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The role of value in the attentional boost effect

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Abstract

Focusing attention on one item typically interferes with the ability to process other information. Yet, target detection can both facilitate memory for items paired with the target (the attentional boost effect) and increase the perceived value of those items (cued approach). Because long-term memory is better for valuable items than for neutral items, we asked whether the attentional boost effect is due to changes in the perceived value of items that are paired with targets. In three experiments, participants memorised a series of briefly presented images that depicted valuable (e.g., food) or neutral (e.g., children's toys) items. Whenever an item appeared, a square flashed in its centre. Participants pressed a button if the square was a target colour but not if it was a distractor colour. Consistent with previous research, target-paired items were remembered better than distractor-paired items and were rated as more valuable. Importantly, if memory for target-paired items is enhanced because they increased in perceived value, then valuable items should have been better remembered than neutral items. However, we found no evidence that value enhanced memory for the items in this task. Thus, it is unlikely that the attentional boost effect is due to changes in perceived value.

Keywords

Attentional boost effect; cued approach; long-term memory; value; attention

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A growing body of evidence suggests that under some circumstances attending to a target can facilitate performance on a second, unrelated task, a phenomenon known as the *attentional boost effect* (e.g., Lin, Pype, Murray, & Boynton, 2010; Swallow & Jiang, 2010; for a review see Swallow & Jiang, 2013). In contrast to interference effects that are typically observed when a target is detected (e.g., Duncan, 1980), participants show better memory for items that are presented at the same time as a target than for items presented at the same time as a distractor. Recently, work by Schonberg and colleagues (2014) found that consistently pairing items with a target also increases their perceived value, an effect they termed *cued-approach*. This study tests whether changes in the perceived value of items presented with targets can account for the attentional boost effect. In other words, do targets facilitate memory for a concurrently presented item by increasing its perceived value?

In a typical attentional boost effect experiment, participants perform separate tasks on two, simultaneously presented but unrelated stimulus streams. For the *encoding task* participants memorise a series of brief, centrally presented items for a later memory test. For the *detection task* participants monitor a second stimulus stream for a pre-specified target (e.g., a blue square rather than an orange square, see Figure 1). Participants press the button when a target appears, but not when a distractor appears. Throughout this paper, we refer to the encoding stimuli as *items* and the detection stimuli as *targets* or *distractors*. In detection tasks like the ones used in the attentional boost effect, target detection typically interferes with the processing of unrelated information for at least 500 ms (Dux & Marois, 2009). Yet, later memory for items that coincided with a target is typically enhanced relative to those that were presented with a distractor or on their own (Swallow & Jiang, 2014b). Thus, increasing attention to a target boosts memory for a concurrently presented item.

The attentional boost effect has been replicated across a variety of experimental conditions: it occurs when targets are rare and when they are as frequent as distractors

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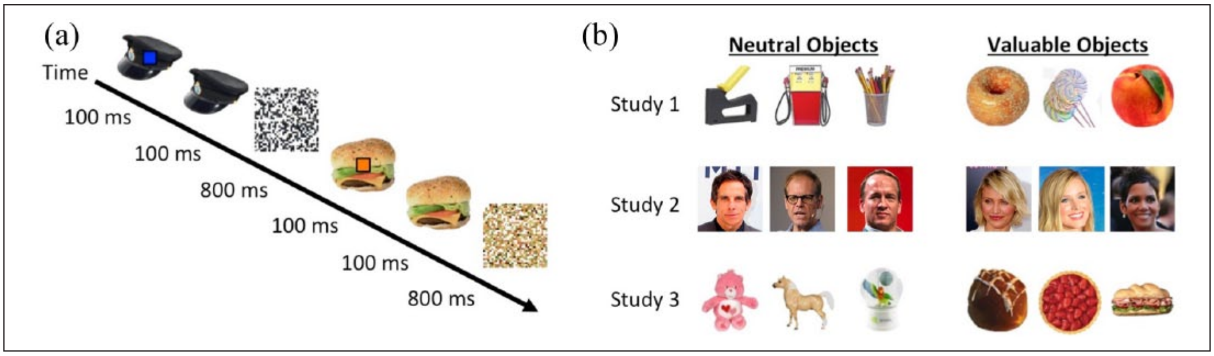

Figure 1. Task and stimuli used in the continuous dual-task. (a) Participants attempted to remember objects that were presented one at a time in the centre of the screen. Objects were presented for 200 ms and masked with a scrambled image for the remainder of the 1000 ms long trial. There was no intertrial interval. Stimuli were presented for 500 ms in Experiments 2 and 3. Participants were also asked to press a button whenever a square (100 ms duration) of a pre-defined target colour (e.g., blue) and not a distractor colour (e.g., orange) appeared in the centre of an object. Squares and objects onset at the same time. (b) Examples of neutral and valuable objects in Experiments 1-3. Face images were acquired from commons.wikimedia.org for illustrative purposes only. They were not used in the experiment.

(Makovski, Swallow, & Jiang, 2011; Swallow & Jiang, 2012), when targets are auditory tones or visual squares or letters (Mulligan, Spataro, & Picklesimer, 2014; Swallow & Jiang, 2010), when targets are perceptually similar to distractors (Swallow & Jiang, 2010, 2014a), and when participants count targets, rather than press a button (Swallow & Jiang, 2012). Target detection enhances memory for a variety of items (scenes, faces, objects, words, and colour patches; Makovski et al., 2011; Spataro, Mulligan, & Rossi-Arnaud, 2013; Swallow & Jiang, 2013), but only if encoding time is limited (Mulligan & Spataro, 2014). Similar target-detection–related enhancements occur in visual adaptation (Pascucci & Turatto, 2013) and perceptual learning paradigms (Seitz & Watanabe, 2009). Thus, the attentional boost effect is a robust phenomenon that must be addressed by current theories of attention.

Many accounts of the attentional boost effect suggest that target detection enhances memory by affecting online encoding processes (Mulligan & Spataro, 2014; Swallow & Jiang, 2013). Consistent with this possibility, several studies suggest that increasing attention to behaviourally relevant events, such as targets, briefly facilitates the perceptual processing of concurrently presented items. Detecting a target increases activity in early visual areas of the brain (Swallow, Makovski, & Jiang, 2012), increases the magnitude of the visual tilt aftereffect (Pascucci & Turatto, 2013), and facilitates perceptual learning (Seitz & Watanabe, 2009). The effects of target detection on perceptual processing are highly selective in time (Swallow & Jiang, 2011), but do not appear to be selective over items (Jiang & Swallow, 2014). In short-term memory, an attentional boost effect occurs when targets are presented during the encoding display, but not when they occur during the retention interval or probe display (Makovski et al., 2011). Combined, these data suggest a *temporal selection account*: a mechanism that enhances the perceptual processing of information (i.e., items) that is present at behaviourally relevant moments in time (i.e., when a target appears).

However, behaviourally relevant events do more than guide attention, they may also influence value learning and memory. For example, Schonberg and colleagues (2014) examined the effect of target detection on the perceived value of concurrently presented food items. Participants performed an auditory target detection task as they viewed images of a variety of snacks (e.g., chips and candy). Afterwards, participants' ratings of snacks paired with a target tone were greater than their ratings of snacks presented on their own. Thus, target detection increased the perceived value of the concurrently presented item (cued-approach). Items paired with targets were also subsequently associated with increased activity in the ventromedial prefrontal cortex, a brain region important for representing the subjective value of different choices (Levy & Glimcher, 2012; Roy, Shohamy, & Wager, 2012). Cued-approach was evident primarily for items that were highly valued before the detection task. Target detection may therefore exaggerate the relative value of items that are paired with targets rather than distractors (e.g., Schonberg et al., 2014).

If target detection increases the perceived value of an item, then changes in the item's value may explain why they are better remembered than items paired with a distractor (*value-driven memory account*). Valuable items are better attended and better remembered than less valuable items, indicating dynamic interactions between systems involved in orienting attention, representing value, learning value, and episodic memory (e.g., Leong, Radulescu, Daniel, DeWoskin, & Niv, 2017). Colours that were recently associated with a high value monetary reward during a choice task bias attention in a search task performed immediately thereafter (Anderson, Laurent, & Yantis, 2011). Relative to neutral stimuli, there is a long-term memory advantage for words that will have a higher value during recall (Cohen, Rissman, Suthana, Castel, & Knowlton, 2014) pictures that make one feel happy (Bradley, Greenwald, Petry, & Lang, 1992), pleasant pictures (Dolcos & Cabeza, 2002; Dolcos, LaBar, & Cabeza, 2004), and attractive faces (Marzi & Viggiano, 2010; Tsukiura & Cabeza, 2011).

The data linking target detection to value and value to memory suggest a new hypothesis: that value-driven memory effects mediate the attentional boost effect. According to this account, detecting a behaviourally relevant event such as a target increases the perceived value of the concurrently presented item, which then biases mnemonic processes towards that item. Given the diversity of effects of value on memory, there are multiple, plausible mechanisms by which changes in an item's value could mediate the effects of target detection on memory after encoding. These include greater elaboration and deeper processing of valuable stimuli (e.g., Cohen et al., 2014), better memory consolidation of valuable stimuli (e.g., Anderson, Wais, & Gabrieli, 2006; Murayama & Kitagami, 2014; Wittmann et al., 2005), and the interaction of systems involved in learning and representing value and those involved in episodic memory (Dolcos et al., 2004; Euston, Gruber, & McNaughton, 2012; Koster, Guitart-Masip, Dolan, & Düzel, 2015; Shohamy & Adcock, 2010; Tompary, Duncan, & Davachi, 2015; Wittmann et al., 2005). Several caveats should be noted. First, most studies on the effects of value on memory have presented the items for significantly longer periods of time than the studies examining the attentional boost effect. For example, Schonberg and colleagues (2014) presented items at a rate of one every 4 s, on average. This rate is unlikely to produce an attentional boost effect (Mulligan & Spataro, 2014). Second and third, the effects of value on long-term memory may not emerge until a day after encoding (Koster et al., 2015; Spaniol, Schain, & Bowen, 2013; Tompary et al., 2015; Wittmann et al., 2005), or may require explicit evaluation of value during encoding (Bradley et al., 1992; Cohen et al., 2014; Dolcos & Cabeza, 2002; Dolcos et al., 2004; Marzi & Viggiano, 2010; Tsukiura & Cabeza, 2011). Whether value will influence memory for items presented in a standard attentional boost effect paradigm, in which the items are presented more rapidly (1 s per trial), are tested within minutes of encoding, are presented within a dual-task paradigm, and are not explicitly evaluated for value, is therefore an open question.

The present study

The main goal of this study was to determine whether the effects of target detection on perceived value could plausibly account for the attentional boost effect. According to the value-driven memory account, attending to an item increases its perceived value, and this increase in value causes it to be better remembered. In addition, because valuable items may also influence memory for their context (Loh et al., 2016; Wallis, Stokes, Arnold, & Nobre, 2015; Wittmann, Schiltz, Boehler, & Düzel, 2008), our secondary goal was to explore the effects of target detection and value on relational memory.

Participants completed a dual-task in which they memorised a series of individually presented items while performing a detection task (Figure 1a). For the detection task, they pressed a button when a target coloured square (rather than a distractor coloured square) appeared. Afterwards, they completed a memory test on the items, reported the colour of the square they believed appeared with the item (as a measure of relational memory), and rated their liking of the items. In three experiments, we compared valuable objects to neutral objects (Experiment 1), attractive to nonattractive faces (Experiment 2), and food to toys (Experiment 3). In all cases, we expected better memory for items paired with targets rather than distractors during encoding (reflecting an expected attentional boost effect). For the value-driven memory account to be supported, target detection also must change the perceived value of the items, which were presented for 1 s or less (reflecting an expected cued approach effect). Though cued approach effects are replicable, several differences in procedure make an effect of target detection on value uncertain for these experiments (Bakkour et al., 2016). In addition, if value is the source of the attentional boost effect, more valuable items must also be better remembered. Finally, those items whose perceived value is most affected by target detection should also show the greatest memory benefit. Therefore, if the effect of target detection on perceived value is greater for valuable items than for neutral items (as it was in Schonberg et al., 2014), an over-additive interaction between value and encoding condition should be observed. If there is no interactive effect of encoding condition and value on participants' liking and wanting ratings, then the effects of encoding condition and value should be additive.

Alternatively, value and target detection may enhance memory via the same mechanism, such as selective attention (cf., Anderson et al., 2011; Leong et al., 2017; Niv et al., 2015). According to the *attention-to-value account*, people remember valuable items and target-paired items better because both receive more attention than neutral or distractor-paired items. If that is the case, then memory for more valuable items should be enhanced. However, little additional benefit may be incurred by pairing a valuable item with a target if both influence memory via the same mechanisms. Similar to manipulations of distinctiveness that reduce the magnitude of the attentional boost effect (cf., Mulligan et al., 2014; Spataro, Mulligan, & Rossi-Arnaud, 2015), the attention-to-value account predicts an under-additive interaction between item value and target detection. For this hypothesis to be supported, valuable items would need to be better remembered, and benefit less than neutral items from being paired with a target. In contrast, the value-driven memory account predicts simply that target detection should increase the value of concurrent items, and that more valuable items should be better remembered.

In these experiments, valuable items were defined as being pleasurable or better able to fulfil a need than neutral items if they were acquired. This conceptualisation of value was motivated by the finding that pairing a target with an item increases how much a participant is willing to pay for it as well as associated activity in ventromedial prefrontal cortex (Schonberg et al., 2014). Activity in this region of the brain, along with orbitofrontal cortex and the striatum, is greater for items expected to produce pleasure or to fulfil a need (Levy & Glimcher, 2012). This valuation system interacts with systems involved in reinforcement learning to guide behaviour, attention, and memory (Leong et al., 2017; Roy, Shohamy, & Wager, 2012; Sadeh, Shohamy, Levy, Reggev, & Maril, 2010; Wimmer, Braun, Daw, & Shohamy, 2014; Wittmann et al., 2005). Value has been manipulated in a variety of ways that do not involve money (see Levy & Glimcher, 2012 and Roy et al., 2012, for overviews), including with pictures of high calorie foods vs. low calorie foods (Killgore et al., 2003), with positive vs. negative social feedback (Jones et al., 2011), and by imagining a pleasant experience from one's past (Bray, Shimojo, & O'Doherty, 2010). Similarly, attractive faces are not only better remembered than neutral faces (e.g.Tsukiura & Cabeza, 2011), they can also serve as positive reinforcers in conditioning tasks (Bray & O'Doherty, 2007). The degree to which value can be conceptualised as a unitary construct, or as reflecting multiple computations (e.g., liking vs. wanting; emotional valence vs. motivation) is an unsettled issue in the literature (Berridge, Robinson, & Aldridge, 2009; Carruthers, 2017; Chiew & Braver, 2011). Therefore, these experiments set out to determine whether a sample of these value manipulations might also be linked to the attentional boost effect.

To preview the findings, although target detection consistently enhanced the perceived value of and memory for a concurrently presented item, memory was similar for valuable and neutral items. Critically, target detection affected memory for both valuable and neutral items similarly. Thus, there was little evidence to support either the value-driven memory account or the attention-to-value account of the attentional boost effect.

Experiment 1: valuable and neutral objects

To examine whether target detection differentially enhances memory for valuable and neutral objects, we varied the value of the objects participants encoded while they performed a target detection task (Figure 1a). Participants should better remember objects paired with a target square than those paired with a distractor square. Of greatest importance for this study, however, was whether value influenced memory for the objects, and whether this effect interacted with the status of the square as a target or distractor. A secondary question was whether memory for the relationship between an object and its context, in this case the object and the colour of the coinciding square, was influenced by target detection and value.

Methods

Participants. In all, 20 undergraduate students (demographics data were not collected due to human error) at Cornell University participated for course credit or $7.50. The sample size was decided *a priori* to match that of earlier studies of the attentional boost effect (e.g., Swallow & Jiang, 2014a). The average effect size for the attentional boost effect in previous experiments with similar encoding and testing conditions (target to distractor ratio of 1:1, short delay between encoding and test, and explicit encoding instructions, cf. Swallow & Jiang, 2012, 2014, 2014b) was $d = 0.89$. With $N = 20$ and $\alpha = .05$, this experiment had a power of .8 to detect an effect of $d \geq 0.58$ in a one-sided, paired samples *t*-test (all power estimates are from G*Power 3; Faul, Erdfelder, Lang, & Buchner, 2007). Data from one additional participant were excluded due to a computer error. All procedures were approved by the Cornell Institutional Review Board and all participants provided informed consent.

Equipment and stimuli. Participants were tested in an interior, normally lit room. They sat unconstrained approximately 57 cm away from a 19-inch CRT monitor (1024 x 760 pixel resolution, 75 Hz refresh rate) connected to a Windows PC. The experimental task was run in MATLAB (www.mathworks.com) with the Psychophysics Toolbox (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997).

Encoding stimuli were selected from a set of 507 images of everyday objects (Brady, Konkle, Alvarez, & Oliva, 2008). Three independent undergraduate research assistants coded these objects as valuable, neutral, or negative. They were told that "A rewarding object is something that is either enjoyable in itself or which brings to mind something enjoyable." In addition, if "any picture seems unrewarding (negative, not neutral—e.g., something disgusting)" it was to be sorted into the negative category. All other images were placed in the neutral category. These instructions separated objects that carried positive subjective value or valence (e.g., candy or a canoe) from objects that were affectively neutral (e.g., a car tyre or keys). None of the objects were categorised as negative. This set was then limited to the 255 objects that were identically coded by all three research assistants. From this set, 80 unanimously categorised *valuable* objects and 80 unanimously categorised *neutral* objects were selected. An additional 20 neutral objects were chosen for the practice trials. Valuable and neutral images were randomly assigned to conditions for each participant.

Procedure and design. Participants first completed the encoding and detection phase of the experiment (Figure 1a). On each trial, an image of an object (256 x 256 pixels) was presented in the centre of the screen. A blue or orange square (20 x 20 pixels) appeared in the centre of the object. After 100 ms, the square disappeared and the object remained on the screen for an additional 100 ms. A mask then replaced the object for 800 ms, for a total trial duration of 1 s. The interval between trials was 0 ms.

Participants were instructed to remember all of the objects for a later memory test. They were also asked to press the space bar as quickly as possible when they detected a square in a pre-specified colour (target) but not when they detected a square of the other colour (distractor). Target and distractor colour was counterbalanced across participants.

Participants first completed 20 practice trials. They then completed 3 sets of 80 trials. Each set consisted of the same 40 valuable and 40 neutral objects, presented in a random order. Half of the objects of each type appeared with a target square and half appeared with a distractor square. The pairings were maintained across all three sets. Participants received performance feedback between sets.

In the second phase of study, participants completed the memory and rating tasks. A single object was presented on each trial. Participants made three judgments in the following order: whether the object was old or new, which colour square had been presented with it (none/blue/orange), and how much they liked the image (1 = not at all to 7 = very much). All 80 old objects from the dual-task encoding phase and 80 new objects (40 valuable and 40 neutral) were tested in a random order.

Data analysis. Because recognition accuracy data are nonlinear, they were analysed using the empirical logit (Cox, 1970; Warton & Hui, 2011).[1] The empirical logit is the log of the odds of a successful outcome in a series of Bernoulli trials, after adding a small number (0.5) to the number of successes and the number of failures. For the old images, the formula was: *logitHit=log, (Number of Hits+0.5)/(Number of Misses + 0.5).* The empirical logit was calculated for four conditions: neutral objects paired with distractors, neutral objects paired with targets, valuable objects paired with distractors, and valuable objects paired with targets. For each type of new object, the likelihood of an incorrect "old" response (false alarm [FA]) rather than "new" response (correct rejection [CR]) was calculated to account for response bias: *logitFA=log, (Number of FAs + 0.5)/(Number of CRs + 0.5)*. The resulting value was then subtracted from logitHit to yield the *adj. accuracy.*

The effects of item value and encoding condition were evaluated with a participant-wise repeated-measures analysis of variance (ANOVA) on the adj. accuracy. The ANOVA included encoding condition (distractor or target) and item type (neutral or valuable) as fixed effects and participant as a random effect. The proportions of correct recognition responses in each condition are reported in the Supplementary Material.

An item-wise linear mixed-effects regression with the items, rather than participants, as the random effect was performed using R's nlme package (Pinheiro, Bates, DebRoy, Sarkar, & Team, 2015). Including item as a random effect in this analysis better supports inferences about the effects of interest in a new sample of items (just as the repeated-measures ANOVA improves inferences about participants who were not sampled for the experiment; Clark, 1973; see also Westfall, Nichols, & Yarkoni, 2017). The mixed-effects model included encoding condition (target/distractor) and post-encoding rating for each object as fixed effects. Ratings of novel objects were used as predictors to avoid conflating the perceived value of the object with cued approach. Only objects assigned to each encoding condition across participants were used (e.g., with target squares for Participant 1, with distractor squares for Participant 2, and novel for Participant 3). Effect sizes are β-weights, which indicate the change in accuracy, in standard deviation units, for each unit change in the predictor variable (e.g., rating).

To evaluate whether value and target detection facilitated memory for their context, memory for the colour of the square that appeared with the image was also examined. Similar to the recognition memory judgement, the likelihood that participants reported that an image appeared with a particular colour square was calculated for correctly recognised old objects (hits) and for incorrectly recognised new objects (FAs). The value obtained for FAs was subtracted from the value obtained for hits (*adj. square accuracy*). This measure adjusts for any bias in reporting that a remembered object was presented with a target or distractor. Responses indicating that no square appeared with an image reported as "old" were removed from the analysis. In addition, participants were excluded if they did not have data in all conditions, or the number of "none" responses to old items was 2 standard deviations above the mean (1, 4, and 7 participants for each of the three experiments). The percentage of the square colour responses that were excluded for the remaining participants were low: *M* =

Table 1. Mean and standard deviation of the hit rates, median response times, and FA rates for the detection task in each experiment.

	Hit rate	Response time (ms)	False alarm rate
Experiment 1			
Neutral objects	.969 (.056)	383 (40)	.048 (.040)
Valuable objects	.968 (.055)	392 (42)	.044 (.038)
Experiment 2			
Male participants			
Male face	.967 (.107)	355 (30)	.042 (.057)
Female face	.967 (.111)	352 (28)	.045 (.064)
Female participants			
Male face	.990 (.012)	361 (29)	.033 (.031)
Female face	.988 (.012)	358 (32)	.034 (.027)
Experiment 3			
Non-fasting			
Neutral objects	.940 (.092)	402 (45)	.043 (.040)
Food	.947 (.086)	397 (54)	.045 (.050)
Fasting			
Neutral objects	.982 (.040)	386 (37)	.040 (.035)
Food	.976 (.047)	381 (39)	.037 (.032)

2.2%, $SD = 2.7\%$, in Experiment 1, $M = 2.4\%$, $SD = 3.0\%$, in Experiment 2, and $M = 1.9\%$, $SD = 2.7\%$, in Experiment 3. Adj. square accuracy was submitted to an ANOVA with object type and encoding condition as fixed effects, and subject as a random effect.

Recognition response times (see Supplementary Material) were evaluated but provided no evidence of a speed-accuracy trade-off. They will not be mentioned further.

Results and discussion

Square detection. Trials on which participants pressed the space bar within 1 s of target presentation were categorised as hits. Key presses on distractor trials were categorised as FA. The hit rate was similar for neutral and valuable objects (Table 1), $t(19) = 0.12$, $p = .904$, as was the FA rate, $t(19) = 0.41$, $p = .688$. However, median response times to target squares were reliably slower when the target was presented with a valuable object rather than a neutral object, $t(19) = -2.63$, $p = .016$. Thus, target detection was slower, but no more accurate for squares presented with valuable objects rather than neutral objects.

Manipulation check: liking ratings. To confirm that valuable objects were liked more than neutral objects, participants' post-encoding liking ratings were examined (see Supplementary Material). Liking ratings were averaged across objects in each condition and entered into a repeated-measures ANOVA with object type (neutral or valuable) and encoding condition (novel, old+target, or old+distractor) as factors. Valuable objects were liked more than neutral objects, $F(1, 19) = 46.3$, $p < .001$, $\eta_p^2 = .709$. Liking also varied across encoding conditions, $F(2, 38) = 7.87$, $p = .001$, $\eta_p^2 = .292$. Old objects presented with a target were liked more than old objects presented with a distractor, $t(19) = 2.73$, $p = .013$, $d = 0.26$, and novel objects, $t(19) = 3.65$, $p = .002$, $d = 0.42$. Liking was not significantly different for novel objects and old objects presented with a distractor, $t(19) = 1.4$, $p = .176$. Encoding condition did not reliably interact with the object's value, $F(2, 38) = 1.09$, $p = .346$. These data confirm that the methods used to identify valuable and neutral objects successfully produced categories that differed in liking. In addition, perceived value was enhanced if the object was presented at the same time as a target, though this did not depend on the initial value of the object (as it did in Schonberg et al., 2014). The difference in liking ratings between target and novel objects could additionally reflect increased positive affective responses to items that are familiar (the mere exposure effect, Zajonc, 1968).

Recognition memory for objects. Objects that had been presented with a target rather than a distractor square were remembered better, $F(1,19) = 12.8$, $p = .002$, $\eta_p^2 = .402$, replicating the attentional boost effect. The value-based memory and attention-to-value accounts of the attentional boost effect predict that memory should be better for valuable objects than for neutral objects. They also make different predictions about the interaction between encoding condition and object value: While the attention-to-value account predicts an under-additive interaction, the value-based memory account predicts that the effects of value and encoding condition on memory will mirror their effects on liking. Contradicting both accounts, however, the object's value did not reliably influence memory for old objects, $F(1, 19) = 0.96$, $p = .34$. Object value also did not interact with encoding condition, $F(1, 19) = 1.78$, $p = .198$. Because no effect of value was observed, a Bayes Factor (BF) analysis (Rouder, Morey, Speckman, & Province, 2012) was conducted to evaluate the evidence for different regression models of the data. Relative to the model of no effects of encoding condition or value on memory (the null model), the model that included only encoding condition best fit the data (BF = 64.171). Evidence for this model was 5.61 times greater than the model that included the encoding condition x value interaction. Thus, there was no evidence that object value influenced memory either on its own or by modulating the attentional boost effect (Figure 2a).

To further explore the effects of value and encoding condition on recognition accuracy, an item-wise analysis was performed with the 159 objects that were presented in each encoding condition across participants (see *Data Analysis*). Results indicated that objects were better remembered when they had been presented with a target rather than a distractor during encoding (Figure 2b), $F(1, 157) = 10.5$, $p = .002$, $\beta = 0.26$. Contradicting the value-driven memory and attention-to-value accounts, however, objects that were liked better were remembered *less* accurately, $F(1, 157) = 8.67$, $p = .004$, $\beta = -0.24$, and this relationship did not interact with the presence of a target during encoding, $F(1, 157) = 0.18$, $p = .667$. Thus, target detection was again found to enhance memory for concurrently presented objects, regardless of the object's perceived value.

Memory for the object-square conjunction. Participants more accurately reported which square appeared with an old item if the item had appeared with a target square during encoding, even after adjusting for response biases, $F(1, 17) = 10.4$, $p = .005$, $\eta_p^2 = .379$. Memory for the square that appeared with an object was numerically greater for neutral than valuable objects, though this difference did not reach significance, $F(1, 17) = 3.21$, $p = .091$, $\eta_p^2 = .159$. The interaction was not significant, $F(1, 17) = 0.01$, $p = .931$. Although target detection facilitated memory for the conjunction of the item and the square, the value of the item did not.

Discussion. In Experiment 1, detecting a target facilitated memory for a concurrent item (the attentional boost effect; e.g., Swallow & Jiang, 2010) and increased the perceived value of that item (as in cued approach, Schonberg et al., 2014). Critically, however, valuable items were not better remembered than neutral items and the effect of target detection was similar for both types of items. Contradicting both the value-driven memory and attention-to-value accounts, there was no evidence that memory was positively affected by an item's value in this task. A noteworthy and novel finding was that target detection influenced relational memory for the colour of the square that appeared with an object. In addition, item value had a marginal negative effect on relational memory.

Experiment 2: attractive and neutral faces

One possible explanation for the lack of an effect of value on memory in Experiment 1 is that the item's value was not sufficiently processed by participants, perhaps because it was too abstract (e.g., the objects were not directly relevant to them). To address this issue, Experiment 2 varied value by varying attractiveness. Attractive faces elicit activity in regions associated with value processing (Bray & O'Doherty, 2007; Roy et al., 2012; Tsukiura & Cabeza, 2011) and are motivationally significant: Male participants will exert greater effort to view pictures of attractive female faces than unattractive female faces (Aharon et al., 2001; Levy et al., 2008), and stimuli that predict attractive (but not unattractive) female faces take on a positive conditioned value (Bray & O'Doherty, 2007). Facial attractiveness can be assessed from minimal visual input, influences processing within 150 ms, diverts attention from task-relevant information, and facilitates later memory (Chen, Liu, & Nakabayashi, 2012; Maner et al., 2003; Marzi & Viggiano, 2010; Olson & Marshuetz, 2005), even when participants passively view the faces (Anderson et al., 2010). The memory advantage for attractive faces may be partially based on increased correlations in the activity of brain regions involved in processing value (e.g., medial and orbitofrontal cortex and basal ganglia) and declarative memory (Hahn & Perrett, 2014; Tsukiura & Cabeza, 2011). Facial attractiveness therefore should be readily accessible during an encoding task and should enhance memory, particularly for faces of a sex one is attracted to (Hahn & Perrett, 2014).

In Experiment 2, participants encoded images of male and female faces. The images were selected based on attractiveness ratings obtained from an independent group of participants. Because both male and female raters tended to rate female faces as more attractive than male faces we were unable to equate attractiveness across face sex.[2] Therefore, the most attractive female faces and the least attractive male faces were used, and data were collected from an equal number of male and female participants. Other ratings related to value, liking and time willing to spend looking at the image, also differed across face type. If memory is enhanced for valuable stimuli, then it should be better for the attractive (female) faces, as in previous work (e.g., Marzi & Viggiano, 2010). Given previous work demonstrating a memory advantage for attractive female faces for both male and female participants (Maner et al., 2003), the female faces should be better remembered by both groups. However, because male participants seem to more strongly and reliably prioritise attractive female faces (Becker, Kenrick, Guerin, & Maner, 2005), it is also possible that the effect of value will be

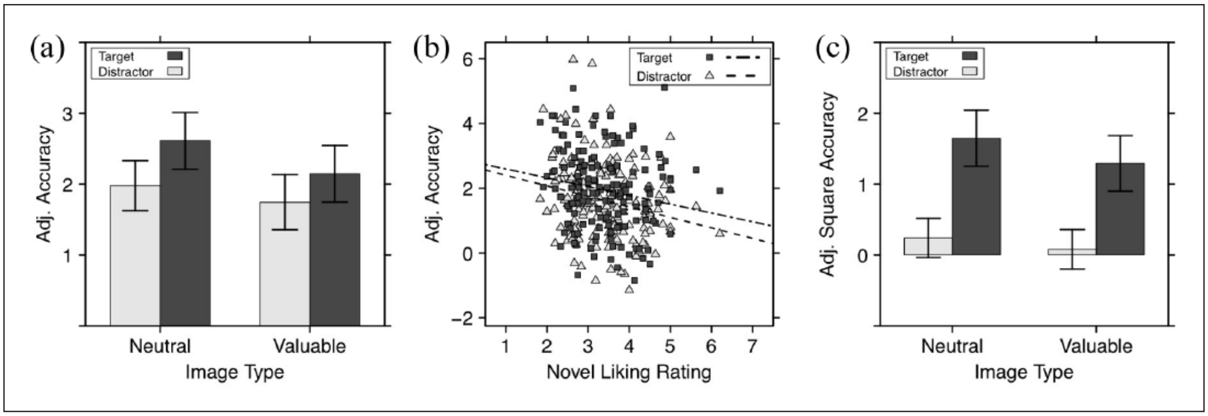

Figure 2. Recognition accuracy and ratings of objects in Experiment 1. (a) Old/new recognition accuracy (in logits) across conditions defined by a priori value and by encoding condition. (b) Recognition accuracy as a function of encoding condition and its mean liking rating when novel. (c) Square recognition accuracy for correctly recognised old objects in each condition defined by a priori value and encoding condition. Error bars represent +/-1 standard error.

exaggerated in male participants for whom attractiveness and sexual interest were more likely to align.

Methods

Participants. In all, 48 undergraduate students (24 female, 24 male, mean age = 20.28, SD = 3.27, two participants did not report age) participated for extra credit or monetary compensation. Additional participants were excluded from all analyses due to a computer or experiment error (N = 3), or difficulty understanding the instructions (N = 1). With α = .05, power was .8 to detect an effect of $d \geq 0.52$ within gender (N = 24) and $d \geq 0.36$ without regard to gender (N = 48) in paired one sample t-tests. For an interaction of between (participants' gender, two levels) and within participants factors (value or encoding condition, two levels), power was .8 to detect an effect of size $\eta_p^2 \geq .041$ (correlation among repeated measures = .5, no correction for nonsphericity).

Equipment and stimuli. Except as noted, the experimental procedures and equipment were identical to those of Experiment 1. Experimental stimuli were 320 colour images of famous faces, sized 256 x 256 pixels, obtained through online searches. These were chosen from a larger set of 470 images, which were rated by an online sample of 80 Mechanical Turk users (42 female, 38 male, mean age = 35.10, SD = 9.95). Users rated the attractiveness of the face (1-7), how much they liked the image (1-7), how long they would look at it (0-100 s), and whether they recognised the person in the image (1-3, corresponding to no/unsure/yes). Based on these data, we chose the 160 most attractive female faces (valuable; M = 4.81, SD = 0.56), and the 160 least attractive male faces, neutral; M = 2.79, SD = 0.52; Welch two sample t-test, $t(316.41) = 33.30$, $p <$ .001. The male and female faces additionally differed in how much participants liked the image, female M = 4.50, SD = 0.60; male M = 2.84, SD = 0.50; Welch two sample t-test, $t(307.12) = 26.82$, $p < .001$, and how long participants would have liked to look at the image, female M = 19.16 s, SD = 4.63; male M = 8.90 s, SD = 3.15; Welch two sample t-test, $t(279.84) = 23.179$, $p < .001$. These values were strongly, positively correlated (attractiveness with liking, r = .957; attractiveness with looking time, r = .894; liking with looking time, r = .894). The selected male and female faces were similarly known to the raters in terms of their means and standard deviations, male M = 2.12, SD = 0.96; female M = 2.14, SD = 0.95; Kruskal–Wallis rank sum test on the means, $\chi^2(1) = 0.49$, p = .486. Though faces could have differed along other dimensions that were not measured, the strong relationship between attractiveness and liking suggests that these differences are unlikely to influence the relative value of the face types. An additional 20 male/female faces were used on practice trials.

Procedure and design. After providing informed consent, participants completed the dual-task encoding phase of the experiment. The design was identical to Experiment 1 except that faces were presented for 500 ms (100 ms with the square), the mask was presented for 500 ms, and there were twice as many images per condition. The old–new recognition test was identical to that used in Experiment 1, except the labels for the liking scale were altered (1 = strongly dislike picture; 7 = strongly like picture).

Results and discussion

Square detection. Hit rate (Table 1) was similar across male and female participants (*participant gender*) and face types: largest, $F(1, 46) = 0.98$, p = .327, for the main effect of participant gender. There were no effects of participant gender or face type on FA rates: largest, $F(1, 46) = 0.54$, p = .465, for the main effect of participant gender. Responses to targets presented with female rather than male faces were slightly faster (~3 ms), $F(1, 46) = 6.86$, $p = .012$, $\eta_p^2 = .13$. Participant gender did not reliably affect response times, main effect, $F(1, 46) = 0.53$, $p = .469$, participant gender x face type interaction, $F(1, 46) = 0.11$, $p = .743$. Thus, detection task performance was similar across conditions, though responses were faster for targets that were paired with female faces.

Manipulation check: face ratings. Liking ratings are reported in the Supplementary Material. Encoding condition influenced liking, $F(2, 92) = 38.7$, $p <. 001$, $\eta_p^2 = .457$, reflecting greater liking of faces paired with targets than faces paired with distractors, $t(47) = 2.56$, $p = .014$, $d = 0.13$, and novel faces, $t(47) = 7.46$, $p < .001$, $d = 0.45$. Liking was also greater for faces paired with distractors than for novel faces, $t(47) = 6.68$, $p < .001$, $d = 0.34$. Overall, ratings were greater for female faces than male faces, $F(1, 46) = 39.2$, $p < .001$, $\eta_p^2 = .460$. No other effects or interactions were significant: largest $F(1, 46) = 0.95$, $p = .335$ for the participant gender x face type interaction. Thus, participants in this experiment liked the female faces more than the male faces, liked faces more if they were presented during encoding (possibly reflecting mere exposure; Zajonc, 1968), and liked faces best if they had been presented with a target. These results extend cued approach to faces (Schonberg et al., 2014) and verify that liking was greater for the attractive female faces than for the unattractive male faces.

Recognition memory for faces. If changes in the perceived value of the background image are responsible for the attentional boost effect, then faces that were perceived as more valuable (i.e., those presented with targets or female faces) should also have been better remembered. Because cued approach was similar for valuable and neutral faces, the value-driven memory account predicts additive effects of value and encoding condition. In contrast, the attention-to-value accounts suggest the attentional boost effect should be smaller for more valuable faces. However, there was little evidence that value enhanced memory in this task: memory for the neutral faces was better than memory for the valuable faces = 33.2, $p < .001$, $\eta_p^2 = .42$, for both male and female participants, $F(1, 46) = 2.64$, $p = .111$. Neither male nor female participants were likely to remember valuable (attractive female) faces better than neutral (nonattractive male) faces. In addition, the attentional boost effect was robust in these data, $F(1, 46) = 34.6$, $p < .001$, $\eta_p^2 = .429$, and was similar in magnitude for both types of face and for both male and female participants: face type x encoding condition interaction, $F(1, 46) = 0.11$, $p = .801$, and participant gender x encoding condition x face type interaction, $F(1, 46) = 0.85$, $p = .36$. The attentional boost effect was larger for female participants than male participants, participant gender x encoding condition interaction, $F(1, 46) = 4.16$, $p = .047$, $\eta_p^2 = .083$. The main effect of participant gender was not significant, $F(1, 46) = 0.07$, $p = .792$. BF analysis indicated that the best fitting model included main effects of face type and encoding condition (BF = 2.127×10^{11}, relative to the null model). Evidence for this model was at least 4.646 times greater than any model with an interaction between face type and encoding condition.

An item-wise analysis was also performed on the 319 faces for which data were available in all four conditions (see *Data Analysis*). Because participant gender significantly affected the novel face ratings, $F(1, 318) = 5.1$, $p = .025$, $\beta = -0.08$, different ratings were used for each group. Results indicated that a face was better remembered when it had been paired with a target square rather than a distractor square, $F(1, 318) = 37.6$, $p < .001$, $\beta = 0.28$, but that this effect decreased as liking increased, $F(1, 632) = 6.42$, $p = .012$, $\beta = -0.17$. Overall, faces were more poorly remembered the more they were liked, $F(1, 632) = 8.35$, $p = .004$, $\beta = -0.19$. In addition, although there was a trend for male participants to perform more poorly than female participants on the memory test, $F(1, 632) = 3.02$, $p = .083$, $\beta = -0.08$, this difference reversed for faces with low liking ratings, $F(1, 632) = 14.3$, $p < .001$, $\beta = -0.3$. No other effects or interactions were significant: largest $F(1, 632) = 2.13$, $p = .145$, for the encoding condition x participant gender interaction[3]. To summarise, faces that were liked more were remembered more poorly, demonstrated a weaker attentional boost effect, and were more accurately recognised by female participants than male participants (Figure 3b). Faces that were liked less (typically male faces) were more accurately recognised by male than female participants, perhaps reflecting an own-gender bias.

Memory for the face-square conjunction. Memory for the square that appeared with the face during encoding (Figure 3c; Supplementary Material) was analysed. The type of square appeared with a face was more accurately reported if the face was paired with a target rather than a distractor, $F(1, 42) = 37.7$, $p < .001$, $\eta_p^2 = .473$. This effect was larger for neutral (unattractive male) faces than for valuable (attractive female) faces, face type x encoding condition interaction, $F(1, 42) = 4.59$, $p = .038$, $\eta_p^2 = .098$. There were no other reliable effects, largest $F(1, 42) = 2.15$, $p = .15$, for the main effect of participant gender.

Discussion. Experiment 2 manipulated value by asking male and female participants to remember faces that differed in their gender, attractiveness, liking, and the amount of time a person might like to view them. The effect of value was examined separately for participants of each sex to allow for the possibility that this particular type of value could be more meaningful for male participants than for female participants (Becker et al., 2005; Levy et al., 2008; Maner et al., 2003). As in Experiment 1, target detection enhanced memory for the concurrently presented faces, increased liking of the paired face (above the effects of

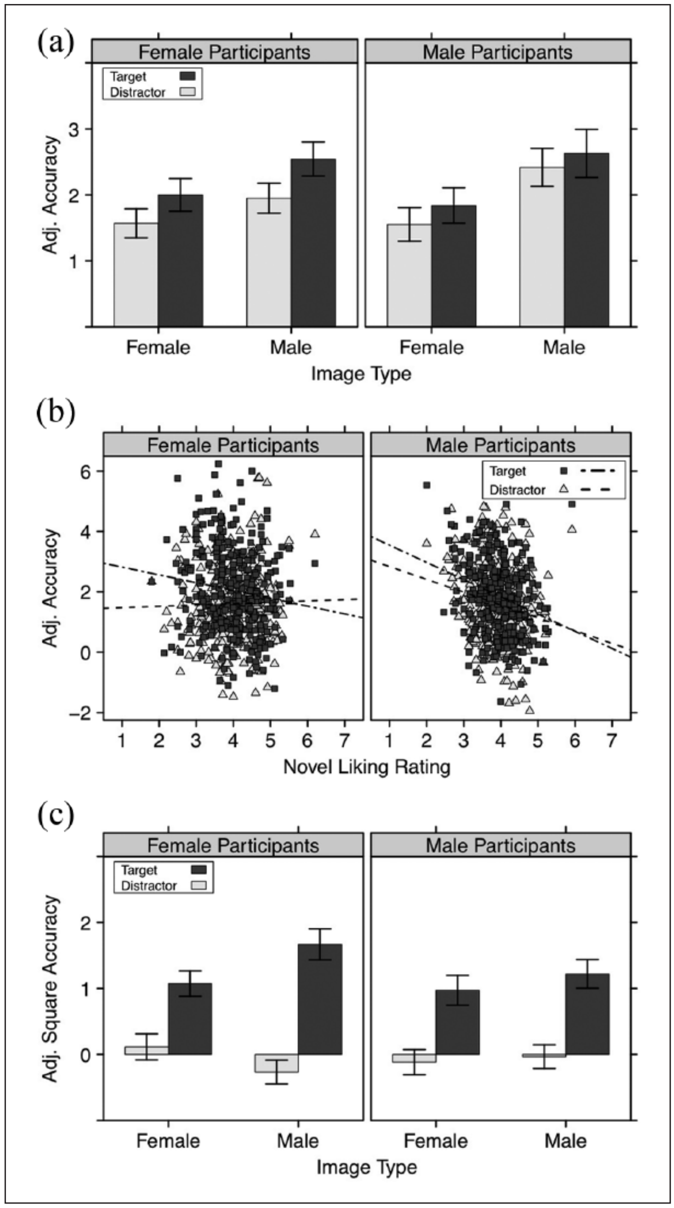

Figure 3. Recognition memory for faces presented in Experiment 3. (a) Recognition accuracy (in logits), across face types and encoding conditions. (b) Recognition accuracy as a function of encoding condition and its mean liking rating when novel. (c) Accuracy for the square that appeared with a correctly recognised old face (adj. square accuracy) across face types and encoding conditions. Error bars represent +/-1 standard error of the mean.

mere exposure, e.g., Zajonc, 1968), and was associated with better relational memory for the square-picture pair (particularly for less valuable faces). However, the item-wise analysis suggests that faces that were liked more were also more poorly remembered and showed a weaker attentional boost effect.

If the effect of target detection on memory for background images is mediated by their effect on the image's perceived value, then memory should be better for valuable faces overall. In addition, these effects should be strongest for individuals for whom the images are motivationally significant, such as males viewing female faces. The data failed to support these predictions. The attentional boost effect was stronger for female participants than for male participants, memory for a face was negatively, not positively, related to how much it was liked, and the magnitude of the attentional boost effect *decreased* as liking increased when liking was treated as a continuous variable in the item-wise analysis. This finding may be surprising given that multiple studies have demonstrated a memory benefit for attractive faces (Anderson et al., 2010; Maner et al., 2003; Marzi & Viggiano, 2010; Tsukiura & Cabeza, 2011), particularly for male participants (Becker et al., 2005). However, other studies report a negative relationship between attractiveness and memory when other factors such as typicality and other inferred personality traits are also modelled (e.g., Bainbridge, Isola, & Oliva, 2013).

Because value did not have the expected effect on memory, the pattern of data in Experiment 2 also contradicts the attention-to-value account. This account predicts that the advantage for target paired items should be smaller for better remembered valuable items. However, because the magnitude of the attentional boost effect was smaller for the better liked images in the item-wise analysis, these data are not consistent with the claim that the same mechanism that improves memory for valuable items also improves memory for target-paired items. In addition, like Experiment 1, relational memory was numerically worse for valuable than for neutral items, and this difference reached significance in Experiment 2. This finding was unexpected, but is potentially consistent with work suggesting that learning value can interfere with declarative memory formation (Wimmer et al., 2014). We return to these findings in the General Discussion.

Experiment 3: food and neutral objects

The data from the first two experiments provided little evidence that value drives the memory advantages for target-paired items in the attentional boost paradigm. These findings are inconsistent with a large literature on the effects of value on long-term memory (though, we note, with longer study times and retention intervals). Experiment 3 therefore again tested the effect of value on memory and the attentional boost effect, but this time with stimuli that are potentially more valuable: images of food. Food is considered a primary reward (Schultz, 1986), and pictures of food elicit activity in valuation and reward-related brain systems, such as the ventromedial prefrontal cortex (e.g., Killgore et al., 2003). The response of these systems to pictures of food is correlated with an individual's sensitivity to reward (Beaver et al., 2006). Experiment 3 therefore used pictures of food and toys as stimuli to increase the salience of the item's value.

To further increase the motivational significance of the food, half of the participants were instructed to avoid consuming any food or drinks (other than water) for at least 4 hr prior to the experiment. Participant's current level of hunger was also evaluated. In addition, participants were told that they would get to choose a food item at the end of the experiment. The perceived value of an item therefore was not completely determined by the stimulus itself or by existing group differences. If value influences memory in tasks that examine the attentional boost effect, then food should be better remembered than toys, particularly for hungry individuals. In addition, because liking an item can be dissociated from wanting to obtain or consume it, in Experiment 3 participants rated how much they wanted the food item. If the value-based memory account is correct, wanting ratings should be positively related to declarative memory.

Methods

Participants. In all, 50 undergraduate students (32 female, 18 male, mean age = 20.44, *SD* = 1.31) participated for extra credit or monetary compensation. All participants were screened for colour blindness. One additional participant did not pass the colour blindness screen. With $\alpha = .05$, power was .8 to detect an effect of $d \geq 0.51$ within groups ($N = 25$) and $d \geq 0.36$ without regard to group ($N = 50$) in one-sided, paired samples *t*-tests. For an interaction of between (fasting, two levels) and within participants factors (value or encoding condition, two levels), power was .8 to detect an effect of size $\eta_p^2 \geq .039$ (correlation among repeated measures = .5, no correction for nonsphericity).

Equipment and stimuli. Participants were tested with a 24-inch BenQ XL2430T LED monitor (1920 x 1080, 144 Hz, 1 ms GTG) connected to a Windows PC running MATLAB and Psychtoolbox.

Experimental stimuli (256 x 256 pixels) were obtained largely from Tim Brady's website (Brady et al., 2008). Four exemplars from each of 20 categories of food items (e.g., cheese, cakes, breads) and toys (toy horses, Frisbees, balls) were identified to produce a set of 80 food images (valuable) and 80 toy images. An additional 10 images from each category were selected for the practice trials. Images were randomly assigned to encoding conditions for each participant.

Participants completed the General Food Cravings Questionnaire-Trait (G-FCQ-T) and the General Food Cravings Questionnaire-State (G-FCQ-S) to provide quantitative measures of trait and state levels of hunger, (Nijs, Franken, & Muris, 2007).

Procedure and design. Participants were randomly assigned to the fasting or no fasting condition. The evening before participants came to the lab, they received an email informing them that they should (or should not) refrain from eating and drinking anything but water for 4 hr prior to their appointment. They were also asked to fill out the online *G-FCQ-T* as soon as they received the email, if possible. Participants who did not complete the questionnaire before the session ($N = 13$) were contacted again after the session and asked to complete it as soon as possible. Seven of these participants completed the questionnaire at a later time.

After providing informed consent participants were tested for colour blindness. They then completed the *G-FCQ-S* and indicated how many hours it had been since they had consumed anything other than water, and what, if

Table 2. Means and standard deviations (in parentheses) of self reported measures of hunger for participants assigned to the fasting and nonfasting groups of Experiment 3.

Group	Time since eating (hr)	Trait hunger	Pre-test state hunger	Post-test state hunger
Non fasting	3.33 (4.14)	3.07 (0.74)	2.38 (1.01)	2.59 (1.09)
Fasting	8.13 (5.04)	3.02 (0.7)	3.05 (0.62)	3.42 (0.79)

anything, they had consumed in the previous 4 hr. Participants were informed that they would get to choose one snack item to take with them at the end of the study. Participants then completed the dual-task encoding phase of the experiment, which was identical to Experiment 1. The old-new recognition test was identical to that used in Experiment 1, except that participants rated how much they currently wanted the pictured item (rather than how much they like it) from 1 (not at all) to 7 (very much). Afterwards, participants completed the *G-FCQ-S* a second time and chose one of four available food items (a bag of cookies, a bag of chips, a candy bar, or an apple).

Results

Square detection. The nonfasting group performed worse on the detection task than did the fasting group, particularly when the squares appeared with neutral objects (Table 1). For target hit rates, this resulted in trends for the main effect of group, $F(1, 48) = 3.32$, $p = .074$, $\eta_p^2 = .065$, and for a group x object type interaction, $F(1, 48) = 3.06$, $p = .086$, $\eta_p^2 = .060$. Neither effect was significant for FA rates or response times, largest $F(1, 48) = 1.67$, $p = .202$, for the main effect of group on response times. For both groups, however, response times were ~4.8 ms faster to squares that appeared at the same time as food. The difference was marginally significant, $F(1, 48) = 3.81$, $p = .057$, $\eta_p^2 = .074$. Object type did not reliably affect hit rates, $F(1, 48) = 0.05$, $p = .832$, or FA rates, $F(1, 48) = 0.003$, $p = .955$. These data suggest weak effects of object value and motivational state on detection task performance.

Manipulation check: trait and state hunger. Participants generally complied with instructions to fast or not (Table 2). The fasting group had eaten less recently, $t(46.2) = 3.68$, $p < .001$, $d = 1.04$, and reported greater state levels of hunger than the nonfasting group, main effect of group (2-way repeated measures ANOVA, with group and time as factors), $F(1, 48) = 9.14$, $p = .004$, $\eta_p^2 = .160$. State hunger reliably increased for both groups over time, main effect of time, $F(1, 48) = 23.0$, $p < .001$, $\eta_p^2 = .324$, time x group interaction, $F(1, 48) = 1.75$, $p = .192$. Trait hunger did not differ across groups, Welch two sample *t*-test: $t(41.3) = -0.24$, $p = .809$.

Manipulation check: wanting ratings. Participants, particularly those in the fasting group, wanted food more than toys (Supplementary Material), $F(1, 48) = 89.3$, $p < .001$, $\eta_p^2 = .650$, and group x object type interaction, $F(1, 48) = 4.06$, $p = .05$, $\eta_p^2 = .078$. A reliable main effect of encoding condition, $F(2, 96) = 21.6$, $p < .001$, $\eta_p^2 = .310$, indicated that wanting was greater for objects presented with targets than for objects presented with distractors, and old objects were wanted more than novel objects. The difference in ratings of old and new object may reflect the mere exposure effect (Zajonc, 1968). The magnitude of these differences was greater for food than for toys, resulting in an object type x encoding condition interaction, $F(2, 96) = 10.9$, $p < .001$, $\eta_p^2 = .185$. This is the first evidence in our study that the effects of target detection on perceived value were greater for items that were already more highly valued (cf. Schonberg et al., 2014).

Recognition memory for objects. As with the first two experiments, the value-driven memory and attention-to-value accounts of the attentional boost effect predict better memory for the valuable objects (food) than for the neutral objects (toys). In addition, because the effects of target detection on perceived value were greater for valuable objects (food), the value-driven memory account predicts an over-additive interaction between encoding condition and object type. In contrast, the attention-to-value account predicts an under-additive interaction.

Recognition memory for the objects is illustrated in Figure 4a and 4b. Memory was better for objects presented with a target square rather than a distractor square, $F(1, 48) = 107$, $p < .001$, $\eta_p^2 = .69$, and, marginally, for participants in the fasting condition than those in the nonfasting condition, $F(1, 48) = 3.69$, $p = .061$, $\eta_p^2 = .071$. However, no interactions among these factors were statistically significant, largest, $F(1, 48) = 2.73$, $p = .105$, for the three way interaction between group, object type, and encoding condition.[4] In a BF analysis, the best fitting model included only main effects of encoding condition and fasting condition ($BF = 5.236 \times 10^{11}$, against the null). Evidence for this model was 3.859 times greater than the best fitting model that included an interaction between object type and encoding condition.

A second item-wise analysis examined recognition memory across the 159 objects with data in each cell of the design (see *Data Analysis*). As illustrated in Figure 4b, objects were better recognised when they were presented with a target rather than a distractor, $F(1, 158) = 96.4$, $p < .001$, $\beta = 0.59$, and by fasting participants than nonfasting participants, $F(1, 312) = 46.6$, $p < .001$, $\beta = 0.42$. However, the difference between groups increased with the object's

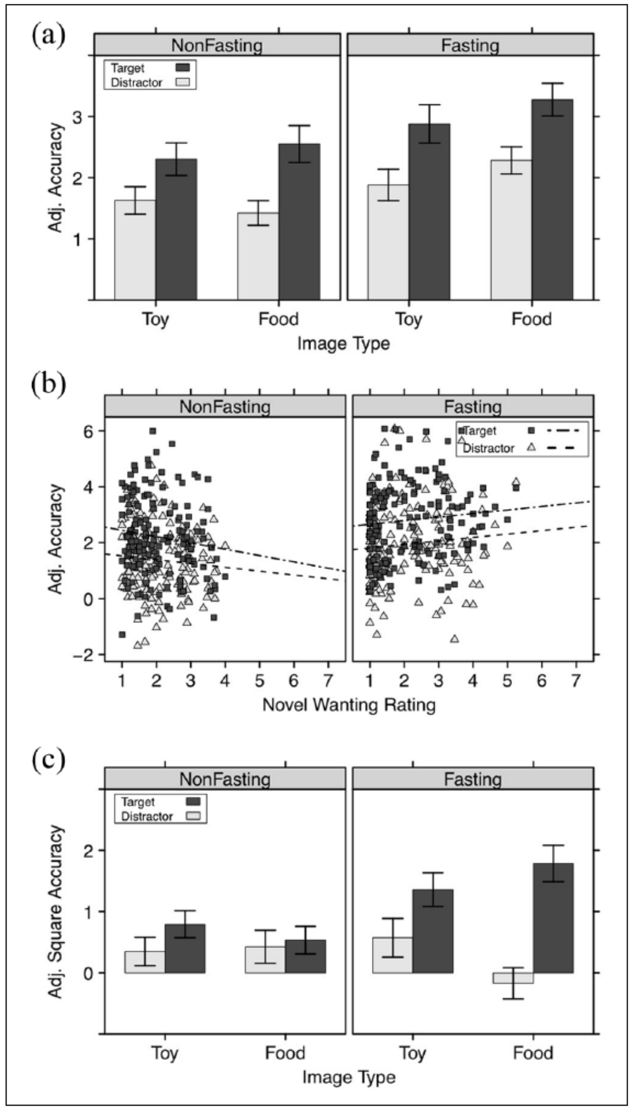

Figure 4. Recognition memory for objects presented in Experiment 3. (a) Correct recognition (in logits) of old objects across object types and encoding conditions. (b) Recognition accuracy as a function of encoding condition and its mean wanting rating when novel. (c) Accuracy for the square that appeared with a correctly recognised old object across face types and encoding conditions. Error bars represent +/-1 standard error of the mean.

value, group x rating interaction, $F(1, 312) = 5.36$, $p = .021$, $\beta = 0.17$. This interaction reflects a negative relationship between memory and wanting in the nonfasting group, combined with a positive relationship in the fasting group. When the data from each group were analysed separately in post hoc tests, however, wanting ratings were not predictive of memory performance, $F(1, 157) = 2.46$, $p = .119$, $\beta = -0.13$ for the nonfasting group and $F(1, 157) = 1.95$, $p = .165$, $\beta = 0.09$ for the fasting group. Other than this interaction, there was no evidence of a reliable effect of the object's value on memory for the object, or on the attentional boost effect.

Memory for the object-square conjunction. Memory for the square that appeared with the old image was evaluated (Figure 4c). Fasting participants were better able to correctly report which square appeared with an old object, $F(1, 41) = 6.62$, $p = .014$, $\eta_p^2 = .139$. The effect of fasting was strongest for items that appeared with a target square during encoding, resulting in a group x encoding condition interaction, $F(1, 41) = 4.38$, $p = .042$, $\eta_p^2 = .096$, and a significant main effect of encoding condition, $F(1, 41) = 9.52$, $p = .004$, $\eta_p^2 = .188$. There were no significant effects of object type, largest $F(1, 41) = 2.21$, $p = .145$, for the three-way interaction.

Discussion. In Experiment 3, pictures of food and toys were used to determine whether changes in perceived value could explain the memory effect observed in an attentional boost effect task. As expected, participants reported wanting the food items more than the toys, and this difference was greater for participants who fasted. Items that were paired with targets were also wanted more than those that were paired with distractors.

Again, the data did not support either the value-driven memory or attention-to-value account of the attentional boost effect. Item value was not found to influence memory in the participant-wise analysis (Figure 4a). In addition, in the item-wise analysis value did not influence memory when the fasting and nonfasting groups were analysed separately. Rather, the most striking aspect of these data is that the effects of value on memory were largely the same in this experiment as they were in Experiments 1 and 2. Though target detection improved memory for the concurrent item in all conditions, the value of the item had only minor effects on memory. Value did not moderate the attentional boost effect: the magnitude of the effect of target detection on memory for the item was similar for valuable and neutral items for both fasting and nonfasting participants. These data support the conclusion that changes in perceived value are unlikely to account for the attentional boost effect.

This experiment yielded our first evidence that value might positively influence memory in the attentional boost effect paradigm: the difference in memory performance for fasting and nonfasting participants increased with wanting ratings in the item-wise analysis (Figure 4b). In addition, fasting participants more accurately reported the colour of the square that appeared with items when the square was a target (Figure 4c). This could reflect better overall task performance in the fasting group than in the nonfasting group (fasting participants responded more quickly to targets than did nonfasting participants, and also showed marginally better overall memory, Figure 4a). Although these findings should be replicated, they provide some preliminary evidence that value could influence memory processes in an attentional boost effect task under some conditions.

General discussion

Three experiments explored the role of value in the attentional boost effect. Participants performed a detection task on a centrally presented square as they memorised a series of individually presented, but unrelated items. Trials varied along two dimensions: whether a target or a distractor square appeared and whether the pictured item was likely to be perceived as valuable or as neutral. We tested participants' memory for the items and their ability to pair the item with the type of square it was presented with during the encoding task. Participants also reported their liking (Experiments 1 and 2) or wanting (Experiment 3) of the picture. These ratings provided a basis for evaluating the effect of target detection on perceived value, helped verify that valuable items were liked or wanted more, and provided a continuous measure of value for each object in an item-wise analysis.

Several findings consistently emerged across all three experiments. First, as in earlier research, those items that were paired with a target square were better remembered than those that were paired with a distractor square, replicating the attentional boost effect (e.g., Lin et al., 2010; Swallow & Jiang, 2010). Second, items that were paired with a target square were perceived to be more valuable than those that were paired with a distractor square, replicating cued approach (Schonberg et al., 2014) in the attentional boost effect paradigm. Third, in a novel finding, we found that memory for the colour of square that appeared with the item was enhanced on target trials. These experiments represent an important extension of the cued approach findings to new stimuli and tasks and are the first to demonstrate a relational memory advantage for target-paired items.

Of central focus was whether changes in the perceived value of items can account for the memory benefit for items that are paired with targets (value-driven memory account). If changes in perceived value are responsible for the effects of target detection on memory in this task, then memory should be enhanced for more valuable items. In addition, earlier findings (Schonberg et al., 2014) suggest that the attentional boost and cued approach effects might be larger for the valuable items than for the neutral items. Yet, we found no evidence for either of these possibilities. In three experiments, neutral items were remembered as well as or better than valuable items regardless of whether they were paired with a target or distractor square. There was no difference in the effect of target detection on memory for objects categorised *a priori* as valuable or neutral (Experiment 1), faces that differed in attractiveness and liking for male and female participants (Experiment 2), or for food and toys regardless of whether the participant was asked to fast (Experiment 3). BF analyses (Rouder et al., 2012) indicated moderate evidence against interactions between value and encoding conditions in all experiments. Furthermore, the effect of target detection on memory was not positively correlated with participants' liking or wanting ratings of the objects.

In addition, if value drives the memory benefit observed in the attentional boost effect, then those conditions that produce the largest differences in value should also produce the largest memory effects. However, this was not the case. Across the four conditions created by crossing *a priori* value and encoding condition, the largest effect on memory was the contrast between the target and distractor conditions. The largest difference in perceived value was the contrast between valuable and neutral items. In Experiment 3, the effect of target detection on perceived value was greater for already valuable items. Yet, the same pattern was not present in the memory data. Thus, even when value and target detection interact to produce larger effects on perceived value, they do not necessarily produce larger effects on memory. The item-wise analyses that treated value as a continuous measure similarly failed to reveal either a positive relationship between value and memory, or a consistent effect of value on the attentional boost effect. Together, the findings from these three experiments suggest that the memory boost for target-paired stimuli is unlikely to be driven by perceived value.

We also found no evidence for an attention-to-value account in these data. This account predicts that valuable items should be remembered better than neutral items in the attentional boost paradigm. It also predicts that valuable items should show a smaller memory benefit than neutral items from being paired with a target (an under-additive effect). We found little support for either prediction in our data. Notably, these conclusions are limited to the role of value in the attentional boost effect and do not call into doubt earlier work on the role of distinctiveness in the attentional boost effect (Mulligan et al., 2014; Spataro et al., 2015). Unlike manipulations of value in this study, this earlier research demonstrated that items that were more distinct were also better remembered.

It is possible that varying value in a different way might have led to different results. However, by employing multiple types of value our experiments cast a relatively broad net. We also manipulated the motivational salience of the items across groups of participants in Experiments 2 and 3. In Experiment 2, we evaluated the effect of attractiveness (which was also varied with gender) by contrasting performance of male and female participants. Attractive faces are particularly likely to be valuable for individuals of the opposite gender (Aharon et al., 2001; Bray & O'Doherty, 2007), though both men and women show memory benefits for attractive female faces (e.g., Anderson et al., 2010; Maner et al., 2003; Marzi & Viggiano, 2010). In our stimuli, attractiveness was strongly correlated with other measures of subjective value, such as liking and time one would spend viewing the images, but also could have varied in other ways that were not controlled. In Experiment 3, we asked half of our participants to fast for four hr prior to participating, which allowed us to compare fasting participants, for whom food was likely to be more motivationally relevant, and nonfasting participants (all of them knew they would receive a snack at the end of the experiment). Nevertheless, the results were the same across all studies and for all groups: value was not positively related to memory and did not consistently modulate the effect of target detection on memory.

For these experiments, valuable items were defined as being pleasurable or better able to fulfil a need than neutral items if they were acquired. It is possible that the independent raters sorted items into valuable and neutral categories based on factors other than value. If so, this could have contributed to the null effects of value in most participant-wise analyses. However, item categories were validated by the participants' liking and wanting ratings: participants in Experiments 1 and 2 liked the valuable items more than the neutral items and participants in Experiment 3, particularly those who had fasted, wanted the food items more than the toys. More importantly, analyses in which we operationalised value on the basis of these ratings again failed to find a positive relationship between value and memory. In many instances, memory decreased as items were typically liked or wanted more (participants in Exp. 1, male participants in Exp. 2, nonfasting participants in Exp. 3).

Several other factors could explain why value did not reliably influence memory in our experiments, but influenced memory in earlier work (e.g., Cohen et al., 2014; Dolcos et al., 2004; Marzi & Viggiano, 2010). Participants in Experiments 1-3 were given a very short time (200-500 ms) to study the items. Longer presentation of the pictures during encoding might increase the effect of the picture's value on memory. Participants were also not instructed to attend to the item's value, which may have reduced its effect on memory. Alternatively, other types of manipulations may be necessary. For example, in one study, emotionally valenced images were paired with coloured squares that indicated whether monetary reward was available on an upcoming task (Wittmann et al., 2008). Memory for images paired with reward cues was better only if the images themselves were positively valenced, an effect that was mirrored by activity in the striatum. Similarly, our experiments paired valuable or neutral items with squares that were either behaviourally relevant targets or distractors. Though these items differed in how much they were explicitly liked or wanted, as common, everyday objects, they may not have elicited strong emotional responses. Finally, the delay between encoding and test is only a couple minutes in standard attentional boost effect paradigms. Previous studies have shown that the effects of value on explicit memory may depend on hippocampal consolidation and therefore take much longer to emerge, possibly as much 24 hr (Anderson et al., 2006; Koster et al., 2015; Sharot & Phelps, 2004; Spaniol et al., 2013; Tompary et al., 2015; Wittmann et al., 2005).

Future research should explore whether having a longer fasting period (e.g., 1 day instead of 4 hr), using a primary reward (e.g., juice), or tailoring stimulus conditions to each participant's preference would result in a memory advantage for valuable items. In addition, obtaining a measure of the items' perceived value before as well as after the target detection task in a pre- and post-test design (as in Schonberg et al., 2014) might reveal an effect of value on memory. This type of design has several advantages but was not employed here to avoid contaminating the memory data and sensitising participants to value during encoding (thus creating demand characteristics). Therefore, future research that acquires value ratings from participants before and after the encoding task will need to ensure that pre-tests of the item's value do not interfere with memory performance or alert participants to the manipulation.

While experiments investigating these issues would be informative, they are not necessary for addressing our main question of interest: whether value can explain the attentional boost effect, which is present in the conditions we tested in this study. Indeed, even if testing the items a day later revealed an effect of value on memory, it would not be able to account for the immediate memory benefits associated with target detection. In addition, increasing the duration of the images to increase the effects of value on memory could eliminate the attentional boost effect (cf. Mulligan & Spataro, 2014). Moreover, participants' liking and wanting ratings, particularly in Experiment 3, conformed to our predictions: Ratings were greater for rewarding objects, attractive faces, and food, and were modulated by the participant's current motivational state. This suggests that although more subtle effects of value on the attentional boost effect may be discovered, it is unlikely that better memory for the target-paired items in these tasks is due solely to the fact that they are also subsequently perceived as more valuable.

Importantly, explanations for the lack of a positive effect of value on memory do not clearly account for the negative effect of value on memory in these experiments. We propose three possible explanations that can be addressed in future research. First, it will be important to determine if the effects were idiosyncratic to these experiments. The negative relationship between value and memory was not observed in all groups or analyses, suggesting that it may not be replicable. A second potential explanation is that competition between the detection task and the encoding task might have been greater when items were liked or wanted more. High value items are more likely to draw attention than low value items and may interfere with task performance (Anderson et al., 2011; Leong et al., 2017). If similar effects are at play in this paradigm, participants might have inhibited the valuable items to maintain performance on the detection task and interference may be greater when targets are presented (producing the interaction in Experiment 2, an effect that needs to be replicated). A third possibility is that the large sample in the item-wise analyses (in which the data points were pictures rather than participants), may have revealed a subtle effect of value on immediate memory that was missed in other studies. Episodic encoding and value learning may compete (Wimmer et al., 2014): Functional connectivity between the hippocampus and striatum is greater both during the successful encoding of an item and when reward learning is reduced. Thus, if this effect is replicable, it may be caused by some form of competition (dual-task or systems level). Either way, the negative relationship between value and immediate memory may be offset by the consolidation advantages for valuable stimuli that emerge over longer delays (Koster et al., 2015; Spaniol et al., 2013; Tompary et al., 2015; Wittmann et al., 2005).

These experiments advance our understanding of the effects of target detection on the way concurrently presented items are processed. Importantly, they provide a valuable replication and extension of the cued approach findings. In all three experiments, items that were paired with a target were perceived as more valuable than novel items or items that were presented on their own. This effect of target detection on liking and wanting was observed within a paradigm that differed significantly from that used by Schonberg and colleagues (2014) (i.e., in presentation rate, target modality and timing, the presence of distractors, the type of items used, and the way value was measured). Like Schonberg and colleagues (2014), in Experiment 3, the effect of target detection on liking depended on the initial value of the item (though not in Experiments 1 and 2). Differences in our data could reflect any of the large number of procedural differences in the cued approach and attentional boost effect paradigms. Two potentially critical factors are the percentage of items that were paired with targets (50% in Experiments 1-3 and 25% in Schonberg et al., 2014) and the amount of time that participants had to respond (1000 ms in Experiments 1-3 and ~380 ms in Schonberg et al., 2014; see also Bakkour et al., 2016). Though target frequency may not modulate the attentional boost effect (Swallow & Jiang, 2012), it may influence the effects of targets on the perceived value of concurrently presented items, particularly when response periods approach 1 s in duration (Chen, Veling, Dijksterhuis, & Holland, 2016). Given these considerations, it would be interesting to explore how target frequency and response deadline manipulations in the attentional boost effect paradigm influence the effects of target detection on perceived value and memory.

These experiments also explored whether target detection and value influenced relational memory. We were interested in whether participants could more accurately report which square appeared with an item when the square was a target square and when the item was valuable. In all experiments, reports of the colour of the square that appeared with an item were more accurate for target-paired items than for distractor-paired items, even after adjusting for response biases. Target detection thus appears to facilitate memory for the concurrent item as well as relational memory for the square that it appeared with.

The finding that target detection influences relational memory provides some insight into the nature of the attentional boost effect. Unlike item memory, relational memory is more strongly associated with processing in the medial temporal lobe and hippocampus (Davachi, 2006; Hannula, Tranel, & Cohen, 2006). In addition, interactions between the medial temporal lobe and regions involved in coding value and reward are thought to support superior memory for valuable information than for neutral information (Dolcos et al., 2004; Hamann, Ely, Grafton, & Kilts, 1999; Koster et al., 2015; Shohamy & Adcock, 2010; Tompary et al., 2015; Wittmann et al., 2005). The relational memory data provide some suggestive evidence of a role for these systems in the attentional boost effect. They also raise the possibility that an item may act as a stronger retrieval cue during the recognition test if it was paired with a target square during encoding. This could be particularly beneficial to recall when targets were less frequent (and more distinctive) than distractors (Schmidt, 1991; Waddill & McDaniel, 1998). However, the role of target detection in context memory finds mixed support in two recent studies. Mulligan, Smith, and Spataro (2016) found no evidence that target detection enhanced memory for the perceptual or contextual details of words that were presented during a target detection task. In contrast, Leclercq, Le Dantec, and Seitz (2014) found that participants were more likely to report recalling episodic details of images that were paired with a target rather than a distractor during encoding. Although there are many differences among all of the studies, it is worth noting that experiments supporting an effect of target detection on relational memory used pictures rather than verbal materials.

Overall, the data best fit accounts of the attentional boost effect that posit that behaviourally relevant events, such as targets in these tasks, briefly enhance the encoding of concurrently presented stimuli via attentional mechanisms (Jiang & Swallow, 2014; Mulligan & Spataro, 2014; Swallow & Jiang, 2013; Swallow et al., 2012). In accordance with this account, target detection (vs. distractor rejection) increased memory for concurrently presented stimuli to a similar degree regardless of the item's value. Relational memory was also enhanced for target trials. This finding is in line with previous accounts of the attentional boost effect that suggests it is caused by an early modulation of encoding processes (Mulligan & Spataro, 2014), or complementarily, as a consequence of attentional mechanisms that select behaviourally relevant moments in time (Swallow & Jiang, 2013). On the latter view, the appearance of a behaviourally relevant event, such as the target in this task, triggers attentional gain mechanisms that broadly facilitate the processing of information encountered at that moment in time (see also Markovic, Anderson, & Todd, 2014). If attending to an item increases its value, then attending to behaviourally relevant events in this way could produce both the cued approach and attentional boost effects. Consistent with this possibility, recent research on cued approach training suggests that it reflects attentional orienting to items as participants anticipate the onset of a target tone (Bakkour et al., 2016).

Conclusion

In three experiments target detection enhanced memory for concurrent items, increased their perceived value, and facilitated relational memory. However, there was no evidence that valuable items were remembered better in this paradigm, arguing against the possibility that the memory benefits are due to changes in perceived value. Rather, the data are consistent with the view that the attentional boost effect likely reflects changes in encoding (Mulligan & Spataro, 2014; Seitz & Watanabe, 2009; Swallow & Jiang, 2013). Whatever these processes may be, our data suggest that their effect on memory is not strongly mediated by perceived value.

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Supplementary material

The Supplementary Material is available at: qjep.sagepub.com

Notes

1. *d*,' was not used because new images would have to be randomly assigned to target and distractor conditions (there were no new images paired with targets or distractors), introducing instability in the results.
2. Of the male participants, 87% reported being most attracted to females and 13% to males. Of the female participants, 69% reported being most attracted to males, 26% to females, 2% to neither, and 2% did not wish to report.
3. Prior familiarity with the faces may have introduced noise in the data. However, all significant effects remained significant, and no other effects reached significance after variance in familiarity was statistically removed from the data.
4. A secondary analysis that used participant's state hunger in place of the categorical fasting factor yielded similar results.

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