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Responding to Emotional Scenes: Effects of Response Outcome and Picture Repetition on Reaction Times and the Late Positive Potential

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Abstract

Processing the motivational relevance of a visual scene and reacting accordingly is crucial for survival. Previous work suggests that the emotional content of naturalistic scenes affects response speed, such that unpleasant content slows responses whereas pleasant content accelerates responses. It is unclear whether these effects reflect motor-cognitive processes, such as attentional orienting, or vary with the function/outcome of the motor response itself. Four experiments manipulated participants' ability to terminate the picture (offset control) and, thereby, the response's function and motivational value. Attentive orienting was manipulated via picture repetition, which diminishes orienting. A total of $N = 81$ participants completed versions of a go/no-go task, discriminating between distorted versus intact pictures that were drawn from six content categories varying in positive, negative, or neutral valence. While all participants responded faster with repetition, only participants without offset control exhibited slower responses to unpleasant and accelerated responses to pleasant content. Emotional engagement, measured by the late positive potential, was not modulated by attentional orienting (repetitions). This lack of modulation indicates that the interaction between repetition and offset control is not due to altered emotional engagement. Together, results suggest that response time changes as a function of emotional content and their sensitivity to attention orienting depends on the motivational function of the motor response.

Keywords

emotional pictures; EEG; LPP; approach and avoidance motivation; reaction times

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Continuous behavioral adjustments in response to incoming sensory information are essential for adaptive behavior. It is well established that the hedonic valence and emotional arousal associated with sensory information serve as guides for these behavioral adjustments (Lang, Bradley, & Cuthbert, 1997). However, the precise processes by which the emotional evaluation of the environment is translated into overt behaviors have been the subject of research for more than a century (Dewey, 1895; Moors, 2013). One difficulty contributing to the lack of progress in this field has been the context-dependency and flexibility of emotional responses: In many situations, human beings tend to approach appetitive and avoid aversive stimuli such as happy or angry facial expressions (for an overview see Nikitin & Freund, 2010). However, emotion researchers widely agree that a model in which affective stimuli are always approached and aversive stimuli are always avoided is an oversimplification when considering all contexts (Frijda, 1988). For example, fearful stimuli may be avoided, but also approached (Cacioppo & Berntson, 1999), with the goal of eliminating the source of fear (Fanselow, 1994). Similarly, anger-evoking situations may be approached with the goal of confrontation (Carver & Harmon-Jones, 2009).

Based on a rich set of such observations, Lang (1994) proposed that overt behavior in emotionally engaging situations may serve tactical (short-term) or strategic (long-term) goals, which in many cases require orthogonal or even opposite responses. Other authors have likewise emphasized the flexibility and malleability of emotional responses, properties that maximize their adaptive value when facing a wide spectrum of different emotional challenges (Miskovic & Keil, 2014). In line with this notion, both appetitive and aversive responses tend to display flexible temporal dynamics, such as the defense cascade in aversive processing (Löw, Lang, Smith, & Bradley, 2008): When first confronted with a highly arousing aversive stimulus, observers may freeze, aiding in avoiding detection and fostering information gathering as well as response selection (Vila et al., 2007). A sequence of defensive reflex modulation, autonomic activation, and defensive behavior then unfolds, contingent upon and in parallel to the initial stimulus evaluation.

How can these flexible behavioral tendencies be systematically investigated in the laboratory while balancing experimental control and ecological validity? Perceptual and motor adjustments to emotional challenges have been studied using pictures of naturalistic scenes differing in affective content. Because affective pictures share many of the same perceptual and sensory features as the real-world objects they depict, affective picture viewing reliably activates ancient motivational circuits in the brain that have evolved to facilitate behaviors that help survival in natural environments (Lang & Bradley, 2010). For example, visual processing is enhanced for motivationally relevant objects (McTeague, Gruss, & Keil, 2015; Mini, Palomba, Angrilli, & Bravi, 1996; Sokolov, 1963). In the same vein, viewing emotionally highly arousing pictures (e.g., depictions of mutilation, injury, or nude bodies) produces a cascade of cognitive and behavioral effects that promote increased information gathering in the service of guiding adaptive action (Bradley, 2009). Emotionally arousing scenes are more readily detected in noise, are rated as more vivid, and are better remembered than neutral scenes (e.g., Markovic, Anderson, & Todd, 2014). Importantly, the size of these modulations can be potentiated, diminished, or reversed, depending on the experimental task, as briefly reviewed in the following paragraph. This suggests that the manner in which emotionally relevant sensory features are translated into motor responses

depends on the nature and function of the motor behavior that is used in a given task (Ihssen & Keil, 2013). The present series of experiments addresses this overarching hypothesis by manipulating response outcome in a go/no-go task.

A plethora of studies have demonstrated that motor responses are modulated by the presence of affectively engaging cues (Phaf, Mohr, Rotteveel, & Wicherts, 2014). These studies fall into two broad categories: Those that quantify the extent to which emotionally arousing distractors interfere with behavior in different cognitive tasks (Bradley, Keil, & Lang, 2012; Iordan & Dolcos, 2015), and those that examine how motor responses to emotional stimuli are modulated by their emotional content (Azevedo et al., 2005; Pereira et al., 2010). The former group of studies has provided strong and converging support for the notion that emotional scenes capture and hold attention (Müller, Andersen, & Keil, 2008), at the cost of concurrent cognitive tasks (Shafer et al., 2012), including intermodal tasks (De Cesarei & Codispoti, 2008).

The present set of experiments focuses on motor responses directed at or in response to emotional cues themselves. Regarding laboratory tasks involving classical response-time paradigms such as choice responses or go/no-go responses, the published literature has highlighted the importance of the dimension along which responses are selected. Studies using standard mouse and keyboard responses have shown relatively faster responses for pleasant compared to neutral pictures, and relatively delayed responses for unpleasant pictures (for an overview of this literature see Ihssen & Keil, 2013). Choice response acceleration for pleasant and response slowing for unpleasant content has been observed in a variety of tasks, including blocked and trial-based designs with emotional pictures (Pereira et al., 2006), human versus animal decisions (Ferrari, Codispoti, Cardinale, & Bradley, 2008), and decisions about facial expressions (Leppänen, Tenhunen, & Hietanen, 2003).

In a series of experiments, Ihssen and Keil (2013) demonstrated that response slowing for unpleasant and acceleration for pleasant stimuli is specific to selective responses (i.e., it does not occur for simple response tasks in which observers respond to the onset of any given stimulus) and is not a result of motor slowing (see also Leppänen et al., 2003). Instead, Ihssen and Keil (2013) concluded that cognitive processes at the level of response selection such as stimulus-response mapping are facilitated by appetitive scene content, and delayed in the presence of aversive cues. However, this interpretation does not address if response time effects are a consequence of the *emotional* engagement of the observer or result from differences in initial *attentional* orienting to pleasant compared to unpleasant cues (Bradley, 2009). Specifically, viewing novel unpleasant cues is associated with pronounced heart rate deceleration (orienting response), compared to novel neutral and pleasant cues (Bradley et al., 2012), and these differences are reflected in electrophysiological recordings of early sensory responses (Keil et al., 2001; Keil, Stolarova, Moratti, & Ray, 2007). Such evidence of initial orienting diminishes with picture repetition (Codispoti, Ferrari, & Bradley, 2006), whereas indices of emotional reactivity such as the startle blink response or late positive potential (LPP) do not diminish across repetitions (Ferrari, Bradley, Codispoti, & Lang, 2011). Thus, if valence-dependent response time slowing depends on initial orienting, it should diminish with repetition. In a subset of experiments, the present study uses the late positive potential to measure emotional reactivity as observers perform a response time task,

to test the hypothesis that attentive orienting, but not emotional engagement, mediates response time slowing.

Electrophysiological work using scalp-recorded electroencephalography (EEG) to assess neural population activity has established that passive viewing of affectively arousing, compared to non-arousing pictures, is associated with amplification (enhancement) of the LPP (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). This centroparietal effect in the EEG-derived event-related potential has been related to heightened activity in widespread brain areas (Keil et al., 2002; Liu, Huang, McGinnis-Deweese, Keil, & Ding, 2012). The modulation of the LPP by emotional content closely correlates with other physiological measures of affective processing, such as skin conductance (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Lang & Bradley, 2010), and with emotional arousal as indicated in self-report data (Keil et al., 2002). It is also robust against habituation, showing discrimination between emotional and neutral scenes after dozens of picture repetitions (Codispoti, Ferrari, & Bradley, 2006). Thus, modulation of the LPP is typically seen as an index of emotional engagement (Sabatinelli, Keil, Frank, & Lang, 2013; Sabatinelli, Lang, Keil, & Bradley, 2007).

Using a go/no-go task with emotional pictures from the International Affective Picture System (IAPS), the current set of experiments examined the extent to which response-time effects in the presence of affective pictures are modulated by picture repetition and by changing the motivational relevance of the task behavior itself. Specifically, the four experiments examine behavioral and neural responses (in Experiments 1 and 2 only) to images of different content (erotic, romance, portrait, professional, attack, and mutilation). In two of these experiments, participants had the ability to control the stimulus offset with correct responses. In the other two studies, stimulus duration was fixed at 1500 ms, giving the participant no control over stimulus offset. Across all experiments, participants completed a go/no-go task, in which they were asked to differentiate between distorted and intact images. In two of the experiments participants responded only to intact images, and in the other two they responded to distorted images, as a control. To assess repetition effects, each of the 60 images were repeated three times in a random order. Thus, four variables were manipulated: emotional content, target type, repetition, and offset control.

This paradigm allows us to address the competing hypotheses discussed above and explore effects of specific contents, potentially sensitive to offset control. Specifically, erotic content and mutilation have been shown to be viewed substantially longer than other contents in rating tasks where observers determine the trial duration (Lang, Bradley, & Cuthbert, 1990). In terms of specific hypotheses, we expect picture content to modulate response time in the no-offset-control conditions, such that erotic content produces the fastest responses, and mutilation content produces the slowest responses—a replication of previous work. Crucially, the notion that content-related response time effects are dependent on the functional role of the motor response itself would be supported by differences in the content-related response time profile between offset-control and no-offset-control conditions. If valence-dependent or outcome-dependent response time differences reflect initial orienting, they should diminish with repetition. The late positive potential will be used as an index of

emotional engagement, allowing us to distinguish diminished orienting from potential reduction/habituation of emotional engagement.

Method

Because the four experiments used the same materials and general procedure, we describe them first before specifying the differences between the four experiments.

Participants

The total sample across the four experiments comprised $N = 81$ (63% women) undergraduate students, recruited from introductory Psychology classes at the University of Florida. Their mean age was 20.4 years (range: 18.0 to 26.7 years). Four individuals reported being left-handed. Data from six additional participants were excluded: Two were excluded for performing at chance (around 50% correct responses), and four participants were excluded because their mean response times were more than two standard deviations above the group mean. All participants were given class credit and gave written informed consent following procedures approved by the Institutional review board of the University of Florida.

Stimuli

Sixty colored photographs from the International Affective Picture System (IAPS), version 1–20 were selected to fall in 6 categories: erotic scenes, romance, portraits, people at work, attack, and injury/mutilation. All photographs depicted humans (Appendix 1 lists their IAPS numbers). For each picture, we constructed a (distorted) non-picture using a swirl effect as implemented using functions of the MATLAB image processing toolbox. This transformation interprets the Cartesian coordinates of each pixel as polar coordinates and then generates a planar image of this projection. The algorithm was applied twice to each picture in sequence, with Cartesian coordinates rotated by 180° during the second transformation, leading to directionally non-biased distortions of each IAPS picture. These stimuli contained the same individual pixels, arranged in a fashion that retained color, luminance, and average spatial frequency while eliminating the scene composition and overall Gestalt of the stimulus. Spatial frequency, brightness, and contrast were calculated for all pictures and their respective distorted versions: Frequency content was determined using 2-dimensional Fourier transform implemented in MATLAB and normalizing the resulting spectrum by the number of pixels. From each picture spectrum, low, mid, and high spatial frequency energy was extracted by averaging normalized contrast energy values within three frequency bands (0 – 1.5, 1.5–6, and 6–12 cycles per degree).

Mean luminance for the central 3° of visual angle of each picture was measured using a Gossen luminance meter. Contrast scores were obtained by extracting the standard deviation of pixels' mean RGB values in each column and then computing the standard deviation of these values. All picture parameters were statistically evaluated for category-related differences using Analysis of Variance (ANOVA) with pictures as observations and between-picture factors of valence (pleasant, neutral, and unpleasant) and subcategory (first vs. second subcategory, e.g., romance, erotic scenes). After the normalization steps describe above, the stimuli used in the study did not significantly differ between emotional contents

or between distorted and original versions on any of the physical dimensions of interest, all $F_s < 2$.

Procedure and Design

Upon arriving at the laboratory, participants were instructed that their task was to respond to one of two picture categories by pressing the left button of a serial mouse with their preferred hand and to not respond to the other category (Figure 1). A mixed factorial design was used combining between-participant factors of TARGET (intact versus distorted picture) and response OFFSET CONTROL (picture remains on screen versus picture disappears) with the within-participant factors of CONTENT (erotic, romance, portraits, people at work, attack, mutilation) and REPETITION (blocks 1 through 3). The between-participant manipulation was implemented in four experiments. A short break was offered after block 1, which was declined by all but three participants.

Experiment 1: Responding to intact pictures, with offset control (N=15, 53% women).—In this experiment, correct responses (mouse click when an intact picture was presented) led to an immediate termination of the display of the target picture. The target pictures were displayed until participants responded, with no timeout given. Non-targets (here: distorted pictures) were always displayed for 1500 ms, irrespective of any motor response. However, when a false alarm (response to the distorted picture) was committed, an 880 Hz tone (500 ms duration) at about 80 dB (SPL) was played through speakers in the experimental chamber immediately. Participants were instructed that this tone represented an error signal. EEG was collected in this experiment.

Experiment 2: Responding to distorted pictures, with offset control (N=12, 58% women).—This experiment paralleled Experiment 1, but correct responses were defined as mouse clicks in response to distorted pictures, with immediate termination of the display following correct responses as described above, and error tones played when responding to intact pictures, serving as non-targets. EEG was collected in this experiment.

Experiment 3: Responding to intact pictures, no offset control (N=28, 64% women).—This experiment was analogous to Experiment 1 in all aspects, except that there was no termination of the display after correct responses. Each stimulus was displayed for 1500 ms irrespective of the response.

Experiment 4: Responding to distorted pictures, no offset control (N=26, 69% women).—This experiment was analogous to Experiment 2 in all aspects except that there was no termination of the display after correct responses. Each stimulus was displayed for 1500 ms irrespective of the response.

All experiments included three blocks, with each picture shown in each block in its intact and distorted version, resulting in 120 trials per block and a total of 360 trials. Pictures were shown at the center of the screen, spanning a horizontal visual angle of 8°. A fixation circle (0.5°) was present at all times during the experiment, and participants were asked to maintain fixation. The inter-stimulus interval varied randomly (drawn from a rectangular distribution) between 1 and 3.5 seconds.

Analysis of behavioral responses

Response time was defined as the time between stimulus onset and button press. Participants were excluded if their individual mean response time across all trials fell outside 2.48 standard deviations (see Table 4 in Van Selst & Jolicoeur, 1994) based on the mean across all 81 participants after removing individual trial outliers. Within participants, individual trials were deemed outliers if they fell more than 2.173 standard deviations outside the mean across an individual condition and block (Van Selst & Jolicoeur, 1994).

Accuracy was defined as 1 minus the proportion of correct rejections in Experiments 1 and 2 (with offset control), in which a correct response (hit) was necessary for target trial to end and therefore no misses were possible. In Experiments 3 and 4 (in which misses could occur), accuracy was defined as the proportion of correct responses (hits and correct rejections) relative to the total number of trials.

EEG recording and analysis (Experiments 1 and 2)

Electroencephalogram (EEG) data were available for participants in Experiments 1 and 2, who had offset control. These recordings aimed to establish the extent to which emotional engagement as measured by the LPP was sensitive to picture repetition in this particular task. EEG was continuously recorded from 257 electrodes by means of an Electrical Geodesics (EGI) dense-array system, using Cz as the recording reference, and keeping impedances below 60 k Ω , as recommended by the manufacturer. Data were sampled at a rate of 250 Hz with an elliptical online bandpass filter having 3dB points set at 0.1 Hz (high-pass) and 100 Hz (low-pass) and roll-offs of 48 dB/octave and 12 dB/octave respectively. Further data processing occurred offline by means of the EMEGS toolbox for Matlab (Peyk, De Cesarei & Junghöfer, 2011). Continuous data were filtered using a 30 Hz low-pass (cut-off at 3 dB point; 45 dB/octave, 12th order Butterworth). Relative to stimulus onset, epochs were then extracted from the continuous EEG that included 400 ms pre- and 1000 ms post-onset for all conditions and groups. Then, statistical parameters were used to identify and remove artifact-contaminated channels and trials as described in Junghöfer, Elbert, Tucker, and Rockstroh (2000). The recording reference (Cz) was first used to detect recording artifacts, and then the data was average referenced to detect global artifacts. Subsequently, bad sensors within individual trials were identified and interpolated based on rejection criteria for amplitude, standard deviation, and gradient. After artifact correction, an average of 23.4 out of 30 trials per condition (6 categories for each the intact and distorted pictures) were retained for analysis, with condition means not significantly differing across participants. Mean trial numbers retained for the intact picture contents (erotic scenes, romance, portraits, people at work, attack, and injury/mutilation) were 23.1, 23.8, 24.5, 21.5, 22.0, and 25.6, respectively.

Statistical Analyses

Accuracy and Response Time—Effects of the experimental manipulations on accuracy and response time were first evaluated using a mixed ANOVA design across the entire sample and the 4 experiments, with two between factors, offset control and target, and two within factors, content and repetition. The factor Offset control compares experiments in which (1) the picture was terminated by a correct response (offset control) and (2) the

picture remained on screen for 1500 milliseconds irrespective of response (no offset control). The factor Target compares conditions in which participants responded to intact or distorted pictures. The factor Content compared picture contents across 6 levels: erotic, romance, portrait, professional, attack, and mutilation. Finally, the factor Repetition compared means in blocks 1 to 3.

The Late Positive Potential—For statistical analysis, the LPP was represented as the mean voltage from 400 – 800 milliseconds taken from sensor POz and its 8 nearest neighbors (Schupp et al., 2000; Schupp, Junghofer, Weike, & Hamm, 2003). EEG data were only available for participants in experiments 1 and 2 (those who had offset control). Differing from the behavioral data, the factor resembling offset control could still be assessed by examining the LPP on Go versus No-Go trials. Thus, a mixed ANOVA design for the first two experiments was conducted, which contained one between-participants factor, Target, and three within-participant factors, Image, Content, and Repetition. Here, the factor Image compares trials in which either an intact or a distorted image were shown.

For both the behavioral and EEG data, significant interactions and main effects involving CONTENT were followed up by two different strategies: (1) Higher-order interactions involving any one of the between-participant factors and CONTENT were followed up by conducting ANOVAs for each experiment separately, with factors of CONTENT and REPETITION. (2) To follow up differences across picture contents, we conducted F-contrast tests (Rosnow, Rosenthal, & Rubin, 2000) with the image categories ordered by valence (pleasant to unpleasant), which resulted in the order: erotic, romance, portrait, professional, attack, and mutilation. This allowed for direct quantification of the hypothesized linear trend in a given block or offset control condition, as well as for intact versus distorted target pictures. For LPP, a quadratic trend was expected with higher amplitudes for arousing contents irrespective of hedonic valence. Likewise, effects of REPETITION were followed by F-contrasts testing linear or quadratic changes across blocks, or by post-hoc t-tests to quantify effects that were not linear in nature. Finally, to explore the degree to which the LPP amplitude evoked by intact pictures and RT were linearly related across all contents, Pearson's correlation coefficient was calculated for data obtained in Experiment 1. Specifically, the coefficient was calculated using all LPP-RT data pairs (participants, repetitions, content) as observations, which resulted in 270 observations (15 participants and 18 LPP-RT pairs).

Results

We first report the findings of the omnibus analysis across the four experiments and then the experiment-specific results.

Accuracy

Across all experiments, mean accuracy was above 0.9. In the omnibus full factorial ANOVA model, only offset control significantly affected accuracy. Specifically, when a participant could control the offset of an image with a correct response, accuracy was significantly higher, $F(1, 77) = 8.83$, $p = .004$, $\eta_p^2 = .076$, such that participants who controlled the offset performed more accurately ($M = 0.99$, $SD = .01$) compared to participants who did not have

offset control ($M = 0.92$, $SD = .09$). This difference was expected because in the offset control conditions pictures were on the screen until a correct response was made, and thus the only source of inaccurate responses were false alarms, whereas in the no offset control conditions, misses were also possible contributing to the total error count. Based on a between-subject univariate ANOVA across the four experiments, the false alarm rate did not differ based on either offset control or target image, $F(3, 91) = 2.45$, n.s. (Experiment 1, $M = 3.60$, $SD = 2.74$; Experiment 2, $M = 2.47$, $SD = 1.87$; Experiment 3, $M = 2.11$, $SD = 1.42$; Experiment 4, $M = 1.78$, $SD = 1.50$), suggesting that behavioral performance was similar across experiments.

Response time

The omnibus ANOVA on response time indicated a main effect of CONTENT, $F(5, 385) = 39.22$, $p < .001$, $\eta_p^2 = .29$, and a main effect of REPETITION, $F(2, 154) = 42.93$, $p < .001$, $\eta_p^2 = .36$. In addition, a two-way interaction between REPETITION and OFFSET CONTROL was observed, $F(2, 154) = 10.39$, $p < .001$, $\eta_p^2 = .12$. These effects were qualified by a four-way interaction between CONTENT, REPETITION, OFFSET CONTROL, and TARGET, $F(10, 770) = 2.05$, $p = .04$, $\eta_p^2 = .03$. To investigate this interaction, follow-up ANOVAs were conducted separately for each experiment.

Experiment 1: Offset control, response to intact picture.—For participants who had offset control and responded to intact pictures ($N = 15$), a follow-up two-way ANOVA showed main effects of both REPETITION, $F(2, 28) = 4.15$, $p = .026$, $\eta_p^2 = .23$, and CONTENT, $F(5, 70) = 10.92$, $p < .001$, $\eta_p^2 = .44$, along with a two-way interaction of REPETITION and CONTENT, $F(10, 140) = 3.89$, $p < .006$, $\eta_p^2 = .22$. To follow-up this two-way interaction, response times across categories were modeled as a positive linear trend by valence, and conducted on each block. Block one displayed a significant linear trend $F(1, 14) = 15.73$, $p = .001$, $\eta_p^2 = .53$, but response times in blocks 2 and 3 did not differ as a function of picture content. Figure 2a also demonstrates that response times slowed selectively for arousing content (including pleasant pictures), in line with previous work using go/no-go tasks (Ihssen & Keil, 2012), which leads to a better fit by a quadratic trend across categories, $F(1, 14) = 26.493$, $p < .001$, $\eta_p^2 = .65$, compared to the linear trend. Thus, valence influenced response times quadratically in the first block, but had no effect on responses during subsequent blocks.

Experiment 2: Offset control, response to distorted picture.—When considering participants who had offset control and responded to distorted pictures ($N = 12$), the post-hoc two-way ANOVA resulted in a main effect of REPETITION, $F(2, 22) = 21.88$, $p < .001$, $\eta_p^2 = .66$. When response time differences across blocks were modeled as a positive linear trend, results indicated that later blocks were associated with faster responses across all contents, compared to earlier blocks, $F(1, 11) = 36.19$, $p < .001$, $\eta_p^2 = .78$ (Figure 2b), suggesting that attentional orienting was the only factor that modulated response time in this experiment. No further effects were identified in this ANOVA, all $F_s < 2$.

Experiment 3: No offset control, response to intact picture.—In this experiment ($N = 28$), a main effect of CONTENT emerged, $F(5, 270) = 44.32$, $p < .001$, $\eta_p^2 = .62$. The

expected linear trend was pronounced, $F(1, 27) = 73.56, p < .001, \eta_p^2 = .73$, suggesting that intact pictures with appetitive valence were associated with faster response times (Figure 2c), replicating previously observed valence patterns across content.

Experiment 4: No Offset control, response to distorted picture.—When participants did not have offset control and responded to distorted pictures ($N = 26$), the follow-up ANOVA indicated main effects of both REPETITION, $F(2, 50) = 18.97, p < .001, \eta_p^2 = .43$ and CONTENT, $F(5, 125) = 9.48, p < .001, \eta_p^2 = .28$, along with a two-way interaction between REPETITION and CONTENT, $F(10, 250) = 4.32, p < .001, \eta_p^2 = .15$. Follow-up linear contrast tests were conducted across CONTENT for each block separately. Block 1 was significantly linear, $F(1, 25) = 35.77, p < .001, \eta_p^2 = .59$, but blocks 2 and 3 were not, suggesting that distorted pictures with a more positive valence were associated with faster response times initially, but that these differences dissipated with repetition (Figure 2d).

A final follow-up test specifically examined the effects of offset control across blocks, irrespective of picture content, to establish the extent to which this manipulation differently affected response times across the duration of the experimental session, indexed by the interaction between REPETITION and OFFSET CONTROL in the omnibus ANOVA. To this end, paired t-tests compared experiments with and without offset control across each of the three blocks. There was no significant difference in block 1, but significant differences were observed for block 2, $t(26) = -2.45, p = .02, d = 0.78$, and block 3, $t(26) = -2.76, p = .01, d = .81$, such that participants with offset control ($M = 519.98, SD = 62.83$) were faster than participants with no offset control ($M = 568.63, SD = 88.93$) in block 2, and participants with offset control ($M = 515.31, SD = 64.35$) were also faster than participants with no offset control ($M = 567.23, SD = 83.15$) in block 3 (Figure 3).

Late Positive Potential

The omnibus ANOVA for the LPP amplitude showed main effects of IMAGE, $F(1, 25) = 11.67, p = .002, \eta_p^2 = .32$, REPETITION, $F(2, 50) = 4.89, p = .01, \eta_p^2 = .16$, and CONTENT, $F(5, 125) = 8.98, p < .001, \eta_p^2 = .26$. In addition, IMAGE and CONTENT interacted, $F(5, 125) = 14.92, p < .001, \eta_p^2 = .37$, as did IMAGE and TARGET, $F(1, 25) = 5.85, p = .023, \eta_p^2 = .19$. All other effects had $F_s < 2.3$ and did not reach significance. The significant main effect of repetition was followed by a trend test, resulting in a significant linear trend, $F(1, 25) = 5.43, p = .028, \eta_p^2 = .18$, with increasing amplitude across blocks: block 1, $M = 1.81, SD = .137$, block 2, $M = 2.41, SD = 1.65$, and block 3, $M = 2.33, SD = 1.68$. Following up the IMAGE by TARGET interaction (Figure 4a), we found that participants responding to intact pictures displayed heightened LPP amplitude for intact pictures, compared distorted pictures, $t(14) = 5.06, p < 0.001$ (picture as target, $M = 3.07, SD = 1.51$, distorted as non-target, $M = 1.80, SD = 1.26$). For those responding to distorted pictures, no LPP difference was observed between image types, $t(11) = 0.58, n.s.$ (distorted picture as target, $M = 1.81, SD = 1.09$, and intact picture as non-target, $M = 1.86, SD = 1.33$).

The IMAGE by CONTENT interaction was followed up by quadratic contrast tests performed for intact and distorted pictures separately. A strong quadratic trend, $F(1, 26) = 38.87$, $p < 0.001$, $\eta_p^2 = .60$ was observed for the LPP evoked by intact pictures, with heightened amplitude for arousing as compared to neutral picture contents as shown in Figure 4b. By contrast, no quadratic (or linear) difference between means was seen for distorted pictures, $F(1, 26) = 1.01$, ns.

Relationship between the LPP and RT

Finally, we explored the extent to which the response time measures taken and LPP amplitude were linearly dependent, and thus captured overlapping aspects of picture processing. Pooling all observations from participants who responded to intact pictures (Experiment 1), Pearson's correlation coefficient showed a weak linear dependency between RT and LPP, $r(268)_p = -.18$, $p = .0029$, thus accounting for a proportion of approximately 3% of shared variability: Greater LPP amplitude weakly predicted faster RT, paralleling the quadratic RT trend across contents in the first block of this experiment. Because LPP amplitude did not vary with the content of distorted pictures, and was small overall, we did not examine LPP-RT relations for Experiment 2.

Discussion

The goal of the present research was to investigate the impact of motivational factors (implemented as control over the stimulus offset) and of repetition on selective (go/no-go) responses to complex scenes varying in emotional content. We followed up on earlier reports (Ihssen & Keil, 2013; Leppänen & Hietanen, 2004; Mirtes Garcia Pereira et al., 2006) showing that pleasant content facilitates and unpleasant content slows selective responses based on non-emotional picture properties (e.g., judging the color of a positively or negatively valenced picture) relative to neutral content. Adopting a perspective of emotions as action dispositions, we hypothesized that (1) effects of emotional content on intact/distorted response times is modulated by the function of the response behavior itself, and (2) if response time slowing is a consequence of selective orienting to aversive content, repetition—known to abolish orienting—eliminates emotion effects on response times.

Results of the current experiments demonstrate that manipulating the response outcome dramatically altered previously reported effects, and it did so as a function of repetition. In the absence of being able to control the offset of an emotional stimulus, a stable pattern of selective response *slowing for intact unpleasant* pictures and response *speeding for intact pleasant* pictures was observed across all repetitions, replicating previous work (e.g., Ihssen & Keil, 2013). By contrast, controlling picture offset with correct go-responses was associated with progressively diminished response time differences between contents across blocks: Although responses in the first block showed strong modulation by content—comparable with earlier work and with non-offset control conditions in this study—these differences fully vanished after one repetition.

Together, these findings support the notion that response time differences between emotional contents represent an adaption to the specific functional properties of the motor response: If presented at a fixed duration, go/no-go responses to affective pictures were resistant to

repetition, suggesting that the response slowing effects for unpleasant content are not a result of differences in attentional orienting or of delayed feature extraction from unpleasant compared to neutral contents (Bradley, 2009).

It is helpful at this point to consider the sensitivity of other measures of emotional reactivity to stimulus repetition: Under a fixed duration regimen, go/no-go responses in these experiments showed slowing for unpleasant and speeding for pleasant content across all repetitions and thus showed response patterns similar to measures of emotional engagement such as startle reflex modulation (Ferrari et al., 2011) or the LPP (which are also resistant to repetition), but different response patterns to measures of orienting and selective attention such as the startle P3 component of the ERP (Schupp, Cuthbert, Bradley, Birbaumer, & Lang, 1997). The startle P3 is typically elicited by a loud, brief auditory startle stimulus when viewing emotional pictures; the P3 is diminished when the pictures are emotionally arousing compared to neutral pictures (Keil, Bradley, et al., 2007). However, the repetition of pictures eliminates this difference (Ferrari et al., 2011). This is interpreted as a diminished selective attention to the content of repeatedly presented emotional pictures. Thus, results from experiments using a fixed picture duration suggest that the emotional content affects response times at the level of the selection or preparation of the motor response, potentially reflecting a freezing-like cognitive-motor inhibition when confronted with aversive stimuli (Azevedo et al., 2005). Such an interpretation is corroborated by the LPP result obtained in the present experiments. As expected, the LPP showed robust modulation as a function of the emotional content (Cuthbert et al., 2000) of intact (but not of distorted) pictures. Importantly, while the overall amplitude of the LPP was amplified for the intact pictures compared to the distorted ones, repetition did not affect the LPP's variation with emotional content.

This finding is complemented by the strong sensitivity of RTs to repetition in conditions where participants controlled the offset. Here, the absence of content effects after one repetition is fully in line with the elimination of selective orienting responses as measured by the startle probe P3 (Codispoti et al., 2006; Cuthbert, Schupp, Bradley, McManis, & Lang, 1998). Thus, RT differences with offset control appear to be driven by initial attentive processing of the picture content, subsequently (after one block) replaced by overall more rapid responses that did not discriminate between picture contents. Such a response pattern could be considered adaptive if the goal of the participant is to proceed rapidly through the experimental session after having seen all of the stimuli in the first block. This interpretation dovetails with findings of relatively prolonged viewing time of emotionally engaging pictures (Lang, Bradley, & Cuthbert, 1990) and with the fact that all but three participants declined the offer of a short break in the middle of the experimental session in the present experiment. Furthermore, our observation of longer RTs and, thereby, longer viewing times for mutilation and erotic content is consistent with an extensive literature showing that people generally choose to view these contents longer than other unpleasant or pleasant content categories (Bradley, Costa, & Lang, 2015; Bradley, Houbova, Miccoli, Costa, & Lang, 2011).

By contrast, we observed stable modulation in the expected direction (faster for pleasant, slower for unpleasant content) only for participants with offset control, suggesting that these

valence-based effects (Ihssen & Keil, 2013; Leppänen et al., 2003) are eliminated if the motor response itself has a salient, potentially desirable, consequence. Extending previous research, the stability of this pattern across blocks clearly found in the current experiments contradicts potential alternative mechanisms involving effects of differential attention capture or orienting.

Go-response times to distorted pictures were used to assess repetition effects in the absence of clear picture content and to account for general effects of offset control. These responses showed the expected pattern when participants possessed offset control: Responses accelerated from block to block but did not vary as a function of the content of the original picture. Unexpectedly, and deviating from previous reports (Ihssen & Keil, 2013), a linear trend was observed for responses times in the first block of responding to distorted pictures when responses did not control the offset of the stimulus. This trend appeared to be driven by the mutilation pictures and was no longer present in the subsequent blocks. Although this unexpected difference warrants replication, one may speculate that some participants may have initially reacted to the distorted mutilations, which, according to anecdotal reports during debriefing, were sometimes characterized as more similar to non-distorted mutilations compared to the pairs of intact and distorted pictures in the other content categories. In a similar vein, the most pronounced response time delays were seen for mutilation pictures, raising the question if response slowing is content-specific or occurs as a function of emotional arousal. Further research may address this question by using highly unpleasant pictures that do not involve mutilation or attack, such as those depicting disgusting content.

Effects across content ceased after just one repetition, but only when participants had offset control, which may suggest that offset control diminishes the initial attentive processing of a picture's content. Alternatively, this effect could also be explained by floor effects, reflective of the participant's motivation to move through the study as quickly as possible upon seeing the pictures once. This explanation is at odds with the fact that response time in Experiment 1 was overall slower than in the other three experiments. However, whether this is a floor effect or an initial attention processing difference, our conclusions would remain the same: that response time is highly influenced by the outcome of the motor response, and emotion effects disappear with repetition if participants are able to accelerate the experimental session by responding faster.

Limitations of the present set of experiment include the different sample sizes across the experiment, with the constraints coming from the availability of the EEG technology for Experiments 1 and 2 resulting in smaller sample sizes. To avoid biased results, trend tests were conducted across contents, and effect sizes were calculated and compared between studies. These analyses suggested that the effects reported were robust and many effects were replicable across the different samples of the experiments, such as the block-level repetition effect in conditions with offset control as shown in Figure 2. The fact that offset control was confounded with EEG recordings may also be viewed as a constraint. However, corresponding behavioral data have been collected in cognitive neuroscience laboratories for decades, with and without concurrent EEG recordings across a wide spectrum of experimental tasks and stimuli (e.g., Bar-Haim, Lamy, & Glickman, 2005; Hillyard & Anllo-

Vento, 1998). Again, several aspects of the results were partly repeated across experiments, rendering the explanation that results are driven by EEG recordings unlikely. A further concern may arise regarding filter settings, which traditionally (Duncan-Johnson & Donchin, 1979), and recently (Keil et al., 2014) have been identified as potential sources of attenuation in long-latency ERPs. However, the Butterworth high-pass filter used in the present study had a gentle roll-off (18 dB attenuation at stop-band, 0.05 Hz) and, compared to unfiltered ERPs, empirically did not result in any reliable difference of the LPP mean. Therefore, we assume that the present results were not driven by filter settings. Finally, using the temporal stability of the LPP to quantify the absence of habituation of emotional engagement amounts to predicting a null-effect, known to lead to reduced power and raising questions regarding sample size limitations (Cortina & Folger, 1998). In the present study, however, the expected LPP differences by content were reliably observed, which seems to point to the sensitivity of LPP data to fluctuations in emotional engagement. The stability (non-difference) of the LPP was also used in conjunction with other measures, which converged to support the notion that the function/outcome of a motor response affects its sensitivity to manipulations in emotional cue content. To address this question in more detail, future work may use a fully balanced design in which EEG recordings are available for all experimental conditions, systematically comparing different emotional cues widely used in the literature.

In summary, the present set of experiments suggests that selective motor responses to emotional scenes are strongly affected by the nature and function of the motor response itself, paralleling findings in the literature studying approach and avoidance responses (Phaf et al., 2014). Specifically, the variation of response times as a function of emotional content appears to reflect flexible adaptations to the experiment and motivational factors in addition to less variable effects on cognitive-motor processes. To characterize these latter processes, which tend to be of interest for experimentalists studying emotion-cognition interactions, it is crucial to use a motor response that does not engage a specific motivation (e.g., to end a presentation of highly unpleasant stimuli). In contrast, for researchers targeting the link between motivation, emotion, and cognition, it is crucial to identify and experimentally manipulate aspects of all three components (e.g., function of the response in order to tap into motivational aspects, valence and arousal of the stimulus to address emotional aspects, and the salience of stimulus features to target attention or information processing). The current research demonstrates that a comprehensive understanding of how people react in response to a changing environment is in need of a model integrating motivation, emotion, and cognition.

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Figure 1.

Stimuli. Example stimuli across three blocks. Sixty stimuli were presented three times. Stimuli varied across six categories: erotic, romance, portrait, professional, attack, and mutilation. Participants were asked to respond only to either distorted or intact pictures, depending on the experiment. In half the experiments, participants controlled the offset of the image with a correct response. In the other half of experiments, pictures had a fixed duration of 1.5 s, regardless of participants' responses. Between each picture presentation, a small fixation circle was presented against a black background for 1–3.5 s.

Figure 2.

Response time. Mean response time across participants shown for each of the six categories, ordered from most pleasant to most unpleasant content and for each of the three blocks.

Panel a represents Experiment 1 ($N = 15$), where a correct response to an intact picture resulted in stimulus offset. Panel b represents Experiment 2 ($N = 12$), where a correct response to a distorted picture resulted in stimulus offset. Panel c represents Experiment 3 ($N = 28$), where a correct response to an intact picture did not result in stimulus offset. Panel d represents Experiment 4 ($N = 26$), where a correct response to a distorted picture did not

result in stimulus offset. Note the scale differences between experiments that varied by offset control. Bars represent standard error of the mean.

Figure 3.

Response time. Mean response time across blocks for participants with offset control versus those with no offset control. Data are averaged across target picture and content. Bars represent standard error of the mean.

Figure 4.

Late positive potential. Panel a represents grand mean ERP waveforms at sensor CPz across each of the six categories, both for participants who responded to intact pictures ($N = 43$) and those who responded to distorted pictures ($N = 38$). Panel b depicts the mean LPP amplitude across a window from 400 to 800 ms post-stimulus onset, averaged over a cluster of eight centroparietal electrodes. These are depicted for those who responded to intact versus distorted images (averaged across blocks) to highlight the quadratic trend seen for

LPPs following intact, but not distorted images, and also depicted separately for each block (only for intact images), to illustrate the lack of repetition effects on the LPP across blocks.

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