated that attentional orienting is easily guided by color differences (e.g., Theeuwes, 1992), thus it is likely that the affective relevance of the reward has been linked to the color of stimuli that became therefore the perceptual characteristic determining the attentional capture. Anderson et al. (2011a) have suggested that basic stimulus features (e.g., color) provide an indispensable basis for an efficient detection of relevant affective information that determines the attentional orienting toward reward-associated stimuli. A recent experiment demonstrated that the stimuli sharing the same basic perceptual feature associated with reward also capture attentional resources, thereby showing that the value attributed to basic feature can be flexibly generalized to other contexts (Anderson, Laurent, & Yantis, 2012b).

Results of the present study showed that the orienting of covert attention toward reward-associated stimuli appears already after only 100 ms. This rapid effect of reward is consistent with Hickey et al. (2010a)'s electrophysiological findings showing that brain activity is influenced at early stages by the perception of reward-associated stimuli. Our findings suggest that this modulation of early brain activity could be translated in a similarly rapid modulation

of involuntary attentional orienting which would influence behavior. More generally, this finding is congruent with our main hypothesis that reward-associated stimuli orient attentional resources because of their affective relevance. Indeed, experiments testing positive and negative emotional stimuli found similar effects as our experiments by showing an attentional orienting appearing after 100 ms (e.g., Brosch et al., 2008; Pourtois, Grandjean, Sander, & Vuilleumier, 2004). Note however that in our attentional paradigm, stimuli used as cues were very briefly exposed, but they were not masked. Therefore, even if these data suggest that attentional modulation of reward occurs at early stage of visual processing, more evidence is needed to investigate to what extent this attentional effect is rapid.

To elucidate the exact underlying attentional mechanisms, we used a paradigm that allows disentangling the initial orienting from disengagement as the two mechanisms potentially involved in the rapid attentional modulation of reward-associated stimuli. Our results suggest that such attentional modulation is driven by initial orienting. This is congruent with eye tracking studies showing that reward-associated stimuli were more likely to draw initial gaze (Anderson & Yantis, 2012a; Hickey & van Zoest, 2012; Theeuwes & Belopolsky, 2012), but that the gaze is not maintained at this location for a longer period of time compared to neutral stimuli (Theeuwes & Belopolsky, 2012). This is consistent with the idea that involuntary attentional orienting toward cue-associated stimuli is an adaptive mechanism that allows the organism to rapidly orient its attentional resources toward the reward-related location, thereby increasing the possibility of obtaining rewards (Hickey et al., 2011). Nonetheless, this finding is different from several experiments investigating the role of initial orienting and difficulty of disengagement on the

involuntary attentional orientation toward affectively negative relevant stimuli (e.g., Fox et al., 2001; Koster, Crombez, Verschuere, & De Houwer, 2004; Mogg, Holmes, Garner, & Bradley, 2008; Van Damme, Crombez, & Notebaert, 2008; Yiend & Mathews, 2001). These studies rather found more evidence for a difficulty of disengagement than for a rapid initial orienting. The difference between these findings and our results may be explained by variation in the method used to measure the involuntary orienting of attention, which was the specific purpose of our study. It has been demonstrated that an interval between the cue and target onsets (cue–target asynchrony, CTOA) of 100 ms or less should be used, because attention may switch to a different location already after 120 ms and the reaction time to detect the target would no longer reflect the initial orienting of attention (Weierich, Treat, & Hollingworth, 2008). Thereby, it might be possible that modulations in initial orienting were not detected in the above mentioned studies that used CTOA longer than 150 ms, whereas by using a CTOA of 100 ms our paradigm was more likely to reveal differences in initial orienting speed. Note, however, that although our attentional paradigm is suitable to measure initial orienting, it might not be the best paradigm to measure subtle variations in difficulty of disengagement, because the cue is no longer visible when the target appears (Weierich et al., 2008).

Finally, to demonstrate that these attentional effects were specifically due to the reward associated with the stimulus, we used a procedure that devaluated the rewarding value of the chocolate odor (Gottfried et al., 2003). Our results showed that the devaluation procedure decreased the hedonic pleasure and the motivational salience of the chocolate odor, and also highlighted that these rewarding properties are critical for involuntary attentional orienting toward the reward-associated stimulus. When the chocolate odor has been devaluated, the attention is no longer rapidly orientated toward the stimulus associated with it. To the best of our knowledge, this is the first demonstration that the attentional modulation of reward-associated stimuli critically depends on the flexible representation of the properties of the associated reward. The fact that attentional orienting is modulated by reward devaluation is congruent with experiments showing that reward devaluation procedures modulate behavior (e.g., Wellman et al., 2005) and brain activity (Gottfried et al., 2003) evoked by the reward-associated stimuli. Recently, Robinson and Berridge (2013) have underlined the importance of the relevance of the reward's representation for the reactions elicited by reward-associated stimuli. They demonstrated that it is not only possible to diminish the behavioral reactions elicited by a CS through reward devaluation, but that it is also possible to amplify them by increasing the relevance of the associated reward for the current needs of the organism. This provides direct support to our main hypothesis that these stimuli modulate involuntary attentional orienting because of their appraised affective relevance (Sander et al., 2005). If the reward is appraised as affectively relevant, then attention is rapidly oriented toward the stimuli associated with it, but when the reward has been devaluated through a past experience and is no longer appraised as relevant,

then attention is no longer rapidly oriented toward the stimuli associated with it.

11. Conclusion

Two experiments supported the idea that involuntary attentional orienting toward emotional stimuli does not depend on the intrinsic properties of the stimulus solely, but rather on the rapid appraisal of the affective relevance of the stimulus (Sander et al., 2005). More precisely, results demonstrated for the first time that attention is rapidly oriented toward perceptually irrelevant and neutral stimuli associated with primary reward, and that this attentional orienting critically depends on the flexible representation of the hedonic and the motivational value of the reward. These findings suggest that attentional modulation toward reward-associated stimuli is driven by an adaptive mechanism that automatically increases the probability of obtaining a reward. Nevertheless, the same mechanism could become maladaptive in psychopathologies characterized by compulsive behaviors, such as addiction, compulsive gambling, or some alimentary disorders, by drawing attention toward stimuli associated with a dysfunctional rewarding outcome. According to the incentive salience hypothesis (e.g., Berridge & Robinson, 1998), the hedonic pleasure during reward consumption (“liking”) and motivation to invest effort to obtain the reward (“wanting”) are two components of reward that influence behavior independently of each other. Further research should investigate more specifically which component allows reward stimuli to rapidly capture attentional resources.

References

- Anderson, B. A., Laurent, P. A., & Yantis, S. (2011a). Learned value magnifies salience-based attentional capture. *PLoS ONE*, 6, e27926. <http://dx.doi.org/10.1073/pnas.1104047108>.
- Anderson, B. A., Laurent, P. A., & Yantis, S. (2011b). Value-driven attentional capture. *Proceedings of the National Academy of Science of United States of America*, 108, 10367–10371. <http://dx.doi.org/10.1371/journal.pone.0027926>.
- Anderson, B. A., Laurent, P. A., & Yantis, S. (2012b). Generalization of value-based attentional priority. *Visual Cognition*, 20, 647–658. <http://dx.doi.org/10.1080/13506285.2012.679711>.
- Anderson, B. A., & Yantis, S. (2012a). Value-driven attentional and oculomotor capture during goal-directed, unconstrained viewing. *Attention, Perception, and Psychophysics*, 39, 6–9. <http://dx.doi.org/10.3758/s13414-012-0348-2>.
- Batty, M. J., Cave, K. R., & Pauli, P. (2005). Abstract stimuli associated with threat through conditioning cannot be detected preattentively. *Emotion*, 4, 418–430. <http://dx.doi.org/10.1037/1528-3542.5.4.418>.
- Berridge, K. C., & Robinson, T. E. (1998). What is the role of dopamine in reward: Hedonic impact, reward learning, or incentive salience? *Brain Research Reviews*, 28, 309–369.
- Berridge, K. C., & Robinson, T. (2003). Parsing reward. *Trends in Neurosciences*, 26, 507–513. [http://dx.doi.org/10.1016/S0166-2236\(03\)00233-9](http://dx.doi.org/10.1016/S0166-2236(03)00233-9).
- Bromberg-Martin, E., Matsumoto, M., & Hikosaka, O. (2010). Dopamine in motivational control: Rewarding, aversive, and alerting. *Neuron*, 68, 815–834. <http://dx.doi.org/10.1016/j.neuron.2010.11.022>.
- Brosch, T., Pourtois, G., & Sander, D. (2010). The perception and categorization of emotional stimuli: A review. *Cognition and Emotion*, 24(3), 377–400.
- Brosch, T., Sander, D., Pourtois, G., & Scherer, K. R. (2008). Beyond fear: Rapid spatial orienting towards positive emotional stimuli. *Psychological Science*, 19, 362–370. <http://dx.doi.org/10.1111/j.1467-9280.2008.02094.x>.

- Cousineau, D. (2005). Confidence intervals in within-subject designs: A simpler solution to Loftus and Masson's method. *Tutorial in Quantitative Methods for Psychology*, 1, 42–45.
- Delplanque, S., Grandjean, D., Chrea, C., Aymard, L., Cayeux, I., Le Calve, B., et al. (2008). Emotional processing of odors: Evidence for a nonlinear relation between pleasantness and familiarity evaluations. *Chemical Senses*, 33, 469–479. <http://dx.doi.org/10.1093/chemse/bjn014>.
- Distel, H., Ayabe-Kanamura, S., Martinez-Gomez, M., Schicker, I., Kobayakawa, T., Saito, S., et al. (1999). Perception of everyday odors—correlation between intensity, familiarity and strength of hedonic judgment. *Chemical Senses*, 24, 191–199.
- Ferdenzi, C., Roberts, C., Schirmer, A., Delplanque, S., Sezen, C., Porcherot, C., et al. (2013). Variability of affective responses to odors: Culture, gender and olfactory knowledge. *Chemical Senses*, 38, 175–186. <http://dx.doi.org/10.1093/chemse/bjs083>.
- Flykt, A. (2006). Preparedness for action: Responding to the snake in the grass. *American Journal of Psychology*, 119, 29–43.
- Fox, E., Russo, R., Bowles, R., & Dutton, K. (2001). Do threatening stimuli draw or hold visual attention in subclinical anxiety? *Journal of Experimental Psychology: General*, 130, 681–700. <http://dx.doi.org/10.1037/0096-3445.130.4.681>.
- Gottfried, J. A. (2011). *Neurobiology of sensation and reward*. Boca Raton: CRC Press.
- Gottfried, J. A., O'Doherty, J., & Dolan, R. J. (2003). Encoding predictive reward value in human amygdala and orbitofrontal cortex. *Science*, 301, 1104–1107. <http://dx.doi.org/10.1126/science.1087919>.
- Hickey, C., Chelazzi, L., & Theeuwes, J. (2010a). Reward changes salience in human vision via the anterior cingulate. *Journal of Neuroscience*, 30, 11096–11103. <http://dx.doi.org/10.1523/JNEUROSCI.1026-10.2010>.
- Hickey, C., Chelazzi, L., & Theeuwes, J. (2010b). Reward guides vision when it's your thing: Trait reward-seeking in reward-mediated visual priming. *PLoS ONE*, 5, e14087. <http://dx.doi.org/10.1371/journal.pone.0014087>.
- Hickey, C., Chelazzi, L., & Theeuwes, J. (2011). Reward has a residual impact on target selection in visual search, but not on the suppression of distractors. *Visual Cognition*, 19, 117–128. <http://dx.doi.org/10.1080/13506285.2010.503946>.
- Hickey, C., & van Zoest, W. (2012). Reward creates oculomotor salience. *Current Biology*, 22, R219–R220. <http://dx.doi.org/10.1016/j.cub.2012.02.007>.
- Khan, R. M., Luk, C.-H., Flinker, A., Aggarwal, A., Lapid, H., Haddad, R., et al. (2007). Predicting odor pleasantness from odorant structure: Pleasantness as a reflection of the physical world. *Journal of Neuroscience*, 27, 10015–10023. <http://dx.doi.org/10.1523/JNEUROSCI.1158-07.2007>.
- Koster, E. H., Crombez, G., Verschuere, B., & De Houwer, J. (2004). Selective attention to threat in dot probe paradigm: Differentiating vigilance and difficulty to disengage. *Behaviour Research Therapy*, 42, 1183–1192. <http://dx.doi.org/10.1016/j.brat.2003.08.001>.
- Matsumoto, M., & Hikosaka, O. (2009). Two types of dopamine neuron distinctly convey positive and negative motivational signals. *Nature*, 459, 837–841. <http://dx.doi.org/10.1038/nature08028>.
- Mogg, K., Holmes, A., Garner, M., & Bradley, B. P. (2008). Effects of threat cues on attentional shifting, disengagement and response slowing in anxious individuals. *Behaviour Research Therapy*, 46, 656–667. <http://dx.doi.org/10.1016/j.brat.2008.02.011>.
- O'Doherty, J. P., Dayan, P., Schultz, J., Deichmann, R., Friston, K., & Dolan, R. J. (2004). Dissociable roles of ventral and dorsal striatum in instrumental conditioning. *Science*, 304, 452–454. <http://dx.doi.org/10.1126/science.1094285>.
- O'Doherty, J. P., Rolls, E. T., Francis, C. S., Bowtell, R., McGlone, F., Kobal, G., et al. (2000). Sensory-specific satiety-related olfactory activation of the human orbitofrontal cortex. *Neuro Report*, 11, 399–403.
- Öhman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology: General*, 130, 466–478. <http://dx.doi.org/10.1037/AXJ96-3445.130.3.466>.
- Posner, M. I., & Cohen, Y. A. (1984). Components of visual orienting. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and performance X: Control of language processes* (pp. 531–554). Hillsdale, NJ: Erlbaum.
- Posner, M. I., Inhoff, A. W., Friedrich, F. J., & Cohen, A. (1987). Isolating attentional systems: A cognitive-anatomical analysis. *Psychobiology*, 15, 107–121.
- Pourtois, G., Grandjean, D., Sander, D., & Vuilleumier, P. (2004). Electrophysiological correlates of rapid spatial orienting toward fearful faces. *Cerebral Cortex*, 14, 619–633. <http://dx.doi.org/10.1093/cercor/bhh023>.
- Robinson, M. F., & Berridge, K. C. (2013). Instant transformation of learned repulsion into motivational "wanting". *Current Biology*, 23, 282–289. <http://dx.doi.org/10.1016/j.cub.2013.01.016>.
- Rolls, E., & McCabe, C. (2007). Enhanced affective brain representation of chocolate in cravers vs. non-cravers. *European Journal of Neuroscience*, 26, 1067–1076. <http://dx.doi.org/10.1111/j.1460-9568.2007.05724.x>.
- Rolls, E. T., & Rolls, J. H. (1997). Olfactory sensory-specific in humans. *Physiology and Behavior*, 61, 437–461.
- Rutherford, H. J., O'Brien, J. L., & Raymond, J. E. (2010). Value associations of irrelevant stimuli modify rapid visual orienting. *Psychonomic Bulletin and Review*, 17, 536–542.
- Sander, D., Grandjean, D., & Scherer, K. R. (2005). A systems approach to appraisal mechanisms in emotion. *Neural Networks*, 18, 317–352. <http://dx.doi.org/10.1016/j.neunet.2005.03.001>.
- Seitz, A. R., Kim, D., & Watanabe, T. (2009). Rewards evoke learning of unconsciously processed visual stimuli in adult humans. *Neuron*, 61, 700–707. <http://dx.doi.org/10.1016/j.neuron.2009.01.016>.
- Talmi, D., Seymour, B., Dayan, P., & Dolan, R. J. (2008). Human pavlovian-instrumental transfer. *Journal of Neuroscience*, 9, 360–368. <http://dx.doi.org/10.1523/JNEUROSCI.4028-07.2008>.
- Theeuwes, J. (1991). Exogenous and endogenous control of attention: The effect of visual onsets and offsets. *Perception and Psychophysics*, 49, 83–90.
- Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception and Psychophysics*, 51, 599–606.
- Theeuwes, J., & Belopolsky, A. V. (2012). Reward grabs the eye: Oculomotor capture by rewarding stimuli. *Vision Research*, 74, 80–85. <http://dx.doi.org/10.1016/j.visres.2012.07.024>.
- Valentin, V. V., Dickinson, A., & O'Doherty, J. P. (2007). Determining the neuronal substrates of goal-directed learning in the human brain. *Journal of Neuroscience*, 27, 4019–4026. <http://dx.doi.org/10.1523/JNEUROSCI.0564-07.2007>.
- Van Damme, S., Crombez, G., & Notebaert, L. (2008). Attention bias to threat: A perceptual accuracy approach. *Emotion*, 6, 820–827. <http://dx.doi.org/10.1037/a0014149>.
- Vogt, J., De Hower, I., Koster, E. H., Van Damme, S., & Crombez, G. (2008). Allocation of spatial attention to emotional stimuli depends upon arousal and not valence. *Emotion*, 8, 880–885. <http://dx.doi.org/10.1037/a0013981>.
- Vuilleumier, P. (2005). How brains beware: Neuronal mechanisms of emotional attention. *Trends in Cognitive Sciences*, 9, 585–594. <http://dx.doi.org/10.1016/j.tics.2005.10.011>.
- Weierich, M. R., Treat, T. A., & Hollingworth, A. (2008). Theories and measurement of visual attentional processing in anxiety. *Cognition and Emotion*, 22, 985–1018. <http://dx.doi.org/10.1080/02699930701597601>.
- Wellman, L. L., Gale, K., & Malkova, L. (2005). GABA-mediated inhibition of basolateral amygdala blocks reward devaluation in macaques. *Journal of Neuroscience*, 25, 577–4586. <http://dx.doi.org/10.1523/JNEUROSCI.2257-04.2005>.
- Yiend, J. (2009). The effects of emotion on attention: A review of attentional processing of emotional information. *Cognition and Emotion*, 24, 3–47. <http://dx.doi.org/10.1080/02699930903205698>.
- Yiend, J., & Mathews, A. (2001). Anxiety and attention to threatening pictures. *Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology*, 54, 665–681. <http://dx.doi.org/10.1080/713755991>.