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Emotional attention: Time course and effects of agonistic and antagonistic overlay of intrinsic and goal relevances

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All data, analysis code and material from the study reported in this article are available through the Open Science Framework repository: <https://osf.io/rnvpg/>.

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Abstract

Emotional attention can be explained within a goal-directed theory framework according to which attention is captured by the goal relevance of stimuli, i.e., their conduciveness nature to a momentarily important goal. However, such an explanation does not consider the attentional impact of intrinsic relevance of stimuli, i.e., their general pleasantness. This problem could be resolved by appraisal theories, suggesting that attention is captured by intrinsic relevance and goal relevance of stimuli, whether the relevance overlay is agonistic (e.g., pleasant and goal conducive) or antagonistic (e.g., unpleasant and goal conducive). Moreover, appraisal theories suggest that early and late attentional capture would be more impacted by intrinsic relevance and goal relevance, respectively. In the present study, we confronted the predictions of appraisal theories with that of goal-directed theory. To this end, 120 participants performed parallelly an induction task to induce different relevance values to three colored squares, and a dot-probe task with two different SOA, to measure early and late attentional captures. This paradigm allowed us to measure attentional capture between a neutral stimulus, a goal-relevant stimulus, and an overlay stimulus. The overlay stimulus was agonistic in one group, while it was antagonistic in the other group. Our results showed evidence in favor of appraisal theories. Namely, the overlay stimulus captured more attention than the goal-relevant and the neutral stimulus, regardless of whether the overlay was agonistic or antagonistic. However, our results were mixed regarding the effects of intrinsic relevance and goal relevance on attentional capture as a function of temporality.

Keywords: emotion, attention, appraisal theory, intrinsic relevance, goal relevance

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In a complex and dynamic world, attention allows individuals to interact with their environment appropriately, allocating cognitive resources to relevant information. Based on this premise, “emotional attention” was introduced to describe how emotional information automatically captures attention (Vuilleumier, 2005). The main question of this research field can be summarized as follows: How can we exhaustively define the emotional nature of stimuli that triggers attentional capture? Over the past decades, the most influential theories on emotions have attempted to answer this question.

Building on the basic emotion concept (Ekman, 1992), a highly influential theory has been proposed that places phylogenetic threats as the main source of attentional capture. This theory underlines the importance of emotions for evolutionary survival and defends the idea that snakes or spiders attract attention because it is important to react quickly to their contact for generations and generations (Öhman, 1993; Öhman & Mineka, 2001; LoBue & DeLoache, 2008). However, this proposition has been challenged by results showing that ontogenetic (i.e., learning-dependent) threats also attract attention (Brosch & Sharma, 2005; Fox et al., 2007). Even more problematic, further studies have evidenced that positive information can capture attention (Pool et al., 2016), such as erotic stimuli (Fromberger et al., 2012; Spiering & Everaerd, 2007; Steimke et al., 2017), baby faces (Brosch et al., 2007; Brosch et al., 2008) and happy faces (de Jong et al., 2007; Joormann & Gotlib, 2007). The two-dimensional theory of emotion (Russell, 1980), which focuses on valence and arousal, proposed an answer to this issue: If both positive and negative stimuli capture attention, it is because attentional capture is sensitive to the arousal of stimuli, independently of their valence (Anderson, 2005; Bradley et al., 2001; Lang, 1995). However, it was pointed out that this conception does not seem satisfactory

because arousal would be the consequence of attentional capture and not its cause (Schimmack, 2005). Schimmack (2005), therefore, proposed to refine this relationship by defining arousal as a marker of attentional capture, reflecting the level of depth of processing allocated according to the relevance of the stimulus (Scherer, 2001).

Currently, one of the most influential proposals in the literature for defining how attention is captured based on the emotional nature of stimuli is related to the goal-directed theory (Moors, 2017; Moors et al., 2017; Moors et al., 2021). This theory, focusing on the importance of goal achievement in emotion generation, suggests that attention would be captured by the goal relevance of stimuli (i.e., the stimulus relevance for achieving current vital goals). One of the challenges of empirically testing this hypothesis is to select goal-relevant stimuli for all participants while measuring attentional capture. A common way of doing this is to use induction to generate and maintain the goal relevance associated with the stimuli throughout the task. For example, Vogt et al. (2013) proposed a paradigm combining a go/no-go task, acting as an induction task, with a dot-probe task, acting as an attentional capture measurement task. This paradigm presents the go/no-go task as a game in which the goal is to win as many points as possible and to introduce the emotional stimuli as allowing points to be won. This paradigm allowed the authors to measure attentional capture of the goal-relevant stimulus in the dot-probe task, while relevance was generated and maintained through the go/no-go task. One of the main advantages of presenting an induction task integrated with the experimental task rather than before it is to avoid the induction effect diminishing during the experimental task.

In their third experiment, Vogt et al. (2013) used three patched colors as stimuli. In the go/no-go task, one allowed to win points, one generated an unpleasant noise, and one was neutral. In line with the goal-directed theory hypothesis, the measure of attentional capture in the dot-probe task revealed that the goal-relevant stimulus captured more attention than

the unpleasant stimulus and that the unpleasant stimulus captured more attention than the neutral stimulus. This paradigm was used in a series of tasks where authors consistently observed an attentional capture toward goal-relevant stimuli (Vogt et al., 2017; Forrest et al., 2022; Müller et al., 2016; Sun et al., 2017).

Moreover, using other induction tasks, other studies have demonstrated attentional capture toward different types of goal-relevant stimuli, such as water bottles after a thirst induction (Mazzietti et al., 2014) and cleanliness-related stimuli after a disgust induction (Mazzietti et al., 2014; Vogt et al., 2011).

Appraisal theory proposals about emotional attention

Combined effects of intrinsic and goal relevance

Although the view that attention is captured according to the goal relevance of stimulus seems coherent, it appears to have an important shortcoming. Indeed, this view does not account for attentional capture toward the unpleasant or pleasant nature of stimuli that do not directly concern the achievement of a current goal (e.g., unpleasant stimuli: snakes or spiders, LoBue & DeLoache, 2008; Öhman, 1993; Öhman & Mineka, 2001; firearms, Brosch & Sharma, 2005; Fox et al., 2007; pleasant stimuli: erotic stimuli, Fromberger et al., 2012; Spiering & Everaerd, 2007; Steimke et al., 2017; baby faces (Brosch et al., 2007; Brosch et al., 2008; and happy faces, de Jong et al., 2007; Joormann & Gotlib, 2007). This problem could be solved when considering appraisal theories according to which attention is captured both by the goal relevance of stimuli and by their intrinsic relevance, i.e., their generally unpleasant or pleasant nature, regardless of the state of the organism (Grandjean & Scherer; Scherer, 2009, 2010). In this line, recent evidence showed that intrinsic relevance and goal relevance have combined effects on attention (Fournier & Koenig, 2023) and somatovisceral responses (Aue & Scherer, 2011). This

result means that attentional capture by a stimulus would be greater if it is both intrinsically pleasant and goal-conducive.

Attentional effect of antagonistic overlay of relevances

To our knowledge, the combined effects of intrinsic relevance and goal relevance on attentional biases were only tested in the case of an agonistic overlay, when intrinsic relevance is pleasant and goal relevance is goal-conducive (Fournier & Koenig, 2023). However, in many cases, relevance overlay can be antagonistic, for example, if stimuli are unpleasant and goal-conducive. We can cite the so-called Miller experiment (1944) in which starving rats were confronted with food positioned at a location where electric shocks were delivered. One might ask whether such a stimulus would capture attention since a stimulus that must be both approached because of its goal conduciveness and avoided because of its unpleasantness ultimately requires no action. However, the rats in the Miller experiment oscillated between avoidance and approach tendencies. These oscillations in action tendency would reflect a loop of reappraisals in which the stimulus was appraised as to be approached, then as to be avoided, etc... Thus, it seems more conceivable to assume that antagonistic stimuli would capture attention in the same way as agonistic stimuli to allow for further appraisal before deciding on the action to be taken.

Attentional effect of relevance and temporality

Concerning the effects of intrinsic and goal relevance on attention, another question arises regarding temporality. Although not articulated within the appraisal framework, several pieces of literature evidenced that early and late attentional biases would be driven more by intrinsic relevance (e.g., affective preferences) and goal relevance (e.g., craving), respectively. For instance, more frequent initial gaze orientations toward high-fat food were evidenced for overweight individuals (who usually appreciate this type of food) compared to healthy-weight individuals, while craving and satiety were controlled

(Castellanos et al., 2009; Nijs et al., 2010; Werthmann et al. 2011). However, maintaining gaze over time was positively correlated with craving. Similar findings were found regarding addictive disorders such as nicotine and alcohol addictions (Field & Cox, 2008). Furthermore, Forrest et al., (2022) showed that goal-conducive stimuli captured more attention than unpleasant stimuli and that the attentional bias toward goal-conducive stimuli was greater when the Stimulus Onset Asynchrony (SOA) was longer (250ms vs. 30ms). Such observations may reflect a difference in appraisal processing time between the two types of relevance. In fact, goal relevance appraisal would be time-consuming due to the compilation of two pieces of information, namely the current importance of a goal and the goal conduciveness of the stimulus. In contrast, intrinsic relevance appraisal would occur quickly (Aue et al., 2007; Grandjean & Scherer, 2008; Lanctôt & Hess, 2007), because it requires little information, namely the pleasantness of the stimulus only (Scherer 2013). In other words, while goal relevance is still being appraised, intrinsic relevance is already available to approximate the relevance level of the stimulus. Regarding the impact on the attentional bias, the impact of the intrinsic relevance would be larger in the combined effects of relevance at an early temporality because goal relevance would still be under appraisal. The more time passes, the more complete the appraisal of the goal relevance is, and the larger its impact on the combined effects of relevances on the attentional bias (see Fournier & Koenig, 2023 for a discussion).

The present study

In the present study, we proposed to test the predictions of the appraisal theory regarding emotional attention and to confront them with those of the goal-directed theory. To do this, we compared early and later attentional capture within three pairs among three stimuli: a neutral stimulus, a goal-relevant stimulus, and an overlay stimulus. The overlay

stimulus was both intrinsically relevant and goal-relevant, and relevances could be agonistic or antagonistic.

According to the appraisal theoretical framework, it can be hypothesized that the overlay stimulus captures more attention than the goal-relevant and the neutral stimuli, while the goal-relevant stimulus captures more attention than the neutral stimulus, regardless of temporality and type of overlay (i.e., agonistic, or antagonistic). This would provide evidence in favor of the hypothesis of combined effects of intrinsic and goal relevance on attention in the case of agonistic and antagonistic relevance overlay. However, it can be hypothesized that the magnitude of attentional capture by the goal-relevant stimulus vs. the neutral stimulus is greater at a late stage than at an early stage of temporality. The same hypothesis can be formulated about the overlay stimulus vs. the neutral stimulus. These hypotheses are motivated by the existence of a greater impact of goal relevance on later attentional capture. In contrast, it can be hypothesized that the magnitude of attentional capture by the overlay stimulus vs. goal-relevant stimulus is greater at an early stage than at a late stage of temporality. As both stimuli are goal-relevant, this would result from the greater impact of intrinsic relevance (contained in the overlay stimulus) on early attentional capture.

According to the goal-directed theoretical framework, the overlay and the goal-relevant stimuli would capture more attention than the neutral stimulus. However, no difference is expected between the overlay and the goal-relevant stimuli, since only goal relevance captures attention. Thus, overlaying intrinsic relevance onto a goal-relevant stimulus would have no effect on attentional capture, regardless of the direction of intrinsic relevance (pleasant or unpleasant) and the temporal stage of attentional measurement (early or late).

To test these hypotheses, we proposed an experimental design similar to those used in the literature combining a dot-probe task and an induction task (Vogt et al., 2013; Vogt et al., 2017; Forrest et al., 2022). Three colored squares were made relevant in an induction task, and the attentional capture generated by these squares was measured in a dot-probe task. The induction task consisted of a Go/No-Go task presented as a game in which the aim was to gain as many points as possible. In this task, the square corresponding to the overlay stimulus earned points and generated noise, the square corresponding to the goal-relevant stimulus earned points, and the square corresponding to the neutral stimulus earned no points and generated no noise. Participants were divided into an agonistic group and an antagonistic group. The difference between groups concerned only the overlay stimulus. The overlay stimulus was agonistic in the agonistic group because it earned points and generated a pleasant noise. In contrast, the overlay stimulus was antagonistic in the antagonistic group because it earned points and generated an unpleasant noise. Parallel to the induction task, participants performed a dot-probe task in which the three stimuli were pitted against each other to measure the difference in attentional capture between them. The task was divided into two blocks, one with a short SOA favoring the measurement of early attentional capture, the other with a long SOA favoring the measurement of late attentional capture. It is important to note that the neutral stimulus also required a key press when it appeared in the induction task, even though it did not earn points. Thus, when it was paired to the overlay stimulus or the goal-relevant stimulus in the dot-probe task, the attentional capture measured reflected only a difference in relevance level, not a difference in action necessity.

A rating task was proposed to participants in which they were asked to rate the level of intrinsic relevance (i.e., unpleasantness and pleasantness), goal relevance (i.e., goal conduciveness), and action tendencies (i.e., approach and avoidance) of the three stimuli.

The rating task was first used as a material check. It was also used as an extension of previous work (Fournier & Koenig, 2023), showing that the approach tendency level of stimuli was best predicted by considering both their pleasantness level and their goal conduciveness level. Here, we tested this hypothesis again, taking into account the unpleasantness level, assuming that their unpleasantness would reduce the approach tendency of stimuli. Further, we tested the hypothesis that the avoidance tendency level of stimuli was best predicted by considering their level of pleasantness, goal conduciveness, and unpleasantness. It was assumed that the avoidance tendency level of stimuli would be reduced by their pleasantness and goal conduciveness and increased by their unpleasantness.

Method

Participants

One hundred and twenty-seven students (96 women; $M = 20.22$ years, $SD = 3.45$) from Lyon University participated in the study. Participants had normal or corrected-to-normal vision. The justification for the sample size was described in the Bayesian analysis section.

Materials

The experiment was run on a 21" iMac in a soundproofed room using SuperLab 6 software (Haxby et al., 1991). "Sennheiser HD 219" headphones were used to deliver the sounds throughout the experiment. A French AZERTY keyboard was used to record participants' responses.

Stimuli

Six colored squares (180*180 pixels) were constructed using Affinity Photo. The luminance of each square was equalized to 34.5 cd/m². Luminance measurement was carried out using the "Konica Minolta LS-110 luminance meter". Three colored squares corresponded to the main stimuli: a blue, a pink, and an orange square, while the other three corresponded

to filler stimuli displayed in the induction task: a green, a yellow, and a red square. Two 650ms noises were used, an unpleasant and a pleasant one. The unpleasant sound (ID: 0360) was taken from the International Affective Digitized Sounds-Expanded (IADS-E; Yang et al., 2018), rated as highly negative ($M = 1.92$, $SD = 1.21$) according to the Self-Assessment Manikin (Bradley & Lang, 1994). This sound was delivered through the headphones at an intensity of 90 dBA, so the sound was unpleasant but not harmful to physical integrity (Koster et al., 2004; Hobbs, 1990). The pleasant sound was taken from the video game "Zelda: Breath of the Wild" sound effects database, snipped from the open-source database VG Resource. This sound was delivered through the headphones at an intensity of 80 dBA.

A rating task was designed to ask 15 questions for each participant about the three stimuli of the main set. Each stimulus appeared 5 times: accompanied by a question about its level of unpleasantness, pleasantness, goal conduciveness, avoidance tendency, or approach tendency. The questions regarding the level of unpleasantness and pleasantness were "How unpleasant do you find this square in general?" and "How pleasant do you find this square in general?". The question regarding the level of goal conduciveness was "How much do you feel that this square could make you win?" The questions regarding the level of avoidance tendency and approach tendency were "How much do you want this square not to appear on the screen?", and "How much do you want this square to appear on the screen?", respectively. In addition, one question was asked about the desire to win, "How much do you want to win?" and two questions were asked about the level of unpleasantness and pleasantness of the noises "In general, how unpleasant is this noise for you?" and "In general, how pleasant is this noise for you?", respectively.

Design and procedure

The rating task, the dot-probe task, and the induction task were presented on a black background on the computer screen.

Rating task design

The rating task was proposed three times: once at the beginning, once in the middle, and once at the end of the experiment. The two questions about the level of unpleasantness and pleasantness of the noise were asked only once at the end of the experiment. Responses were given on a quantitative nine-point scale, from 1 (*not at all*) to 9 (*extremely*), using the keyboard keys 1 to 9.

Induction and dot-probe task design

The dot-probe task corresponded to the successive appearance of four events. First, a white fixation cross (16*16 pixels) with two empty squares with white outlines (400*400 pixels) whose centers were at 250 pixels to the left and the right of the cross appeared during a random variable time (from 500 to 1000ms). Second, two stimuli appeared simultaneously in the center of each square during 100ms for the short SOA block or 250ms for the long SOA block. Third, a white dot (26*26 pixels) appeared during 100ms in the center of one of the two squares immediately after the stimuli offset. Fourth, after the disappearance of the dot, responses required to indicate whether the dot appeared in the left square by pressing the “s” key or the right square by pressing the “ù” key.

The induction task consisted of the successive appearance of four events: First, one of the six stimuli from the main or the filler set appeared in a square in the center of the screen for 250ms. Second, the stimulus was replaced by a red question mark in the center of the screen that remained for 1,500ms or until the space bar was pressed. Third, a feedback screen appeared for 650ms indicating whether the response was correct or not and whether points were gained or lost. Fourth, a final screen indicated the current score of the participant during 500ms.

Procedure

First, a consent form was completed. Then, participants were randomly assigned to the agonistic or the antagonistic group, to one of the two block orders (100ms SOA first or 250ms SOA first), and to one of the six possible combinations of associations between the three stimuli of the main set (blue, pink, and orange square) and the three stimulus types (overlay, goal-relevant, and neutral). All these variables were counterbalanced with an equivalent number of participants assigned to each possible combination.

Participants were asked to sit at sixty centimeters from the screen and to put the headphones over their ears. Then, they were asked to place their left index on the "s" key, their right index on the "ù" key, and one of their thumbs on the space bar of the computer keyboard. They were informed that the top five scores would win a FNAC gift certificate of 50€, 40€, 30€, 20€, and 10€, respectively. Then, the instructions were presented and divided into three phases.

First, the induction task was presented alone. The associations between the three stimuli of the main set and their assigned relevance induction type were explained to the participants. It was explained that when one of the stimuli of the main set appeared in the induction task, the space bar had to be pressed when the red question mark appeared. If the space bar was pressed after the overlay stimulus appeared, the feedback screen informed a gain of 20 points, and a noise was produced (i.e., unpleasant for the antagonistic group and pleasant for the agonistic group). If the space bar was pressed after the goal-relevant stimulus appeared, the feedback screen informed a gain of 20 points. If the space bar was pressed after the neutral stimulus appeared, the feedback screen only informed that the response was correct. If the space bar was not pressed after a stimulus of the main set appeared, the feedback screen informed that the response was missed. If the space bar was pressed after a stimulus of the filler set appeared, the feedback screen informed a loss of 20 points. Then, participants were asked to recall the roles assigned to the stimuli and to perform at least 20 trials without error.

Second, the dot-probe task was presented alone. Participants were asked to stare at the fixation cross throughout the whole experiment and to respond as quickly and precisely as possible (Chica et al., 2014) by pressing the “s” key if the dot appeared in the left square, and the “ù” key if it appeared in the right square. The three possible pairs among the three stimuli of the main set could appear (the overlay stimulus vs. the goal-relevant stimulus, the overlay stimulus vs. the neutral stimulus, and the goal-relevant stimulus vs. the neutral stimulus). Once the instructions had been presented, participants performed twelve practice trials until no errors were made. It was said to motivate participants that good performance in the dot-probe task increased the probability that winning stimuli would appear in the induction task.

Finally, participants were explained that a full trial of the experiment consisted of the succession of a trial of the dot-probe task and a trial of the induction task, as illustrated in Figure 1. After they were asked again to recall the relevance induction types assigned to the stimuli, participants performed twelve whole training trials of the experiment. If everything was understood correctly, the experimenter turned off the light and left the room.

The entire experiment consisted of the completion of the initial rating task, the first block of the dot-probe and induction tasks, the intermediate rating task, the second block of the dot-probe and induction tasks, and the final rating task. Each block contained 144 randomized trials. In the dot-probe task, each of the three possible pairs was presented 24 times with a given stimulus in the left square, and 24 times with the same stimulus in the right square. In half of these trials, the dot appeared on the left square, and in the other half on the right square. In the induction task, each of the six stimuli among the main set or the filler set appeared 24 times. Thus, the two blocks of the experiment consisted of a total of 288 trials.

At the end of the experiment, participants were asked if they had worn the headphones for the duration of the task and if they remembered the stimuli and their role. Finally, they were told that they would be contacted again if they won one of the FNAC gift certificates.

Bayesian Analysis

Two points motivated the use of Bayesian analyses: The first point concerns the information richness compared to the Null Hypothesis Significance Test (NHST; Kruschke, 2013; Kruschke 2014). Indeed, obtaining a credibility level of evidence via a measure of the hypothesis likelihood, such as the Bayes Factor (BF), is more informative than the binary acceptance/rejection decision based on an arbitrary threshold such as p-value. Second, the Bayesian analysis allows us to support the null hypothesis rather than not being able to reject it (such as in the case of the NHST). Specifically, Bayesian models allow measuring the level of evidence in favor or against whether data are better predicted as a function of the inclusion of a given effect as a predictor. The interpretation of the BF is quite simple. BF_{10} , the BF providing the likelihood ratio in favor of the hypothesis that the data are better predicted by including a given effect as a predictor, can be interpreted as follows: $BF_{10} \geq 3$ highlights moderate evidence, $BF_{10} \geq 10$ highlights strong evidence, and $BF_{10} \geq 100$ highlights decisive evidence (Kass & Raftery, 1995). BF_{01} , the BF providing the likelihood ratio in favor of the hypothesis that the data are better predicted by not including a given effect as a predictor, can be interpreted in the same way: $BF_{01} \geq 3$ highlights moderate evidence, $BF_{01} \geq 10$ highlights strong evidence, and $BF_{01} \geq 100$ highlights decisive evidence.

The sample size was determined using the sequential Bayes Factor Design Analysis (Schönbrodt & Wagenmakers, 2018). The idea of such a design is to first determine a minimum number of participants (n_{\min}) needed to correctly detect the expected effects, knowing a given BF threshold. Then, starting from the n_{\min} , the inclusion of participants is performed until all BFs of expected effects exceed the threshold, or until the defined maximum number of participants (n_{\max}) is reached. To guarantee the proper practice of the analysis, we followed the rules used in the step-by-step example proposed by Stefan et al. (2019) by defining the BF threshold as 6. The n_{\min} was set to 60 and the n_{\max} to 120. Since the

BF of one expected effect did not exceed the threshold until the n_{\max} , the inclusion reached 120 participants and then stopped.

Transparency and Openness

The level 2 requirement of the Transparency and Openness Guidelines (Nosek et al., 2015) was met for this article. The Journal Article Reporting Standards (Kazak, 2019) were followed. The sample size analysis, data exclusion, manipulation, and measurement were reported. Data, pre-treatment, code analyses, and material from the study are available through the Open Science Framework repository: <https://osf.io/rnvpg/>. This study was not preregistered. Data were analyzed using R (version 1.4): Models were fitted with 100,000 iterations using the package *BayesFactor* version 0.9.12-4.4 (Morey & Rouder, 2022) and the package *brms* (Bürkner, 2021). Default priors of the *brms* and *BayesFactor* packages were used (Rouder et al., 2012). The 95% CI of the standardized coefficients was computed using the package *bayestestR* version 0.9.0 (Makowski et al., 2019).

Data processing

Seven participants were eliminated. Three reported removing the headphones from their ears, and the remaining four were identified as not being sufficiently engaged in the task. This identification was based on the error threshold of more than 5% error in the dot-probe task. For the remaining participants, the incorrect answers were discarded (223 of 34560 data).

The preprocessing of dot-probe task data is a matter of debate in the literature. While selecting a method a priori can be problematic because parameters and quality of RTs distribution vary across studies (Ratcliff, 1993), post hoc selection can inflate results (Molloy & Anderson, 2020). Thus, we proposed to use a data-driven preprocessing selection based on the method that makes the RT distribution most robust. To this end, preprocessing methods commonly found in the literature were selected. On the one hand, for extreme RTs processing, it has been proposed to discard RTs defined as extreme (e.g., RTs outside the

range of 150ms and 750ms, Carlson & Fang, 2020). Or, it has been proposed to use a winsorizing method, a method aiming to replace extreme RTs with values defined as the limits of the distribution, calculated from the quartiles and the interquartile range of the distribution (see Price et al., 2015, for an example about Winsorizing; Molloy & Anderson, 2020; Erceg-Hurn & Mirosevich, 2008). On the other hand, for outlier RTs, it has been proposed to discard RTs deviating from the mean by 3 times the standard deviation (Price et al., 2015). Thus, we identified the combination of these three types of methods that made the RT distribution the most robust. This analysis is reported in Supplemental material. The identified method consisted of applying winsorizing, then discarding RTs deviating from the mean by 3 times the standard deviation. At the end, 99.1% of the 34337 data were retained in which 4.98% were winsorized.

To obtain a measure of attentional capture for each stimulus against the other for each participant and each SOA condition, Attentional Bias Indexes (ABI; Fournier & Koenig, 2023; Vogt et al., 2013) were calculated. ABI were calculated by subtracting the mean RTs of trials where the dot replaced the most relevant stimulus of the pair to the mean RTs of trials where the dot replaced the other stimulus of the pair. For the three pairs in the dot-probe task, the more relevant stimulus vs. the other stimulus were defined as goal-relevant stimulus vs. neutral stimulus, overlay stimulus vs. goal-relevant, overlay stimulus vs. neutral stimulus. Positive ABI means that the stimulus defined as the most relevant captured more attention than the other stimulus.

Data analysis plan

Analyses were conducted on the ABI of the three pairs of stimuli computed from the two levels of temporality of the two groups of participants. To test our hypotheses, the best-fit model on ABIs was identified according to the inclusion or exclusion of predictors driven by the proposals of the two theoretical frameworks. To this end, a Bayesian linear mixed model

was used, whose most restrictive fit considered participant, block order, and the type of induction made on colored squares as random effects.

Regarding the hypotheses of the appraisal theory and the goal-directed theory, both predict that the best-fit model would include a Pair main effect. However, according to the appraisal theory, this effect should include 3 modalities with positive ABI. This would mean that goal relevance of stimuli captures attention, and that overlaying intrinsic relevance and goal relevance increases attentional capture. According to goal-directed theory, the Pair main effect would include 2 modalities only: one consisting of overlay stimulus vs. goal-relevant stimulus and another grouping goal-relevant stimulus vs. neutral stimulus and overlay stimulus vs. neutral stimulus. Specifically, the ABI of the overlay stimulus vs. the goal-relevant stimulus would be zero, and the ABI of the grouped modality should be positive. This would mean that only goal relevance of stimuli captures attention and not intrinsic relevance.

Regarding the additional hypotheses of the appraisal theory, the interaction effect between Pair x Group should be absent from the best-fit model. This would mean that the relevance overlay captures attention similarly, whether the overlay is agonistic or antagonistic. Furthermore, the best-fit model should include an interaction effect between Pair x SOA. A greater ABI was expected for the long compared to the short SOA condition for the pairs contrasting the goal-relevant stimulus vs. the neutral stimulus and the overlay stimulus vs. the neutral stimulus. In contrast, a reduced ABI was expected for the long compared to the short SOA condition for the pair contrasting the overlay stimulus vs. the goal-relevant stimulus. This would reflect that intrinsic relevance impacts more attention at an early stage of temporality while goal relevance impacts more attention at a later stage of temporality.

Bayesian t-tests were used to test differences between or within modalities of interest (one-tailed for the superiority test and two-tailed for the equality test). The median and 95% CI of

Cohen's d posterior distributions were reported regarding effect size. 95% CI corresponds to the Highest Density Interval of the posterior distribution.

Results

Questionnaire analysis

The analysis regarding questionnaire data is reported in the supplemental material. First, a control was conducted from the three rating task data to check the reliability of the relevance inductions we manipulated. This control showed that participants were correctly involved in the task and that the noises assigned to the agonistic and antagonistic groups were rated as pleasant and unpleasant, respectively. Regarding the relevance inductions performed on stimuli, both groups rated the overlay stimulus and the goal-relevant stimulus as more goal conducive than the neutral stimulus. In addition, the overlay stimulus was rated as more pleasant for the agonistic group and more unpleasant for the antagonistic group than the goal-relevant stimulus and the neutral stimulus. In sum, these controls ensured the reliability of the relevance inductions that we manipulated.

Second, we tested whether approach and avoidance tendencies reported about stimuli were better predicted by taking into account their reported level of pleasantness, unpleasantness, and goal conduciveness. Using two Bayesian mixed models in which approach and avoidance tendencies reported about stimuli were entered as outcome, the results showed that each best-fit model included the pleasantness, unpleasantness, and goal conduciveness of stimuli as predictors. Moreover, the results revealed that both pleasantness and goal conduciveness of stimuli increased approach tendency while unpleasantness of stimuli decreased it. In contrasts, both pleasantness and goal conduciveness of stimuli decreased avoidance tendency while unpleasantness of stimuli increased it.

Emotional attention analysis

Confronting hypotheses of appraisal theory and goal-directed theory

Regarding the confrontation between the hypotheses of the appraisal theory and the goal-directed theory, evidence in favor of the appraisal theory was found. First, including the Pair main effect proposed by the appraisal theory compared to the goal-directed theory increased model likelihood on ABI, $BF_{10} > 1000$. Second, best-fit model on ABI included the Pair main effect proposed by appraisal theory, $BF_{10} > 1000$. Finally, positive ABI was found for all three pair modalities: goal-relevant stimulus vs. neutral stimulus, $BF_{10} > 1000$, $d = 0.20$, 95% CI [0.08, 0.33], overlay stimulus vs. goal-relevant stimulus, $BF_{10} > 1000$, $d = 0.38$, 95% CI [0.24, 0.50], overlay stimulus vs. neutral stimulus, $BF_{10} > 1000$, $d = 0.55$, 95% CI [0.41, 0.69]. Descriptive statistics are reported in Figure 2. These results suggest that goal relevance captures attention and that overlaying intrinsic relevance and goal relevance captures even more attention.

Attentional capture as a function of relevance overlay direction

With respect to the question of attentional capture depending on agonistic or antagonistic relevance overlay, the inclusion of the Pair \times Group interaction effect decreased the best-fit model likelihood on ABI, $BF_{01} = 16.95$. Specifically, ABI equivalence proofs were found by comparing each pair of the agonist overlay group with its corresponding pair of the antagonist overlay group: goal-relevant stimulus vs. neutral stimulus, $BF_{01} = 8.10$, $d = 0.08$, 95% CI [-0.18, 0.31], overlay stimulus vs. goal-relevant stimulus, $BF_{01} = 8.27$, $d = 0.07$, 95% CI [-0.17, 0.32], overlay stimulus vs. neutral stimulus, $BF_{01} = 8$, $d = 0.07$, 95% CI [-0.33, 0.17]. Descriptive statistics are reported in Figure 3. These results suggest that attentional capture generated by intrinsic relevance and goal relevance overlay does not differ as a function of the overlay direction, whether agonistic or antagonistic.

Early and later attentional capture of relevance

With respect to the question of attentional capture as a function of temporality, results are mixed. Indeed, although the inclusion of the Pair \times SOA interaction effect seems to decrease

the best-fit model likelihood on ABI, the BF threshold was not reached, $BF_{01} = 2.83$. Direct comparison of ABI between SOA within pairs was nevertheless performed to better understand these mixed results. Regarding the pair of goal-relevant stimulus vs. neutral stimulus, although ABI seemed to be greater at a late rather than a short temporality, BF threshold was not reached, $BF_{10} = 2.22$. Regarding the pair of overlay stimulus vs. goal-relevant stimulus, although ABI seemed to be greater at a short rather than a late temporality, BF threshold was not reached, $BF_{10} = 5.01$. However, evidence in favor of greater ABI at a late than a short temporality was found for the pair of overlay stimulus vs. neutral stimulus, $BF_{10} > 100$, $d = 0.22$, 95% CI [0.05, 0.41]. Descriptive statistics are reported in Figure 4. Thus, the results about the attentional impact of relevance as a function of temporality are mixed. On the one hand, they do not allow us to conclude clearly in favor or against a different attentional impact of intrinsic relevance and goal relevance as a function of temporality, since the decision threshold regarding inclusion/rejection of the effect in the model was not reached. On the other hand, the planned contrast on the pair of the overlay stimulus vs. the neutral stimulus suggests that the attentional capture generated by overlaying intrinsic and goal relevance was greater at late temporality than at early temporality.

Discussion

The current most influential definition of emotional attention proposed by the goal-directed theory suggests that attention is only captured by the goal relevance of stimuli (Vogt et al., 2013; Vogt et al., 2017; Forrest et al., 2022). However, this definition does not take into account the attentional impact of intrinsic relevance of stimuli (i.e., their general pleasantness). In contrast, the appraisal theory proposes a definition in which intrinsic relevance and goal relevance have combined effects on attention (see, e.g., Fournier & Koenig, 2023). Broadly speaking, it means that the attentional capture toward stimuli is increased if they are both intrinsically and goal relevant. Our results provided

evidence in favor of the appraisal theory hypothesis that attentional capture is enhanced by the overlay of intrinsic and goal relevance. This attentional capture was similarly enhanced whether the relevance overlay was agonistic (i.e., overlay of pleasantness and goal conduciveness) and antagonistic (i.e., overlay of unpleasantness and goal conduciveness). Furthermore, a growing body of evidence suggests that early attentional capture would be more impacted by intrinsic relevance while later attentional capture would be more impacted by goal relevance. Although our main results did not allow us to draw any clear conclusions in favor or against this hypothesis, exploratory results seem consistent with this hypothesis. Finally, our findings showed that both approach and avoidance tendencies related to stimuli are triggered by the appraisal of their intrinsic relevance (i.e., unpleasantness and pleasantness), and their goal relevance (i.e., goal conduciveness).

First, our result showed that goal-relevant stimulus captured more attention than neutral stimulus. This result was in line with the hypotheses of the appraisal theory and the goal-directed theory, both emphasizing the importance of goal relevance in emotion triggering (Moors, 2017; Moors et al., 2017; Moors et al., 2021; Scherer, 2009, 2010). However, our results highlighted that the magnitude of the attentional capture differed between the three stimulus pairs. This result is against the goal-directed theory hypothesis because if only goal relevance impacts attentional capture, equivalent attentional capture would have been measured between the pairs of goal-relevant stimulus vs. neutral stimulus and overlay stimulus vs. neutral stimulus. In contrast, the overlay stimulus captured more attention than the goal-relevant stimulus, whether they were paired together, or individually paired with the neutral stimulus. These findings provide evidence in favor of the appraisal theory hypothesis suggesting that attentional capture is impacted

by the combined effects of intrinsic relevance and goal relevance (Fournier & Koenig, 2023).

Second, our results showed that the attentional capture by the overlay stimulus did not differ depending on whether the relevance overlay was agonistic or antagonistic. This means that the attentional capture by the overlay stimulus increases even in case of unpleasantness and goal conduciveness. This result sheds new light on the framework of the appraisal theory. To discuss this result, it is necessary to further qualify what intrinsic relevance and goal relevance are in nature.

Appraising the relevance of a stimulus would be like making a prediction (Barrett, 2017). More precisely, a probability distribution of the stimulus relevance would be simulated by Bayesian inference based on available prior beliefs about the stimulus characteristics (Seth & Friston, 2016). Concerning intrinsic relevance, it implies inferring the likelihood that the stimulus is more generally pleasant or unpleasant based on past experiences with the stimulus in general. Concerning goal relevance, it implies inferring the likelihood that the stimulus can conduce or obstruct the achievement of a currently important goal based on past experiences involving the stimulus in the context of this goal. The notion of prediction means that the relevance appraisal of a stimulus can be erroneous, which can be dramatic for the individual's well-being and survival (e.g., underestimating the goal conduciveness nature of a stimulus, such as the thirst-quenching nature of a cactus for a thirsty individual in the desert). To deal with this problem, the brain would follow an adaptative principle dictating to constantly seek to minimize the prediction error (Friston, 2005; 2010).

Regarding the increase in the attentional bias by the agonistic overlay of intrinsic relevance and goal relevance, we suggest that it reflects a way for the brain to minimize prediction error. If a stimulus is appraised as both pleasant and goal-conductive, the

probability that the stimulus must be approached for well-being and survival is maximized because both relevances generate approach tendency (Fournier & Koenig, 2023).

Regarding the increase in the attentional bias by the antagonistic overlay of intrinsic relevance and goal relevance, we suggest that the explanation differs somewhat. As explained above, the brain struggles to deal with prediction errors and constantly seeks to minimize them (Friston, 2005; 2010). If a stimulus is appraised as both goal-conducive and unpleasant, it follows that the stimulus must probably be approached and avoided for well-being and survival, because the relevances generate both approach and avoidance tendencies. In this case, the prediction error is highly maximized because intrinsic relevance and goal relevance are in conflict. Thus, we suggest that the antagonistic overlay of intrinsic and goal relevance captures attention to resolve this conflict through a more in-depth appraisal leading to a decrease in prediction error.

Our results about relevance and action tendency shed light on their hypothesized relationship in appraisal theories (Grandjean & Scherer, 2014). The approach tendency and the avoidance tendency of stimuli were best predicted by the conjunction of their pleasantness, goal conduciveness, and unpleasantness. On the one hand, the approach tendency of stimuli was increased by their pleasantness and their goal conduciveness and decreased by their unpleasantness. On the other hand, the avoidance tendency of stimuli was increased by their unpleasantness and decreased by their pleasantness and their goal conduciveness. These findings are in line with the hypothesis that approach tendency is generated by the pleasant nature of the intrinsic relevance appraisal and the goal-conducive nature of the goal relevance appraisal, while the unpleasant nature of the intrinsic relevance appraisal generates avoidance tendency. According to appraisal theories (Grandjean & Scherer, 2014), avoidance tendency is also generated by the goal obstructive nature of goal relevance. However, the design of the present experiment did

not include a goal obstructiveness induction, which prevented us from assessing the relationship between goal obstructiveness and action tendency.

The above observations raise a critical point about the notion of valence, widely used in the literature on emotion (Arioli et al., 2021; Lewis et al., 2019; Ossenfort & Isaacowitz, 2021; Yeung & Fernandes, 2021). This notion was defined as the degree of repulsion or attraction of stimuli for individuals (Lewin, 1938/1951), and was later extended to the differentiation of emotions (Feldman Barrett & Russell, 1998; Kron et al., 2015; Posner et al., 2005). So, broadly speaking, valence could be defined by a continuum from avoidance tendency to approach tendency (Scherer, 2013). However, our results showed that stimuli can be associated with both approach and avoidance tendencies. Thus, considering valence as unidimensional is somewhat problematic for characterizing the emotional nature of stimuli. We emphasize the importance of considering valence as multidimensional, depending on the stimuli's intrinsic and goal relevance (Scherer, 2013; Scherer & Moors, 2019; Shuman et al., 2013).

Concerning the hypothesis that early and late attentional biases would be driven more by intrinsic relevance and goal relevance, respectively, our results were mixed. Indeed, regarding the best-fit model, our results did not allow us to conclude in favor or against a different impact of intrinsic relevance and goal relevance according to temporality.

Planned comparisons were nevertheless carried out to observe the direction in which results tended to evolve. This analysis did not allow us to conclude that early and late attentional capture differed within the pairs of the goal-relevant vs. neutral stimulus and the overlay vs. goal-relevant stimulus. However, a greater attentional capture by the overlay stimulus as opposed to the neutral stimulus was found at a late temporality than at early temporality. This result, which should be taken with caution, suggests that the

attentional capture generated by overlaying intrinsic and goal relevance was greater at a late temporality than at an early temporality.

One reason we failed to show that early and late attentional biases would be driven more by intrinsic relevance and goal relevance, respectively, may be related to the fact that the SOA we used for the early temporality was too long. In a prior experiment (Fournier & Koenig, 2023), we proposed that in the combined effects of relevance on attention, the time window in which the attentional bias would be driven more by intrinsic than goal relevance would be approximately 100ms. The short SOA of the present study was defined based on this statement. However, we did not account for the dot presentation time of 100ms. Thus, the early attentional bias that we measured was probably already taking into account some of the goal relevance. To overcome this issue, we suggest that choosing a shorter SOA to assess early attentional bias, such as 30ms, as done by Forrest et al. (2022), would be better suited to compare the different impacts of intrinsic and goal relevance.

Limits and perspective

The current study presents two major limitations. First, the experimental design did not include a goal obstructiveness induction. This would have been interesting to assess the impact of an agonistic overlay of unpleasantness and goal obstructiveness and an antagonistic overlay of pleasantness and goal obstructiveness on attentional biases. Further, it would have been interesting to assess if approach and avoidance tendencies would be best predicted by accounting for goal obstructiveness in addition to pleasantness, unpleasantness, and goal conduciveness. Goal obstructiveness induction was not included in our study due to the complexity of the experimental design and the instructions for participants to remember. An initial experimental design also included a goal obstructiveness induction. However, participants struggled to retain the inductions assigned to the four colored squares, in addition

to integrating the instructions of the dot-probe and the induction task to be performed in parallel. Thus, we decided to remove the goal obstructiveness induction.

One criticism might be that it is difficult to draw broader conclusions from our results. Indeed, intrinsic and goal relevances were modeled by sound induction and point gain in the context of a game. Manipulating relevance experimentally is not easy, and this study constitutes a first step in the research field of attentional capture generated by relevance overlay. We believe that our results can be extended to other intrinsic and goal-relevance types (e.g., pleasant or unpleasant food and hunger), which should be tested in further studies.

Second, early attentional bias was studied by using a 100ms SOA. However, as explained above, the early attentional bias we measured corresponded instead to the impact of relevance observed within a 100 to 200ms time window. We suggest that the use of shorter SOA values (e.g., 30ms) would be more appropriate to study the impact of intrinsic relevance on attention.

Finally, as the reliability of the dot-probe task is discussed in the literature, particularly in the case of demonstrating attentional capture by positive stimuli, we wish to justify the use of this paradigm as a measure of attention. In their meta-analysis, Pool et al. (2016) reported on studies testing attentional capture toward positive stimuli. Considering only the studies using the dot-probe task, the attentional effect size appears very poor (number of studies = 57, Hedge's $g = 0.07$, $SD = 0.33$). However, their moderator analyses (all attentional tasks confounded) showed that attentional capture was significantly larger when goal relevance was considered. Thus, by focusing only on the studies in this meta-analysis involving dot-probe tasks and taking into account goal relevance, the effect becomes robust (number of studies = 14, Hedge's $g = 0.42$, $SD = 0.35$). This point therefore constitutes an argument in favor of using dot-probe tasks as a measure of attention, as long as goal relevance is taken into account.

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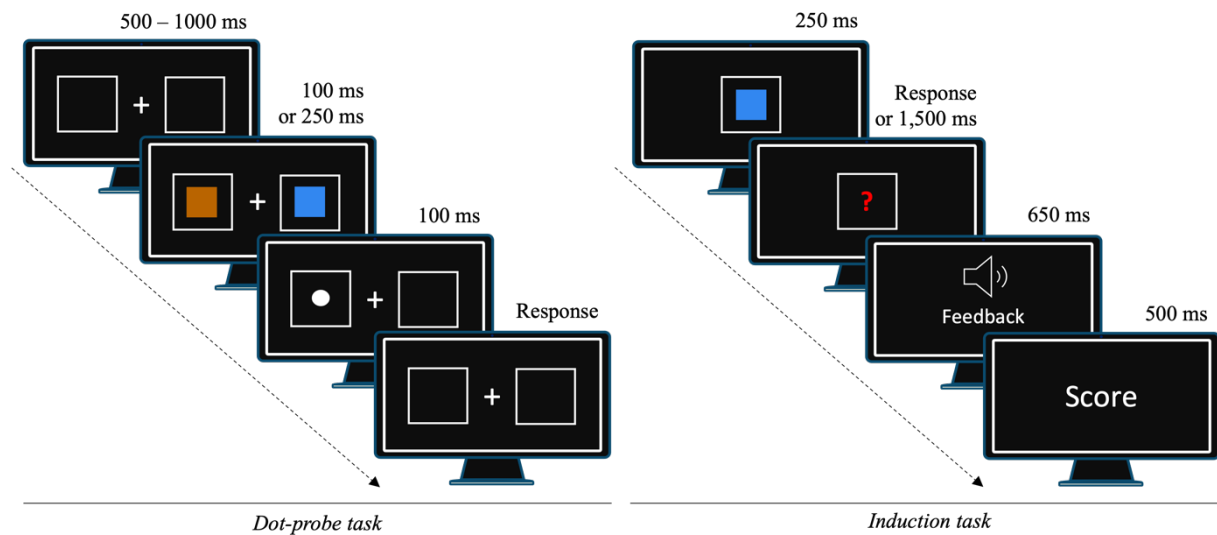
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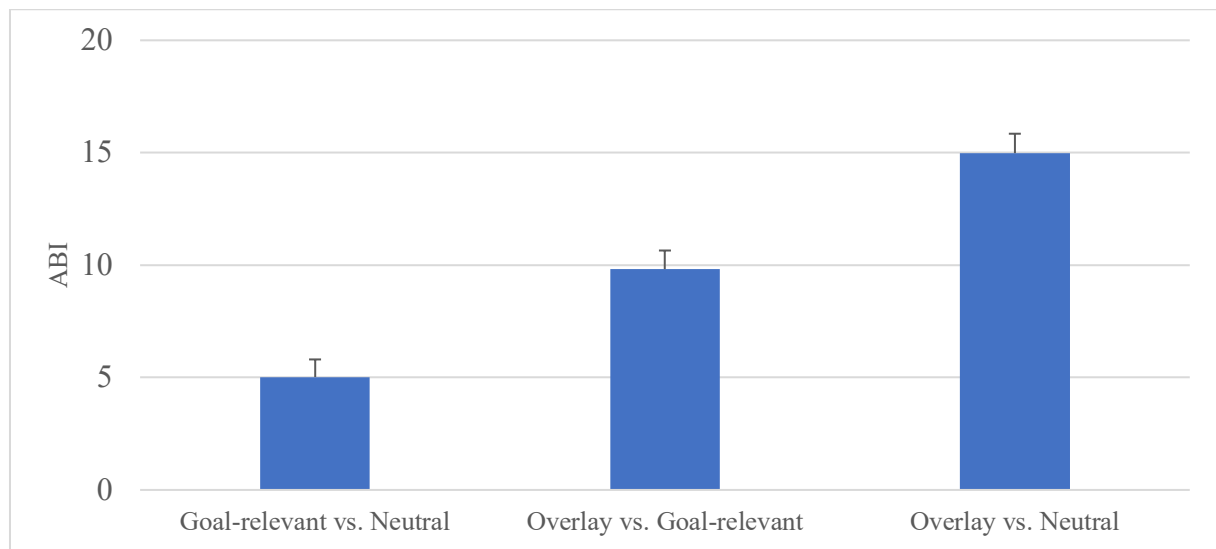
Figure 1.
Schematic Overview of the Experimental Design



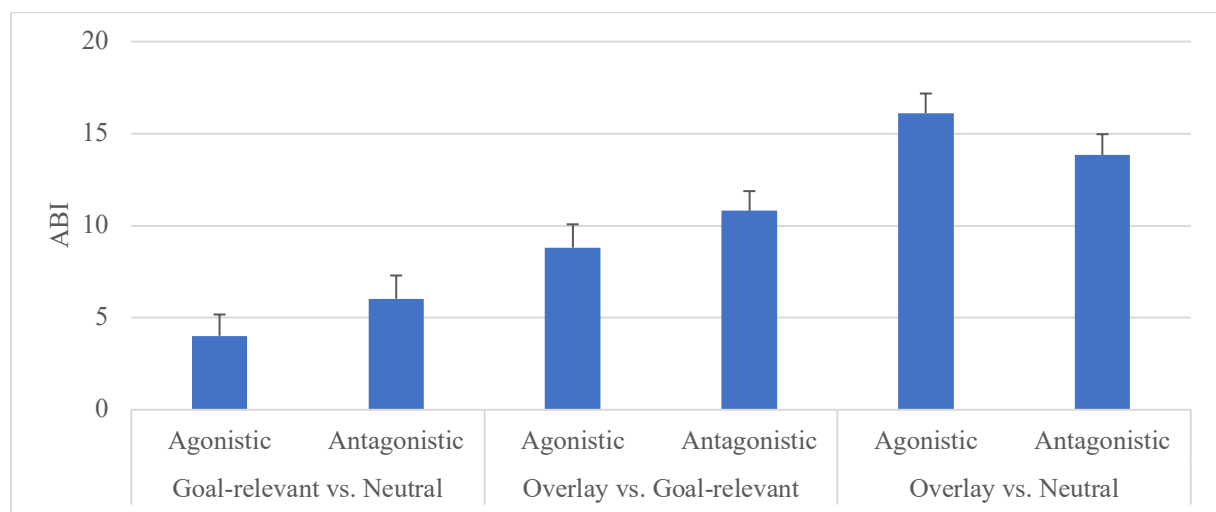
Note. The dot-probe task consisted of the appearance of four screens: a fixation cross with two empty squares, the cues in the two squares, the dot in one of the squares, and the response screen. The induction task immediately started after the participant's response to the dot-probe task and consisted of the appearance of four screens: a cue in the center of a square, a red question mark in the square, a feedback that could be accompanied by a noise depending on the cue that appeared, and the updated score.

Figure 2

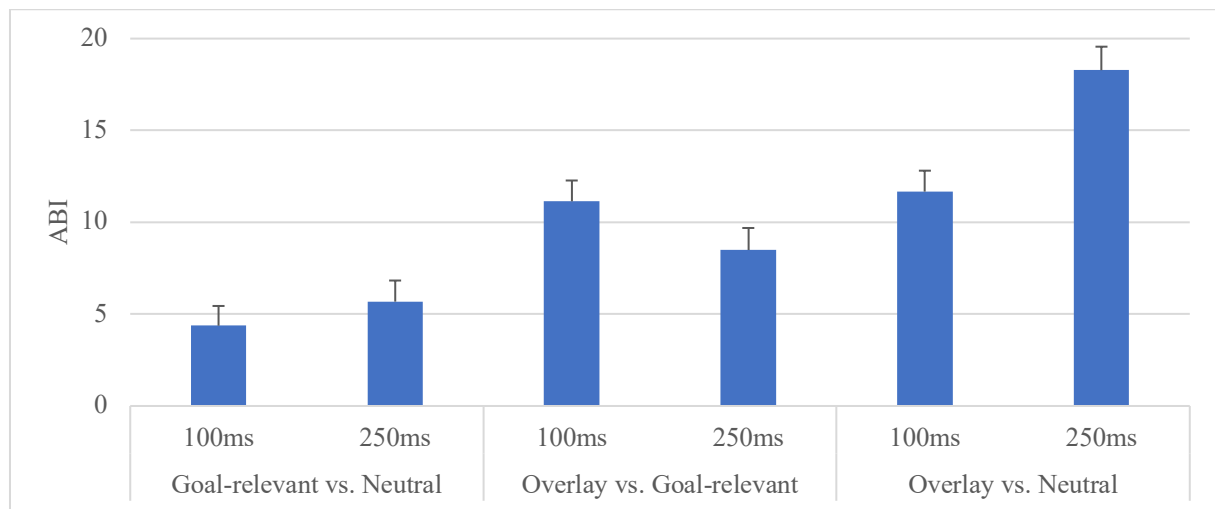
ABIs and Standard Errors as a Function of Pair type



Note. ABI were calculated by subtracting the mean RTs of trials in which the dot replaced the first stimulus of the pair from mean RTs of trials in which the dot replaced the second stimulus of the pair. Goal-relevant vs. Neutral refers to the pair contrasting the goal-relevant stimulus with the neutral stimulus. Overlay vs. Neutral refers to the pair contrasting the overlay stimulus with the neutral stimulus. Overlay vs. Goal-relevant refers to the pair contrasting the overlay stimulus (i.e., both goal conducive and intrinsically relevant, regardless of whether it was pleasant or unpleasant) with the goal-relevant stimulus.

Figure 3*ABI and Standard Errors as a Function Pair type and Group*

Note. ABI were calculated by subtracting the mean RTs of trials in which the dot replaced the first stimulus of the pair from mean RTs of trials in which the dot replaced the second stimulus of the pair. Goal-relevant vs. Neutral refers to the pair contrasting the goal-relevant stimulus with the neutral stimulus. Overlay vs. Neutral refers to the pair contrasting the overlay stimulus with the neutral stimulus. Overlay vs. Goal-relevant refers to the pair contrasting the overlay stimulus (i.e., both goal conducive and intrinsically relevant), with the goal-relevant stimulus. Agonistic refers to the agonistic group in which the intrinsic relevance assigned to the overlay stimulus was pleasant, whereas antagonistic refers to the antagonistic group in which the intrinsic relevance assigned to the overlay stimulus was unpleasant.

Figure 4*ABI and Standard Errors as a Function of Pair type and SOA*

Note. ABI were calculated by subtracting the mean RTs of trials in which the dot replaced the first stimulus of the pair from mean RTs of trials in which the dot replaced the second stimulus of the pair. Goal-relevant vs. Neutral refers to the pair contrasting the goal-relevant stimulus with the neutral stimulus. Overlay vs. Neutral refers to the pair contrasting the overlay stimulus with the neutral stimulus. Overlay vs. Goal-relevant refers to the pair contrasting the overlay stimulus (i.e., both goal conducive and intrinsically relevant), with the goal-relevant stimulus. 100ms and 250ms refers to the two SOA values. Valid refers to the trials in which the dot replaced the first stimulus of the pairs, while Invalid refers to the trials in which the dot replaced the second stimulus of the pair.