



Arousal (but Not Valence) Amplifies the Impact of Salience

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Abstract

Previous findings indicate that negative arousal enhances bottom-up attention biases favoring perceptual salient stimuli over less salient stimuli (Sutherland & Mather, 2012). The current study tests whether those effects were driven by emotional arousal or by negative valence by comparing how well participants could identify visually presented letters after hearing either a negative arousing, positive arousing or neutral sound. On each trial, some letters were presented in a high contrast font and some in a low contrast font, creating a set of targets that differed in perceptual salience. Sounds rated as more emotionally arousing led to more identification of highly salient letters but not of less salient letters, whereas sounds' valence ratings did not impact salience biases. Thus, arousal, rather than valence, is a key factor enhancing visual processing of perceptually salient targets.

Keywords: Emotional arousal, visual salience, valence, individual differences

Experiencing a surge of arousal can impair or enhance subsequent attention and memory encoding (for review see Mather & Sutherland, 2011). The arousal-biased competition model posits that a critical factor predicting whether enhancement or impairment of stimuli processing will occur immediately after an increase in arousal is whether the stimuli are highly salient or not (Mather, Clewett, Sakaki, & Harley, 2016; Mather & Sutherland, 2011). Arousal enhances processing of highly salient stimuli while suppressing processing of less salient stimuli.

This model has been tested by inducing arousal with naturalistic negative sounds (such as brief clip of a baby crying; Sutherland & Mather, 2012), with sound cues that predict an electric shock (Lee, Sakaki, Cheng, Velasco, & Mather, 2014), and with negative arousing pictures (Lee, Itti, & Mather, 2012). In these studies, negative arousing stimuli drive attention and learning in the next few seconds to favor salient stimuli while ignoring or suppressing competing non-salient stimuli. However, these studies do not address whether it is arousal or negative valence that increases the impact of perceptual salience. We examined this issue in the current study.

In general, manipulating targets' perceptual salience biases visual processing. For instance, consider a circular arrangement of eight grey letters appearing briefly on a white background (Fig. 1). The three letters that appear in a darker grey are more salient than the five letters appearing in a lighter grey, both because they have greater contrast with the background, and because they have a higher likelihood of contrasting with the letters around them as they are fewer than those of the other category. Their greater contrast with what is around them increases their salience (Itti & Koch, 2000). Indeed, participants were more likely to notice and remember the more salient letters in this type of array

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(Sutherland & Mather, 2012). Furthermore, hearing a negative arousing sound before viewing an array of letters increased attention to the more perceptually salient letters and decreased attention to the less perceptually salient letters (Sutherland & Mather, 2012). Thus arousal induced by negative emotion amplified the selectivity of bottom-up attention.

Does arousing positive emotion also enhance bottom-up attention, or are these effects limited to negative arousal? Previous studies showing enhanced perception or attention after emotionally arousing stimuli (Bocanegra & Zeelenberg, 2009; Sutherland & Mather, 2012), have focused on the effects of arousing negative emotion. However, both arousing positive and negative stimuli disrupt neutral target detection in rapid serial visual displays (Wang, Kennedy, & Most, 2012).

In contrast, other studies have shown that positive emotion has no influence on subsequent visual search. Exposure to a fearful facial expression 600 ms before a visual search array can enhance visual search for neutral targets embedded among neutral distracters, while happy faces do not have this effect (Becker, 2009; see also Olatunji, Ciesielski, Armstrong, & Zald, 2011), which suggests that positive and negative arousal may not have the same influence on attention. However, it is not clear whether the happy faces were actually emotionally arousing. Thus it is still an unresolved question whether highly arousing positive stimuli enhance subsequent attention biases.

According to the arousal-biased competition (ABC) model (Mather & Sutherland, 2011), experiencing emotional arousal of either valence should increase selective attention to salient stimuli, as previously demonstrated with negative arousing sounds and high contrast letters (see Sutherland & Mather, 2012). To test the hypothesis that arousal is the critical factor biasing attention towards more salient stimuli and away from less salient

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stimuli, in the current experiment we use the same procedure as Sutherland and Mather (2012) but included both positive and negative arousing sounds to examine whether the arousal or valence of the stimuli was the critical factor amplifying attention biases towards perceptually salient targets.

Methods

Stimuli

The audio clips were selected to cover a range of valence and arousal values, with 20 high arousal positive, 20 high arousal negative and 40 low arousal neutral sounds. Most audio clips were from the International Affective Digitized Sound (IADS) system (Bradley & Lang, 2007), however, these were supplemented by 6 neutral and 14 positive sounds selected from the Internet. Each clip lasted 6 s and was composed of ecologically valid content, such as physical assault, explosions, laughter and erotica. Sounds were normalized using Audacity (<http://www.audacityteam.org/>) to make volume ranges similar across sound clips. Audacity mean decibel values computed for each sound did not differ significantly across the three emotion categories $F(1,77) = 1.18, p = .31$. The sounds were presented via headphones from an iMac computer at volume level 5.

The letters were presented on a white background in uppercase bold Arial font and the entire array of letters subtended $11.08^\circ \times 14.58^\circ$. The red-green-blue (RGB) values of the high-salience letters were 102 102 102, and the RGB values of the low-salience letters were 204 204 204. The use of the letter 'I' was omitted due its similarity to lower case 'L.' The experiment was conducted on an iMac monitor with a white point value of X: 0.9505 Y: 1.0 Z: 1.0891.

Participants

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Fifty-five adults (39 female) participated for course credit (ages 18 – 29; $M = 20.4$, $SD = 2.042$). All participants reported having normal or corrected-to-normal vision and hearing. We based our sample size on previous studies using this paradigm (Sutherland & Mather, 2015, 2012)

Procedure

Each participant used a chin rest and completed five practice trials before the main 80-trial experiment. Participants were directed to fixate on a central fixation cross throughout each trial (Figure 1). After the first four seconds of fixation, six seconds of audio was followed by an inter-stimulus-interval (ISI) that ranged from 750 ms to 3000 ms (jittered to avoid anticipatory eye movements). Next, the letters were presented for 200 ms and after another 200 ms the fixation cross was removed, and participants were cued to report via key press the letters seen. Three of the eight letters appeared in the higher contrast font, forming a set of salient targets. The other five letters formed the non-salient set. Participants were told that every letter was an equally relevant target, and were asked to report as many targets as possible regardless of font darkness. For each location in the array, the selected letter and its salience type were randomized across all trials. Recall was self-paced and the letters could be reported in any order.

After completing the 80 experimental trials, participants rated the valence and arousal of each sound on a 9-point scale (1=negative, 5=neutral and 9=positive; 1=no arousal and 9=arousing, for the two rating scales, respectively).

Results

Average Emotion Ratings. As shown in Supplementary Table 1, participants' average valence ratings followed a negative < neutral < positive ordering, with all pairwise

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comparisons across categories significant (all $p < .001$). In contrast, for arousal ratings, neutral < positive < negative, also with all pairwise comparisons significant (all $p < .001$).

Preset Sound Emotion Categories Did Not Modulate Effects of Salience. As our dependent measures in the following analyses, we used the average proportion of low salience letters and the average proportion of high salience letters from each trial that were recalled. These variables had normal distributions, as indicated by non-significant one-sample Kolmogorov-Smirnov tests ($p = .25$ and $.54$ for low and high salience measures, respectively). A 3 (emotion: negative high arousal, neutral low arousal, positive high arousal) x 2 (letter salience: low, high) within-subjects ANOVA revealed a large main effect of letter salience, $F(1, 54) = 84.94, p < .001, \eta_p^2 = .61$. Thus, our manipulation of salience was successful. However, there were no significant effects of pre-categorized emotion type, thus neither arousal (neutral vs. positive and negative) nor valence (positive versus negative) seemed to have an impact on subsequent processing. However, in the sections that follow, we outline evidence that individual arousal ratings were related to recall of low and high salience letters. In the Supplementary Analyses we report on parallel analyses that showed no significant relationships between individual valence ratings and recall of low and high salience letters.

Item Analyses Showed Strong Relationship of Participants' Arousal Ratings and Effects of Salience. Despite the fact that participants' average ratings were consistent with our expectations for each sound type category (see "Average Emotion Ratings" section above and the minimum and maximum average rating per category in Supplementary Tables 1B-C), when we examined how consistent arousal ratings for each sound were across participants we found that 79 of 80 sounds had ratings in all three of the following arousal

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categories: low (rated below 5 on the arousal scale; total N ratings = 1224), medium (rated with a 5; N = 928), and high (rated above 5; N = 2234). For the 40 of the 80 sounds selected to be low arousal, on average only 42% of participants agreed with our categorization (i.e., rated them below 5 on the arousal scale). For the 40 sounds selected to have high arousal, on average 71% of participants agreed with our categorization (i.e., rated them above 5 on the scale). Thus, there was substantial variability in ratings, and sounds from the low arousal category were frequently rated as arousing. Thus, in this first item analysis, we did a within-item comparison to see if, on average, participants performed differently for the same sound depending on how arousing they found that sound.

We conducted an item analysis with the 79 sounds that had ratings in all three arousal rating categories, using a 2 (letter salience: low, high) X 3 (arousal: low, medium, high) repeated-measures ANOVA. The dependent measures were average proportions of letters recalled by all participants who used that rating category for that sound item. Consistent with the previous analyses, there was a large effect of letter salience, $F(1, 78) = 1079.46, p < .001, \eta_p^2 = .93$. In addition, there was a main effect of arousal, $F(2, 156) = 5.90, p = .003, \eta_p^2 = .07$. These main effects were qualified by an interaction effect, $F(2, 156) = 16.89, p < .001, \eta_p^2 = .18$ (Fig. 2A). When a particular sound was given a higher arousal rating, participants were less likely to recall low salience letters and more likely to recall high salience letters shown after that sound played than when it was given a lower arousal rating.

Using Self-Rated Arousal Categories Revealed Significant Effects of Arousal on Salience Biases. Next, we examined participants' performance on the letters task by categorizing trials by their self-rated arousal ratings for the sounds, using the same low, medium and

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high categories as in the item analyses above. There were the same total number of trials rated as low, medium and high arousal as detailed above, however, here we compared differences across these types of trials within participants. All participants had ratings in each arousal category. A 2 (letter salience: low, high) X 3 (arousal: low, medium, high) repeated-measures ANOVA revealed a main effect of letter salience, $F(1, 54) = 77.56$, $p < .001$, $\eta_p^2 = .59$, and an interaction of arousal and salience, $F(2, 108) = 3.55$, $p = .03$, $\eta_p^2 = .06$ (Fig. 2B). Trials with sounds rated as highly arousing had lower recall of low salience letters and higher recall of high salience letters than the other trials.

Role of Individual Differences in Overall Arousal on Salience Biases. According to effect size conventions (Cohen, 1988; Han, Gabriel, & Kohl, 2015), the item analysis yielded a large interaction effect for arousal and salience, whereas the participant analysis yielded a medium effect for the same interaction. If people who tended to rate more of the items as being highly arousing also tended to be those participants who recalled more high salience than low salience letters, this could lead to the difference in effect size of the within-subject and the within-item analyses. To examine the possible influence of individual differences, for each person, we subtracted the number of low arousal ratings (below 5) from the number of high arousal ratings (above 5) they gave across all 80 sounds. This rating difference score was positively correlated with the average proportion of high salience letters they recalled, $r(55) = .28$, $p = .04$, while showing a non-significant negative correlation with the proportion of low salience letters they recalled, $r(55) = -.19$, $p = .17$. Thus, participants who generally found the sounds more arousing were more biased towards recalling high salience letters but not low salience letters.

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We used the rating difference score to divide participants into terciles consisting of the lowest ($N = 18$), medium ($N = 19$) or highest arousal ($N = 18$) raters. A 2 (letter salience: low, high) X 3 (arousal group: low, medium, high) mixed ANOVA revealed the omnipresent main effect of letter salience, $F(1, 52) = 89.45, p < .001, \eta_p^2 = .63$. There was no main effect of arousal group, $F(1, 52) = .13, p = .88, \eta_p^2 = .01$, but there was a marginally significant interaction of letter salience and arousal, $F(1, 52) = 2.76, p = .07, \eta_p^2 = .10$ (see Fig. 2C), that was consistent with the bivariate correlations between the rating difference score and letter recall performance.

Given these indications of individual differences in overall arousal response leading to variability in salience biases, we repeated the original within-subjects ANOVA that had yielded the medium effect size for the interaction between letter salience and arousal (Fig. 2B), but this time with participants' rating difference score as a covariate. Once again, there was a significant interaction of letter salience and arousal, but this time with a larger effect size, $F(2, 106) = 8.02, p = .001, \eta_p^2 = .13$. Thus, when variability from individual differences in overall arousal responses to the sounds was controlled for, the within-subjects effects of individual arousal responses to each sound were more evident. In addition to this larger interaction effect, separate ANOVAs with either the low or high contrast proportions of letters recalled as the DVs (again with the rating difference score as a covariate) both yielded significant effects of arousal, $F(2,106) = 6.58, p=.002, \eta_p^2 = .11$, and $F(2,106) = 4.67, p=.01, \eta_p^2 = .08$, respectively, indicating that arousal response was significantly associated with decreased low salience letter recall as well as with increased high salience letter recall.

Discussion

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In this study we examined whether perceptually salient stimuli grab attention even more under emotional arousal. Our previous work demonstrates that emotionally arousing negative stimuli increase attention to and encoding of highly salient targets but have no influence or decrease attention to non-salient targets (Lee et al., 2012; Lee et al., 2014; Sutherland & Mather, 2012). These findings are consistent with the ABC model (Mather & Sutherland, 2011) that posits that emotional arousal amplifies the impact of stimulus priority, or the combined influence of bottom-up and top-down attention (Fecteau & Munoz, 2006). However, to date, studies demonstrating that emotion increases the impact of salience have used negative arousing stimuli to elicit arousal (Lee et al., 2012; Lee et al., 2014; Sutherland & Mather, 2012). To our knowledge, the current study is the first to examine whether these effects of emotional stimuli on subsequent attention were due to emotional arousal or to negative valence (for comparison of positive and negative arousal effects on retrograde effects see Sakaki, Fryer, & Mather, 2014).

In the current study, when we used experimenter-determined arousal and valence categories to examine whether sounds from different arousal or from different valence categories had different effects on salience biases, we found no significant effects of arousal or valence when using these pre-determined categorizations. However, when we conducted analyses based on individual ratings of arousal and valence, we found that higher subjective arousal was consistently associated with greater bias towards high salience stimuli. In none of these analyses did we find any significant relationship between valence and performance on the subsequent letters task (see Supplementary Analyses).

Higher arousal was associated with higher recall of high salience letters and lower recall of low salience letters, not only at the item and trial level, but also at the participant

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level, such that participants who generally reported higher arousal responses also had stronger biases favoring high salience rather than low salience stimuli. Thus, increased arousal is associated with the tendency to be even more influenced by bottom-up salience. Valence ratings showed no relationship to subsequent salience biases. Follow-up hierarchical linear model analyses revealed no significant interactions of valence and arousal, either (see Supplementary Results and Tables 3A and B). These results extend the findings of Sutherland and Mather (2012) to indicate that arousal, rather than valence, increases attention to salient targets. Thus our results support the ABC model, which proposes that negative arousal and positive arousal amplify the effects of bottom-up attention during visual encoding (Mather & Sutherland, 2011).

Previous studies have examined the influence of positive moods on attention (Fredrickson & Branigan, 2005; Gasper & Clore, 2002; Rowe, Hirsh, & Anderson, 2007). Yet these studies did not address whether brief exposure to a highly arousing positive stimulus would influence attention to neutral stimuli presented shortly after the emotional response was elicited. In an attempt to examine this possibility, two studies used pictures of faces expressing happiness that had no influence on subsequent visual search (Becker, 2009; Olatunji et al., 2011). In our study we used positive stimuli that were more highly arousing, such as intense laughter and erotica (see Bradley & Lang, 2007) to induce arousal just before an attention task. Consistent with the studies using relatively low arousal positive face stimuli, we found no effects of valence on processing subsequent stimuli.

Our study had some limitations. We did not design the study to examine the interaction of arousal and valence and categorizing items by individual ratings limited our ability to examine interactions between arousal and valence. However, a follow-up

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hierarchical linear model analysis (see Supplementary Results) found no interaction of arousal and valence and no effects of valence while showing a significant effect of arousal on recall of salient letters. Thus, this alternative analysis also indicated that arousal had more influence over the impact of salience than did valence.

In addition, we relied on arousal and valence ratings made by participants after they completed the task. It is possible that this ordering influenced ratings. With the current design, we cannot rule out that participants inferred that a sound was more arousing if their attention showed a more selective focus toward salient stimuli on that trial.

Furthermore, our findings indicate that bottom-up attention to salient targets is enhanced by emotional arousal, but whether this influence occurs during perception or in working memory cannot be distinguished from our data. In future research, recording eye movements during this task could provide a measure of attention separate from memory.

A key question for future research is why arousal makes salient stimuli stand out even more and non-salient stimuli even less conspicuous. A recent extension of the ABC model ('glutamate amplifies noradrenergic effects' or GANE model) proposes that norepinephrine-glutamate interactions can account for the opposing effects of arousal on salient versus non-salient representations (Mather et al., 2016). It has long been known that, under arousal, the locus coeruleus releases norepinephrine. However, GANE proposes that the amount of norepinephrine released in different regions depends not only on locus coeruleus activity, but also on local cortical excitation levels. The brain's primary excitatory neurotransmitter, glutamate, stimulates more norepinephrine release in highly active brain regions under arousal, leading to hot spots of amplified activity. In contrast, elsewhere, low levels of norepinephrine released under arousal tend to inhibit activity. Although this is the

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first model of how the brain could implement differential modulation depending on salience under arousal, it remains to be tested in future work.

In summary, the results of the present study indicate that emotional arousal, rather than negative valence, increases the impact of bottom-up salience after the emotional stimulus is removed and no longer competing for attention. These results extend the findings of Sutherland and Mather (2012) and provide additional evidence for the ABC model, which proposes that emotional arousal amplifies the effects of bottom-up salience during visual encoding. More generally, they indicate that one cannot accurately predict the effects of arousal on subsequent processing without taking into account the salience of the incoming stimuli. It makes sense that arousal, which signals important events or stimuli, would amplify processing of salience or high priority information. These interactions of arousal and salience may explain findings that arousal increases memory of central details, which are typically the most salient within a scene (Reisberg & Heuer, 2004; Yegiyan & Lang, 2010; see Mather & Sutherland, 2011 for further discussion). While valence does not appear to play a key role in the arousal-salience interactions we observed, recent evidence suggests that negative and positive moods signal whether to continue with current information processing strategies or to switch to a different strategy (Huntsinger, 2013). Arousal and valence may work together to modulate which representations are most active, and then whether behavior output conforms to or counters currently active representations.

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Figure 1. Schematic depiction of experimental procedure with example of low and high salience items presented in and alongside their respective RGB values

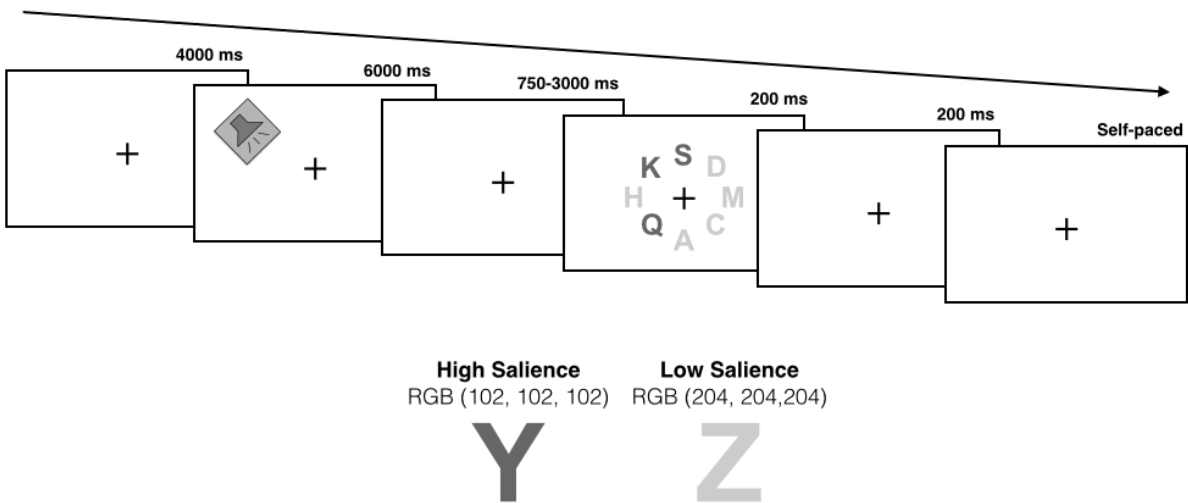
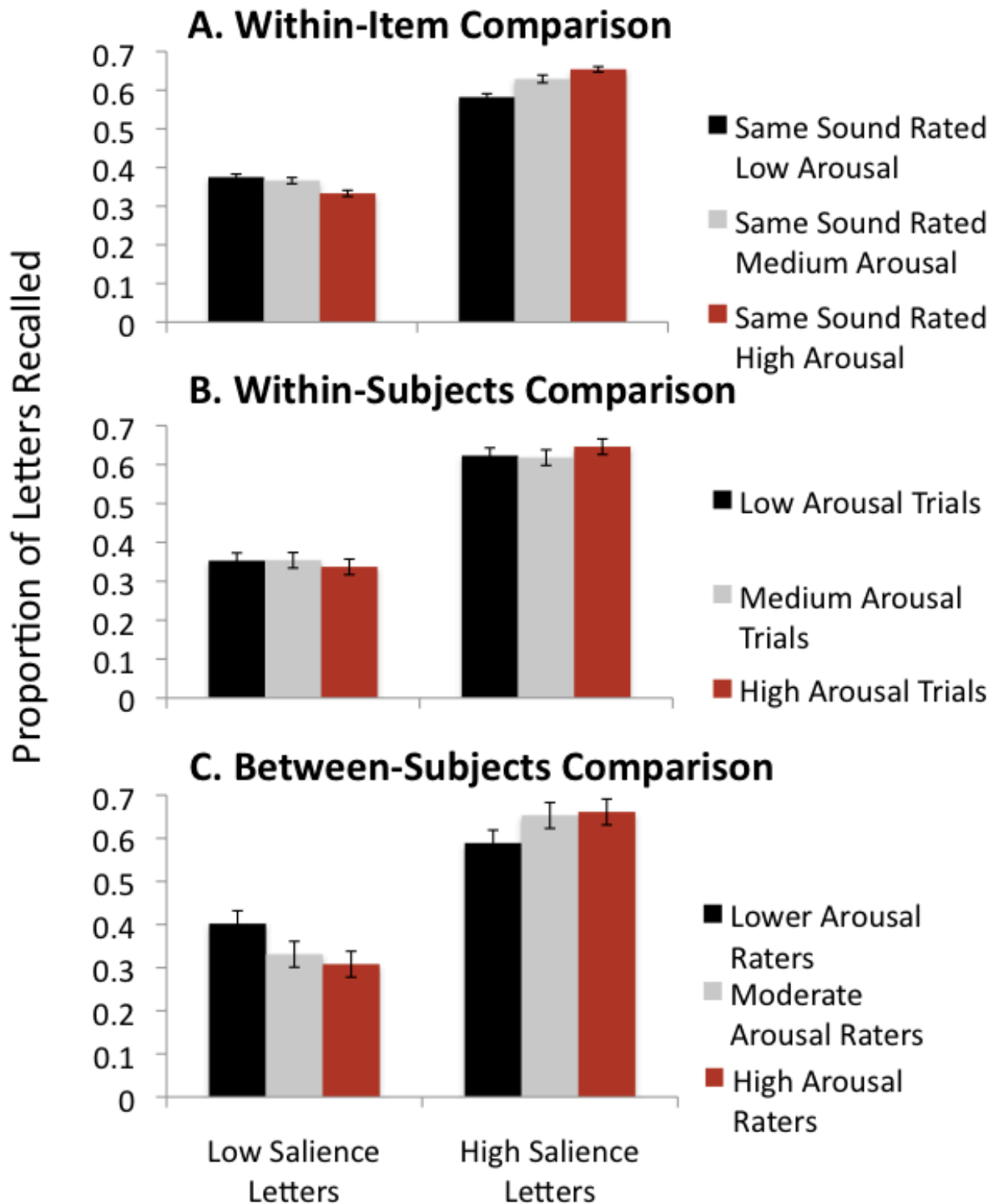


Figure 2. (A) Mean values from an item analysis comparing, for each sound item, the average performance on the letters task for trials in which the sound was rated as low, medium or high arousal. (B) In a within-subjects comparison of arousal, recall of low and high salience letters is shown for sounds participants rated as low, medium or high arousal. (C) Participants were categorized into three groups depending on whether they were among the lowest, middle or highest group for the difference score of how many high arousal minus low arousal ratings they gave to the sounds; recall of the low and high salience letters is shown for each group.



Supplementary Results for Sutherland and Mather

Item Analyses Showed No Significant Relationship of Participants' Valence Ratings and Effects of Salience. We conducted an item analysis with valence ratings, examining whether letter recall after hearing a particular sound varied depending on whether the sound was perceived to be negative (rated below 5 on the valence scale; total N ratings = 1608), neutral (rated 5; N = 1413), or positive (rated above 5; N = 1365). These ratings were more likely to match our item categorizations than did the arousal ratings, with 87% agreement with our categorization for negative sounds (i.e., rated below 5), 83% agreement for positive sounds (i.e., rated above 5), and 56% agreement for neutral sounds (i.e., rated as a 5). There were 72 sounds that had ratings in all three valence categories, and among these sounds, as expected, there was a significant main effect of salience, $F(1, 71) = 612.80, p < .001, \eta_p^2 = .90$. There was no significant effect of valence, $F(2, 142) = .13, p = .88, \eta_p^2 < .01$, nor a significant interaction of letter salience and valence, $F(2, 142) = 2.60, p = .08, \eta_p^2 = .04$. However, given the marginal nature of the interaction, we note the pattern of means here. For low contrast letters, the proportions recalled were .36, .36 and .34 for negative, neutral and positive sound ratings, respectively. For high contrast letters, the proportions recalled were .62, .63 and .66 for negative, neutral and positive sound ratings, respectively. Thus, the trend was for sounds to be associated with more of a high-salience bias when they were positively rated than when they were negatively rated, which is the opposite of what would be expected if it were negative valence (rather than arousal) that drove the effects of negative arousing sounds on attention in Mather and Sutherland (2012).

Using Self-Rated Valence Categories Revealed No Significant Effects of Arousal on Salience Biases. We conducted a 2 (letter salience: low, high) X 3 (emotion: negative, neutral, positive) repeated-measures ANOVA based on participants' individual valence ratings (see item-analysis section above for total N items per emotion category). Although, as expected, there was a significant main effect of letter salience, $F(1, 54) = 86.45, p < .001, \eta_p^2 = .62$, there was no significant main effect of valence, $F(2, 108) = 1.13, p = .33, \eta_p^2 = .02$, nor significant interaction of letter salience and valence, $F(2, 108) = 2.26, p = .11, \eta_p^2 = .04$.

Role of Individual Differences in Overall Valence Ratings on Salience Biases. To examine the question of whether how negative or positive people generally found the sounds was related to individual differences in salience bias, we computed a difference score for each participant (number of sounds rated as positive - number of sounds rated as negative). Unlike with the arousal ratings individual difference scores, this individual difference in valence ratings was not related to either the average proportion of high salience letters they recalled, $r(55) = -.21, p = .12$, nor the proportion of low salience letters they recalled, $r(55) = .09, p = .53$.

As with the arousal rating individual biases presented in the main text, we categorized participants into terciles consisting of the most negative (N = 18), neutral (N = 19) or most positive (N = 18) raters. A 2 (letter salience: low, high) X 3 (valence group: negative, neutral, positive) mixed ANOVA revealed a main effect of letter salience, $F(1, 52) = 83.37, p < .001, \eta_p^2 = .62$, but no significant main effect of valence group, $F(1, 52) = 1.86, p = .17, \eta_p^2 = .07$, nor interaction, $F(2, 52) = .78, p = .46, \eta_p^2 = .03$. Furthermore, when individual valence difference scores were

included as a covariate in the 2 (letter salience: low, high) X 3 (emotion: negative, neutral, positive) repeated-measures ANOVA based on participants' individual valence ratings conducted previously, all effects of emotion were still non-significant. Thus, individual differences in whether participants generally rated the sounds negatively or positively had no significant relationship with their attentional biases to salient vs. non-salient stimuli.

Average Ratings Within the Self-Determined Categories Were More Extreme for Valence than Arousal. In the analyses that categorized items based on individual ratings reported above for valence and in the main text for arousal, we found significant relationships between performance and arousal but not valence. This raises the question of whether the ratings within these categories were more extreme (and therefore potentially more impactful) for arousal than for valence. In Supplementary Table 2, we report participants' average valence and arousal rating for each of the categories we had used in the individual-ratings-based analyses. These categories were based on individual ratings (low = 1-4, medium = 5, and high = 6-9) and the medium arousal/valence condition was defined just as "5" ratings and so had by definition had a mean of 5 and no variability. However, we examined the other two categories in a 2 (scale category: low, high) X 2 (rating type: valence, arousal) within-subjects ANOVA with raw ratings as the dependent variable. There was of course a main effect of scale category, $F(1, 54) = 1416.65, p < .001, \eta_p^2 = .96$. There was no significant effect of rating type, $F(1, 54) = .22, p = .65, \eta_p^2 < .01$. However, there was an interaction of scale category and rating type, $F(1, 54) = 13.23, p = .001, \eta_p^2 = .20$. As can be seen in Supplementary Table 2, the average

ratings were more extreme for valence than for arousal. In addition, in Supplementary Table 2 one can see that the valence ratings, variability was lower for the negative (low) ratings than the positive (high) ratings, whereas for the arousal ratings, variability was lower for the high arousal than the low arousal ratings, but overall variability was similar across valence and arousal ratings. One-sample Kolmogorov-Smirnov tests were non-significant for both average valence ($p = .63$) and average arousal ($p = .14$) ratings, indicating both distributions were normal. Thus, it seems unlikely that something different about the distributions of ratings for valence and arousal was increasing the likelihood of detecting effects of arousal compared with valence.

Valence and Arousal Did Not Significantly Interact in Hierarchical Linear Models. To examine whether valence and arousal ratings interacted to predict recall of high or low contrast letters while using participant's individual ratings, we used two hierarchical linear model (HLM) analyses. Participants were used as the grouping variable and were thus a level 2 predictor; all of the other predictors reported in the HLM were level 1 predictors. We included participants' individual arousal ratings, valence ratings and the interaction between arousal ratings and valence ratings as predictors. Moreover, using HLM allowed us to simultaneously include the mean decibel (db) level of each sound as a predictor to control for the variance in recall related to varying levels of physical intensity between the different audio clips. The fact that we had found the strongest effects of arousal in our ANOVA models when we conducted an item analysis comparing performance with the same sounds when they had different ratings suggested that item

differences in sound intensity may also contribute to performance, which would fit with our theoretical perspective as louder sounds are more arousing than soft volume sounds and historically have been used as an arousal induction in studies. In these studies, loud noise led to more selective attention towards goal-relevant stimuli or information (Hockey & Hamilton, 1970; Hockey, 1970b, 1970a; Smith, 1982). Our theoretical framework predicts that, insofar as louder decibel levels were effective at inducing arousal, they should further disadvantage processing of low salience relative to high salience letters.

In the first HLM analysis, the number of high-salience letters recalled was the dependent variable. Here, as shown in Supplementary Table 3A, there was a significant main effect of arousal, such that greater arousal ratings predicted more recall of high salience letters, providing results consistent with our ANOVA models. Also, consistent with ANOVA models, there was no significant effect of valence. Although in the predicted direction, decibel level was not a significant predictor. Critically, there was not a significant interaction of arousal and valence.

In the second HLM analysis, the number of low-salience letters recalled was the dependent variable. Here, as shown in Supplementary Table 3B, in contrast with the high-salience letter analysis, arousal had a negative association with recall, although the effect was not significant. However, in this analysis, decibel level had a significant negative relationship with recall of the low-salience letters. Thus, for low-salience recall, the influence of arousal appeared to be more strongly associated with the sounds' relative decibel level than with the subjective arousal ratings. Consistent with previous analyses, there was no significant effect of valence. In

addition, there was no significant effect of arousal and valence.

Supplementary Table 1A. *Participants' average ratings for sounds across the three emotion categories (with SD in parentheses)*

	Pre-set Sound Category		
	Negative	Neutral	Positive
Valence Ratings	2.45 (.61)	4.88 (.50)	7.11 (1.00)
Arousal Ratings	6.65 (1.18)	4.41 (1.01)	6.07 (1.08)

Supplementary Table 1B. *Participants' average ratings for sounds across the three emotion categories (with SD in parentheses) and the minimum and maximum average rating by item within each category for the sounds from the IADS set.*

	Pre-set Sound Category		
	Negative	Neutral	Positive
Valence Ratings			
Mean	2.45 (.61)	4.85 (.54)	6.85 (1.09)
Min-Max Rated Item	1.16-4.02	3.95-6.47	5.65-7.42
Arousal Ratings			
Mean	6.65 (1.18)	4.49 (1.02)	5.96 (1.25)
Min-Max Rated Item	5.40-7.93	3.55-5.83	5.31-6.93

Supplementary Table 1C. *Participants' average ratings for sounds across the three emotion categories (with SD in parentheses) for the sounds not from the IADS set.*

	Category		
	Negative	Neutral	Positive
Valence Ratings			
Mean	None	5.01 (.44)*	7.22 (1.03)*
Min-Max Rated Item	None	4.80-5.20	6.65-7.91
Arousal Ratings			
Mean	None	3.94 (1.17)*	6.12 (1.07)
Min-Max Rated Item	None	3.36-4.65	5.75-6.64

Note: * $p < .05$ in t-test comparison against the IADS sounds used from the same category (e.g., positive sound valence ratings).

Supplementary Table 2. *Participants' average ratings for sounds across the three categories determined from their own ratings (with SD in parentheses)*

	Rating Score Categories for Valence and Arousal		
	Rated 1-4 (Low)	Rated 5 (Medium)	Rated 6-9 (High)
Valence Ratings	2.40 (.48)	5.00 (.00)	7.39 (.69)
Arousal Ratings	2.63 (.71)	5.00 (.00)	7.11 (.49)

Supplementary Tables 3A and B

Hierarchical linear model (HLM) analysis using the arousal ratings (1 = least arousing, 9 = most arousing) of the sounds, the valence ratings of the sounds (1 = most negative, 5 = neutral, 9 = most positive), the interaction of arousal and valence ratings, and the mean dB (physical intensity) of the sounds to predict the number of high salience letters recalled (A) and in a separate HLM, the number of low salience letters recalled (B).

(A) High-Salience Recall				
Effect	<i>b</i>	<i>SE</i>	<i>t</i>	<i>p</i>
Intercept	1.904000	0.056570	33.66	< 0.001
Arousal Rating	0.013410	0.005798	2.31	0.021
Valence Rating	0.004433	0.006427	0.69	0.490
Arousal Rating × Valence Rating	0.000062	0.003100	0.02	0.984
Mean dB	0.000778	0.000867	0.90	0.369

(B) Low-Salience Recall				
Effect	<i>b</i>	<i>SE</i>	<i>t</i>	<i>p</i>
Intercept	1.733511	0.094117	18.42	< 0.001
Arousal Rating	-0.007073	0.006780	-1.04	0.300
Valence Rating	-0.003934	0.007518	-0.52	0.601
Arousal Rating × Valence Rating	0.001800	0.003629	0.50	0.620
Mean dB	-0.002527	0.001014	-2.49	0.013