The Role of Affect in Late Perceptual Processes:

Evidence from Bi-stable Illusions, Object Identification, and Mental Rotation

Trym Lindell

Oslo Metropolitan University

Janis H. Zickfeld

Aarhus University

Rolf Reber

University of Oslo

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Author Note

Trym Lindell, Department of Computer Science, Oslo Metropolitan University, Janis H. Zickfeld, Department of Management, Aarhus University, Denmark; Rolf Reber, Department of Psychology, University of Oslo, Norway.
Address correspondence to Trym Lindell, Department of Computer Science, Oslo Metropolitan University, Pilestredet 52, 0167 Oslo, Norway, Email: trym.lindell@oslomet.no; or Rolf Reber, Department of Psychology, University of Oslo, Postboks 1094 Blindern, 0317 Oslo, Norway; Email: rolf.reber@psykologi.uio.no.
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Abstract:

Computational views of perception do not consider affect to be required to solve a perceptual task. Previous research provided evidence for an affective component in early perceptual processes but it is unclear whether late perceptual processes yield concomitant affect. Three studies using three different tasks explored changes in affect related to late perceptual processes by exposing participants to a visual object and measuring activity in facial muscles (zygomaticus major and corrugator supercilii) using facial EMG as indicators for affect. In the first task, change of muscle activity was measured before and after participants indicated that the perspective of bi-stable illusions shifted. In the second task, change of muscle activity was measured before and after participants indicated that they identified an object that emerged from a pattern mask. The third task examined the affective consequences, as measured by facial EMG, of solving mental rotation tasks. The three studies found that shifts in bi-stable illusions, identification of objects, and solving mental rotation problems yielded increasing zygomaticus major activity, indicating increased positive affect after task completion. Simultaneously, corrugator supercilii activity decreased after successful perception. These studies suggest that success in perception is inherently affective, even when memory, comparison, and decision processes are involved.

Keywords: Bi-stable illusions, object identification, mental rotation, positive affect, fEMG, disambiguation

Public Significance Statement

Although computational models of perception do not consider affect to be necessary to solve a perceptual task, previous research found affective responses concomitant with early perceptual processes. However, it is unclear whether affect goes along with later perceptual processes that include categorization, memory, and decision processes. This study explores affect in later perception by measuring activity of the zygomaticus, the smiling muscle. Across three studies, we provide evidence in support of affect being a general consequence of successful perception even in complex tasks that include complex cognitive processes.

The Role of Affect in Late Perceptual Processes:

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The last two decades have witnessed increasing interest in the interaction between early perceptual processes and affect. A first line of research examined reward processes in perception (e.g., Jepma et al., 2012; Nicki, 1970). In the study by Jepma et al., presentation of ambiguous figures led to activation of brain areas related to curiosity; later disambiguation led to activation in areas related to reward. A recent line of research in this tradition showed that aesthetic perception is related to Bayesian surprise, suggesting that positive affect accompanying perceptual learning may be a signal of learning success and optimization (Sarasso et al., 2022). A recent theory of aesthetic appreciation, embedded in the predictive coding framework, considers positive affect as a reward that follows the reduction of prediction errors (Sarasso et al., 2020). As predictive coding, reducing prediction errors, and reward processes are ubiquitous in perception, the theory provides a neuroscientific explanation for the possibility that affective processes are an inherent part of perception.

A second line of research examined processing fluency (or fluency), which is the ease with which a mental operation is executed. Generally, fluency has positive effects on affective evaluation of stimuli (see Reber, et al., 2004). Various studies have shown that individuals prefer stimuli that can be perceived with greater ease (e.g., Reber et al., 1998) and devaluate not attended stimuli (see Raymond et al., 2003), a result that can be interpreted within fluency theory (Reber, 2012).

The affective nature of preference has also been supported using facial electromyography (fEMG). fEMG is a technique which measures activity in facial muscles associated with emotional expression. Dimberg (1990) reviewed a range of studies from his lab utilizing fEMG and reported specific facial muscle activity in response to specific affective responses, suggesting that facial muscle responses are a general aspect of emotional reactions. This notion has later been supported by authors focusing on positive and negative valence (Larsen et al., 2003). fEMG enables assessment of participants’ affective responses without their knowledge, avoiding potential demand effects of affective judgments. This technique has been applied in research on perceptual fluency (Winkielman & Cacioppo, 2001) and motor fluency (Cannon et al., 2010). Both studies observed that higher fluency increased positive affect, as measured through increased activity of the zygomaticus major (ZM) muscle. Zygomaticus activity has been shown to indicate positive affect (Brown & Schwartz, 1980; Dimberg, 1990; Lang et al., 1993; Larsen et al., 2003, Sato, 2020) but neither mental effort (unless it is supramaximal; Van Boxtel & Jessurun, 1993) nor cognitive load elicit changes in ZM activity (Hess et al., 1998). By contrast, activity of the corrugator supercilii does not only indicate negative affect (Brown & Schwartz, 1980; Lang et al., 1993; Larsen et al., 2003; Sato, 2020) but also physical effort (De Morree & Marcora, 2010), mental effort (Van Boxtel & Jessurun, 1993), and cognitive load (Hess et al., 1998).

A third line of research examined perception of static visual images and revealed that successful gestalt completion yielded positive affect (Erle et al., 2017; Flavell et al., 2018; Topolinski et al., 2015). The presence of gestalts in dot patterns elicited positive affect even though the object outlined by the gestalt could not be identified, nor did participants solve any task. Another experiment compared responses to passively looking at possible and impossible Necker cubes (Topolinski et al., 2015). The observed fEMG responses indicated a decrease in positive affect within 500 ms for impossible

Necker cubes. In a pilot experiment, participants needed around two seconds to distinguish the possible from the impossible versions in a forced-choice task. These observations suggest changes in positive affect in early perceptual stages and do not necessarily stem from conscious knowledge of having solved a task.

Other studies observed increases in ZM activity in perception involving other forms of gestalt completion, using Kanizsa shapes (Erle et al., 2017). In Kanizsa shapes, the incomplete edges of triangles or squares are embedded in context figures; the triangle or square shapes are automatically inferred from the edges through gestalt completion (Kanizsa, 1976). Flavell et al. (2018) noted that Kanizsa and the control shapes used in Erle et al. did not only differ on gestalt completion but on factors like symmetry, familiarity, or nameability. They observed an effect of Kanizsa-figures on ZM activity above and beyond the effects of these possible confounding variables (see also Erle & Topolinski, 2018).

One might argue that such findings are best interpreted as fluency effects. However, some observations contradict a perceptual fluency account. Erle et al. (2017) found that Kanizsa shapes were not liked less than were triangles and squares where the edges were outlined. This means that shapes that are presumably easier to see than Kanizsa shapes were not liked more, a finding not in line with a fluency account and more in line with an explanation in terms of successful gestalt completion.

In another study, Makin et al. (2012) showed that affirmative answers elicited more positive affect, as measured by ZM activity. In one experiment, the authors showed patterns with reflection symmetry and random patterns. Some participants had to respond “YES” to the reflection patterns and “NO” to the random patterns; other participants had to respond “YES” to the random patterns and “NO” to the reflection patterns. Contradicting a fluency account there was no significant difference between reflection and random patterns, but participants showed higher ZM activity when they had to respond “YES” than when they had to respond “NO”. This finding again suggests that not ease of perception of the stimulus *per se* but another element of the perceptual task elicits positive affect. Although “YES”-responses may speed up a decision, there is to our knowledge no direct evidence that affirmative responses increase stimulus fluency. Again, this result is not in line with a fluency account.

All research so far has used static stimuli to examine affective responses measured by fEMG. These findings were interpreted as affective responses to the success of early perceptual processes, such as gestalt completion, that did not include later cognitive processes like matching visual input with long-term memory, keeping a stimulus in working memory, comparison of two visual stimuli, or a match-no-match decision. To address these knowledge gaps, we explored whether later stages of perception that include memory and decision processes are accompanied by affective processes, using fEMG in three perceptual tasks.

We extend the extant research in two ways. First, we examine dynamic aspects of affect concomitant with perception. We have discussed theoretical arguments (Sarasso et al., 2020) and empirical evidence (Erle et al., 2017) that positive affect may signal success at perceiving a stimulus. However, the positive affect observed in gestalt completion tasks may be caused by early recognition of “good gestalt” that does not generalize to more complex tasks that include comparison and decision processes. To test whether successful perception or – alternatively – processes in early perception, such as perceptual grouping, account for positive affect, we need to examine dynamic processes of perception where the time of successful solution can be determined. Only when affect increases at the time the perceptual task is solved can we conclude that successful perception induces positive affect. That is why we – in contrast to previous studies – measure affect not at stimulus onset but when a perceptual task is successfully solved.

Second, there is good reason to assume that effects of earlier perceptual processes differ from effects of later cognitive processes. Fodor (1983) and Pylyshyn (1999) proposed that early perceptual processes are domain-specific and hence different from domain-general processes at later stages of perception, such as decision processes. It seems possible in principle that early perceptual processes yield affective outcomes, as briefly discussed by Pylyshyn (1999) and shown by Erle et al. (2017), Flavell et al. (2018), and Topolinski et al. (2015). However, affective outcomes of perception may be limited to such early perceptual processes and not extend to cognitive processes at later stages of perception of a stimulus.

Although Firestone and Scholl (2016) noted that affective processes may influence cognitive processes involved in later stages of perception, to our knowledge nobody has claimed that successful object identification or the solution of mental rotation tasks leads to affective consequences. From a computational viewpoint, affect is not necessary to achieve the solution of these tasks. Hence, such computational accounts would not predict affective consequences of task solution.

On the other hand, success may always yield positive affect and failure negative affect. This notion is part of Weiner’s (1985) attributional theory of emotion where positive or negative outcomes lead to positive or negative emotions, respectively. However, the evidence for Weiner’s claim of outcome-related emotions comes from achievement contexts, and it seems far-fetched to generalize results on success at exams to the solution of basic perceptual tasks, such as identification of an object or deciding whether two digits have the same or mirrored orientation. In our studies, we address an issue neglected by perception researchers who were interested in the cognitive processes following early visual perception but not in concomitant affective processes.

To summarize, earlier research has shown that positive affect, as measured by fEMG, is a consequence of early perceptual processes in gestalt completion tasks. As more positive affect was observed in gestalt completion tasks than in a more fluent variant of the same task, Erle et al. (2017) proposed that successful perception, not fluency yields positive affect. However, it is unclear whether such effects are limited to early perceptual phases (see Pylyshyn, 1999) or extend to tasks that include cognitive processes, such matching templates in long-term memory (object identification), and comparison of two stimuli and subsequent decision processes (mental rotation), as a general theory of outcome-related affect would predict (Weiner, 1985).

The Current Studies

The current studies focused on three different perceptual tasks, both replicating and extending extant research by examining (1) static and dynamic stimuli and (2) tasks that require memory, comparison, and decision processes.

In the first task, we showed participants bi-stable illusions where identical shapes can be viewed in two different ways, often as if a viewer would be looking from two different viewpoints (see Long & Toppino, 2004). Participants had to look at bi-stable figures and indicate a switch by pressing a key. Compared to the possible and impossible Necker cubes presented in Topolinski et al. (2015), this task added a dynamic component because we were interested in affective responses when the perspective of the bi-stable illusion switched. We assessed the affective response by measuring the ZM and corrugator supercilii (CS) activity when the participants indicated that the shape view switched.

In a second task including object identification, the image of an object slowly emerged from a pattern mask (see Feustel et al., 1983) until the mask completely disappeared after 30 seconds. Object identification includes at least two components, first extracting information from the visual stimulus and second matching the visual input with representations of the object in long-term memory (Johnson et al., 1996; Torfs et al., 2010). We constructed the object identification procedure in this study similar to the stimulus materials of an fMRI study by James et al. (2000). Participants had to press a button when they were able to identify the object, and ZM and CS activity were measured.

The third task was a mental rotation paradigm (Cooper & Shepard, 1973; Shepard & Metzler, 1971) in which participants are presented with rotated shapes or digits in various angles from each other (shapes) or from the upright position (digits) and have to determine whether the rotated stimulus is identical to a target. According to a model presented by Gill et al. (1998), this task requires participants to generate a visual image, keep one stimulus in a visual buffer while looking at the other stimulus, inspect and compare the two stimuli and finally decide whether the two stimuli are identical. Indeed, using a refractory period paradigm, Ruthruff et al. (1995) showed that the mental rotation task cannot be performed without central resources, excluding the possibility that mental rotation tasks can be solved using early perceptual processes only. Response times increase with rotational angle but are also affected by other factors. Koriat and Norman (1985) presented unfamiliar stimuli in various angles to participants and showed that response times decreased with increased familiarization at the same rotational angle. In our experiment, participants had to judge whether the rotated stimulus was identical or mirrored. We used both familiar and unfamiliar symbols in our study because familiarity has been shown to influence affect in the mere exposure paradigm (e.g., Zajonc, 1968; see Bornstein, 1989; Montoya et al., 2017). Moreover, Koriat and Norman (1985) have shown that when participants get familiar with previously unfamiliar stimuli, response times decrease. In other words, we expect familiar stimuli to be processed more fluently, which increases positive affect. It would therefore be interesting to see whether familiar stimuli lead to affective responses that are different from unfamiliar stimuli, and whether familiarity moderates a potential effect of successful solution of the mental rotation task on the zygomaticus response.

Across all tasks, we predicted positive affect to increase after successful solution of a perceptual task, be it switches in bi-stable illusions, object identification, or mental rotation. We did not have other predictions but explored effects of successful task solution on corrugator activity as an indicator of negative affect and effort. Finally, we manipulated multiple variables – and by extension their fluency – that are known to affect the speed with which participants solve mental rotation tasks: rotational angle, familiarity and mirroredness.

General Methods

Studies and participants

In total, we conducted three separate studies with three different main experimental tasks. The studies followed the APA ethical standards and have been approved by the internal ethical committee of the Department of Psychology at the University of Oslo (#2066326).

Study 1 included four experimental tasks, two of which were perceptual. The other two tasks were non-perceptual, but due to issues in the methodology that made interpretation difficult, we did not include them in the main article. For the sake of complete reporting, they are reported in detail in the Supplementary Materials, Section 6. Experimental Task 1 was a bi-stable illusion task and was presented first, Experimental Task 2 was an object identification task and was presented second. Study 2 contained both perceptual tasks from Study 1 but in reversed order to control for possible order effects. Study 3 was conducted last and introduced Experimental Task 3, which consisted of a mental rotation task.

Sample Size Justification.

Due to the initially exploratory nature of the current studies, we did not have any specific a-priori effect size to base our sample size on. For Study 1, we collected as many participants as possible from the research pool for the rest of the semester. Based on the main models across the three studies and our main effect of interest (muscle type x time interaction), we conducted sensitivity power analyses suggesting that we were able to detect interaction effects as small as $\beta = .10$ with 87% power in Study 1 and 88% power in Study 2, and as small as $\beta = .05$ with 99% power in Study 3 (see Supplementary Materials Table 1). Given that we increased the number of observations in Tasks 2 and 3, we opted to collect the same number of participants for the replication in Study 2 and the extension in Study 3.

In Study 1, we recruited 22 participants ranging from 18 to 42 years (5 male and 17 female; average age *M* = 23.4 years, *SD* = 6.2). Study 2 included 22 participants ranging from 19 to 33 years of age (6 male and 16 female; average age *M* = 23.3 years, *SD* = 3.1). Finally, Study 3 sampled 21 participants ranging from 19 to 30 years of age (10 male, 11 female; average age M = 24.8, SD = 3.2). Twenty-two participants originally participated, but due to a software error the data from one participant was excluded.

All participants were right-handed and had normal or corrected to normal vision. We mainly recruited students from the University of Oslo. Some participated as part of an introductory course and received partial course credit, whereas others were compensated with 100 NOK for their participation. The participants were informed about the general purpose of the experiment and the use and sharing of the data. Participants were told that the fEMG electrodes measured electrical activity, as done in previous studies (e.g., Fridlund & Cacioppo, 1986). This was done to avoid participants becoming self-aware of their facial responses and to avoid introducing demand characteristics. After the experiment, participants received a full debriefing concerning methods and purpose of the study.

Transparency and Openness

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study. All data, analysis code, and research materials are available at https://osf.io/wq4g5/?view_only=6fdd567bdaa0415eb3dc8c8d56e1c1a0. Data were analyzed using R, version 4.0.3 (R Core Team, 2020) and the packages *lme4* (version 1.1-25, Bates et al., 2015), *ggpubr* (version 0.4.0, Kassambara, 2020), *dplyr* (version 1.0.2; Wickham et al., 2020), *sjPlot* (version 2.8.6, Lüdecke, 2020), *tidyr* (version 1.1.2, Wickham, 2020), *metafor* (version 2.4-0, Viechtbauer, 2010), and *simr* (version 1.0.5, Green & MacLeod, 2016). The studies' design and their analyses were not pre-registered.

fEMG procedure

Prior to the day of the experiment, participants were asked to arrive at the lab with minimal make-up and male participants were asked to come recently shaved.

Upon arrival, participants were first asked to turn off their cellphones and leave it away from the experiment area of the lab. They were then asked to remove any metal objects that might touch their skin like piercings, rings and other jewelry.

Electrode sites were first cleaned using an alcohol solution to remove skin oils and make-up or creams. The electrode sites were then abraded using NuPrep skin prep gel (Weaver and Company, Aurora, USA) and a Q-tip cotton swab. The abrasive gel was then removed, and conductive gel (Sigma gel, Parker Labs, Fairfield USA) placed on the electrode sites and allowed to seep into the skin while the electrodes were prepared with adhesive collars and conductive gel. The gel-filled electrode cavity was checked for air bubbles and attached to the electrode sites following guidelines by Fridlund & Cacioppo (1986) for measuring ZM and CS activity. The ground electrode was placed centrally on the upper part of the participant's forehead. The center of the two electrodes used to measure each muscle's activity was always spaced 19mm apart. Distance was estimated by ensuring that the outer circumference of the adhesive disks (ADD204, Biopac Systems Inc., Goleta, CA) used to attach the electrodes intersected without overlap. Inter-electrode resistance was measured using a standard multimeter. If resistance was higher than five kΩ, the electrode preparation between the two sites was repeated (except alcohol application) until resistance was below the threshold. The wireless Bionomadix recorder was then attached to the participant's upper left arm and electrodes were attached to the recorder. The wires were also fastened using tape to reduce movement of the wires during recording.

The lights in the room were then turned off to reduce line noise and signal quality was visually inspected by the experimenter by asking the participants to mimic the experimenter’s facial movements. Importantly, participants were not asked to smile or frown to avoid hinting at the purpose of the electrodes.

Finally, participants were seated in front of the monitor that was separated from the recording station by movable walls. They were instructed to sit as still as possible and not to talk during the experiment unless they wished to stop the experiment. Participants were asked whether they had any final questions before the experiment was started.

Apparatus

Experiments were designed in E-prime 2.0 and E-prime 3.0. fEMG signals were recorded at 1000hz using silver/silver chloride (Ag/AgCl) electrodes from Biopac (EL654), Bionomadix wireless recorders (BN-EMG2) and a Biopac MP150 (Biopac Systems Inc., Goleta, CA). Signals were recorded using Biopac AcqKnowledge 4.3.

The participants viewed the experiment on a 55” Samsung ED55D LED TV capable of up to 120 Hz refresh rate and responded via a keyboard.

The E-prime experiments were run on a desktop connected to the monitor viewed by the participants. Trigger signals were sent from the E-prime desktop to the MP150 recording device which was connected to a separate desktop running AcqKnowledge where the raw data was stored.

Preprocessing

The raw fEMG signal was filtered online in AcqKnowledge according to guidelines by Fridlund and Cacioppo (1986) using a low pass (500hz), high pass (10hz) and notch filter adapted for the Norwegian line noise (50hz) and integrated online using 20 data points.

Epochs were extracted and z-scored along the time axis on a trial-by-trial basis to reduce intra-participant and trial differences (similar to Winkielman & Cacioppo, 2001). Given that we could not estimate the strength of the muscle responses a-priori, we could not create trial exclusion criteria based on responses reaching a given threshold. This was further problematic as our experiments included tasks that may involve explicit, sudden affective responses that potentially could produce large and variable amplitude signals, potentially making them hard to disentangle from movement artefacts. However, such affective signals should be time-locked to responses, while movement artefacts were assumed to happen at random times as they are not task-related. The z-scoring procedure applied at the trial level was used to normalize the amplitude of both affective signals and artefacts so that time-locked affective signals would persist on a trial averaged participant level, while non-time-locked artefacts would be averaged out. Furthermore, we recorded both ZM and CS such that their pattern of activity could be compared. Given that movement artefacts would result in increased activity on both muscle sites, activity patterns in opposite directions most probably do not appear due to such artefacts, which served as an additional control.

All offline preprocessing scripts were written in Python 3.6 using the NumPy module.

fEMG research on affective responses has previously utilized time-binning of a section of the fEMG signal. The specific time period used, and the size of the time bins varies between studies. In some cases, this may appear to have left some of the signal outside the analysis window (e.g., Figure 2 in Topolinski et al., 2015, where the signal seems to go beyond the measured time frame of 4000 ms).

When selecting (1) the appropriate time window to analyze and (2) the size of the time bins, multiple aspects have to be taken into account when the signal's duration and shape are unknown (Fridlund & Cacioppo, 1986).

If the signal is short and bi-directional (contains one increasing and one decreasing part) and the time bins are too large, such a signal may be lost within a time-bin because positive and negative values might average out. On the other hand, if the signal is longer, a short time window may not describe the full shape and development of the signal. Because of this issue, we have chosen epoch analysis windows-specific to each task based on previous research using similar tasks but measuring different types of responses (where possible). The time course of the responses in these experiments allows us to estimate the timeframe of the fEMG signals under the assumption that they depend on the same underlying processes. Detailed procedures for each task are described below.

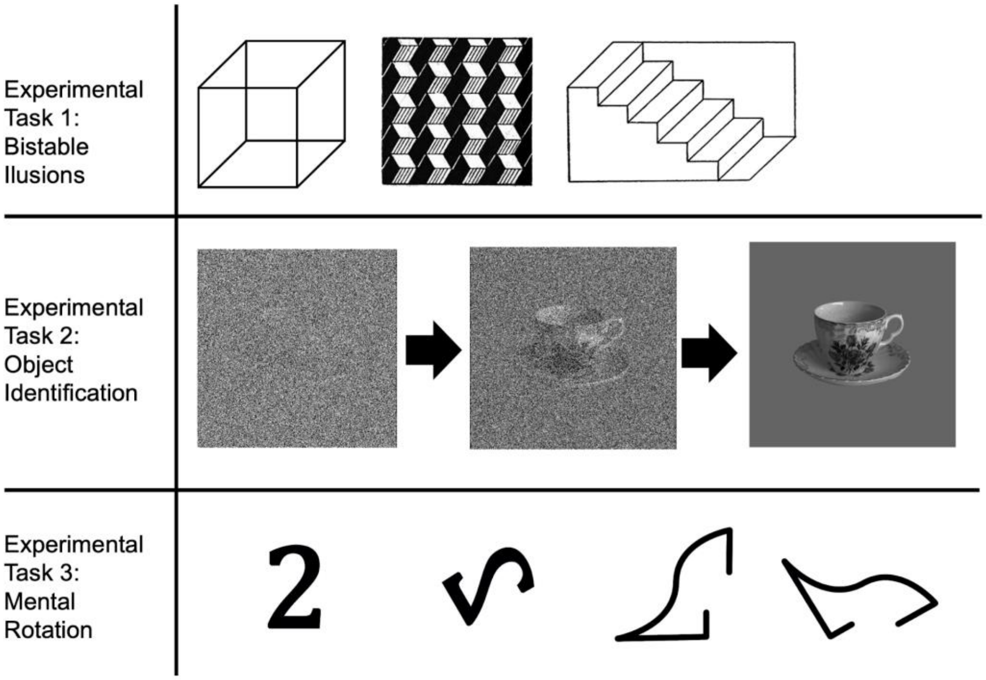
Experimental Tasks and Results

Experimental Task 1: Bi-stable Illusions

In Task 1, participants viewed a series of six bi-stable illusions (Figure 1; https://osf.io/n5kzj/), consisting of simple line drawings that could be seen from two different perspectives, in individual random order. The participants were instructed to report a switch between the two perspectives by pressing the space button. All participants had to provide five switch responses for each illusion. After five switches, participants responded whether they had previously seen the illusion[1] and moved on to a new illusion, resulting in a total of 30 switch responses per participant; Both Study 1 and 2 employed the same experimental design for this task.

Figure 1.

Example Stimuli for Each Experimental Task.



Epoch Selection

The perceptual switch in bi-stable illusions have previously been examined using pupillometry (Einhäuser et al., 2008). In this study the pupil response was significantly different from baseline from 244 ms prior to perceptual switch until 1552 ms after the

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[1] The original files containing information on familiarity of the illusion were lost due to an error and could therefore not be analyzed.

perceptual switch. Thus, we selected a time window of +/- 1500 ms from the reported perceptual switch and divided this time window into 250 ms time-bins.[2]

Experimental task 2: Object identification

The experimental task was adapted from James et al. (2000). Participants viewed a series of 15 videos randomly selected from a pool of 34 videos in Study 1, and all 34 videos in Study 2 (see Figure 1, https://osf.io/gh3ue/). In each video, images of objects or animals (adapted from Brodeur et al., 2010; 2014) were gradually revealed from behind a visual noise mask over a period of 30 seconds. The clear image stayed on screen for 3 s after all noise had been removed. The participants were instructed to press the space button when they were certain they could identify the object. However, we did not require participants to write the object name in order to prevent interference from motor activity, due to writing, with the facial muscle signal. We also allowed the clarification of the image to run to completion after identification in order to have a continuous, uninterrupted process. Therefore, we cannot be sure about whether the participants identified the object correctly.

Epoch selection

In James et al. (2000) the blood oxygen level dependent (BOLD) response found during their experiment appears to evolve over a timescale of multiple seconds. For this reason, we extracted a +/- 5000 ms time window, centered at reported identification from the fEMG signal. This time window was divided into time-bins of 1000 ms.

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[2] An a posteriori justification for the time window of Task 1 comes from the fixation times between switches. The time window of +/-1500 ms would be too long if the time between switches had been short; if so, the time windows for two subsequent switches would overlap. However, this was not the case: Median time between switches in Experiment 1 were 4504.5 ms in Study 1 and 5536.0 ms in Study 2. These median times show that time windows in the majority of cases did not overlap; and if they did, the overlap most probably was at the fringes and did not include the time bins around the switch that were of special interest.

Experimental task 3: Mental rotation

In Task 3, participants viewed a series of 240 images consisting of two symbols presented side by side, similar to Cooper and Shepard (1973). One symbol was described to be the target and the other symbol as the probe that could be a rotated or unrotated version of the target. Moreover, the probe could have the same orientation as the target (unmirrored) or be a mirror image of the target (mirrored). Prior to the start of each trial, participants were asked to focus on a fixation cross that appeared on the side of the screen where the target stimuli would appear. The fixation cross stayed on the screen for 5000 ms before the target and the probe appeared.

Each probe could be rotated at 0, 60 or 120 degrees and could be either a *familiar* symbol (Latin letters or Arabic numerals) or an *unfamiliar* symbol (designed for the purpose of the study, see Figure 1; https://osf.io/qnvfy/). In addition, probes could be mirrored or unmirrored, meaning that they did or did not match the target in the 0 degree condition or after rotation by 60 or 120 degrees.

Participants were asked to identify whether each stimulus pair represented stimuli that were mirrored or unmirrored by pressing either the left or right arrow key with their right hand. Response conditions were counterbalanced so that half of the participants responded with the left arrow key to mirrored images and the other half with the right arrow key to mirrored images and vice versa for unmirrored images.

After a response was provided, the stimuli stayed on screen for 5000 ms before the experiment moved on to the next trial.

Epoch selection

Mental rotation takes increasing time with increasing rotation and is affected by familiarity (Koriat and Norman, 1985). As the time between trial start and participant response is variable, we extracted epochs starting at 500 ms prior to the response. This was done to allow comparison between conditions as longer pre-response epochs could include the period when participants were viewing the fixation point if response times were sufficiently short. Hence, part of the fEMG response might not be task related. The post-response time window was set to the length of time in which stimuli stayed on the screen (5000 ms) such that affective responses were not confounded by other factors like changes in the image. The epoch was time-binned using time-bin sizes of 250 ms.

Results

Correlations between Facial Muscles

First, we explored the correlations between the ZM and CS activity across studies, tasks, participants and over time. We observed a small negative correlation that was not statistically significant (r = -.05 [-.14, .04]). We provide a detailed overview in the Supplementary Material (Section 2).

Main Analysis Strategy

We employed growth curve analysis to model changes in fEMG across the different tasks (Mirman, 2014). The bi-stable illusion and object identification tasks were analyzed separately. For all analyses we set our alpha level at .05.

For each task and study, we first explored a base model including the intercept and up to third-order (cubic) orthogonal polynomials in order to model the trajectory across time. An overview of all models and their respective fits is presented in Supplementary Table 2. In general, we observed that a quadratic model provided the best fit for the bi-stable illusion and a cubic model the best fit for the object identification and mental rotation tasks.

For the bi-stable illusion and object identification tasks, we employed piecewise growth curve analysis (PGCA) in order to model responses before and after the perceptual switch or object identification (Kohli & Harring, 2013; Mirman, 2014). PGCA divides the overall curve into different segments, each including their own intercept and slope. For this procedure, changes in the growth curve are modelled by so-called *knots*. We set our knot at the time participants indicated the perceptual switch in the bi-stable illusion task or when they indicated identification in the object identification task. As it should be expected that participants needed some time to indicate their response by a button press, we used the first time bin including 0 as the knot (i.e. the time bin from -250 ms to 0 ms in the bi-stable illusion task; the time bin from -1000 ms to 0 ms in the object identification task). For each model, we dummy coded time before the button press (pre-time or Time 1) and time after the button press (post-time or Time 2). In a first model, we included both time codes and their interaction with muscle type (ZM vs. CS). We then calculated follow up models for each muscle type separately. In all models, we included participant and trial random effects on each time term. In Study 1 and 2, we did not record the exact identity for each stimulus and therefore used the trial number to control for the different stimuli, well knowing that stimuli were presented in random order.

For the analysis of Study 3, we used on growth curve models without segmentation, as we did not include a pre-period. As noted earlier, it was difficult to select a standardized pre-solution period because participants completed the individual mental rotation problems at different speeds. With longer pre-solution periods, differences in speed might have resulted in different visual input for different trials, for example, the fixation cross for short response times. In this model, we included participant and trial random effects on each time term, as well as participant-by-muscle type random effects on the linear and quadratic time terms. In Study 3, we recorded the identity of each stimulus and included stimulus type instead of trial as a random effect.

Task 1: Bi-stable Illusions

For the bi-stable illusion in Study 1, we observed significant interaction effects of muscle type with both pre- and post-time (Table 1). ZM responses first slowly decreased until they showed an increase right before participants indicated a perceptual switch. Simultaneously, CS responses first increased slightly and then decreased at the perceptual switch (Figure 2, upper left panel). Focusing on each muscle type separately, we observed a significant linear increase for ZM responses for the post-time period. The CS showed the reversed effect, with a significant linear decrease post-time (Table 2). For both muscle types, we did not observe significant effects pre-time.

For the replication of the bi-stable illusion task in Study 2, we again observed significant interaction effects of muscle type with both pre- and post-time. The findings were similar to Study 1. The ZM response first showed a decrease until it increased at around the perceptual shift. By contrast, the CS muscle showed a shallow increase until its response decreased at around the perceptual shift (Figure 2, upper right panel). Focusing on the separate effects, we observed a significant linear decrease for the ZM for pre-time, and a significant linear increase post-time. The CS showed the reverse effects, though neither the linear increase for pre-time nor the linear decrease for the post-time were statistically significant. To summarize, in both studies, zygomaticus activity increased right after the keypress, indicating an increase in positive affect after the perspective of the bi-stable figure switched.

Table 1.

Fixed Effects of the Final Model by Task and Study.

Study Model	B	β [95% CI]	*t*	*p*
Bi-stable Illusion Study 1				
Intercept	-.02	.00 [-.02, .02]	-.98	.330
Time 1 (T1)	.01	.05 [.01, .09]	2.23	.026
Time 2 (T2)	-.01	-.07 [-.11, -.03]	-3.49	<.001
Muscle Type (MT)	.03	-.00 [-.03, .03]	2.14	.032
T1*MT	-.02	-.10 [-.14, -.06]	-5.08	<.001
T2*MT	.03	.16 [.12, .20]	8.19	<.001
Bi-stable Illusion Study 2				
Intercept	-.01	.00 [-.02, .02]	-.48	.633
T1	.01	.03 [-.01, .07]	1.49	.136
T2	-.01	-.05 [-.10, .00]	-1.95	.052
MT	.05	-.00 [-.03, .03]	3.01	.003
T1*MT	-.03	-.11 [-.15, .08]	-5.81	<.001
T2*MT	.03	.16 [.12, .19]	8.03	<.001
Object Identification Study 1				
Intercept	.03	-.00 [-.03, .03]	1.26	.207
T1	.03	.10 [.04, .16]	3.42	.001
T2	-.07	-.34 [-.42, -.27]	-8.92	<.001
MT	-.04	.00 [-.05, .05]	-2.03	.042
T1*MT	-.04	-.15 [-.21, -.09]	-5.12	<.001
T2*MT	.11	.53 [.47, .59]	17.80	<.001
Object Identification Study 2				
Intercept	.01	-.00 [-.02, .02]	.28	.783
T1	.03	.09 [.03, .14]	3.21	.001
T2	-.06	-.24 [-.33, -.16]	-5.63	<.001
MT	-.10	.00 [-.03, .03]	-6.14	<.001
T1*MT	-.02	-.06 [-.10, -.02]	-3.11	.002
T2*MT	.10	.44 [.40, .47]	22.26	<.001

Table 1 cont'd

Random Effects		*BI1*	*BI2*	*OI1*	*OI2*
σ^2		.15	.18	.12	.16
τ_{00}	Trial	.00	.00	.00	.00
	PP	.00	.00	.00	.01
τ_{11}	Trial.T1	.00	.00	.00	.00
	Trial.T2	.00	.00	.00	.00
	PP.T1	.00	.00	.00	.00
	PP.T2	.00	.00	.00	.00
ρ_{01}		-.78	-.84	-.89	-.60
		-.67	-.45	.45	-.28
		-.99	-.88	-1.00	-.78
		-.54	-.57	-1.00	-.35
N	PP	22	22	22	22
	Trial	30	30	15	34
Observations		15840	15840	6420	14620

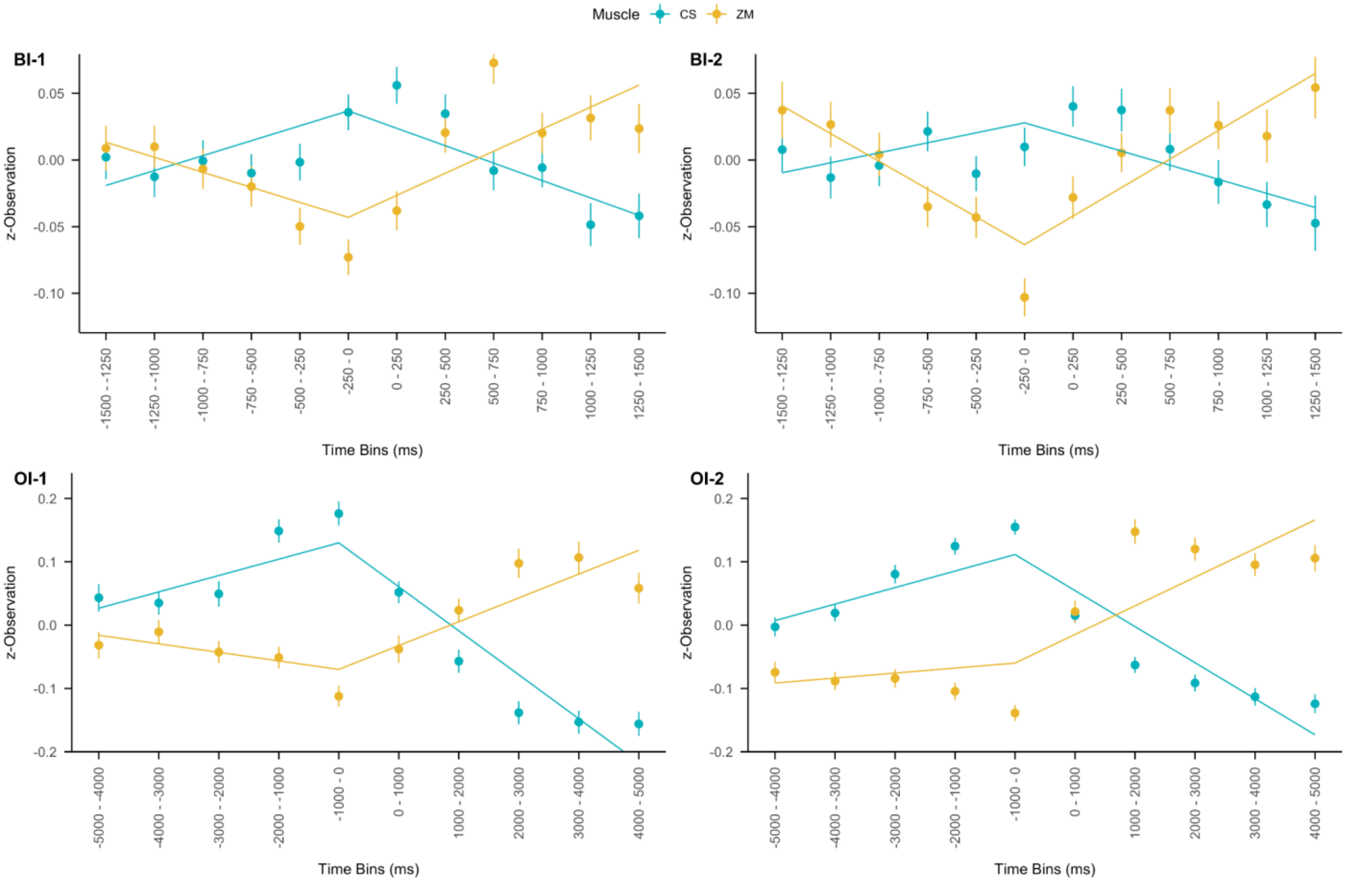
Note. Muscle Type contrast coded (-.5 = corrugator; .5 = zygomaticus). BI = Bi-stable illusion; OI = object identification; MT = Muscle Type.

Task 2: Object Identification

For the object identification task in Study 1, we observed significant interactions of muscle type with both pre- and post-time (Table 1). Similar to the bi-stable illusions, ZM activity first decreased slightly and then increased abruptly briefly before participants indicated recognition (see Figure 2, lower left panel). By contrast, the CS response first slightly increased but abruptly decreased at around recognition. Focusing on the separate effects, we observed a significant increase in ZM activity after recognition. We observed the reversed pattern for CS activity (Table 2).

Figure 2.

Zygomaticus (yellow) and Corrugator (blue) Activity for the Two Perceptual Tasks (BI = Bi-stable Illusion; OI = Object Identification) across Study 1 and 2.



Note. Circles represent observed data (error bars indicate ±SE), and lines represent growth curve model predictions from the piecewise growth curve model. The knot is set at the first time bin including 0. Note that y-axes differ for bi-stable illusion and object identification tasks.

Table 2.

Fixed Effects Separately for Zygomaticus Major (ZM) and Corrugator Supercilii (CS) Pre (Time 1) and Post (Time 2) Stimulus Onset (knot).

	B	β [95% CI]	t
Bistable Illusion Study 1			
ZM			
Intercept	.01	.00 [-.02, .02]	.58
Time 1 (T1)	-.01	-.05 [-.11, .01]	-1.89
Time 2 (T2)	.02	.09 [.03, .14]	3.23**
CS			
Intercept	-.02	.00 [-.02, .02]	-.86
T1	.01	.05 [-.00, .10]	1.91
T2	-.01	-.07 [-.13, -.02]	-2.64**
Bistable Illusion Study 2			
ZM			
Intercept	.04	.00 [-.02, .02]	1.66
T1	-.02	-.08 [-.13, -.03]	-3.29**
T2	.02	.10 [.02, .18]	2.41*
CS			
Intercept	-.01	.00 [-.02, .02]	-.51
T1	.01	.03 [-.02, .08]	1.56
T2	-.01	-.05 [-.12, .01]	-1.53
Object Identification Study 1			
ZM			
Intercept	-.02	.00 [-.03, .03]	-.73
T1	-.01	-.05 [-.12, .02]	-1.40
T2	.04	.18 [.08, .28]	3.41**
CS			
Intercept	.02	-.00 [-.03, .03]	.66
T1	.03	.10 [.01, .19]	2.25*
T2	-.07	-.35 [-.44, -.26]	-7.58***
Object Identification Study 2			
ZM			
Intercept	-.09	.00 [-.02, .02]	-2.46*
T1	.01	.02 [-.04, .09]	.69
T2	.05	.18 [.08, .28]	3.47**
CS			
Intercept	.01	-.00 [-.02, .02]	.15
T1	.03	.10 [.01, .18]	2.25*
T2	-.06	-.27 [-.39, -.14]	-4.22***

Note. *<.05, **<.01, ***<.001

Findings for the object identification task were replicated in Study 2. We again observed significant interactions of muscle type pre- and post-time (Table 1). Similar to Study 1, ZM responses first slightly decreased and then abruptly increased right before recognition. For CS activity the pattern was reversed (Figure 2, lower right panel). CS activity first showed a small increase until it abruptly decreased at recognition. Focusing on the separate effects, we again observed a significant linear increase after recognition for the ZM activity. The pattern was again reversed for the CS, showing a significant linear increase before and a significant linear decrease after recognition (Table 2). In general, effects were stronger for the object identification task compared to the bi-stable illusion task. We observed stronger increases for ZM and stronger decreases for CS activity after the button presses.

Task 3: Mental Rotation

For the mental rotation task, we did not employ piecewise growth curve modelling, as we only focused on responses at and after reported rotation. Therefore, we focused on a base model including the intercept and up to third order (cubic) orthogonal polynomials in order to model the trajectory across time. Based on the model comparison (Supplementary Table 2), the cubic model showed the best fit, but we decided to focus on the quadratic model after inspecting the growth curves (Figure 3). Since all models failed to converge using maximum likelihood estimation, we estimated them using restricted maximum likelihood (REML). Fixed effects for the final model are presented in Table 3 (Basic Model). We observed that muscle type had a significant effect on linear and quadratic growth. In order to quantify the separate effects, we performed a follow up model for each muscle separately. For CS, we observed a strong decrease at around the response and a slight increase at around 4000 ms ($\beta = -.08$

[-.12, -.05]; Figure 3). In contrast, ZM activity showed an increase at the response and continued to rise while the stimulus pair stayed on screen (β = .05 [.00, .10]). Separate models for ZM and CS are depicted in Supplementary Table 3.

Table 3.

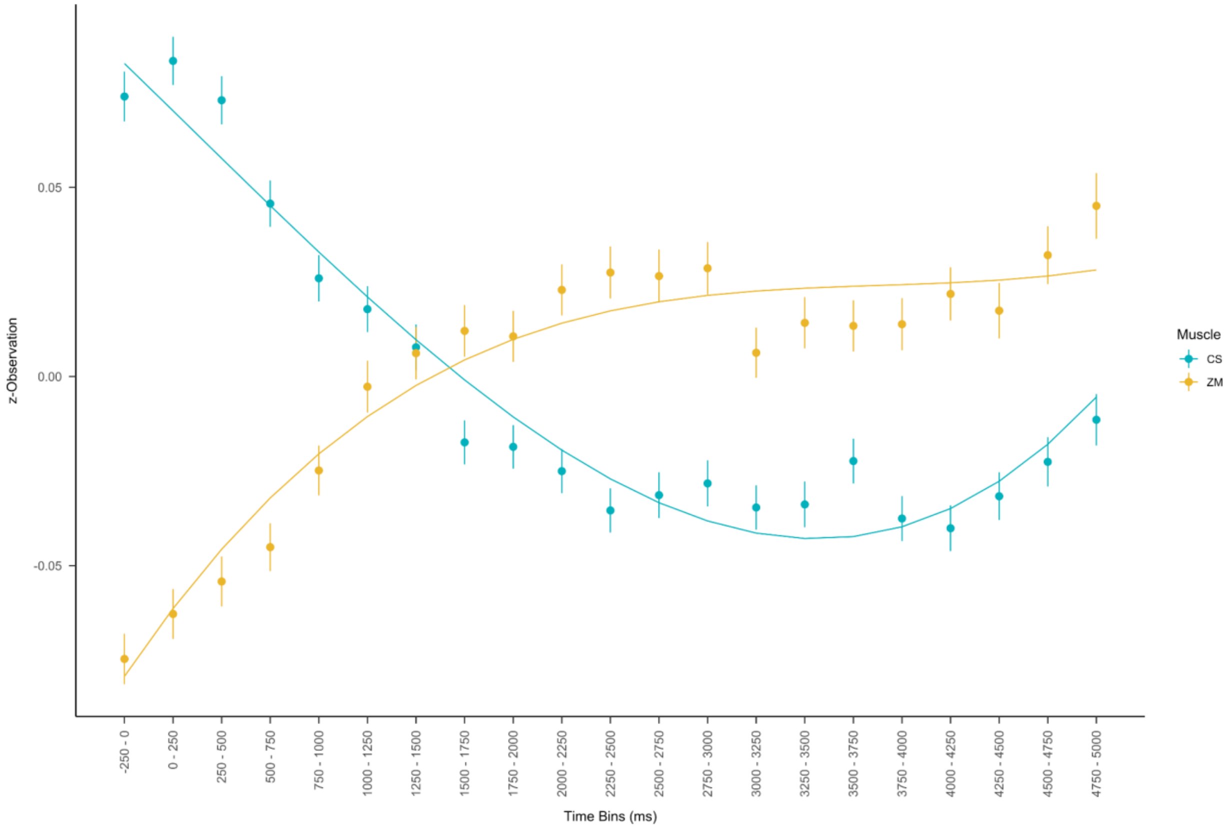
Fixed Effects of Main Model and Extended Model in Study 3.

Model	B	β [95% CI]	*t*	*p*
Basic Model				
Intercept	-.00	-.00 [-.01, .00]	-1.86	.063
Linear	-.16	-.08 [-.12, -.03]	-3.38	<.001
Quadratic	.10	.05 [.02, .07]	3.68	<.001
Cubic	.03	.01 [.00, .03]	2.25	.024
Muscle Type (MT)	.00	.01 [-.00, .02]	1.98	.047
Linear:MT	.27	.13 [.07, .19]	4.28	<.001
Quadratic:MT	-.16	-.08 [-.11, -.04]	-4.50	<.001
Extended Model				
Intercept	-.00	-.01 [-.01, .00]	-1.81	.158
Linear (L)	-.18	-.08 [-.12, -.03]	-3.49	.001
Quadratic (Q)	.11	.05 [.02, .07]	3.38	.001
Cubic	.03	.01 [.00, .02]	2.19	.028
Muscle Type (MT)	.00	.01 [.00, .02]	1.98	.047
L:MT	.22	.11 [.05, .17]	3.41	<.001
Q:MT	-.17	-.08 [-.11, -.04]	-4.14	<.001
L:MT(C):FM(F)	.04	.02 [-.01, .04]	1.36	.173
L:MT(Z):FM(F)	.02	.01 [-.02, .04]	.74	.460
Q:MT(C):FM(F)	.01	.00 [-.02, .03]	.29	.772
Q:MT(Z):FM(F)	.00	-.00 [-.02, .02]	.00	<.999
L:MT(C):MR(M)	-.02	-.01 [-.03, .01]	-.96	.335
L:MT(Z):MR(M)	.05	.02 [.00, .05]	2.30	.022
Q:MT(C):MR(M)	-.00	-.00 [-.02, .02]	-.04	.969
Q:MT(Z):MR(M)	.00	.00 [-.02, .02]	.13	.892
L:MT(C):ROT	.00	.01 [-.00, .02]	1.36	.173
L:MT(Z):ROT	.00	.01 [.00, .02]	2.63	.009
Q:MT(C):ROT	-.00	-.00 [-.01, .01]	-.87	.285
Q:MT(Z):ROT	-.00	-.00 [-.01, .01]	-.50	.621

Note. MT = Muscle Type (C = corrugator -.5, Z = zygomaticus .5); L = Linear; Q = Quadratic; FM = Familiarity (F = Familiar); MR = Mirroredness (M = Mirrored), ROT = Rotation.

Figure 3.

Zygomaticus (yellow) and Corrugator (blue) Activity for the Mental Rotation Task in Study 3.



Note. Circles represent observed data (error bars indicate ±SE), and lines represent growth curve model predictions.

We then tested for the influence of familiarity (familiar, .5 or unfamiliar, -.5), mirroredness (mirrored, .5 or unmirrored, -.5), and degree of rotation (0, 60, or 120) on the differences in muscle activity. In additional analyses we observed that these variables influenced participant's accuracy and reaction times in the mental rotation task (see Supplementary Material Section 5). We added these three predictors as three-way interactions with the linear or quadratic effect and muscle type. An overview of results is presented in Table 3 (Extended Model). As in the original model, we observed significant effects of muscle type on the linear and quadratic effects.

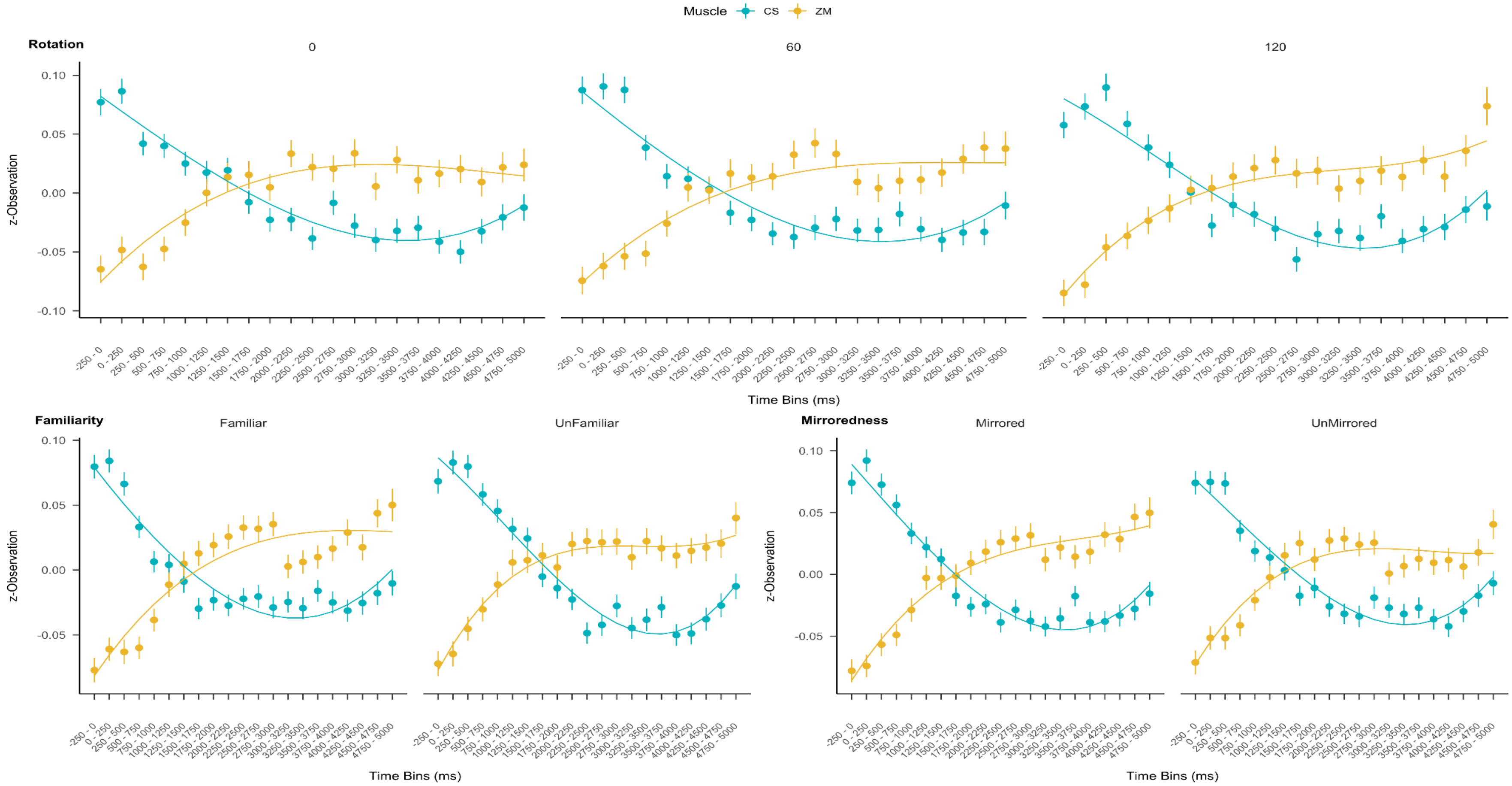
We also observed a significant three-way interaction for zygomaticus and mirroredness on the linear effect. There was a steeper linear increase in zygomaticus activity for mirrored stimuli (β = .02 [.00, .05]). Finally, we also observed a significant effect of zygomaticus and rotation on the linear effect. Linear increases in zygomaticus activity were stronger with increasing degree of rotation (β = .01 [.00, .02]). We did not observe any significant interactions involving familiarity, the corrugator response, or the quadratic effect. An overview of the different trajectories is provided in Figure 4.

General Discussion

In three studies, we provided evidence that successful completion has positive affective consequences in three different perceptual tasks. In all studies, the moment a person could successfully solve the perceptual task, ZM activity increased and CS activity decreased (with one exception where the decrease in CS-activity was not statistically significant). These findings go beyond earlier studies for two reasons. First, by looking into dynamic aspects of perception, such as the instantaneous shifts of viewpoints in bi-stable shapes, identification of a perceptual object, and solution of mental rotation tasks; and second, by including tasks whose solution needs cognitive processes, such as memory, comparison, and decision processes that go beyond early visual processing examined in earlier studies (Erle et al., 2017; Flavell et al. 2018; Topolinski et al., 2015).

Figure 4.

Zygomaticus (yellow) and Corrugator (blue) Activity for the Perspective Taking Task in Study 3 Separate for Degree of Rotation, Familiarity and Mirroredness.



Note. Circles represent observed data (error bars indicate ±SE), and lines represent growth curve model predictions.

The first experimental task yielded two main results. First, it confirmed our main prediction that affect gets more positive, as indicated by the increase in ZM activity, when the bi-stable figure switches from one perspective to the other. This result replicates and extends the finding by Topolinski et al. (2015) that the perception of possible Necker cubes elicited more positive affect than the perception of impossible Necker cubes. It is noteworthy that in the Topolinski et al. study, impossible cubes resulted in a decrease in ZM activity compared to baseline activity measured before stimulus presentation whereas ZM activity for possible cubes remained essentially unchanged. This pattern suggests that the inability to resolve impossible Necker cubes led to a decrease in positive affect. Note that our study was different in that participants had to respond to spontaneous shifts, not to unresolvable stimuli. In the present study, we were able to show that spontaneous shifts in perspective increase positive affect, as measured by ZM activity. We focus our discussion on ZM activity and less on CS activity because, as noted in the introductory section, ZM activity indicates positive affect but is unrelated to cognitive load and mental effort whereas CS activity may indicate cognitive load and mental effort in addition to negative affect (Hess et al., 1998; Van Boxtel and Jessurun, 1993).

Second, CS activity decreased after the shift from one perspective to the other. This finding is in line with earlier findings that positive affect leads to an increase in the activity of the ZM but a decrease of the CS (Larsen et al., 2003).

Moreover, there was a decrease in ZM activity but not in CS activity right before the shift in the bi-stable illusion task in Study 2 but not Study 1. As this is an unpredicted and unreplicated result, we cannot make strong conclusions, even though it is in line with fMRI-findings by James et al. (2000) and could be explained by an increase in effort before task resolution. Future studies may attempt to identify the exact temporal nature of the affective responses before the shift in perspective.

We replicated this overall pattern for the second task. The object identification task in Experiment 2 used a clarification procedure to slow down the identification process. The result could be seen both in terms of processing fluency that yields positive affect (Winkielman et al., 2003) or could help explain why ambiguity resolution is reinforcing (Jepma et al., 2012; Nicki, 1970) by acting as a reward. Importantly, object identification does not only need extraction of information from the visual stimulus but also matching the visual input with representations of objects in memory (e.g., Johnson et al., 1996; Torfs et al., 2010). Our finding reveals that positive affect is not bound to early perceptual processes that include automatic low-level perceptual processes like gestalt resolution but can include higher-order processes like retrieving information from long-term memory and matching it with the incoming information. Increasing Zygomaticus activity right after the object has been identified indicates that success at these later processes yields positive affect. Although we cannot categorically exclude the possibility that positive affect after object identification stems from early perceptual processes, early gestalt perception in the clarification procedure presumably precedes the ability to name the object by several seconds, such that it is hard to conceive that the observed ZM-activity in this experiment stems from the same source as ZM-activity in the gestalt completion experiment by Topolinski et al. (2015).

For the mental rotation task (Task 3), we found that ZM activity increased and CS activity decreased from the moment the participants had solved the task, as shown by the growth curves. These results reiterate the findings from the first two studies where the increase in ZM activity could be consistently observed and the decrease of CS activity three of four times. Task solution leads to an increase in positive affect, as indicated by the increase in ZM activity, and to a decrease in negative affect and effort, as indicated by the decrease in CS activity. In line with the first two experiments, this observation shows that completion of mental rotation leads to an affective response.

This observation extends the findings of the first two experiments because mental rotation includes cognitive processes that go beyond early perceptual processes and higher-order processes that differ from matching with long-term memory representations (in the object identification task). According to the model by Gill et al., 1998), mental rotation includes building an image, keeping a stimulus in a visual buffer, comparing two stimuli, and deciding whether the two stimuli are congruent (match) or mirrored (non-match). Our main finding for the mental rotation task thus shows that positive affect as an inherent part of the perceptual process extends to a complex perceptual task.

Beyond the increase of ZM activity and decrease of CS activity, we found two interactions that denote steeper increases in ZM activity for mirrored than for unmirrored stimuli and for increasing degrees of rotation. There was no such increase for familiarity.

Although effect sizes for these interactions were small, their existence challenges a pure fluency account and therefore support – by excluding the main competitor – the successful solution account. Of course, fluency might still play a role but it is overshadowed by a stronger countereffect, presumably successful task solution. If mainly fluency had caused positive affect in this study, we would have expected a steeper increase in positive affect for unmirrored, unrotated, and familiar stimuli because these are the stimuli that were easiest to solve, as depicted in Supplementary Material Section 5. However, the results contradicted the prediction from a pure fluency account.

In line with Erle et al. (2017) and Sarasso et al. (2020), we assume that success at solving the task, not fluency yields the most positive affect.

Both the bi-stable illusion task and the object identification task with the clarification procedure do not provide an answer to the question whether fluency or successful gestalt resolution or task solution account for the results; both accounts could explain these results. By contrast, the results on the mental rotation task clearly contradict a pure fluency account in that increase of positive affect is steeper for increasing angles and mirrored stimuli despite the observation that these conditions resulted in slower response times.

Finally, could such successful perception have the form of an Aha-experience, that is, a sudden shift from ignorance to understanding (Skaar & Reber, 2020; Topolinski & Reber, 2010)? Although sudden switches of viewpoint in bi-stable illusions or identification of a previously clouded object at one moment in time might elicit states similar to Aha-experiences, there is reasonable doubt that solving mental rotation tasks include an Aha-moment. The solution of such tasks could be achieved by imagining the rotation of the whole target shape to determine congruence with the original shape (Shepard & Metzler, 1971). However, studies manipulating the task (Pylyshyn, 1979), material factors (Yuille & Steiger, 1982) or measuring eye-movements (Just & Carpenter, 1976) found that mental rotation tasks may be solved in a piecemeal manner, akin to stepwise problems that do not lead to sudden insights (Metcalfe & Wiebe, 1987).

The current study shows that positive affect emerges right after the solution of a perceptual task. This observation goes beyond earlier findings that showed increases in positive affect for static gestalt completion tasks and beyond effects of automatic early visual processing. The results support the notion that outcome-related affect after success is not only observed as full-fledged positive emotion in achievement-related situations (Weiner, 1985) but also as subtle positive affective response, measured by ZM-activity, in perceptual tasks like monitoring shifts in bi-stable illusions, identifying objects, and mental rotation tasks. These studies, together with previous research on early perceptual processes (Erle et al., 2017; Flavell et al., 2018; Topolinski et al., 2015) show that affect may be an integral part of successful perception that includes cognitive processes. We thus conclude that perception is not only a computational process but also an affective process. We have found a new limit regarding the affective consequences of solving perceptual tasks by providing evidence for affective consequences in dynamic perceptual tasks that include complex cognitive processes not necessary for gestalt completion.

There remain three basic challenges for the future. First, there is now evidence for affect both in early visual processing (Erle et al., 2017; Flavell et al., 2018; Topolinski et al., 2015) and at later stages of perception (object identification and especially mental rotation). However, how general is affect in perception? Is all or at least most perceptual processing inherently affective or are there perceptual phenomena that do not yield changes in affect? How does affect change with the complexity of or prior experience with the perceptual task? Moreover, it is still unclear whether higher-order processes involved in solving additions and syllogisms (see Supplementary Material, Section 6) or, for example, epistemic cognition (see Loev, 2022) might have similar affective consequences.

Second, positive affect increased as result of successful solution of a perceptual task, be it the switch of perspective in bi-stable illusions, object identification, or mental rotation. The question arises whether positive affect always ensues as a result of success at solving a task, in line with the notion of outcome-related emotions (Weiner, 1985) and the predictive coding account by Sarasso et al. (2020). It is even possible that early visual processes and successful outcomes are two different sources of positive affect. On the one hand, there are findings where no task was given and there was hardly any success at completing a gestalt (Topolinski et al., 2015). The same authors also observed less ZM-activity within 500 ms after the onset of passively viewed impossible (versus possible) Necker cubes, that is, long before participants could distinguish possible versus impossible cubes, which took about two seconds. However, this experiment showed no increase in positive affect from baseline for possible Necker cubes, only a decrease in positive affect for impossible ones. Although more research will have to follow up this finding; just seeing a possible shape may not be sufficient to elicit positive affect; perceivers may need to solve a task, even if this task remains implicit. Gestalt completion in fragmented pictures (Topolinski et al., 2015) or the Kanizsa shapes (Erle et al., 2017; Flavell et al., 2018) requires a constructive process to see a gestalt or shape.

On the other hand, it is hard to conceive that positive affect arising after successful object identification and especially after successfully solving a mental rotation task is due to early visual processes. The clarification procedure prolonged object identification such that fragments presumably formed hints of a gestalt (similar to the images used in Topolinski et al., 2015) long before the object could be identified. Finally, it is unclear how early visual processes could contribute to positive affect in the mental rotation task because the solution of the task cannot be achieved by early perception (Ruthruff et al., 1995) and needs time-consuming working memory, comparison, and decision processes (Gill et al., 1998). To summarize, the best conclusion to date is that successful solution of a perceptual task elicits positive affect, in line with the notion of outcome-related emotions (Weiner, 1985) and predictive coding (Sarasso et al., 2020). An explanation in terms of outcome-related emotions is compatible with predictive coding accounts discussed earlier because successful solution could be framed in terms of successful prediction.

The third challenge is to find what functions affective responses during perception might have. One could argue that affective responses that accompany perceptual processes are epiphenomena without an effect on their own; they evaporate without having any consequence and function. However, it is conceivable that affect built into the perceptual process may have important functions in guiding attention (De Sousa, 1987; Reber, 2016). It is therefore of utmost interest to find consequences of affective responses during the perceptual process that could not be explained by purely cognitive processes in perception.

Limitations

While our studies extend existing research (Erle et al., 2017; Flavell et al., 2018; Topolinski et al., 2015) by exploring affective perception beyond early visual processing, our experiments come with limitations that must be considered when interpreting and building on our results.

Our analysis explored affective responses tied to the period surrounding the participants' responses. These responses are not compared to a neutral baseline and we thus only explore changes in direction of affect as it evolved over time. Readers are cautioned not to interpret our results as evidence for absolute positive affect, that is, positive affect above a baseline level. Similarly, we have chosen knots based on the time of participants’ response, but affective responses may peak or trough outside the observed response window, which may negatively affect our ability to identify significant changes in the affective response as we would only be analyzing a subset of the response. Despite the possibility that the missing baseline limits interpretations in terms of absolute changes in affect, we nevertheless were able to show relative changes immediately after the response.

For the bi-stable illusions, participants were required to provide five responses per stimulus for each trial to advance. Note that it is not easy to verify these self-reports, at least for the experimental setup in our task. It may be possible that some participants pressed the response key without experiencing a switch in order to proceed to the next shape, which would reduce the signal to noise ratio for such participants. Nevertheless, we could observe a significant change in affect right after reported switches.

For the object identification task, we did not immediately ask participants to name the object after they indicated identification by pressing a key. This was done to get a continuous signal; an immediate response might have influenced facial muscle activity. Although all participants indicated that they were able to identify the objects in the task, we cannot guarantee that participants did not respond too early in some trials and later realized that they wrongly identified the object. This may have caused additional affective responses that could add noise to the trial. Again, we observed a significant change in affect right after reported identification. Moreover, error rates usually are low in this kind of task (Feustel et al., 1983).

All the mentioned limitations would have increased noise and weakened the signal, which in all cases would have worked against our main hypothesis. It therefore speaks for the robustness of the findings that we were able to find the predicted pattern of results across all studies and tasks.

Finally, we did not assess subjective affective responses. Although there are continuous self-report measures that could capture the time-course of affect (Ruef & Levenson, 2007; Schubert, 2010; Wagner et al., 2021)these might have interfered with the EMG-signal at the time of a switch (Task 1), identification (Task 2) or judgment of rotated shapes (Task 3). Moreover, monitoring and reporting affect over time, solving the tasks, and pressing the key when the task is solved would require extensive practice before the experiment could start. The effects of this double task on task solution and affective responses are unknown. Finally, subtle affective states – like mental states in general – may remain unconcious and therefore inaccessible to introspection (see Nisbett & Wilson, 1977; Winkielman & Berridge, 2004). This raises the question whether the EMG measurements indeed correspond to affective feelings. However, multiple studies show correspondence between Zygomaticus and corrugator activity with self-report measures of affect (e.g., Brown & Schwartz, 1980; Lang et al., 1993; Larsen et al., 2003; Sato, 2020). There is evidence for such a correspondence in materials similar to the ones used in the current study. Topolinski et al. (2015) assessed subjective affective responses with static images. They found for both Gestalt completing tasks and possible versus impossible Necker cubes that subjective affect matched the affect measured by EMG. These observations suggest that in the type of stimuli used in this study, muscle activity of the zygomaticus major corresponds to subjective feelings.

Conclusion

Three experiments have shown that successful task solution result in affective changes in positive direction, supporting the notion of outcome-related affect (Weiner,

1985) in perceptual tasks. We observed an increase in positive affect, as indicated by ZM activity. By showing that the increase in positive affect was more pronounced for stimuli with higher angles and when they were mirrored, the findings in Task 3 supported the notion that successful solution causes affective responses, by the exclusion of a pure processing fluency account. The processes underlying successful task solution and its affective processes await further research. Most relevantly, we observed positive affect as a consequence of successful solution of perceptual tasks, going beyond affect emerging from early visual processing of gestalts by including tasks whose solution need memory, comparison, and decision processes. The challenge for the future will be to test the generality of this effect, to examine whether affect from early visual processing in which participants have just to watch an image is distinct from affect derived from successful solutions of more complex tasks, and to explore the consequences of the affective processes inherent to perception for subsequent processing, such as guiding attention.

Author Contributions

Trym Lindell: Methodology, Software, Investigation, Writing - Original Draft, Project Administration; Janis Zickfeld: Methodology, Formal Analysis, Data Curation, Writing - Original Draft; Rolf Reber: Conceptualization, Methodology, Writing - Original Draft, Funding Acquisition.

References

Bates, D., Maechler, M., Bolker, B., Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software, 67*(1), 1-48. https://doi.org/10.18637/jss.v067.i01

Beatty, J. (1982). Task-evoked pupillary responses, processing load, and the structure of processing resources. *Psychological Bulletin*, *91*(2), 276. https://doi.org/10.1037/0033-2909.91.2.276

Bornstein, R. F. (1989). Exposure and affect: Overview and metaanalysis of research 1968–1987. *Psychological Bulletin*, *106*(2), 265–289. https://doi.org/10.1037/0033-2909.106.2.265

Brodeur, M.B., Dionne-Dostie, E., Montreuil, T., & Lepage, M. (2010). The Bank of Standardized Stimuli (BOSS), a new set of 480 normative photos of objects to be used as visual stimuli in cognitive research. PLoS ONE, 5, e10773. https://doi.org/10.1371/journal.pone.0010773

Brodeur, M.B., Guérard, K., Bouras, M. (2014). Bank of Standardized Stimuli (BOSS) phase II: 930 new normative photos. PLoS ONE, 9, e106953. https://doi.org/10.1371/journal.pone.0106953

Brown, S. L., & Schwartz, G. E. (1980). Relationships between facial electromyography and subjective experience during affective imagery. *Biological Psychology*, *11*(1), 49-62. https://doi.org/10.1016/0301-0511(80)90026-5

Cannon, P. R., Hayes, A. E., & Tipper, S. P. (2010). Sensorimotor fluency influences affect: Evidence from electromyography. *Cognition & Emotion*, *24*(4), 681-691. https://doi.org/10.1080/02699930902927698

Cooper, L. A., & Shepard, R. N. (1973). Chronometric studies of the rotation of mental images. In W. G. Chase (ed.), *Visual information processing* (pp. 75-176). Academic Press. https://doi.org/10.1016/B978-0-12-170150-5.50009-3

De Morree, H. M., & Marcora, S. M. (2010). The face of effort: frowning muscle activity reflects effort during a physical task. *Biological Psychology*, *85*(3), 377-382. https://doi.org/10.1016/j.biopsycho.2010.08.009

de Sousa, R. (1987). *The rationality of emotion*. Cambridge, MA: MIT Press.

Dimberg, U. (1990). Facial electromyography and emotional reactions. *Psychophysiology*, *27*(5), 481-494. https://doi.org/10.1111/j.1469-8986.1990.tb01962.x

Einhäuser, W., Stout, J., Koch, C., & Carter, O. (2008). Pupil dilation reflects perceptual selection and predicts subsequent stability in perceptual rivalry. *Proceedings of the National Academy of Sciences*, *105*(5), 1704-1709. https://doi.org/10.1073/pnas.0707727105

Erle, T. M., Reber, R., & Topolinski, S. (2017). Affect from mere perception. Illusory contour perception feels good. *Emotion, 17*(5), 856-866. https://doi.org/10.1037/emo0000293

Erle, T. M., & Topolinski, S. (2018). Disillusionment: How expectations shape the enjoyment of early perceptual processes. *Experimental Psychology*, *65*(6), 332. https://doi.org/10.1027/1618-3169/a000419

Feustel, T. C., Shiffrin, R. M., & Salasoo, A. (1983). Episodic and lexical contributions to the repetition effect in word identification. *Journal of Experimental Psychology: General*, *112*(3), 309-346. https://doi.org/10.1037/0096-3445.112.3.309

Firestone, C., & Scholl, B. J. (2016). Cognition does not affect perception: Evaluating the evidence for “top-down” effects. *Behavioral and Brain Sciences, 39*, Article e229. https://doi.org/10.1017/S0140525X15000965.

Flavell, J. C., Tipper, S. P., & Over, H. (2018). Preference for illusory contours: Beyond object symmetry, familiarity, and nameability. *Emotion*, *18*(5), 736-738. https://doi.org/10.1037/emo0000386

Fodor, J. A. (1983). *The modularity of mind*. MIT press.

Fridlund, A. J., & Cacioppo, J. T. (1986). Guidelines for human electromyographic research. *Psychophysiology*, *23*(5), 567-589. https://doi.org/10.1111/j.1469-8986.1986.tb00676.x

Gill, H. S., O'Boyle, M. W., & Hathaway, J. (1998). Cortical distribution of EEG activity for component processes during mental rotation. *Cortex*, *34*(5), 707-718. https://doi.org/10.1016/S0010-9452(08)70774-3

Green, P., & MacLeod, C. J. (2016). SIMR: an R package for power analysis of generalized linear mixed models by simulation. *Methods in Ecology and Evolution*, *7*(4), 493-498. https://doi.org/10.1111/2041-210X.12504

Hess, U., Philippot, P., & Blairy, S. (1998). Facial reactions to emotional facial expressions: Affect or cognition? *Cognition & Emotion*, *12*(4), 509-531. https://doi.org/10.1080/026999398379547

James, T. W., Humphrey, G. K., Gati, J. S. Menon, R. S., & Goodale, M. A. (2000). The effects of visual object priming on brain activation before and after recognition. *Current Biology*, *10*(17), 1017–1024. https://doi.org/10.1016/S0960-9822(00)00655-2

Jepma, M., Verdonschot, R. G., Van Steenbergen, H., Rombouts, S. A., & Nieuwenhuis, S. (2012). Neural mechanisms underlying the induction and relief of perceptual curiosity. *Frontiers in Behavioral Neuroscience,* 6, 5. https://doi.org/10.3389/fnbeh.2012.00005

Johnson, C. J., Paivio, A., & Clark, J. M. (1996). Cognitive components of picture naming. *Psychological Bulletin*, *120*(1), 113-139. https://doi.org/10.1037/0033-2909.120.1.113

Just, M. A., & Carpenter, P. A. (1976). Eye fixations and cognitive processes. *Cognitive Psychology*, *8*(4), 441-480. https://doi.org/10.1016/0010-0285(76)90015-3

Kanizsa, G. (1976). Subjective contours. *Scientific American, 234*(4), 48–53. https://www.jstor.org/stable/24950327

Kassambara A. (2020). ggpubr: 'ggplot2' Based Publication Ready Plots. R package version 0.4.0. https://CRAN.R-project.org/package=ggpubr

Kohli, N., & Harring, J. R. (2013). Modeling growth in latent variables using a piecewise function. *Multivariate Behavioral Research*, *48*(3), 370-397. https://doi.org/10.1080/00273171.2013.778191

Koriat, A., & Norman, J. (1985). Mental rotation and visual familiarity. Perception & Psychophysics, *37*(5), 429-439. https://doi.org/10.3758/BF03202874

Lang, P. J., Greenwald, M. K., Bradley, M. M., & Hamm, A. O. (1993). Looking at pictures: Affective, facial, visceral, and behavioral reactions. *Psychophysiology*, *30*(3), 261-273. https://doi.org/10.1111/j.1469-8986.1993.tb03352.x

Larsen, J. T., Norris, C. J., & Cacioppo, J. T. (2003). Effects of positive and negative affect on electromyographic activity over zygomaticus major and corrugator supercilii. *Psychophysiology*, *40*(5), 776-785. https://doi.org/10.1111/1469-8986.00078

Loev, S. (2022). Epistemic Feelings are Affective Experiences. *Emotion Review*, 17540739221104464. https://doi.org/10.1177/17540739221104464

Long, G. M., & Toppino, T. C. (2004). Enduring interest in perceptual ambiguity: alternating views of reversible figures. *Psychological Bulletin*, *130*(5), 748-768. https://doi.org/10.1037/0033-2909.130.5.748

Lüdecke, D. (2020). sjPlot: Data Visualization for Statistics in Social Science. R package version 2.8.6, https://CRAN.R-project.org/package=sjPlot

Makin, A. D. J., Wilton, M. M. Pecchinenda, A., & Bertamini, M. (2012). Symmetry perception and affective responses: A combined EEG/EMG study. *Neuropsychologia*, *50*(14), 3250–3261. https://doi.org/10.1016/j.neuropsychologia.2012.10.003

Metcalfe, J., & Wiebe, D. (1987). Intuition in insight and noninsight problem solving. Memory & Cognition, 15, 238–246. http://dx.doi.org/10.3758/BF03197722

Mirman, D. (2017)*. Growth curve analysis and visualization using R.* Chapman and Hall/CRC. https://doi.org/10.1201/9781315373218

Montoya, R. M., Horton, R. S., Vevea, J. L., Citkowicz, M., & Lauber, E. A. (2017). A re-examination of the mere exposure effect: The influence of repeated exposure on recognition, familiarity, and liking. *Psychological Bulletin*, *143*(5), 459-498. https://doi.org/10.1037/bul0000085

Nicki, R. M. (1970). The reinforcing effect of uncertainty reduction on a human operant. *Canadian Journal of Psychology/Revue Canadienne de Psychologie*, 24(6), 389. https://doi.org/10.1037/h0082875

Nisbett, R.W., & Wilson, T. D. (1977). Telling more than we can know: verbal reports on mental processes. *Psychological Review*, *84*, 231–259. https://doi.org/10.1037/0033-295X.84.3.231

Pylyshyn, Z. W. (1979). The rate of “mental rotation” of images: A test of a holistic analogue hypothesis. *Memory & Cognition*, *7*(1), 19-28. https://doi.org/10.3758/BF03196930

Pylyshyn, Z. (1999). Is vision continuous with cognition? The case for cognitive impenetrability of visual perception. *Behavioral and Brain Sciences*, *22*(3), 341-365. https://doi.org/10.1017/s0140525x99002022

R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org

Raymond, J. E., Fenske, M. J., & Tavassoli, N. T. (2003). Selective attention determines emotional responses to novel visual stimuli. *Psychological Science*, *14*(6), 537-542. https://doi.org/10.1046/j.0956-7976.2003.psci_1462.x

Reber, R. (2012). Processing fluency, aesthetic pleasure, and culturally shared taste. In A. P. Shimamura & S. E. Palmer (Eds.), *Aesthetic science: Connecting mind, brain, and experience* (pp. 223-249). Oxford University Press.

Reber, R. (2016). *Critical feeling. How to use feelings strategically*. Cambridge University Press.

Reber, R., Schwarz, N., & Winkielman, P. (2004). Processing fluency and aesthetic pleasure: Is beauty in the perceiver's processing experience? *Personality and Social*

Psychology Review, *8*(4), 364–382. https://doi.org/10.1207%2Fs15327957pspr0804_3

Reber, R., Winkielman, P., & Schwarz, N. (1998). Effects of perceptual fluency on affective judgments. *Psychological Science*, *9*(1), 45–48. https://doi.org/10.1111%2F1467-9280.00008

Ruef A. M., & Levenson R. W. (2007) Continuous Measurement of Emotion: The affect rating dial. In J. A. Coan (J. J. B. Allen (eds.), *Handbook of emotion elicitation and assessment* (pp. 286–297). Oxford University Press.

Ruthruff, E., Miller, J., & Lachmann, T. (1995). Does mental rotation require central mechanisms?. *Journal of Experimental Psychology: Human Perception and Performance*, *21*(3), 552. https://doi.org/10.1037/0096-1523.21.3.552

Sarasso, P., Neppi-Modona, M., Rosaia, N., Perna, P., Barbieri, P., Del Fante, E., Ricci, R., Sacco, K., & Ronga, I. (2022). Nice and Easy: Mismatch Negativity Responses Reveal a Significant Correlation Between Aesthetic Appreciation and Perceptual Learning. *Journal of Experimental Psychology: General*, *151*(6), 1433-1445. http://dx.doi.org/10.1037/xge0001149

Sarasso, P., Neppi-Modona, M., Sacco, K., & Ronga, I. (2020). Stopping for knowledge": The sense of beauty in the perception-action cycle. *Neuroscience & Biobehavioral Reviews*, *118*, 723–738. https://doi.org/10.1016/j.neubiorev.2020.09.004

Sato, W., Kochiyama, T., & Yoshikawa, S. (2020). Physiological correlates of subjective emotional valence and arousal dynamics while viewing films. *Biological Psychology*, *157*, 107974. https://doi.org/10.1016/j.biopsycho.2020.107974

Schubert E. (2010). Continuous self-report methods. In P. N. Juslin (ed.), *Handbook of music and emotion: Theory, research, applications. 2nd ed*. (pp. 223-253). Oxford University Press.

Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science, 171*(3972), 701-703. https://www.jstor.org/stable/1731476

Skaar, Ø. O., & Reber, R. (2020). The phenomenology of Aha-experiences. *Motivation Science*, *6*(1), 49–60. https://doi.org/10.1037/mot0000138

Topolinski, S., Erle, T. M., & Reber, R. (2015). Necker's Smile: Immediate Affective Consequences of Early Perceptual Processes. *Cognition, 140*, 1-13. https://doi.org/10.1016/j.cognition.2015.03.004

Topolinski, S., & Reber, R. (2010). Gaining insight into the „Aha“-experience. *Current Directions in Psychological Science*, *19*(6), 402-405. https://doi.org/10.1177/0963721410388803

Torfs, K., Panis, S., & Wagemans, J. (2010). Identification of fragmented object outlines: A dynamic interplay between different component processes. *Visual Cognition*, *18*(8), 1133-1164. https://doi.org/10.1080/13506281003693593

Van Boxtel, A., & Jessurun, M. (1993). Amplitude and bilateral coherency of facial and jaw-elevator EMG activity as an index of effort during a two-choice serial reaction task. *Psychophysiology*, *30*(6), 589-604. https://doi.org/10.1111/j.1469-8986.1993.tb02085.x

Viechtbauer, W. (2010). Conducting meta-analyses in R with the metafor package. *Journal of Statistical Software, 36*(3), 1-48. URL: https://www.jstatsoft.org/v36/i03/

Wagner V, Scharinger M, Knoop C. A., & Menninghaus W. (2021). Effects of continuous self-reporting on aesthetic evaluation and emotional responses. *Poetics*, *85*, 101497. https://doi.org/10.1016/j.poetic.2020.101497

Weiner, B. (1985). An attributional theory of achievement motivation and emotion. *Psychological Review*, *92*(4), 548-573. https://doi.org/10.1037/0033-295X.92.4.548

Wickham, H., François, R., Henry, L, & Müller, K. (2020). *dplyr: A Grammar of Data Manipulation*. R package version 1.0.2. URL: https://CRAN.R-project.org/package=dplyr

Wickham, H. (2020). tidyr: Tidy Messy Data. R package version 1.1.2. URL: https://CRAN.R-project.org/package=tidyr

Winkielman, P., & Berridge, K. C. (2004). Unconscious emotion. *Current Directions in Psychological Science*, *13*(3),120–123. https://doi.org/10.1111/j.0963-7214.2004.00288.x

Winkielman, P., & Cacioppo, J. T. (2001). Mind at ease puts a smile on the face: psychophysiological evidence that processing facilitation elicits positive affect. *Journal of Personality and Social Psychology*, *81*(6), 989-1000. https://doi.org/10.1037/0022-3514.81.6.989

Winkielman, P., Schwarz, N., Fazendeiro, T. A., & Reber, R. (2003). The hedonic marking of processing fluency: Implications for evaluative judgment. In J. Musch & K. C. Klauer (Eds.), *The psychology of evaluat-ion: Affective processes in cognition and emotion* (189–217). Lawrence Erlbaum.

Yuille, J. C., & Steiger, J. H. (1982). Nonholistic processing in mental rotation: Some suggestive evidence. *Perception & Psychophysics*, *31*(3), 201-209. https://doi.org/10.3758/BF03202524

Zajonc, R. B. (1968). Attitudinal effects of mere exposure. *Journal of Personality and Social Psychology, Monograph Supplement*, *9*(2), 1–27. https://doi.org/10.1037/h0025848