Investigating the Effect of Sensory Experiences on Visual Attention

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Abstract

After viewing emotional scenes, people tend to remember central details, such as a weapon, more vividly than peripheral details, such as other witnesses. This phenomenon is an example of boundary restriction. Boundary restriction is a memory error in which the boundaries of a scene are remembered as narrower than they actually were. Contrastingly, boundary extension is the tendency for people to erroneously remember the background of a scene as more expansive than it was. While boundary extension is a highly robust phenomenon, boundary restriction has yielded inconsistent findings within the literature. Previous studies have primarily used negatively valenced images to indirectly manipulate arousal and have found conflicting effects on boundary restriction. The present study aimed to manipulate physiological arousal directly using the cold pressor task. Participants viewed 24 neutral images of everyday objects while completing the cold pressor task or without the cold pressor task. After a 5 minute delay, participants saw the same unchanged 24 images again, but were told that some of the images may have been altered such that they were more zoomed in or out than they were originally. Participants selected the extent to which they believed the images had changed. As we expected, participants in the cold pressor condition made more boundary restriction errors – selecting that the image was farther away than the original – and fewer boundary extension errors than the control participants. Our results suggest that arousal has an important role in boundary judgements and our memory for proximity.

Keywords: Memory, Attention, Arousal, Cold pressor task, Scene perception

Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University, and, to the best of my knowledge, this thesis contains no material previously published except where due reference is made. I give permission for the digital version of this thesis to be made available on the web, via the University of Adelaide's digital thesis repository, the Library Search and through web search engines, unless permission has been granted by the School to restrict access for a period of time

Table 1

My relative contributions to each aspect of the current project

Role	Role Description	Student	Supervisor I
CONCEPTUALIZATION	Ideas; formulation or evolution of overarching research goals and aims.	**40%**	60%
METHODOLOGY	Development or design of methodology; creation of models.	**40%**	60%
INVESTIGATION	Conducting a research and investigation process, specifically performing the experiments, or data/evidence collection.	**100%**	0%
DATA CURATION	Management activities to annotate (produce metadata), scrub data and maintain research data (including software code, where it is necessary for interpreting the data itself) for initial use and later re-use.	**0%**	100%
FORMAL ANALYSIS	Application of statistical, mathematical, computational, or other formal techniques to analyse or synthesise study data.	**20%**	80%
SOFTWARE	Programming, software development; designing computer programs; implementation of the computer code and supporting algorithms; testing of existing code.	**80%**	20%
VALIDATION	Verification, whether as a part of the activity or separate, of the overall replication/reproducibility of results/experiments and other research outputs.	**80%**	20%
VISUALIZATION	Preparation, creation and/or presentation of the published work, specifically visualization/data presentation.	**90%**	10%
WRITING – ORIGINAL DRAFT	Preparation, creation and/or presentation of the published work, specifically writing the initial draft (including substantive translation).	**100%**	0%
WRITING – REVIEW & EDITING	Preparation, creation and/or presentation of the published work by those from the original research group, specifically critical review, commentary, or revision – including pre- or post-publication stages.	**80%**	20%
PROJECT ADMINISTRATION	Management and coordination responsibility for the research activity planning and execution.	**80%**	20%
SUPERVISION	Oversight and leadership responsibility for the research activity planning and execution, including mentorship external to the core team.	**0%**	100%
RESOURCES	Provision of study materials, laboratory samples, instrumentation, computing resources, or other analysis tools.	**0%**	100%

Note. This table is based on the CRediT Contributor Roles Taxonomy (For details see: https://credit.niso.org). CRediT is “a high-level taxonomy, including 14 roles, that can be used to represent the roles typically played by contributors to research outputs. The roles describe each contributor’s specific contribution to the scholarly output”.

Investigating the Effect of Sensory Experiences on Visual Attention

Heightened emotional arousal can cause us to selectively narrow our attention toward the central aspects of scenes (Mathews & Mackintosh, 2004). One illustration of this narrowing effect is ‘weapon focus’, which occurs when individuals can remember an assailant’s weapon in greater detail than they can remember the broader scene of the crime itself (Fawcett et al., 2011). This phenomenon is an example of boundary restriction, wherein central details, such as a weapon, are remembered better than peripheral details, such as other witnesses (Fawcett et al., 2011). Boundary restriction refers to a memory error in which the boundaries of a scene are remembered as narrower than they were, resulting in a proximity error – people remember being closer to the scene than they actually were. One explanation for this phenomenon suggests that heightened arousal lowers cognitive capacity, and leads to increased attention to central objects in a scene (Green et al., 2019). Previous studies (Mathews & Mackintosh, 2004; Safer et al., 1998) have found that participants demonstrated boundary restriction errors after viewing emotionally negative images. However, boundary restriction has not been consistently observed across all negative stimuli. For example, despite using a similar methodology to Safer et al. (1998), Candel et al. (2003) did not find significant boundary restriction effects for negatively valenced images. In the present study, we aimed to investigate whether arousal – rather than the negative valence of an image – is the underlying mechanism in the boundary restriction effect. We did this by directly manipulating arousal using a cold pressor task paired with neutral images of everyday objects.

While some evidence suggests that negatively valenced images induce boundary restriction (Mathews & Mackintosh, 2004), other evidence has suggested that negatively valenced images simply reduce boundary extension (Menetrier et al., 2013). Boundary extension is the tendency for people to erroneously remember the background of a scene as more expansive than it actually was. Boundary extension is an extremely robust and consistent phenomenon that persists across age and gender (Seamon et al., 2002); with real-life scenes (Intraub et al., 1996) and abstract images (McDunn et al., 2014); and across multiple memory testing modalities (e.g., Intraub, 2006; Intraub 2004). Boundary extension is the norm for almost all scene memories (see Hubbard et al., 2010 for a review). The prevailing theory suggests that boundary extension may be a source-monitoring error (Intraub, 2010). When viewing an image, a scene memory is encoded as a mix of basic visual information from the image, and top-down scene schemas from a person's memory that extrapolate information beyond the boundaries of the image (Bainbridge & Baker, 2020; Intraub, 2012). When the scene memory is retrieved, the sensory and schematic information become indistinguishable, and individuals consequently extend the boundaries of the original image in their mind's eye (Intraub, 2012). Positively and neutrally valenced scenes have been shown to induce boundary extension (Mathews & Mackintosh, 2004; Menetrier et al., 2013), while negatively valenced scenes have demonstrated inconsistent effects on boundary judgement. When showing participants negatively valenced images, some studies have found boundary restriction effects (Mathews & Mackintosh, 2004; Safer et al., 1998), some studies have found attenuated boundary extension (Menetrier et al., 2013; Touryan et al., 2007), while others have found no effect on boundary judgement errors (Candel et al., 2003; Davies et al., 2007).

One explanation for the inconsistencies within the findings on boundary restriction is that – rather than image valence affecting boundary judgement errors – *arousal* may be the variable that influences individuals' boundary judgements. The incidental arousal caused by individuals' subjective reactions to negative visual stimuli is highly variable between studies, which could lead to the varied results observed in the literature. Indeed, Mathews and Mackintosh (2004) only found boundary restrictions effects for the negative images with the highest arousal ratings, and only for participants with high trait arousal. These findings highlight both the individually different reactions people can have to images, and the potential importance of arousal's role in boundary restriction. In a 2019 study, Green et al. investigated the role of arousal in isolation by using noise blasts as an external stressor to manipulate arousal while participants encoded neutral images. They found that participants experienced more arousal for the images paired with the noise than for the images without the noise. Participants also rated images paired with the noise as less pleasant. The noise produced a heightened arousal effect and led to a reduction in boundary extension errors and an increase in boundary restriction errors. These results indicate that heightened arousal may have increased participant's perception of threat, leading to selective attention to central objects in the scene as a way to locate potential danger (Cole et al., 2013; Green et al., 2019). As such, arousal may have increased participant's tendency to remember images with narrower boundaries by reducing their opportunity to extrapolate beyond the image borders. This reduction in extrapolation could have decreased the source-monitoring errors that cause boundary extension and led to the memory for restricted boundaries (Green et al., 2019).

The present study built on Green et al.'s (2019) findings. Green et al. directly manipulated arousal instead of image valence and found that participants made more boundary restriction errors when neutral images were paired with an aversive noise blast than when they were not. However, the Green et al. study used a within-subjects design where noise blasts were randomised so that participants could not anticipate which images would be paired with the aversive stimulus. This randomised presentation of the aversive stimulus may have led participants to experience an overall increased state of arousal that bled into how they responded to images presented without the stimulus (Green et al., 2019). Thus, here we used a between-subjects design to isolate the effects of arousal manipulation to only the images that were paired with the arousing stimulus. Because of our between-subjects design, we needed a stress manipulation that could be administered for the entire encoding phase without risk to the participant (e.g., of temporary or permanent hearing loss). Thus, in the present study, we used a cold pressor task instead of the noise blasts. The cold pressor task is a procedure for experimental stress induction that has been shown to induce a robust and reliable increase in physiological arousal, and was also appropriate for use over the whole encoding phase (Edens & Gil, 1995; Schwabe & Schachinger, 2018).

The present study also expanded on Green et al. by a measuring physiological arousal. Previous studies investigating boundary judgement have predominantly relied on self-report measures to assess participants' arousal levels in response to stimuli (Green et al., 2019; Mathews & Mackintosh, 2004; Safer et al., 1998). These self-report measures may present issues with the accuracy of arousal data due to potential differences in participants' ability to accurately report their own arousal. One limitation mentioned by Green et al., was that participants may have misunderstood the question "how emotionally arousing was that image?" as being about the image itself – rather than the emotional arousal the participant felt while viewing the image. As such, our study addressed this issue by using objective measures of arousal in addition to subjective self-report measures. Objective measures of autonomic nervous system changes give excellent temporal indications of changes in arousal (Bali & Jaggi, 2015). Here, we selected to measure heartrate variability and Galvanic Skin Response (GSR). Heartrate variability reflects changes in the time intervals between consecutive heartbeats (Minarini, 2020). Parasympathetic nerves slow heartrate, causing an increase in heartrate *variability*, while sympathetic nerves increase heartrate, causing a decrease in heartrate variability (Minarini, 2020). Thus, heartrate variability typically *decreases* in response to arousal due to parasympathetic withdrawal (i.e., deactivation) caused by stress (Koenig et al., 2014). On the other hand, GSR is a measure of skin conductance, which varies with the state of sweat glands in the skin (Dawson et al., 2000). Unlike most cardiovascular functions, which are influenced by parasympathetic and sympathetic activity, the sweat glands of the hands are primarily regulated by the sympathetic nervous system (Dawson et al., 2000). As such, GSR is a good measure of sympathetic response to stressors. Indeed, the cold pressor task has been shown to reliably *increase* sympathetic activation as measured by changes in GSR (Koenig et al., 2014). Thus, measuring heartrate variability and GSR allows us to assess changes in the sympathetic and parasympathetic branches of the autonomic nervous system in response to the cold pressor task. Note here that we expected to find a decrease in heartrate variability and an increase in GSR.

To summarise, evidence for the effect of negative valence on boundary restriction is mixed, but the role of arousal in boundary judgements may elucidate these mixed findings. Thus, in the present study we aimed to investigate the effect of arousal on boundary judgement errors, in isolation of valence. We used the cold pressor task to elicit arousal and presented participants with neutrally valenced images. First, we predicted that participants in the non-cold pressor (control) condition would make more boundary extension errors than participants in the cold pressor condition. Second, we predicted that participants in the cold pressor condition would make more boundary restriction errors than participants in the control condition. Third, we predicted that participants in the cold pressor condition would find the images more arousing than participants in the control condition. Fourth, we predicted that participants in the cold pressor condition would find the images less pleasant than participants in the control condition. Finally, we predicted that participants in the cold pressor condition would experience greater physiological arousal as measured by heartrate variability and GSR than participants in the control condition.

Method

Participants

Using G*Power (Erdfelder et al., 1996), we calculated the sample size required to detect a medium between-subjects effect size (*d* = 0.50) of arousal on boundary judgement differences (based on an a priori from Green et al., 2019, adjusted for between-subjects design, Lakens, 2013). At alpha = .05, power = .80, the recommended sample size is 102 (51 per condition). This sample size is consistent with other boundary judgement studies, which have used samples sizes of 80–150 participants (Green et al., 2019; Mathews & Mackintosh, 2004).

We recruited 44 participants (9 male, 35 female, 0 non-binary) with self-declared normal colour vision and normal or corrected-to-normal visual acuity through snowball sampling and from a psychology undergraduate research participant pool.[1] Participants were aged 17–58 years (*M* = 23.00, *SD* = 8.48). Participants from the participant pool received course credit, while those recruited from outside the pool were entered into a draw to win a local retail voucher.

Design

We used a between-subjects design with participants randomly assigned to one of two conditions – cold pressor task or no cold pressor task during the encoding phase. Our main dependent variables were the amount of boundary extension and restriction errors that participants made.

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[1] We did not meet the desired sample size due to time constraints, but we have continued data collection with a view to publish this study post submission. Thus, the data should be interpreted here with caution.

Materials

Cold pressor task: We used a replication of Nahleen et al.'s (2019) cold pressor task with 11 litres of water at 7°C ± 2°C and a circulating pump. Participants in the cold pressor condition immersed their non-dominant hand in a water cooler filled with iced water for the duration of the encoding phase (3–7 minutes). The water temperature of 7°C ± 2°C was chosen based on Mitchell et al.'s (2004) findings that it caused less pain compared to temperatures of 5°C or lower. Mitchell et al. (2004) observed that participants, on average, could tolerate immersion for 60 seconds (females) and 140 seconds (males) at 7°C before reaching their pain threshold. Selecting 7°C ± 2°C increased the likelihood of participants immersing their hand for the entire duration the encoding phase. However, due to the length of the encoding phase, we expected that participants would immerse and remove their hand multiple times once they reached their pain tolerance threshold.

NeuLog^{TM}: We used NeuLog^{TM} monitors to measure participants' heartrate and Galvanic Skin Response (GSR) during the encoding phase. The monitors were placed on participants' dominant hand. Heartrate was measured with a heartrate monitor on the index finger, and GSR was measured with skin electrodes placed on the middle finger and thumb. Both measurements were taken at 10 Hz (10 samples per second). During data collection we found that the heartrate monitor was highly sensitive to participants' hand movements, which led to inaccurate recordings of beats per minute (BPM). However, the monitor still gave accurate recordings of beat-to-beat variance in heartrate. As such, we elected to compare heartrate variability in our results instead of heartrate as originally planned.

Images: We selected 24 neutrally valenced images from the International Affective Picture System (IAPS; Lang et al., 2008) and the Nencki Affective Picture System (NAPS; Marchewka et al., 2014).

Experiences survey: Participants also completed a questionnaire unrelated to the present study. Data from this questionnaire will be analysed by the supervisor to investigate how participants evaluate their participation experience when completing an unpleasant task (the cold pressor task) compared to a cognitive task alone (the boundary judgement task). We asked participants to rate their participation experience of the experiment. Participants rated the cold pressor task across four subscales in line with Stirling et al. (2021): negative emotions (e.g., "This study was emotionally exhausting"), perceived benefits (e.g., "This study was interesting"), positive emotions (e.g., "This study was relaxing"), and mental costs ("This study was mentally exhausting"). All items were rated on a 7-point Likert scale. Participants also compared their participation experience to everyday stressors (e.g., "Being late to class") on a 7-point Likert scale (Stirling et al., 2021; Yeater et al., 2012). The results from this questionnaire are not presented in this thesis.

Procedure

The University of Adelaide Human Research Ethics low risk Sub-Committee (HREC) granted ethics approval (23/17). All stimuli and questionnaires were presented on Qualtrics online software.

Encoding Phase: Participants were recruited and then randomly assigned to the cold pressor condition or the control condition. Participants gave informed consent by selecting the “Yes – Let’s begin the experiment” option after reading the information and consent forms on screen. Participants then completed two demographic questions (age and gender). We presented participants with 24 neutral images of everyday objects, which they viewed for 2 seconds each. The order of image presentation was randomised. After participants viewed each image, they were asked to rate “how pleasant was that picture?” (1 = *very unpleasant*, 7 = *very pleasant*) and “how emotionally arousing did you find that picture?” (1 = *not at all* *emotionally arousing*, 7 = *highly emotionally arousing*) on 7-point Likert scales (Porter et al. 2014). Participants viewed and rated the 24 images while completing the cold pressor task or without the cold pressor task. Using NeuLog^{TM} monitors, we recorded the heartrate and GSR of all participants while they viewed and rated the images. Following the procedures of Mathews and Mackintosh (2004), and other boundary judgement errors studies (e.g., Beighley et al., 2019; Green et al., 2019), we did not inform participants that we would be testing their memory for the images. Upon finishing the encoding phase, participants completed an unrelated filler-task (a game of sudoku) for 5 minutes before beginning the test phase.

Test Phase: We presented participants with the original images again in a randomised order. However, we told participants that some of the images may have been changed such that the camera was either closer to, or farther away from the central object in the picture (Candel et al., 2003; Green et al., 2019; Takarangi et al., 2015). In fact, none of the images had been altered (Bainbridge & Baker, 2020; Beighley et al., 2019; Green et al., 2019). For each image, we asked participants to judge whether the “camera distance” had changed compared to when they first saw the image. Participants used a sliding scale to indicate whether they believed the image was “much closer than the original” (boundary extension error), “much farther than the original” (boundary restriction error) or “the same as the original”. After completing the boundary judgement task by responding to all 24 images, participants completed the experiences questionnaire. We then fully debriefed all participants, informing them that we used limited disclosure of our aims to allow boundary judgement errors to occur without interference from attempts to memorise the images.

Results

Boundary Judgement

We calculated mean camera distance judgements for the cold pressor condition and the control condition. Camera distance judgements were measured on a scale from -50 (boundary restriction) to +50 (boundary extension), where 0 = no change. Here we compared errors only (boundary extension and boundary restriction). We calculated mean boundary distance by grouping all distance ratings of > 0 to 50 as boundary extension errors and all ratings of < 0 to -50 as boundary restriction errors. We ran an independent t-test and found that participants in the cold pressor condition made more expansive boundary extension errors (*M* = 13.96, *SD* = 5.16) than the control group (*M* = 8.63, *SD* = 6.60; *t*(42) = 2.98, *p* = .005, *d* = 0.90, 95% CI [0.27, 1.51]). Participants in the cold pressor condition also made more expansive boundary restriction errors (*M* = -12.74, *SD* = 6.28) than participants in the control condition (*M* = -7.84, *SD* = 6.31; *t*(42) = -2.58, *p* = .01, *d* = -0.78, 95% CI [-1.39, -0.16]). These results demonstrate that participants in the cold pressor condition made greater errors in both directions (boundary extension and restriction) compared to the control, but there was no difference in the type/direction of errors made by each group. Indeed, participants in the cold pressor condition were generally worse at the boundary judgement task than participants in the control condition. However, it should be noted that while the scale contained 100 points, participants clustered around the “zero” or “no change” rating. Consequently, we wanted to determine whether there was a difference in error *type* regardless of the extent of the error.

To test whether there was a difference in the type of error between conditions, we calculated how frequently participants in each condition judged the images as “closer up” than the original (a boundary extension error) or “farther away” than the original (a boundary restriction error) by adding up a total of error type for each participant. We ran a Hotelling's T^2 one-way multivariate analysis of variance (one-way MANOVA) on the frequency of boundary judgement error type (boundary extension versus boundary restriction) by condition (cold pressor versus control) to determine the effect of condition on error type. We found that the model met all the Hotelling's T^2 assumptions, except for multicollinearity. A Pearson correlation ($|r| > .90$) showed evidence of multicollinearity within the model. Therefore, we investigated the model itself to determine whether a Hotelling's T^2 one-way MANOVA was an appropriate analysis, or whether we should instead run a series of independent t-tests. The model had a low R-squared value (.06), which suggests that a small proportion of the variation in the dependent variables is explained by the independent variables (conditions). This low R-squared suggests that even if multicollinearity is present, the model may not be heavily reliant on the independent variables (Williams, 2015). Additionally, the correlation between coefficients X1 and X2 (-.95) indicates a high correlation between the two predictors, but it does not necessarily imply that multicollinearity is causing problems. Some correlations between coefficients are expected in regression models, especially when predictors are correlated in the dataset (Williams, 2015). Thus, we decided to continue with the MANOVA despite the indication of multicollinearity.[2]

Hotelling's T^2 found that overall, participants made more boundary extension errors (M = 13.25, SD = 5.94) than boundary restriction errors (M = 10.41, SD = 5.94), which is consistent with earlier literature that suggests boundary extension errors are the norm for most scene memories (Hubbard et al., 2010). The differences between conditions on error

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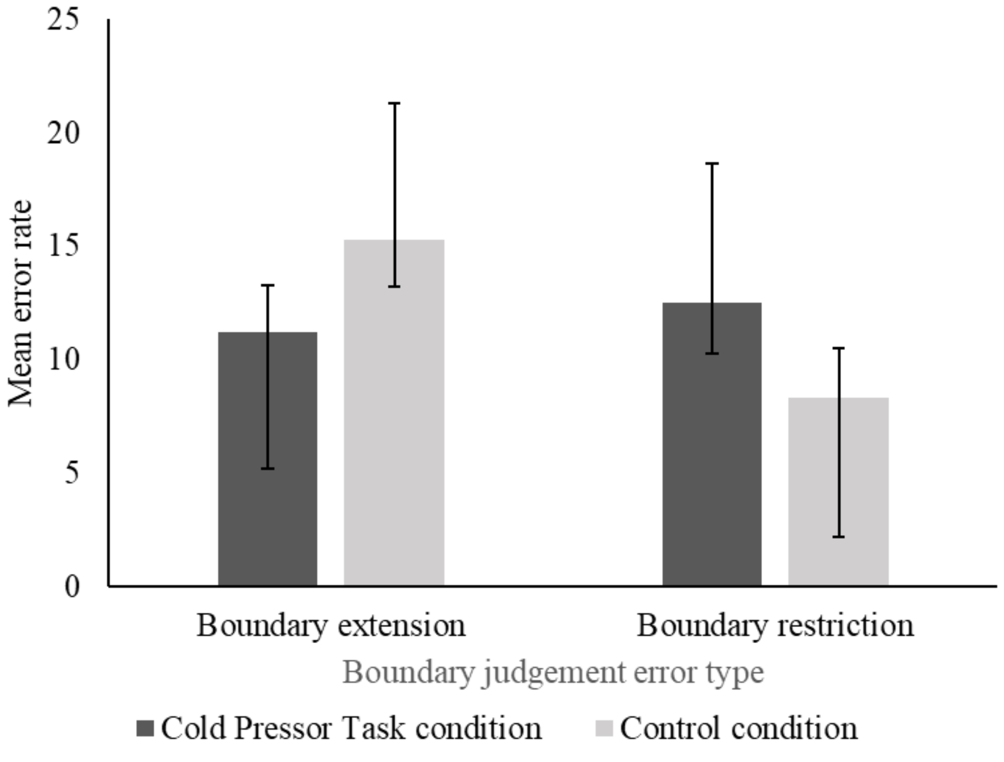
[2] While we decided to continue with the MANOVA, we ran independent t-tests to confirm whether the MANOVA findings were reliable despite the multicollinearity violation. Independent t-tests were consistent with the MANOVA: The cold pressor condition boundary extended less ($M = 11.23$, $SD = 5.13$) than the control group ($M = 15.27$, $SD = 6.12$; $t(42) = -2.38$, $p = .02$, $d = -0.72$, 95% CI [-1.32, -0.10]). The cold pressor condition also boundary restricted more ($M = 12.77$, $SD = 5.13$) than the control group ($M = 8.73$, $SD = 6.12$; $t(42) = 2.38$, $p = .02$, $d = 0.72$, 95% CI [0.10, 1.32]).

type was also statistically significant ($F(2, 41) = 12.680$, $p < .001$; Wilks' $\Lambda = 3.21$; partial $\eta^2 = .135$). Consistent with our hypotheses, pairwise comparisons using the Bonferroni correction indicated that boundary extension errors did differ depending on condition. As predicted in our first hypothesis, participants in the control condition made more boundary extension errors ($M = 15.27$, $SD = 6.12$) than participants in the cold pressor condition ($M = 11.23$, $SD = 5.13$; $F(1, 42) = 5.65$, $p = .02$, partial $\eta^2 = .12$). Additionally, in support of our second hypothesis, pairwise comparisons demonstrated that boundary restriction errors differed depending on condition. Participants in the cold pressor condition made more boundary restriction errors ($M = 12.5$, $SD = 5.05$) than participants in the control condition ($M = 8.32$, $SD = 6.12$; $F(1, 42) = 6.11$, $p = .018$, partial $\eta^2 = .13$). These boundary judgement results are presented in Figure 1.

Figure 1

Mean error rate for boundary extension errors and boundary restriction errors by condition



Note. The error bars represent 75% Confidence Interval.

Recall that our sample size (*N* = 44) was smaller than our power analysis suggests (*N* = 102). Due to our small sample size, we wanted to confirm the reliability of our findings using Bayes analysis. We ran two independent Bayesian t-tests with default Cauchy prior (Rouder et al., 2009) and found $BF_{10} = 3.19$ for the difference in boundary extension errors between conditions. The statistical interpretation proposed by Wetzels et al. (2011) suggests that this indicates substantial evidence for this difference. However, we found $BF_{10} = 2.68$ for the difference in boundary restriction errors between conditions. The statistical interpretation proposed by Wetzels et al. (2011) suggests that this indicates only anecdotal evidence for this difference. As such, we emphasise the need for caution when interpreting our results here. Nevertheless, these findings do suggest that the cold pressor task was able to reduce the number of boundary extension errors that participants made, and thus further data collection for this paradigm is warranted.

Heartrate Variability

To preface, the results obtained through the following approach should be interpreted with caution. We converted beats per minute (BPM) into RR intervals to establish a basic measure of heartrate variability (Martínez et al., 2017). However, this method provides a simplified view of heartrate variability and does not account for its full complexity, especially with regard to frequency-domain parameters (Martínez et al., 2017). A more robust assessment of heartrate variability would require additional RR interval data and spectral analysis. Consequently, our approach may not be ideal for precise heartrate variability evaluations in clinical contexts that require a high level of accuracy. However, this variability measure does give us a good indication of arousal for research purposes.

We used a Root Mean Square of Successive Differences (RMSSD; Shaffer & Ginsberg, 2017) to measure heartrate variability for each condition. The RMSSD was obtained by calculating the successive time differences between heartbeats in milliseconds, which captures beat-to-beat variance in heartrate. Beat-to-beat variance is highly correlated with short-term heartrate variability and parasympathetic activity (Shaffer & Ginsberg, 2017). Our heartrate measurement period ranged from 3–7 minutes, which makes RMSDD the most appropriate measure as it is recommended for short-term to ultra-short-term variability scores ranging from 1–20 minutes (Esco & Flatt, 2014; Shaffer & Ginsberg, 2017).

To calculate the RMSSD, BPM was converted to RR intervals in milliseconds (60,000/BPM). Afterward, we calculated the squared values of successive differences. The resulting values were then averaged and square-rooted to give the RMSSD value. The final values are the root mean square of successive differences in RR intervals, which represents short-term heartrate variability (Shaffer & Ginsberg, 2017). We ran a one-tailed independent t-test for heartrate variability for the two conditions and found that, in the opposite direction of our hypothesis, participants in the cold pressor condition (M = 28.87, SD = 15.95) had greater heartrate variability than participants in the control condition (M = 21.46, SD = 6.01; t(26.85) = 2.04, p = .03, d = 0.62 95% CI [-∞, -0.10])[3][4], indicating greater parasympathetic arousal. These results are presented in Figure 2.

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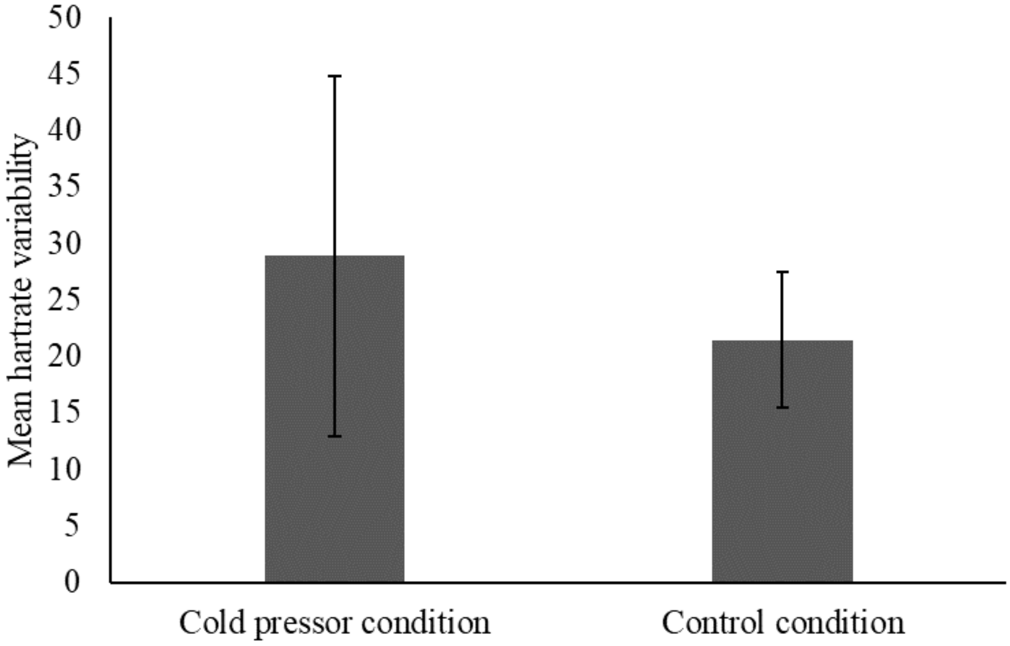
[3] Brown-Forsythe test was significant (p < .05), suggesting a violation of the equal variance assumption. Thus, we ran a Welch Independent t-test. The Welch is reported here, but note that the Student independent t-test was also significant (t(42) = 2.04, p < .05, d = .62).

[4] This was a one-sided t-test, looking at the alternative hypothesis (cold pressor group > control group), thus the lower limit is infinite (Wagenmakers et al., 2017).

Figure 2

Mean heartrate variability by condition



Note. The error bars represent standard deviation.

Galvanic Skin Response

Galvanic Skin Response (GSR) was measured using Neulog^{TM} skin electrodes, at 10 Hz (10 samples per second), and is quantified here in micro-Siemens (µS). First, we removed noise generated by the tonic component of the GSR signal, which is generated by natural participant movements (such as breathing) and is unrelated to arousal (Ohme et al., 2009). We used a median filter to remove this noise by computing the median GSR score of a central measure with surrounding samples based on a +/-4 second time interval (Ohme et al., 2009). We then ran an independent t-test to compare GSR values between the cold pressor condition and the control condition. Despite our prediction that participants in the cold pressor condition would have greater GSR values than participants in the control condition, we found that there was no difference in GSR for the two conditions, control = 2.38µS (*SD* = 2.18) and cold pressor = 1.64µS (*SD* = 0.97; *t*(42) = 1.45, *p* = .15, *d* = 0.44, 95% CI [-0.16, 1.03]).

Pleasantness and Arousal

To test the difference between the cold pressor condition and the control condition ratings of image arousal and pleasantness we ran independent t-tests. Despite our prediction that participants in the cold pressor condition would rate the images as more arousing and less pleasant than participants in the control condition, we found that participants in the control condition rated the images as equally arousing (*M* = 2.41, *SD* = 0.89) as the participants in the cold pressor condition (*M* = 2.56, *SD* = 0.88; (*t*(42) = 0.54, *p* = .60, *d* = 0.16, 95% CI[-0.43, 0.75]). Similarly, participants in the control condition rated images as equally pleasant (*M* = 3.39, *SD* = 0.55) as the participants in the cold pressor condition (*M* = 3.40, *SD* = 0.58; *t*(42) = 0.07, *p* = .95, *d* = 0.02, 95% CI [-0.57, 0.61]) for the two conditions.

Discussion

The aim of this study was to investigate the effect of arousal on boundary judgement errors for neutrally valenced images. Our first hypothesis, that participants in the control condition would make more boundary extension errors than participants in the cold pressor condition was supported. Additionally, our second hypothesis, that participants in the cold pressor condition would make more boundary restriction errors than participants in the control condition, was also supported. Taken together, our results indicate that the cold pressor task led to a reduction in participants’ tendency to boundary extend and an increase in their tendency to boundary restrict compared to the control. To determine whether these changes in boundary judgement behaviour were due to arousal, we must evaluate whether the cold pressor task induced heightened arousal in the participants.

We used objective measures of autonomic nervous system response – heartrate variability and Galvanic Skin Response (GSR) – to investigate whether the cold pressor task increased participants' state of arousal. In a surprising finding, we observed that heartrate variability was greater for participants in the cold pressor condition than for those in the control condition, which indicates increased parasympathetic activation. Typically, researchers find that acute pain, such as that induced by the cold pressor task, causes a decrease in parasympathetic activation (Koenig et al., 2014). However, finding heightened parasympathetic activation during the cold pressor task is not unique to our study. A study by Acevedo et al. (2020) also found that participants' heartrate variability, as measured by RMSSD, increased while they underwent the cold pressor task, suggesting an increase in parasympathetic activity. Despite observing this increase in parasympathetic activity, Acevedo et al.'s measure of sympathetic influence on the heart (pre-ejection period), demonstrated that participants also experienced increased sympathetic activation in response to the cold pressor task. The researchers concluded that the cold pressor task produced a complex activation of the autonomic nervous system. Thus, although it is typical to find that the cold pressor task lowers parasympathetic activity, heightened parasympathetic activity still indicates that, as predicted, participants in the cold pressor condition experienced greater arousal than participants in the control. However, contrary to our prediction, we found that GSR was not greater for participants in the cold pressor condition than for participants in the control condition. Our null finding for GSR suggests that the cold pressor task did not significantly increase participants' sympathetic activation. This result is contradictory to consensus within the literature on skin conductance, which indicates that the cold pressor task increases sympathetic activation, resulting in increased GSR (Deuter et al., 2012; Jha et al., 2017; McGinley & Friedman, 2014; Reeves & Shapiro, 1983). The robust literature demonstrating that the cold pressor task reliably increases sympathetic activation suggests that it is unlikely that our participants did not experience increased sympathetic activation as a result of the cold pressor (Koenig, 2014). As such, it is possible that methodological issues may have impacted the accuracy of our GSR measurement, leading to our null finding. These potential methodological issues will be discussed below. Overall, our objective measures of arousal indicate that the cold pressor task increased participants' parasympathetic activation but did not significantly alter their sympathetic response.

Our first subjective measure of arousal – how participants rated image arousal – suggests that the cold pressor task did not significantly alter participants' self-identified arousal. Contrary to our third hypothesis, participants in the cold pressor condition did not rate the images as more emotionally arousing than participants in the control. These results are consistent with Experiment 1 from Green et al., which found that an aversive stimulus did not affect how participants rated image arousal. However, they are inconsistent with Experiment 2 from Green et al., which used a different self-report measure and found that the aversive stimulus did increase participants' ratings of image arousal. Similarly to Experiment 1 from Green et al., after we presented each image we instructed participants to rate how emotionally arousing they found the image. As Green et al. note., it is possible that the framing of this instruction did not cause participants to introspect on their own state of arousal. Instead, participants may have been simply judging the neutral image as unarousing. Our findings highlight an important debate within the field of arousal – whether subjective self-report measures can accurately and meaningfully measure arousal compared to objective measures (Adwusi et al., 2021). The reliability of self-reports of arousal can be affected by various physiological, psychological, and environmental factors (Xu & Huang, 2020). For example, highly anxious individuals often misperceive their own physiological arousal, resulting in a non-significant correlation between their subjective and objective measures of arousal (Mauss et al., 2004; Miers et al., 2011). However, subjective measures of arousal are still the “gold-standard” for assessing pain, such as the pain induced by the cold pressor task (Mouraux & Ianneti, 2018). To address the subjectivity of the pain and arousal experience, Wideman et al. (2018) recommend that researchers and clinicians use a multimodal assessment model of pain that includes subjective and objective measures. Thus, we suggest that future research on the effects of arousal on boundary judgements incorporates objective measures of arousal, such as heartrate and blood pressure, and robust subjective measures, such as the State-Trait Anxiety Inventory (Spielberger et al., 1970), to capture an in-depth representation of participants’ arousal.

Our second subjective measure of arousal – how participants rated image pleasantness – suggests that the cold pressor task did not change how participants perceived image pleasantness. Contrary to our fourth hypothesis, participants in the cold pressor condition did not rate the images as less pleasant than participants in the control. This result is inconsistent with Green et al. (2019) who found that images presented with an aversive stimulus were rated as less pleasant than images that were presented alone. Unlike Green et al., our results indicate that the cold pressor task did not change how participants perceived image valence, suggesting that the boundary restriction effects we observed were not due to negative image valence. This finding provides important evidence to suggest that participants in the cold pressor condition boundary restricted due to arousal caused by the cold pressor task, and not because the cold pressor changed how participants perceived image valence.

Overall, our findings suggest that the cold pressor task heightened participants’ arousal, as measured by heartrate variability, which led them to decrease their tendency to boundary extend and increase their tendency to boundary restrict. These results are consistent with the findings of Green et al. (2019) that arousal, as induced by noise, enhanced boundary restriction and attenuated boundary extension. However, unlike Green et al. who measured arousal using self-reported data, our objective measure of arousal indicates that participants in the cold pressor condition experienced heightened parasympathetic arousal compared to the control. Given the robust literature on the cold pressor task, it is likely that participants also experienced heightened sympathetic arousal, but our measures did not support this (Koenig, 2014). The effects that heightened arousal had on boundary judgement errors are consistent with past research, which demonstrated that heightened arousal increases peoples' perception of threat (Cole et al., 2013). Heightened threat perception may increase a person's attention to central objects in a scene as a way to locate potential danger (Cole et al., 2013; Green et al., 2019). Indeed, Chan et al. (2020) found that participants who anticipated bodily harm from the cold pressor task showed a hypervigilant viewing pattern of the foreground of scene images. Greater attention to central objects in a scene may in turn induce a feeling of greater proximity to the object upon recall of the image (Cole et al., 2013). Consistent with Green et al. (2019), who manipulated arousal directly, and Mathews and Mackintosh (2004) and Safer et al. (1998), who indirectly manipulated arousal, we found that heightened arousal may increase individuals' tendency to make boundary restriction memory errors. Increased threat perception induced by arousal may reduce an individual's capacity to employ top-down scene schema that extrapolates information beyond the boundaries of the scene, which can produce the boundary extension effect (Green et al., 2019; Intraub, 2010). Without the mental representations generated by this extrapolation of information, individuals may be less likely to make a source-monitoring error, leading to an attenuation of boundary extension and an increase in boundary restriction (Green et al., 2019).

Our finding that arousal can induce boundary restriction errors has methodological implications for the boundary judgement field. Very few previous studies have observed boundary restriction for neutrally valenced images (Bainbridge & Baker, 2020; Green et al., 2019). In fact, past studies on boundary restriction have demonstrated inconsistent results, with some studies finding boundary restriction effects for negative images (Mathews &

Mackintosh, 2004; Safer et al., 1998), while other studies found no boundary restriction effects (Candel et al., 2003; Davies et al., 2007). These studies may have failed to consistently induce boundary restriction because arousal was only manipulated using negatively valanced images. Instead, we manipulated arousal directly with the cold pressor task and used neutrally valenced images. Because we did not use images to elicit arousal, we were able to keep the content and composition of the images consistent, which is a more methodologically suitable way to manipulate arousal (Green et al., 2019; Porter et al., 2014). Consistent image content and composition is especially important considering recent research by Bainbridge and Baker (2020) that suggests image composition can significantly impact how individuals make boundary judgements. How arousing an image is perceived to be is highly subjective and can vary greatly between individuals. For example, the perceived unpleasantness of an image can vary by age (Charles et al., 2001), gender (Davies et al., 2012), or personality (Lang et al., 1993). In contrast, the cold pressor task has been shown to reliably elicit sympathetic and parasympathetic arousal responses across age and gender (Edens & Gil, 1995; Schwabe & Schachinger, 2018; von Baeyer et al., 2005). Thus, directly manipulating arousal through an external stimulus, such as the cold pressor task, may provide the boundary judgement field with a consistent way to elicit boundary restriction effects, even for neutral images.

Our study has limitations. First, the results of this study should be interpreted with caution because it is currently statistically underpowered. The results are based on 44 participants out of the 102 participants required to detect a medium between-subjects effect size (*d* = 0.50) as calculated in our power analysis. As such, our results are more likely to be affected by type II errors due to low statistical power (Shreffer & Huecker, 2023). Second, our non-significant finding for the GSR of participants in the cold pressor condition and the control condition could be due to our between-subjects methodology. The majority of participants in the cold pressor condition were unable to immerse their hand for the full duration of the encoding phase and instead immersed and removed their hand multiple times throughout the task. This resulted in a pattern within the raw data which indicates that GSR sharply decreased when participants placed their hand in the cold pressor task and sharply increased when they removed their hand. GSR is a highly subjective measure and baseline GSR can vary greatly between individuals depending on their threshold conductivity, their emotional introversion and their emotional extroversion (Foglio et al., 2008). The subjectiveness of GSR means that, even with a control group, it is difficult to compare individuals' GSR between groups (Foglio et al., 2008). As such, without a measurement of participants' baseline GSR we cannot determine whether the cold pressor task significantly changed participants' GSR from their individual baseline compared to participants in the control. To address the subjectiveness of the GSR measure, future research could collect a measurement of GSR prior to the encoding task and during the encoding task so that participants' change from baseline could be compared using a within-subjects design. Finally, inaccurate heartrate readings from the NeuLog^{TM} heartrate monitor meant that we were only able to evaluate basic heartrate variability. To address this inaccuracy in measurement, future research could collect heartrate data using more precise tools such as ECG equipment, which would allow for more accurate interpretation of arousal measures.

Recent research by Bainbridge and Baker (2020) suggests that image composition may play an important role in boundary judgement. Bainbridge and Baker suggest that the majority of boundary judgement studies used images with one central, close-up object against a generic background. We used similar images in this study – a single, close-up everyday object (e.g., a pen or cup) against a plain background (e.g., a woodgrain or blank wall). Bainbridge and Baker suggest that these object-orientated scenes are not representative of scenes we view in real life, which are usually composed of many objects that are both close-up and far away from the viewer. The researchers found that while close object images usually elicit boundary extension, scenes that were more representative of real-life scenes can elicited boundary restriction. Thus, while the current study observed boundary restriction for object-orientated scenes, future research could investigate how arousal affects boundary judgements for naturalistic images that are more representative of real-life scenes.

To summarise, our results show that arousal, as induced by the cold pressor task, had an effect on boundary judgement errors. The cold pressor task led to a decrease in boundary extension errors and an increase in boundary restriction errors compared to the control. Our results support burgeoning evidence within the boundary judgement literature that arousal may be an important component of the boundary restriction phenomenon.

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