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Transient tasks and enduring emotions: the impacts of affective content, task relevance, and picture duration on the sustained late positive potential

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Abstract The present experiments were designed to examine the influences of picture duration, task relevance, and affective content on neural measures of sustained engagement, as indexed by the late positive potential (LPP). Much prior work has shown that the event-related potential in and around the P3—here referred to as the *early LPP*—is modulated by affective content, nonaffective task relevance, and stimulus duration. However, later portions of the LPP (>1,000 ms) may represent either a return to baseline *or* a continued physiological process related to motivational engagement. In the present experiments, we tested whether modulation of the later LPP depends on varying motivational engagement using stimulus duration, affective content, and task relevance. The results of Experiment 1 revealed that stimulus duration modulates the sustained LPP (i.e., 1,000–2,000 ms) in response to affective, but not task-relevant, stimuli from a modified counting oddball task. The results of Experiment 2 revealed that the sustained increase in the LPP is sensitive to both emotional content and task relevance when the task requires sustained engagement with target stimuli (e.g., determining the duration of stimulus presentation). The impacts of emotional content and task relevance had additive effects on the later portion of the LPP. In sum, both emotional content and task relevance can result in a protracted increase in the later LPP. These data suggest that affective content automatically sustains engagement, whereas task relevance only prolongs engagement when it is necessary for task completion.

Keywords Affective content · Task relevance · Picture duration · Late positive potential (LPP)

The late positive potential (LPP) is an event-related potential increasingly studied in the context of emotion and visual attention (Ferrari, Codispoti, Cardinale, & Bradley, 2008; Pastor et al., 2008; Weinberg, Ferri, & Hajcak, 2013). In studies of emotion, the LPP consists of a P3-like peak that continues in a sustained, slow wave. Whereas the P3 is typically maximal from 300 to 400 ms, the LPP may persist for several seconds (Foti, Hajcak, & Dien, 2009). Evidence suggests that the LPP is sensitive to *motivational significance* (Codispoti, Ferrari, & Bradley, 2006; Franken, Nijs, & Pepplinkhuizen, 2008; Gable & Harmon-Jones, 2010; Gable & Poole, 2012; Hajcak & Olvet, 2008; Keil et al., 2001; Pastor et al., 2008; Schupp et al., 2004). For instance, affective pictures evoke larger LPPs than do nonaffective pictures during both passive viewing and tasks requiring active participation. LPP amplitudes are enhanced when participants attend to more arousing as compared to neutral portions of emotional stimuli (Dunning & Hajcak, 2009; Hajcak, Dunning, & Foti, 2009). In sum, the LPP is a neurophysiological measure that appears to reflect increased engagement with motivationally salient visual stimuli.

Consistent with the notion that the LPP is sensitive to motivational relevance, the LPP can be modulated by nonaffective manipulations that increase stimulus salience. LPPs are larger to neutral task-relevant than to neutral task-irrelevant stimuli (Ferrari, Bradley, Codispoti, & Lang, 2010; Ferrari et al., 2008). Similarly, studies using an oddball paradigm have shown that target stimuli produce larger LPPs than do nontarget stimuli (for a review, see Kok, 2001). These studies suggest that the LPP can be modulated by nonaffective stimuli, provided that they are task-relevant.

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Previous studies have suggested that task relevance and affective content work in conjunction to enhance the LPP. Ferrari and colleagues (2008) demonstrated that affective task-relevant stimuli produce larger LPP amplitudes than do neutral task-relevant stimuli. Weinberg, Hilgard, Bartholow, and Hajcak (2012) used a modified oddball task and found that affective targets produced larger LPPs than did either neutral targets or task-irrelevant affective stimuli. In sum, affective content and task relevance appear to have additive effects on the LPP.

Although studies have consistently shown that the LPP is modulated by affective and task-relevant stimuli, these studies have differed markedly in terms of the duration that stimuli were presented for and of whether they assessed later and more sustained portions of the LPP. Specifically, studies examining the LPP in relation to task relevance (i.e., oddball tasks) have tended to utilize relatively brief stimulus presentation durations (i.e., 30 to 1,000 ms) and to focus on early portions of the LPP (i.e., up to 1,000 ms). In contrast, studies on the emotional modulation of the LPP have involved affective content presented for several seconds and have examined modulation of the LPP throughout stimulus presentation (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Hajcak & Olvet, 2008).

Although previous studies have suggested that affective modulation of the LPP persists throughout stimulus presentation, the time course of the LPP (i.e., early vs. later modulation) has not been fully evaluated when stimulus duration was manipulated. If the LPP is a measure of motivated engagement, it seems likely that stimulus duration should influence the sustained modulation of the LPP. In particular, the more protracted increase in the LPP (>1,000 ms) may be most sensitive to stimulus duration. This is critical to understanding whether the later LPP is a measure associated with psychological engagement in general.

Present experiments

Whereas affective content elicits a sustained increase in the LPP, task relevance has never been shown to elicit a more protracted increase in the LPP. Specifically, the LPP is increased for target stimuli, but this positivity is not sustained beyond 1,000 ms. However, it is possible that task relevance may cause only *transient* engagement with visual stimuli (Gable & Adams, 2013). Indeed, existing studies have only utilized tasks that required relatively short-lived, rather than more protracted, engagement with visual stimuli to determine task relevance. In an oddball task, for instance, stimulus categorization requires relatively fleeting engagement with the stimulus content, and this might be reflected in a relatively transient increase in the LPP. In contrast, task relevance might lead to a more *sustained* modulation of the LPP if the task required more enduring involvement with stimulus content.

In the present experiments, we tested the possibility that emotional modulation of the sustained LPP depends on stimulus duration, whereas modulation of the sustained LPP by task relevance might depend on whether the task requires sustained engagement with picture content. Previous studies have shown that the early (<1,000 ms) portion of the LPP is modulated by the motivational engagement required by the task demands. However, later portions (>1,000 ms) may represent a simple return to baseline *or* a continued physiological process relating to motivational engagement. We sought to investigate whether the later LPP could be modulated by motivational engagement, similarly to the early LPP. Specifically, we sought to examine whether sustained task engagement would modulate the later LPP using stimulus duration.

To this end, two experiments were designed to examine the influences of picture duration, affective content, and task relevance on the earlier (<1,000 ms) and later (>1,000 ms) portions of the LPP. In Experiment 1, we varied the duration of pictures and investigated the time course of the LPP in response to affective content and task-relevant stimuli. Task relevance was manipulated by having participants simply count appearances of a specific neutral picture. Here, the stimulus duration manipulation was irrelevant to the task. Using this manipulation, LPP modulation by task relevance should be evident, but potentially short-lived (i.e., should only occur early), regardless of stimulus duration. In contrast, and consistent with previous work, we predicted that affective content would modulate the LPP throughout the duration of stimulus display. Thus, we predicted that display duration would influence only the *emotional* (not the task-related) modulation of the later LPP in Experiment 1.

In Experiment 2, we expanded on the findings from Experiment 1 by making stimulus duration task-relevant. In Experiment 2, participants had to estimate the display duration of target stimuli. Thus, for target stimuli, participants had to remain engaged throughout the entire stimulus presentation. We hypothesized that task-relevant stimuli should sustain engagement and be associated with a protracted increase in the LPP in Experiment 2. In addition, for Experiment 2 we used neutral and affective stimuli as targets. We predicted that affective modulation and task relevance would have additive effects on the later portion of the LPP.

Experiment 1

Experiment 1 utilized a modified oddball paradigm and pictures presented for either 500 or 2,000 ms. Task relevance was manipulated by asking participants to count the number of times that a designated neutral image (i.e., the target) appeared in a block of trials. Whereas the target stimulus was always neutral, the standard (i.e., nontarget) images included pleasant, neutral, and unpleasant pictures.

Experiment 1 was designed to investigate how picture duration would impact the modulation of the earlier and later portions of the LPP by task relevance (i.e., target vs. standard) and emotional content (i.e., emotional vs. neutral standards) using a fairly typical method of determining target status in oddball tasks (i.e., content). Firstly, the experiment was designed to test whether task-relevant (i.e., target) stimuli modulate sustained engagement as a function of picture duration. Because the task required relatively transient engagement with visual stimuli (i.e., identifying and counting targets), we expected to find an increased LPP for target relative to neutral standard pictures in the early portion of the LPP, regardless of picture duration. However, because task relevance would decrease once stimuli were rapidly categorized, we did not expect to find target-related modulation of the later LPP (i.e., beyond 1,000 ms) for either short- or long-duration targets.

Secondly, the experiment was designed to directly test whether task-irrelevant affective stimuli modulate sustained engagement as a function of picture duration. That is, we examined whether emotional nontarget stimuli (i.e., standards) would increase the later portion of the LPP for long-duration pictures. Since engagement with emotional content is relatively automatic and persistent, we expected to find an enhanced LPP for affective as compared to neutral standards in the early time window, regardless of picture duration. Moreover, we predicted that the later portion of the LPP would be increased for emotional relative to neutral standards—but only when pictures were presented for a longer period. In sum, we predicted that the time course of the modulation of the LPP by emotional content would depend on the stimulus presentation duration, whereas the modulation of the LPP by task relevance would not depend on stimulus presentation duration.

Method

A group of 39 undergraduates (25 women and 14 men) participated in exchange for course credit. Four images (one pleasant, one unpleasant, and two neutral) were selected from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2008).[1] The pleasant and unpleasant images were matched for arousal and relative valence. One of the neutral and both the pleasant and unpleasant images served as standards in an emotional oddball task; the other neutral image served as the target.

Prior to viewing, participants were shown the neutral target picture and told to keep track of the number of times the picture was presented in each block. Participants recorded the number of times they had seen the target picture at the end of each block. A total of 300 trials were presented randomly within three blocks. Each nontarget picture was presented 80 times (240 nontarget trials total), and the target picture was presented 60 times. Picture duration varied randomly, such that half of the pictures (both target and standards) in each block were displayed for 500 ms, and the other half were displayed for 2,000 ms. The interstimulus interval varied between 2,500 and 5,000 ms.

Electroencephalography (EEG) assessment and processing

EEG was recorded from 59 tin electrodes mounted in a stretch Lycra Quik-Cap (Electro-Cap, Eaton, OH) and referenced online to the left earlobe. A ground electrode was mounted midway between FPz and Fz. The electrode impedances were under 5,000 Ω. Signals were amplified with a Neuroscan SynAmps RT amplifier unit (El Paso, TX), low-pass filtered at 100 Hz, high-pass filtered at 0.05 Hz, notch filtered at 60 Hz, and digitized at 500 Hz. Artifacts (e.g., horizontal eye movements and muscle movements) were removed by hand. Then, a regression-based eye movement correction was applied (Semlitsch, Anderer, Schuster, & Presslich, 1986), after which the data were again visually inspected to ensure proper correction.

The data were epoched from 200 ms before picture onset until 2,000 ms after picture onset and were re-referenced using the average of the left and right mastoids. Following epoching, the data were filtered with a low pass of 35 Hz (48 dB), using a unidirectional FIR filter, and baseline corrected using the prestimulus interval. Aggregated waveforms for picture type and picture duration were created. To investigate the impact of picture duration on the modulation of the LPP by target status and emotional content over time, the LPP was evaluated in an earlier (400–1,000 ms) and a later (1,000–2,000 ms) time window, on the basis of previous research indicating differential sensitivity of the LPP to experimental manipulations in these time windows (Weinberg & Hajcak, 2011; Weinberg et al., 2012). Because pleasant and unpleasant images were hypothesized to have similar impacts on the LPP, the pleasant and unpleasant stimuli were averaged together to create an aggregate LPP to the affective standards.[2] The LPP was measured as the mean EEG activity from five centro-parietal

[1] The particular IAPS stimuli used were as follows: neutral target = 2102, neutral = 2383, pleasant = 4608, and unpleasant = 6250.

[2] A 2 (Valence: pleasant vs. unpleasant) × 2 (Duration: short vs. long) × 2 (Time Window: early vs. late) repeated measures analysis of variance (ANOVA) revealed no main effect of valence, $F(1, 38) = 0.01$, $p = .925$, $\eta_p^2 < .01$, and the overall interaction of valence, duration, and time window was nonsignificant, $F(1, 38) = 2.10$, $p = .156$, $\eta_p^2 = .05$. Because unpleasant versus pleasant valence did not have a main effect or interaction, affective stimuli were combined in subsequent analyses.

sites (Pz, CPz, Cz, CP1, and CP2) within each of these windows (Weinberg et al., 2012).

Results

A 3 (Picture Type: target, neutral, affective) × 2 (Picture Duration: 500 vs. 2,000 ms) × 2 (Time Window: early vs. late) repeated measures analysis of variance (ANOVA) revealed a significant three-way interaction, $F(2, 76) = 7.57$, $p = .001$, $\eta_p^2 = .17$ (see Fig. 1). Follow-up interactions were examined to test specific hypotheses about the effect of picture duration on the targets and affective standards.

Modulation by affective content as a function of picture duration

In order to examine the effect of picture duration on LPPs to the affective standards, early and late time windows were considered in separate 2 (affect vs. neutral) × 2 (Picture Duration: 500 vs. 2,000 ms) repeated measures ANOVAs for each time window (early and late).

Early window Picture duration did not influence LPP amplitudes in the early time window, $F(1, 38) = 0.09$, $p = .76$, $\eta_p^2 = .002$. Also, whereas LPP amplitudes did differ as a function of affect, $F(1, 38) = 32.00$, $p < .001$, $\eta_p^2 = .45$, we found no interaction between affect and duration, $F(1, 38) = 2.84$, $p = .10$, $\eta_p^2 = .07$ (see Fig. 2). Consistent with past research on the early LPP, these results demonstrate that affective pictures elicited a larger LPP than did neutral pictures in the early window, regardless of duration.

Late window Picture duration also did not influence LPP amplitudes in the late time window, $F(1, 38) = 2.28$, $p = .14$, $\eta_p^2 = .06$, but LPP amplitudes did differ as a function of affect, $F(1, 38) = 13.65$, $p < .001$, $\eta_p^2 = .26$. These main effects were qualified by a significant interaction between affect and duration, $F(1, 38) = 13.53$, $p < .001$, $\eta_p^2 = .26$. LPP amplitudes to affective standards were similar to those to neutral standards in the short display, $t(38) = 0.74$, $p = .46$, $d = 0.24$. In the long display, LPP amplitudes were larger to affective than to neutral standards, $t(38) = 4.46$, $p < .001$, $d = 1.45$ (see Fig. 2b).

Comparisons between the long and short picture durations revealed that LPP amplitudes were larger to affective standards in the long display than in the short display, $t(38) = 3.878$, $p < .001$, $d = 1.25$. LPP amplitudes were similar between the long and short picture durations to neutral standards, $t(38) = 1.34$, $p = .19$, $d = 0.43$. These results revealed that affective pictures elicit a larger late-window LPP than neutral pictures do when affective pictures are presented for an extended duration, but not when pictures are displayed for a short duration.

Modulation by task relevance as a function of picture duration

In order to examine the effect of picture duration on LPPs to target stimuli, the early and late time windows were considered in separate 2 (Task Relevance: target vs. neutral standard) × 2 (Picture Duration: 500 vs. 2,000 ms) repeated measures ANOVAs for each time window (early and late).

Early window Picture duration influenced LPP amplitudes in the early time window, $F(1, 38) = 5.31$, $p = .02$, $\eta_p^2 = .12$, such that LPPs were larger in the short than in the long display.[3] LPP amplitudes differed as a function of task relevance, $F(1, 38) = 49.41$, $p < .0001$, $\eta_p^2 = .57$, such that LPP amplitudes were larger to targets than to neutral standards (see Fig. 2a). Consistent with past research (e.g., Ito & Cacioppo, 2000), these results demonstrate that targets elicited a larger LPP than did neutral standards in the early window. The interaction between task relevance and picture duration on LPP amplitude was not significant, $F(1, 38) = 1.08$, $p = .30$, $\eta_p^2 = .02$.

Late window Picture duration did not influence LPP amplitudes in the late time window, $F(1, 38) = 0.24$, $p = .62$, $\eta_p^2 = .01$. However, LPP amplitudes differed as a function of task relevance, $F(1, 38) = 4.06$, $p = .05$, $\eta_p^2 = .10$ (see Fig. 2b), such that LPP amplitudes were larger to neutral standards than to targets. These results suggest that neutral standards elicited a slightly larger LPP in the late window, regardless of picture duration. The interaction between picture type and picture duration for LPP amplitudes was not significant, $F(1, 38) = 1.75$, $p = .19$, $\eta_p^2 = .04$.

Discussion

These results revealed that within the early window of the LPP, affective modulation did not differ between the long and short presentation durations. In the later window, however, affective pictures did evoke larger LPP amplitudes than neutral pictures did when they were presented for the long, but not for the short, duration. For all target stimuli, task relevance evoked larger LPP amplitudes in the early, but not in the later, LPP window. This suggests that although the counting task may have a strong initial impact on engagement, the effect was short-lived. As predicted, these results suggest that modulation of sustained processing by affective stimuli depends on picture presentation duration, but modulation of processing by target status (i.e., task relevance) did not depend on presentation duration.

As we suggested above, the transient modulation of the LPP by task relevance could reflect the fleeting demands of

[3] The early time window in the short display condition includes the offset event-related potential evoked by picture display ending. Differences between the short and long picture durations in the early time window were likely due to the potential evoked by picture offset.

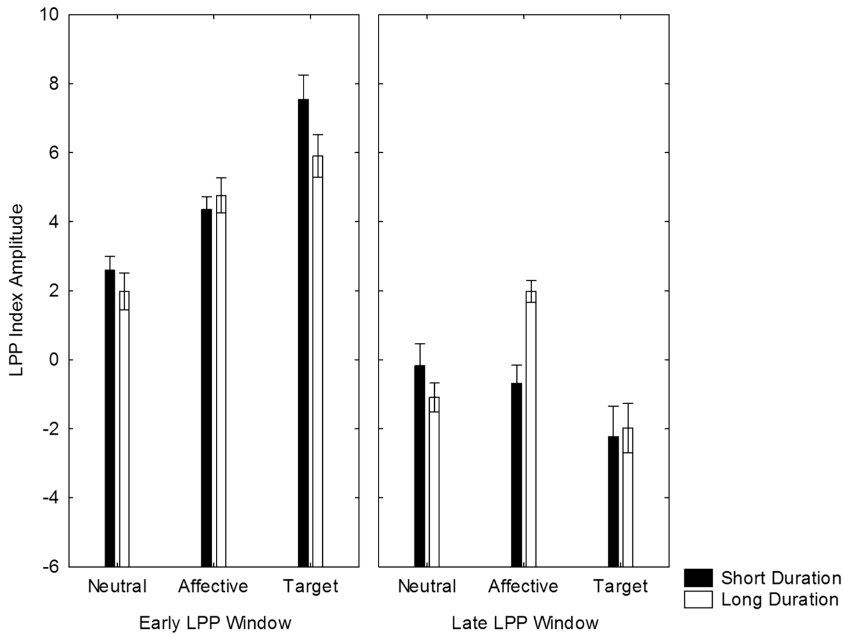

Fig. 1 Interaction of picture type (target, affective standard, and neutral standard) and picture duration (500 vs. 2,000 ms) in the early (**a**) and late (**b**) time windows of the late positive potential (LPP). Bars represent within-subjects confidence intervals (Cousineau, 2005)

the counting task. We sought to test this possibility in Experiment 2 using a task relevance manipulation designed to sustain engagement.

Experiment 2

To test whether task relevance could have a lasting temporal effect and modulate the later LPP, we incorporated a task that required persistent engagement with target stimuli. Specifically, Experiment 2 utilized a task in which participants determined the duration of target presentation. This task was designed to sustain engaged processing throughout the entire target presentation period (i.e., 2 s). Using this manipulation of task relevance, we predicted that the later portion of the LPP would be increased for targets relative to standards. However, because the task involved making a duration estimation (i.e., 2 or 3 s), task relevance might *only* increase the later portion of the LPP; that is, targets might not increase the initial portion of the LPP using this design.

In addition, Experiment 2 was planned to determine how affective content and task relevance interact to modulate sustained engagement. We included both affective and neutral pictures as target stimuli. On the basis of previous research, we predicted that affective content and task relevance would have additive effects on the later portion of the LPP. That is, the motivational influence of affective content and task relevance should summate to enhance the later portion of the LPP.

To further expand on the findings from Experiment 1, we also used five pictures for each affective and neutral category. This was done to ensure that our findings were not artifacts of the pictures used in Experiment 1. Because much research has been done investigating the LPP to passive viewing of affective pictures (e.g., affective standards), we used only neutral standards in Experiment 2.

Method

A group of 21 undergraduates (13 women and eight men) participated in exchange for course credit.

Twenty images (five pleasant, five unpleasant, and ten neutral) were selected from the IAPS (Lang et al., 2008). The pleasant and unpleasant images were matched for arousal and relative valence. Five neutral, five pleasant, and five unpleasant images served as the targets in an emotional oddball task; the other five neutral images served as the standards.[4] The inclusion of five images for each category was used to ensure that any observed effects were not the results of specific images.

The task consisted of three separate blocks: one with pleasant targets, one with unpleasant targets, and one with neutral targets. The same five standards were presented for each block. Each target appeared three times, for a total of 15 target presentations per block and 45 target presentations across all three blocks. Each standard was presented 12 times per block, for a total of 48 standard presentations per block and 144 total standard presentations across all three blocks. Each standard was presented for 2,000 ms. Prior to the start of each block,

[4] Stimuli were again drawn from the IAPS (Lang et al., 2008): neutral targets = 2357, 2381, 2393, 2480, 2870; unpleasant targets = 3016, 3051, 3101, 3102, 3120; pleasant targets = 4608, 4623, 4626, 4660, 4689; and neutral standards = 2191, 2383, 2385, 2396, 2840.

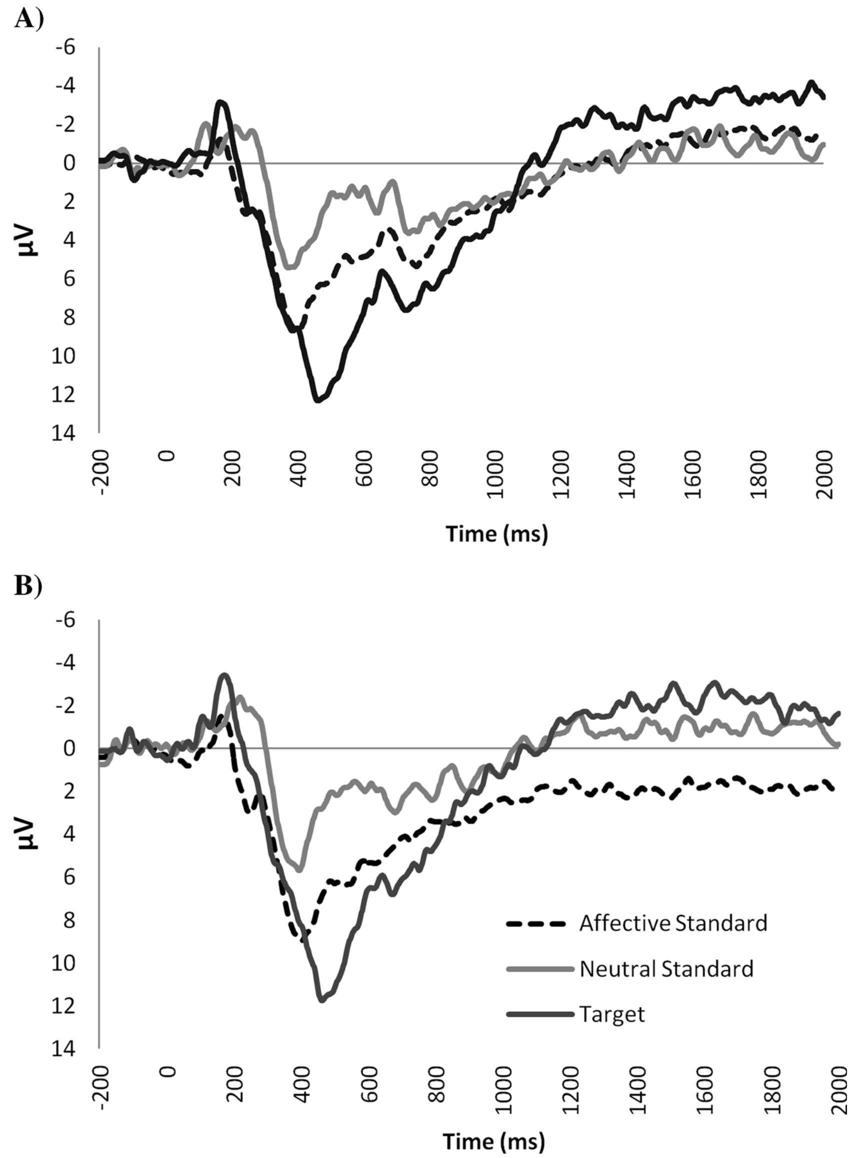

Fig. 2 Waveform **a**: Neutral standard, affective standard, and target event-related potentials (ERPs) in the short display at the index sites Cz, CPz, CP1, CP2, and Pz. Waveform **b**: Neutral standard, affective standard, and target ERPs in the long display at the index sites Cz, CPz, CP1, CP2, and Pz

participants were shown a slide depicting the targets for that block. Each target stimulus was displayed for either 2,000 or 3,000 ms. Because pleasant and unpleasant targets were hypothesized to have similar impacts on the LPP, as found in Experiment 1, pleasant and unpleasant targets were averaged together to create an aggregate LPP to affective targets.[5]

Participants were shown examples of each duration prior to the first block of the experiment and told that they would be asked to discriminate whether the target had appeared for a short (2,000-ms) or a long (3,000-ms) duration by pressing a corresponding button.[6] To remain consistent with Experiment 1, we did not investigate LPP amplitudes past 2,000 ms. All stimuli were presented for at least 2,000 ms because the results of Experiment 1 indicated that the long presentation was the variable of interest.

We chose the duration judgment task because we hypothesized that it would sustain engagement until at least 2,000 ms. In addition, analyzing LPP amplitudes up to 2,000 ms eliminated the confound of varying stimulus offset times for the 2,000-ms or 3,000-ms presentations. For these

[5] As in Experiment 1, a 2 (Valence: pleasant vs. unpleasant block) × 2 (Task Relevance: target vs. standard) × 2 (Time Window: early vs. late) revealed no main effect of valence, $F(1, 15) = 2.14$, $p = .163$, $\eta_p^2 = .13$, and the overall interaction of valence, target/standard, and time window was also nonsignificant, $F(1, 15) = 0.61$, $p = .447$, $\eta_p^2 = .04$. Because unpleasant versus pleasant valence did not have a main effect or interaction, affective stimuli were combined in the further analyses.

[6] The mean correct identification of short-duration targets was 85.7%, whereas the mean correct identification of long-duration targets was 85.4%.

reasons, we focused our analyses on the 1,000- to 2,000-ms window.

EEG assessment and processing

EEG was recorded from 31 tin electrodes mounted in a stretch Lycra Quik-Cap (Electro-Cap, Eaton, OH) and referenced online to the left earlobe. A ground electrode was mounted on the midline in front of Fz. The electrode impedances were under 5,000 Ω. Signals were amplified with a Neuroscan SynAmps RT amplifier unit (El Paso, TX), low-pass filtered at 100 Hz, high-pass filtered at 0.05 Hz, notch filtered at 60 Hz, and digitized at 500 Hz. Artifacts (e.g., horizontal eye movement and muscle movements) were removed by hand. Then, a regression-based eye movement correction was applied (Semlitsch et al., 1986), after which the data were again visually inspected to ensure proper correction.

The data were epoched from 200 ms before picture onset until 2,000 ms after picture onset, and were re-referenced using the average of the left and right mastoids. Following epoching, the data were filtered with a low pass of 35 Hz (48 dB), using a unidirectional FIR filter, and baseline corrected using the prestimulus interval. Aggregated waveforms for picture type and picture duration were created. To investigate the modulation of the LPP by target status and emotional content over time, the LPP was evaluated in the same time windows as in Experiment 1.

For purposes of economy, in Experiment 2 we only used a 31-electrode cap. The LPP was measured as the mean EEG activity from two of the centro-parietal sites used in the previous experiment (Cz and CPz) within each of these windows. The other electrodes included in Experiment 1 were not available on the cap used in Experiment 2. LPPs to the standards in both affective blocks were averaged together prior to analyses. Participants who correctly determined the duration on less than 70 % of the trials ($N = 4$) were removed from the analysis.

Results

Modulation as a function of affective content and task relevance

A 2 (Task Relevance: target vs. standard) × 2 (Block: affective vs. neutral) × 2 (LPP Window: early vs. late) repeated measures ANOVA revealed a significant three-way interaction: $F(1, 16) = 11.716$, $p = .003$, $\eta_p^2 = .42$. Follow-up analyses were conducted in the early and late windows (see Fig. 3a and b).

Early window Task relevance did not influence LPP amplitudes in the early time window, since LPPs were similar in response to neutral targets and neutral block standards, $t(16) = 0.53$, $p = .603$, $d = 0.27$. LPPs were larger in response to affective targets than to affective block standards, $t(16) = 6.36$, $p < .001$, $d = 3.18$. However, LPPs were also larger in response to affective targets than to neutral targets, $t(16) = 8.10$, $p < .001$, $d = 4.05$, suggesting that affective content alone enhanced LPP amplitudes in the early time window (see Fig. 4a).

Late window Task relevance influenced LPP amplitudes in the late time window, such that LPPs were larger in response to neutral targets than to neutral block standards, $t(16) = 2.19$, $p = .043$, $d = 1.10$. LPPs were also larger in response to affective targets than to affective block standards, $t(16) = 3.53$, $p = .002$, $d = 1.76$, and larger in response to affective targets than to neutral targets, $t(16) = 2.49$, $p = .024$, $d = 1.24$, suggesting that affective content summed with task relevance to enhance LPP amplitudes in the late time window (see Fig. 4b).

Discussion

The results from Experiment 2 revealed that affective targets produced larger early LPPs than did standards or neutral targets. LPPs to neutral task-relevant stimuli were similar in amplitude to neutral standards, suggesting that the duration estimation task did not enhance LPPs in the early window. The lack of task relevance modulation in the early window was likely due to the paradigm employed: Participants did not need to immediately attend to target stimuli in order to determine duration. In contrast, in the late window both affect and task relevance enhanced the LPP. Affective and neutral targets produced larger LPPs than did the standards. In addition, late LPPs were larger to affective than to neutral targets. These results suggest that affective content summed with task relevance to enhance LPP amplitudes in the 1,000- to 2,000-ms window. Employing a paradigm in which participants needed to engage sustained attention in order to correctly categorize target stimuli as being long or short in duration increased LPPs to neutral task-relevant stimuli, as compare to task-irrelevant stimuli.

General discussion

Through two experiments, we found that modulation of the later portion of the LPP in response to task-relevant stimuli depends on the nature of the task, whereas modulation of the LPP by affective content depends on stimulus duration. Specifically, in Experiment 1, target stimuli enhanced early LPPs, as compared to neutral standards, but failed to enhance later LPPs, regardless of stimulus duration. This contrasts with the affective standards, which enhanced early LPPs as

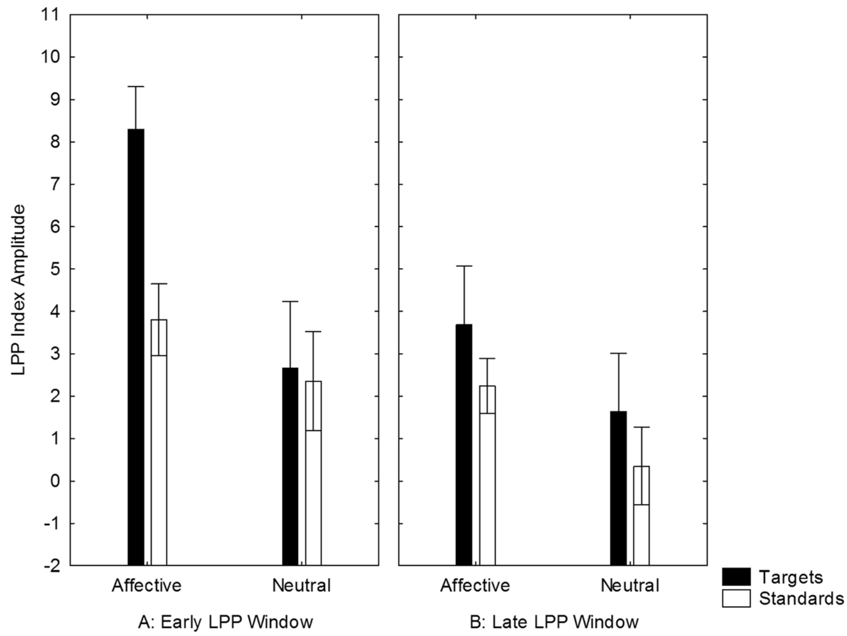

Fig. 3 Interaction of picture type (target vs. standard) and block (affective vs. neutral) in the early (**a**) and late (**b**) time windows of the late positive potential (LPP). Bars represent within-subjects confidence intervals (Cousineau, 2005)

compared to the neutral standards, but only enhanced the later LPP when presentation duration extended throughout the late LPP window. Likewise, in Experiment 2, affective content enhanced LPP amplitudes in both the early and late windows. These data are consistent with the notion that emotional content continues to sustain engagement for the entire picture presentation period, and that this is reflected in the continued modulation of the LPP. In Experiment 2, however, task relevance did increase the later LPP. Moreover, task relevance and affective content summed to increase the later portion of the LPP. This suggests that the later portion of the LPP is not simply a return to baseline, but rather represents a sustained physiological process related to continued engagement.

In Experiment 1, task relevance (i.e., targets) increased the early portion of the LPP (Ferrari et al., 2010; Ferrari et al., 2008). However, targets did not modulate the later LPP window for either long or short picture durations. This effect was likely due to the transient demands of the task: Participants had no need to sustain engagement with visual stimuli when counting targets; once they had noticed and counted the target, they could disengage from the picture. That is, the counting task did not require sustained engagement with the visual stimuli, and therefore, no task-related increase emerged in the later portion of the LPP. This suggests that the impact of task relevance on the LPP is transient.

We tested this possibility in Experiment 2 using a duration judgment task that required sustained engagement with visual stimuli in order to categorize the targets. The results suggest that the duration task enhanced engagement for both affective and neutral targets in the later portion of the LPP. With regard to the early window, the first 1,000 ms was irrelevant for the task, and the LPP was only enhanced by affective content. Other methodological differences in Experiment 2 (as compared to Exp. 1) may have contributed to the LPP, such as the blocked presentation or the use of only neutral standards. However, these differences could not explain the observed between-condition differences in Experiment 2. These data suggest that the impact of task relevance over the time course of the LPP seems to depend entirely on the nature of the task—that is, how long an engagement is required to categorize the targets.

Past studies provided some evidence that the modulation of the LPP by affective content and task relevance might involve distinct neural bases. Sabatinelli, Keil, Frank, and Lang (2013) indicated that reentrant projections from the amygdala into the parieto-occipital cortex might be responsible for the increased LPP to affective stimuli. On the other hand, Moratti, Saugar, and Strange (2011) found that bidirectional connections between the prefrontal and occipital cortices contribute to the LPP involving task-related engagement. Although both the affective and task-relevant modulations of the LPP seem to be the results of cortical connections to occipital–parietal regions, affective modulation may stem from subcortical regions, whereas task-relevant modulation seems to stem from prefrontal regions. These potential sources of the LPP may explain the results of the present study: affective content and task relevance differentially modulate LPP duration and amplitude. Nevertheless, more work will be necessary to fully understand the neural circuitry behind this phenomenon. In future studies, researchers might want to use the present paradigm with fMRI to see whether relevance and content both engage the same circuits.

Together, these experiments suggest that task relevance can have either a transitory or a more sustained effect on the LPP.

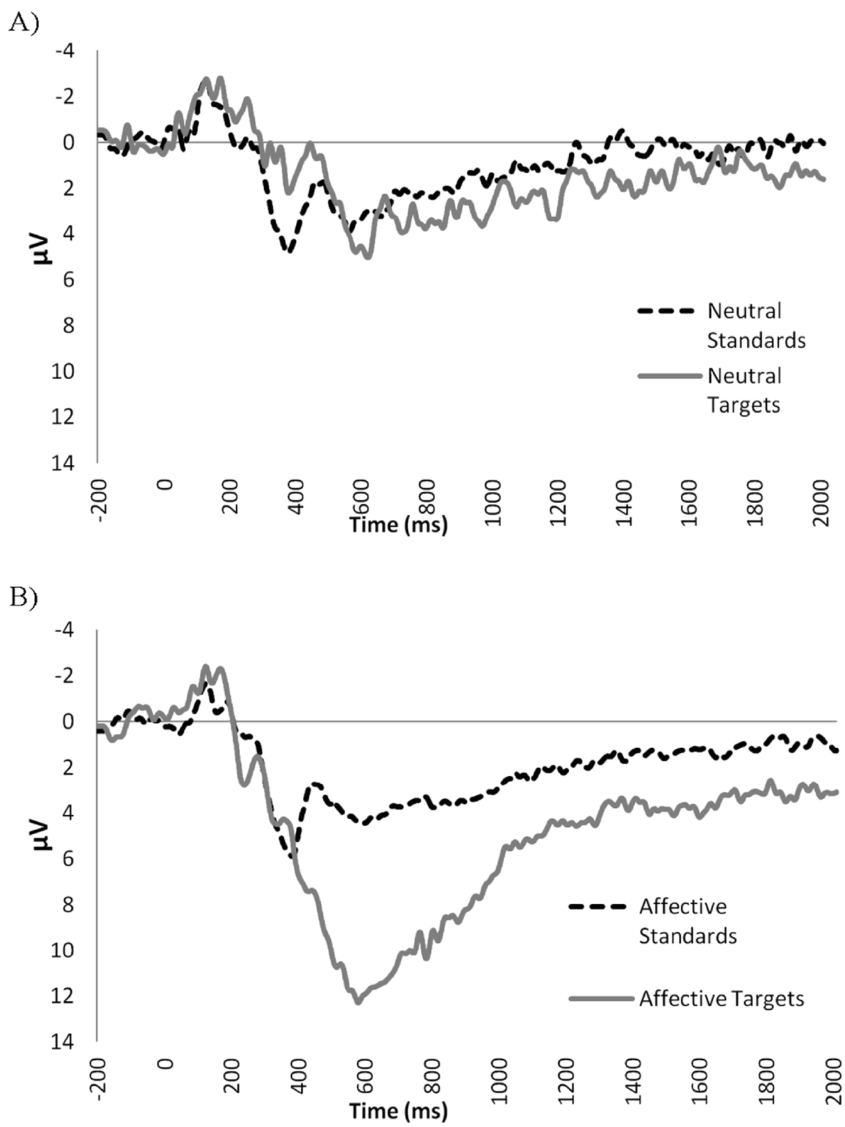

Fig. 4 Waveform **a**: Neutral target and neutral block standard event-related potentials (ERPs) at the index sites Cz and CPz. Waveform **b**: Affective target and affective block standard ERPs at the index sites Cz and CPz

Manipulating task relevance using a counting task enhanced the early LPP but did not influence the later LPP. In contrast, manipulating task relevance using a duration judgment task enhanced the later LPP, but did not modulate the earlier portion of the LPP. Consistent with past research, these results support the notion that the increased LPP reflects stimulus salience and motivated engagement with visual stimuli. Moreover, the present results extend this past work by showing that task relevance has a transient effect on the LPP. These results suggest that, whereas affective content increases the LPP throughout the stimuli display, task relevance only continues to increase the LPP for as long as the task requires continued engagement.

Based on results of the present study, we think that the time course of attentional engagement is reflected in the LPP. The temporal characteristics of the positive-going wave contributing to the P3 and LPP are determined by the task used to elicit them. In much past work, the P3 has been elicited using very simple signal detection tasks. The LPP is transient and more P3-like when the task requires relatively short engagement, but more protracted and LPP-like when there is sustained engagement. Perhaps the time course of the LPP indexes when something is relevant or important. The present experiments suggest that sustained engagement throughout the stimulus duration enhances the later LPP.

The present set of experiments extended previous research that had demonstrated that target stimuli evoke larger LPPs than do standard stimuli (Ferrari et al., 2008; Weinberg et al., 2012), by not only testing extended displays of both standards and targets, but also by manipulating task relevance to sustain engagement. The results from our two experiments revealed that affective content induced sustained engagement that depended on picture duration; moreover, neutral task-relevant stimuli were capable of protracted engagement when the task required it. Together, these results suggest that affective content and task relevance determine the time course of engagement in different ways: Affective content immediately engages and sustains engagement, whereas task relevance only modulates engagement when it is necessary for task completion.

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