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OBSERVATION

# When the Body Matches the Picture: The Influence of Physiological Arousal on Subjective Familiarity of Novel Stimuli

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Numerous studies show that bodily states shape affect and cognition. Here, we investigated whether incidental physiological arousal impacted perceived familiarity for novel images depicting real-world scenes. Participants provided familiarity ratings for a series of high- and low-arousal emotional images, once after a cycling session (to increase heart rate) and once after a relaxation session (to reduce heart rate). We observed a novel match-effect between internal (physiological) and external (stimulus) arousal sources, where participants rated highly arousing images as more familiar when bodily arousal was also high. Interestingly, the match-effect was greater in participants that scored low on self-report measures of interoception, suggesting that these individuals are less able to correctly perceive bodily changes, and thus are more likely to confuse their physiological arousal with an external source. Overall, our findings underscore the importance of interactions between the mind, body, and stimulus, especially when it comes to subjective judgments of familiarity.

***Public Significance Statement***

The present study provides first evidence that changes in bodily arousal (i.e., an increase and decrease in heart rate) influence the perceived familiarity of novel emotional images. Our main results reveal that highly arousing images are judged as more familiar when experiencing increased levels of bodily arousal (following a cycling session) compared to lower levels of bodily arousal (following a relaxation session). We observed a novel "match" effect between internal (physiological) and external (stimulus) arousal sources in eliciting enhanced feelings of familiarity. Concretely, participants rated novel highly arousing pictures as more familiar while experiencing high bodily arousal (postcycling) compared to low bodily arousal (postrelaxation). These findings underline the importance of body-mind interactions in familiarity judgments.

*Keywords:* bodily arousal, familiarity ratings, body-mind interactions, interoception

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Emotion theories have long emphasized contributions of bodily feedback, including autonomic arousal, to affective experience (for review, Carr et al., 2018; James, 1884). Recent research focuses on its role in basic perceptual, attentional, and memory processes (Critchley & Garfinkel, 2015; Laird & Lacasse, 2014). There is now substantial evidence that cardiovisceral feedback, from the phasic discharge of arterial baroreceptors, influences basic emotional processing (e.g., Pfeifer et al., 2017). For example, it is easier to detect fear faces presented during cardiac systole (when visceral feedback is maximal) than during diastole (Garfinkel et al., 2014). Similar autonomic-cognitive links extend to memory, where familiar stimuli elicit arousal (e.g., Morris et al., 2008; Topolinski, 2012). Memory performance for words presented during systole (vs. diastole) is lower, especially for low-confidence items (Garfinkel et al., 2013). Novel faces presented around systole are falsely endorsed as "old" when participants rely

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on impressions of familiarity without conscious recollection (Fiacconi et al., 2016). Cardiac feedback thus influences familiarity judgements, particularly with uncertainty about the presented material. Interestingly, such visceral influences can be nonspecific, as incidental arousal signals (e.g., a low-amplitude vibration) enhance feelings of familiarity (Goldinger & Hansen, 2005).

Visceral experiences also influence social judgments. For instance, participants worry more about global warming, desertification, or drought when actually feeling warm (Risen & Critcher, 2011); presumably because participants perceive their bodily state as related to the target stimulus (Schwarz, 2015). Similar "visceral fit" effects hold when participants' bodily arousal is manipulated by means of a short cycling or relaxation session. Specifically, participants detect more high-arousal words (e.g., *terror, champion*) during increased bodily arousal, and more low-arousal words (e.g., *boredom, flower*) during reduced bodily arousal (Kever, Grynberg, et al., 2015). Similar effects occur with a constructive recognition task, in which a target word is first hidden by a mask and then becomes progressively visible (Kever et al., 2017, Kever et al., 2019).

Building on this research, the present study examines familiarity judgments for novel images, while focusing on the role of a (mis-)match between stimulus-arousal and bodily- arousal. We manipulated participants' bodily arousal through a short cycling and relaxation session, then presented high- and low-arousal emotional pictures and collected familiarity ratings. Unlike traditional recognition-memory tasks, participants did not complete an encoding phase, but reported subjective familiarity for pictures that were all novel to them (they believed that pictures came from various media outlets). We hypothesized that high-arousal images would seem more familiar when experiencing high arousal (postcycling) compared to low arousal (postrelaxation), because of the "match" between external (stimulus) and internal (body) arousal. This "(mis)match" logic also predicts that when relaxed, high arousal images should appear novel (Ranganath & Rainer, 2003). For low-arousal stimuli, bodily arousal should lead to a general misattribution effect and thus higher overall familiarity ratings (Jacoby et al., 1989).

Furthermore, the effect of arousal on familiarity should depend on individual differences in ability to sense internal bodily changes, that is, interoception (Craig, 2003). Such differences shape the relationship between physiological state, subjective experience, and information processing (e.g., Herbert et al., 2007; Kever, Pollatos, et al., 2015; Wiens, 2005). Accordingly, we measured participants' interoceptive sensibility (IS) via self-reports of interoception (Garfinkel et al., 2015). Note that the current literature leads to two opposite predictions concerning IS. One is that high IS individuals better sense their bodily states and rely on them more when judging familiarity (aligning with notions that "gut feelings" are susceptible to arousal manipulations; Goldinger & Hansen, 2005). Consequently, high IS individuals would show greater match and misattribution effects when in a highly arousing state. Alternative prediction is that low IS individuals are poor at isolating the specific origins of their bodily states, and thus conflate their own physiological arousal with an external stimulus, enhancing match and misattribution effects. This prediction follows reports that low IS individuals are more vulnerable to visceral influences on memory and body ownership (Garfinkel et al., 2013; Tsakiris et al., 2011).

# Method

## Participants, Stimuli, and Materials

Participants were 115 University of California, San Diego undergraduates ($M_{age}$ = 20.3 years, $SD_{age}$ = 2.1 years; 29 males). Power for main and interaction effects was estimated with Superpower package in R (Lakens & Caldwell, 2019) in a sample of 100 participants (Brysbaert, 2019). Thousand simulations for a $2 \times 2 \times 2$ within-subjects design [Block (2: cycling/relax) $\times$ Stimulus Arousal (2: high/low) $\times$ Stimulus Valence (2: negative/positive)] were performed with a seed set to 2019. Based on pilot data, the assumed standard deviation was .1, the factor correlation .8, and the means [2.8,4.1,3.1,3.8,2.6,4.0,3.0,3.8]. The alpha level used as a significance threshold was set to .01. Statistical power (based on the percentage of $p < \alpha$ results) for the interaction effect of particular interest to us (Block $\times$ Stimulus Arousal) was 100% with a $\eta_p^2$ of .72. For the paired *t*-tests, the simulation predicts power of 100% for Cycling_HighArousal versus Cycling_LowArousal and Relaxation_HighArousal versus Relaxation_LowArousal with effect sizes of −.5.9 and 10.61, respectively.

Stimuli were 96 pictures from IAPS (International Affective Picture System; Lang et al., 1999). Using IAPS ratings, we categorized pictures into four groups, according to valence (positive vs. negative) and arousal level (high vs. low). We then created two blocks of 48 stimuli, each including 24 high-arousal (12 positive, 12 negative) and 24 low-arousal (12 positive, 12 negative) pictures. Blocks did not differ in mean picture valence or arousal (for a description of picture characteristics, see online supplementary materials).

The Multidimensional Assessment of Interoceptive Awareness (MAIA; Mehling et al., 2012) and Body Consciousness Questionnaire (BCQ; Miller et al., 1981) were administered to measure individual differences in general interoceptive sensibility, private and public body consciousness, and body competence.

## Procedure

After providing informed consent, participants placed the Polar RS800CX strap around their chest, allowing for the precise and noninvasive recording of heart rate (HR) at 1-Hz frequency (Williams et al., 2016). Next, participants were randomly assigned to either a cycling or relaxation session (within-subject conditions, stimuli blocks, and cycling/relaxation sessions were fully counterbalanced). During cycling, participants pedaled on a bicycle ergometer for 7 min. Target HR was set at 65% of the estimated maximal HR (65% of [220 (beats per minute) minus age]), corresponding to moderate-intensity exercise. During relaxation, participants sat in an armchair while listening to relaxing music for 7 min. After each session, participants completed three 10-point Likert scales evaluating their subjective feelings of activation, stress, and pleasantness.

Both sessions were followed by a picture-rating task. Participants were told they would see images from TV, movies, magazines, newspapers, and advertisements that appeared over the last 20 years. On each block, participants rated their perceived familiarity of the pictures on a horizontal scale from 1 (*not at all familiar*) to 7 (*very familiar*). Each trial started with a 1,000-ms fixation cross, followed by the 2500-ms picture presentation, and the rating screen. Once both blocks finished, participants filled out computerized versions of the MAIA and BCQ, and then debriefed.

## Results

### Analysis Strategy

Data were analyzed with frequentist methods in SPSS (Version 26) as well as Bayesian statistics in JASP, the latter allowing to compare the predictive performance of two hypotheses (van Doorn et al., 2020) and to monitor evidence as data accumulate (Rouder, 2014).

Paired-sample *t*-tests with Bonferroni correction were conducted to compare participants' HR, subjective ratings of activation, pleasantness, and stress during the cycling and relaxation session.

Familiarity ratings were analyzed with multilevel models (MLMs), which allow for effective handling of missing observations, stimulus-level random-effects, and fewer covariance assumptions (West et al., 2014). Post hoc analyses were conducted on the significant effects using paired-sample *t*-tests with the Bonferroni correction, and Bayesian paired samples *t*-tests performed with a default Cauchy prior width of $r = .707$ for effect size on the alternative hypothesis (Rouder et al., 2012). These Bayesian analyses yield Bayes factors (BFs; Dienes, 2014; Rouder et al., 2009) varying between 0 and $\infty$, where values below 1 provide increasing evidence in favor of the null hypothesis and values above 1 increasing evidence for the alternative hypothesis.

### Manipulation Check: Heart Rate and Subjective Activation Scales

Heart rate data of 21 participants were discarded due to technical problems during recording ($N = 94$). Table 1 displays participants' mean HR during the cycling/relaxation block and after, during familiarity ratings. Our arousal manipulation was successful, with higher mean HR during cycling than during relaxation, $t(93) = 33.32$, $p < .001$. Moreover, participants maintained higher HR postcycling compared to postrelaxation, $t(93) = 12.41$, $p < .001$.

We also analyzed participants' ratings of activation, pleasantness, and stress by Block (cycling/relaxation; see Table 2). Ratings of activation and stress were higher after cycling than after relaxation, $t(114) = 9.12$, $p < .001$; $t(114) = 4.09$, $p < .001$. The relaxation session was evaluated as more pleasant than the cycling, $t(114) = 4.51$, $p < .001$.

**Table 1**
*Mean Heart Rate (Beats Per Minute; BMP) as a Function of Experimental Block (Cycling/Relaxation) and Time (During/After)*

| Experimental block | Time: During arousal manipulation block *M* (*SD*) | Time: After block (familiarity ratings) *M* (*SD*) |
|---|---|---|
| Cycling | 118.73 (10.80)[a] | 91.79 (13.94)[b] |
| Relaxation | 81.06 (9.88)[c] | 80.52 (10.20)[c] |

*Note*. Means with different superscript letters (a, b, c) are statistically different at $p < .001$.

**Table 2**
*Mean Ratings of Activation, Stress, and Pleasantness, as a Function of Experimental Block (Cycling/Relaxation)*

| Experimental block | Activation *M* (*SD*) | Stress *M* (*SD*) | Pleasantness *M* (*SD*) |
|---|---|---|---|
| Cycling | 6.33 (2.45) | 3.11 (1.92) | 6.73 (2.21) |
| Relaxation | 3.33 (2.01) | 2.37 (1.44) | 7.73 (1.98) |

### Familiarity Ratings

Familiarity ratings of 4 participants were discarded due to technical problems during recording ($N = 111$). Familiarity ratings were analyzed using an MLM with Block (2: cycling/relaxation) × Stimulus Arousal (2: low/high) × Stimulus Valence (2: negative/positive) as fixed effects. Interindividual differences in interoceptive sensitivity were included as random intercept.

Figure 1 displays the key finding. Critically, we observed the predicted Block × Stimulus Arousal interaction, $F(1, 10{,}443) = 6.08$, $p = .014$. Participants rated high-arousal images more familiar after cycling than after relaxation, $t(110) = 3.85$, 95% CI [.12, .37], $p < .001$, although there was no difference for low-arousal images, $t(110) = 1.34$, 95% CI [−.04, .22], $p = .366$. The results of the corresponding two-tailed Bayesian paired samples *t*-tests yielded BFs (H1/H0) of 116 for the high arousal images and .21 for the low arousal images. According to Jeffreys (1961), this constitutes decisive evidence supporting an effect of Block for high-arousal images, but substantial evidence supporting the null hypothesis for low-arousal images.

Findings also revealed a main effect of Block, $F(1, 10{,}443) = 23.53$, $p < .001$, $BF_{10} = 6.78$ (substantial evidence), such that familiarity ratings were higher during cycling, when collapsing across high- and low-arousal stimuli.

For analyses involving additional stimulus characteristics, including stimulus valence, please see online supplementary materials. Importantly, there was no 3-way interaction with valence that qualifies the key finding of two-way interaction of Block × Stimulus Arousal reported here.

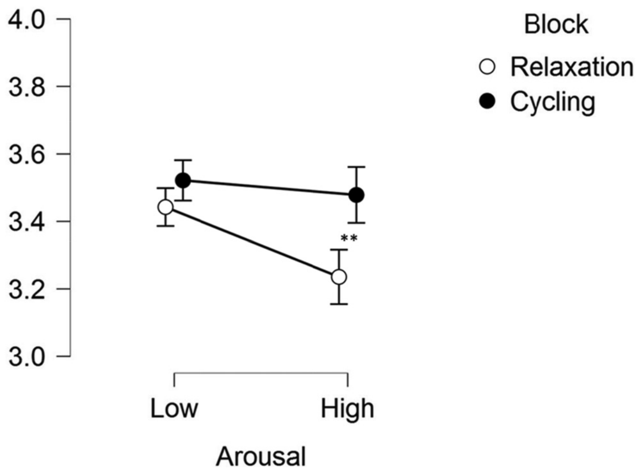
### Individual Difference Measures

To assess how IS and bodily awareness measures impacted familiarity ratings, we included total MAIA scores and BCQ subscales as a fourth continuous factor in separate MLMs, along with fixed-effects for Block (2: cycling/relax) × Stimulus Arousal (2: low/high) × Stimulus Valence (2: negative/positive).

#### *MAIA*

We observed a marginal MAIA × Block × Stimulus Arousal interaction on familiarity ratings, $F(1, 10{,}435.98) = 3.37$, $p = .066$, whereas the original Block × Stimulus Arousal interaction remained significant, $F(1, 10{,}435.98) = 5.35$, $p = .021$. A breakdown of this three-way interaction demonstrated that the familiarity match-effects were localized to participants with lower MAIA scores.

**Figure 1**
*Familiarity Ratings by Block (Relax Versus Cycling) and Stimulus Arousal (Low Versus High)*




*Note.* Error bars show ±1 within-subject (repeated-measures) *SEM*.
** $p < .01$.

### *BCQ*

We observed similar three-way interactions for Private BCQ × Block × Stimulus Arousal, $F(1, 10{,}436) = 7.46$, $p = .006$, and Public BCQ × Block × Stimulus Arousal, $F(1, 10436) = 10.62$, $p = .001$. The Block × Stimulus Arousal interaction also remained significant in both the Private BCQ MLM, $F(1, 10{,}436) = 10.62$, $p = .001$, and Public BCQ MLM, $F(1, 10436) = 10.38$, $p = .001$. Once again, the match-effects on familiarity occurred more for participants with lower scores on the private and public scale.

## Discussion

The present study suggests that incidental internal (physiological) and external (stimulus) arousal combine to enhance familiarity judgments for pictures that are objectively novel. Participants judged arousing pictures as more familiar when experiencing high bodily arousal (compared to low bodily arousal), indicating that familiarity increases when stimulus' arousal matches one's physiological state. Emphasizing a different aspect of this pattern, novel arousing pictures appear unfamiliar only if participants view them in a relaxed state. These match/mismatch effects were greater in participants with low IS, suggesting confusability between arousal sources, as we discuss shortly.

We interpret our results as consistent with ideas of "visceral fit" (Risen & Critcher, 2011) and excitation transfer (Reisenzein, 1983; Schachter & Singer, 1962). These ideas assume the simultaneous presence of two elements: (a) bodily arousal and (b) a stimulus that serves as a plausible arousal source.

Earlier studies revealed processing advantages for emotional words matching one's current high and low arousal states (Kever, Grynberg, et al., 2015; Kever et al., 2017). Note, however, that in our study low-arousal stimuli were also rated as familiar in the aroused state (no match). This is why we propose that cycling leads to general misattribution of arousal, making all stimuli feel more familiar (Fiacconi et al., 2016; Goldinger & Hansen, 2005).

However, the notions of (mis)fit or (mis)mismatch are important because relaxation made high-arousal stimuli appear especially unfamiliar. A memory-focused account suggests that high-arousal stimuli are usually distinct, and elicit physiological responses (Bradley, 2009; Bradley & Lang, 2000); as well as affect-based associations—all making them memorable (Phelps, 2012). When a perceiver is in a relaxed state, their salience against the background bodily state increases, and is a cue to novelty, either via low-level mismatch mechanisms (Ranganath & Rainer, 2003) or via attributional and source-monitoring inferences (Jacoby et al., 1989; Johnson et al., 1993). When a perceiver is externally aroused, familiarity judgements for high-arousal stimuli become complicated. Stimulus-related arousal is either confounded with cycling-related arousal, or just less perceptible against the aroused bodily state. Consequently, people rate the images as familiar. As mentioned, for low-arousal stimuli, familiarity is increased both after cycling and relaxation, but for different reasons: (a) a match-effect in the relaxation condition and (b) a misattribution effect postcycling. A future study with a baseline condition would strengthen this interpretation and clarify whether familiarity ratings for low-arousal images increase following relaxation or equal baseline ratings.

Our findings do not allow for strong statements regarding underlying mechanisms, but source confusion and misattribution seem at play (Jacoby et al., 1989; Johnson et al., 1993). This is consistent with more pronounced match effects in participants with low IS, who presumably show greater source confusion. Still, the role of IS needs clarification, as it is complex. Some findings suggest that high IS enhances integration of bodily signals (e.g., Tsakiris et al., 2011) and facilitates processing of social and emotional signals (Arnold et al., 2019). Other findings suggests that low IS reduces the impact of embodiment cues (weight and softness) in value judgements and social impressions (Häfner, 2013). However, we found stronger influences of bodily processes on judgments in low IS participants. We assume that low IS individuals poorly isolate their own bodily states, and thus (mis)attribute their arousal to an external source (e.g., an emotional image), resulting in feelings of familiarity. Consistently, participants, who are made aware of the proper source of their arousal are less influenced by it in their height estimations (Storbeck & Stefanucci, 2014); or emotional responses (Cantor et al., 1975; Zillman, 1971). Alternatively, high IS individuals sense their bodily arousal so intensely, that they dismiss it as a valid signal in familiarity judgements. Clearly, further studies are needed and should include objective and self-report measurements of interoception and its different facets, such as accuracy vs attention (for a detailed discussion, see Murphy, 2019).

In conclusion, our findings contribute to the literature on body-mind interactions and arousal-familiarity links. Our study hints that transient internal states shape beliefs about having witnessed an emotional event, even though no actual memory trace exists.

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