Arousal modulates the motor interference effect stimulated by pictures of threatening animals

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Previous research related to the motor interference effect from dangerous objects indicated that delayed responses to dangerous objects were associated with more positive parietal P3 amplitudes, suggesting that great attentional resources were allocated to evaluate the level of danger (i.e., negative valence). However, arousal covaried with valence in this research. Together with previous studies in which the P3 amplitude was found to be increased along with a higher arousal level in the parietal lobe, we raised the issue that more positive parietal P3 amplitudes might also be affected by a high arousal level. To clarify whether valence or arousal impacted the motor interference effect, this study used a motor priming paradigm mixed with a Go/NoGo task and manipulated the valence (negative, neutral and positive) and arousal (medium and high) of target stimuli. Analysis of the behavioral results identified a significant motor interference effect (longer reaction times (RTs) in the negative valence condition than in the neutral valence condition) at the medium arousal level and an increased effect size (increment of RT difference) at the high arousal level. The results indicated that negative valence stimuli may interfere with the prime elicited motor preparation more strongly at the high arousal level than at the medium arousal level. The ERP results identified larger centroparietal P3 amplitudes for the negative valence condition than for the neutral valence condition at a high arousal level. However, the inverse result, i.e., lower centroparietal P3 amplitudes for the negative valence condition than for the neutral valence condition, was observed at a medium arousal level. The ERP results further indicated that the effect size of the behavioral motor interference effect increased because subjects are more sensitive to the negative valence stimuli at the high arousal level than at the medium arousal level. Furthermore, the motor interference effect is related to the negative valence rather than emotionality of the target stimuli because different result patterns emerged between the positive and negative valence conditions. Detailed processes underlying the interaction between valence and arousal effects are discussed.

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2 **threatening animals**

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Abstract

12   Previous research related to the motor interference effect from dangerous objects indicated

13   that delayed responses to dangerous objects were associated with more positive parietal P3

14   amplitudes, suggesting that great attentional resources were allocated to evaluate the level of

15   danger (i.e., negative valence). However, arousal covaried with valence in this research. Together

16   with previous studies in which the P3 amplitude was found to be increased along with a higher

17   arousal level in the parietal lobe, we raised the issue that more positive parietal P3 amplitudes

18   might also be affected by a high arousal level. To clarify whether valence or arousal impacted the

19   motor interference effect, this study used a motor priming paradigm mixed with a Go/NoGo task

20   and manipulated the valence (negative, neutral and positive) and arousal (medium and high) of

21   target stimuli. Analysis of the behavioral results identified a significant motor interference effect

22   (longer reaction times (RTs) in the negative valence condition than in the neutral valence

23   condition) at the medium arousal level and an increased effect size (increment of RT difference)

24   at the high arousal level. The results indicated that negative valence stimuli may interfere with the

25   prime elicited motor preparation more strongly at the high arousal level than at the medium arousal

26   level. The ERP results identified larger centroparietal P3 amplitudes for the negative valence

27   condition than for the neutral valence condition at a high arousal level. However, the inverse result,

28   i.e., lower centroparietal P3 amplitudes for the negative valence condition than for the neutral

29   valence condition, was observed at a medium arousal level. The ERP results further indicated that

30   the effect size of the behavioral motor interference effect increased because subjects are more

31   sensitive to the negative valence stimuli at the high arousal level than at the medium arousal level.

32   Furthermore, the motor interference effect is related to the negative valence rather than

33   emotionality of the target stimuli because different result patterns emerged between the positive

34   and negative valence conditions. Detailed processes underlying the interaction between valence

35   and arousal effects are discussed.

36   **Keywords:** motor interference effect, motor priming paradigm, threatening animals, arousal,

37   valence

1 Introduction

Increasing production safety accidents occur in factories when workers interact with more types of machines. For example, during the process of operating a machine, dicing or saw blades in the machine may cut off a worker's finger if his or her prepared motor actions are not inhibited in time. According to a survey, human factors cause approximately 88 % of work-related accidents (Huang et al., 2012). Thus, it is necessary to explore how we process our prepared motor actions to avoid touching dangerous elements in a machine, which might provide a reference for safety management that reduces the occurrence of work-related accidents from a cognitive perspective.

There has been evidence that dangerous objects may delay an individual's response speed; this phenomenon is known as the motor interference effect from dangerous objects (Anelli, Borghi, & Nicoletti, 2012). Using a motor priming paradigm, previous research has investigated mechanisms of the motor interference effect from behavioral and event-related potential (ERP) perspectives. Anelli et al. (2012) adopted a motor priming paradigm using different means of grasping right hands as primes (a grasping or static human hand or a grasping robotic hand) and dangerous or safe objects as targets. Participants were asked to respond to artifacts or natural attributes of the targets. The results showed delayed responses for dangerous targets compared with those for safe targets, suggesting that the threat imposed by an object may conflict with an individual's prepared motor actions and thus cause slower response times (RTs). To further investigate the neuro-origin of the motor interference effect from dangerous objects, Liu et al. (2017) adopted a motor priming paradigm mixed with a Go/NoGo task. Left or right grasping hands were used as prime stimuli, and dangerous (a rectangular saw blade and a round saw blade) or safe (a ruler and a disc) objects were used as target stimuli. A green or red dot was superimposed on the center of the targets as a Go or NoGo signal, respectively. The participants were asked to

61   prepare the ipsilateral hand responses that corresponded to the handedness of the prime. They were

62   asked to execute the prepared responses until the green dot (Go signal) emerged and to inhibit their

63   responses while they observed the red dot (NoGo signal). The behavioral results replicated a

64   classical motor interference effect from dangerous objects, as found by Anelli et al. (2012).

65   Moreover, the ERP results revealed a more positive parietal P3 amplitude in a dangerous condition

66   than in a safe condition. As the parietal P3 component represents attentional resource allocation

67   (Isreal, Chesney, Wickens, & Donchin, 1980), Liu et al. (2017) concluded that the motor

68   interference effect originated from danger evaluation because many attentional resources were

69   recruited to evaluate the dangerousness of the target to prevent the touching of dangerous stimuli.

70   The motor interference effect from dangerous objects can be explained by the notion that

71   a dangerous target activates an aversive motivational system that may elicit an avoidance response.

72   The activation of the aversive motivational system is deemed to be related to the valence attribute

73   of stimuli (Lang, Bradley, & Cuthbert, 1997). Valence reflects subjective appraisal of stimulus

74   pleasantness (positive versus negative); specifically, a more negative valence stimulus may elicit

75   a deeper activation of the aversive motivational system (Lang, Bradley, & Cuthbert, 1990; Lang,

76   Davis, & Öhman, 2000). However, another important attribute (i.e., arousal, reflecting the level of

77   activation sensitivity from calmness to excitation) of threatening stimuli was neglected by Liu et

78   al. (2017) according to the dimensional models of emotions (Russell, 1980), resulting in the issue

79   that arousal level covaried with valence factor. The dangerous targets (rectangular or circular

80   sawblades) might not only activate an aversive motivational system (elicited by negative valence

81   of the dangerous targets) but also elicit a high-level excitation state (elicited by a high arousal level

82   of the dangerous targets) because attentional resources are automatically recruited to process the

83   dangerous targets (Blanchette, 2006; Fox et al., 2000; Öhman, Flykt, & Esteves, 2001; Tipples,

84   Young, Quinlan, Broks, & Ellis, 2002). However, the safe targets (i.e., rule or disc) might not

85   activate the aversive motivational system and only elicit a medium-level excitation state (elicited

86   by a medium arousal level of the safe targets). Furthermore, existing evidence indicates that

87   amplitudes of parietal P3 components increase along with a higher level of arousal (Cuthbert et

88   al., 2000; Keil et al., 2002; Polich, 2007; Sabatinelli et al., 2007; Schupp et al., 2003). Therefore,

89   the presence of more positive parietal P3 amplitudes in dangerous conditions compared with those

90   in safe conditions, reported by Liu et al. (2017), could also be explained by the notion that the

91   arousal level of dangerous targets was higher than that of safe targets. Additionally, an alternative

92   explanation of the behavioral motor interference effect might still exist because positive valence

93   stimuli were not involved in the study by Liu et al. (2017). Specifically, there has been evidence

94   that, compared with process neutral valence stimuli, both negative and positive valence stimuli

95   processing could increase attentional resources allocated to a task (Cuthbert et al., 2000; Keil et

96   al., 2002). One might argue that the occurrence of the motor interference effect might be attributed

97   to emotionality (either negative or positive valence) rather than negative valence of background

98   stimuli because both negative and positive valence background stimuli could distract attention

99   from the main Go/NoGo task, which might increase the RTs in dangerous conditions, as in the

100   study by Liu et al. (2017).

101   To clarify whether manipulating the valence factor confounded the arousal levels in Liu et

102   al. (2017), arousal levels should be matched when comparing results between negative and neutral

103   valence conditions. Existing evidence indicates that arousal could modulate the valence effect on

104   a cognitive task (Zsido et al., 2020a, b). Zsido and colleges utilized a novel paradigm in which

105   participants were instructed to search for numbers in a matrix. The number matrix was presented

106   as superimposed on an emotional picture. They manipulated factors of valence (negative, neutral

107   and positive levels) and arousal (medium and high levels) of the emotional pictures to investigate

108   which of the two factors had a greater impact on cognitive processing. The results indicated a

109   significant interaction between arousal and valence factors. At the medium arousal level,

110   performance was worse in the negative valence condition than in the neutral and positive valence

111   conditions. However, at the high arousal level, performance of the negative valence condition was

112   improved and became similar to the performance of the neutral and positive valence conditions.

113   The results suggested that arousal could significantly modulate the valence effect on a cognitive

114   task. Negative valence background stimuli could distract attention from the main cognitive task at

115   the medium arousal level, which impaired performance in this condition. The decrement in

116   performance could be compensated with increasing arousal levels (at the high arousal level) of the

117   background stimuli because an increased arousal level could speed up the cognitive system, which

118   in turn improved task performance in negative valence conditions to a level similar to that in

119   neutral and positive valence conditions at the high arousal level.

120   By referring to the studies from Zsido's lab, we systematically manipulated factors of

121   valence and arousal to investigate whether these two factors impact the motor interference effect

122   from dangerous objects. The study continued to use the experimental paradigm (a motor priming

123   paradigm mixed with a Go/NoGo task) adopted by Liu et al. (2017) with the following exceptions:

124   1) The background targets were selected from the International Affective Picture System (IAPS)

125   (Lang et al., 2005), in which levels of valence and arousal factors have been standardized and

126   defined. Only touchable animal pictures were selected for the background target stimuli because

127   touchable stimuli could interact with the motor preparations induced by a priming stimulus (a left

128   or right grasping hand). Moreover, selecting animal pictures as the targets could also exclude a

129   confounding factor that might be caused by different categories of targets. 2) Valence (negative,

130   neutral and positive) and arousal (medium and high) levels of target stimuli were systematically

131   manipulated according to Zsido et al. (2020b). Positive valence was included to clarify whether

132   the motor interference effect from dangerous objects occurs because negative valence implies

133   delayed responses for background targets or whether it occurs because emotionality (either

134   negative or positive) of target stimuli distracted attention from the Go/NoGo task, which in turn

135   delays responses. Of note, the arousal levels were matched among negative, neutral and positive

136   valence in the animal category of target stimuli, and the mean scores of the high arousal level

137   (mean = 5.68) are lower than those of in the study by Zsido et al. (2020b) (mean = 7.57). The

138   effectiveness of the manipulation is discussed in the General Discussion. 3) Emotional pictures

139   were used as backgrounds with a Go/NoGo signal (yellow capital letters "M" or "W")

140   superimposed on the center. Participants were instructed to prepare the ipsilateral hand responses

141   that corresponded to the handedness of the prime and to decide whether to execute the prepared

142   responses according to the Go/NoGo signal. Responding to the superimposed targets imitated a

143   situation in which executing a prepared response encountered an emergent dangerous stimulus

144   because emotion is triggered by accidental stimuli in usual life settings (Delplanque, Silvert, Hot,

145   & Sequeira, 2005; Yuan et al., 2007). The current design that did not require subjects to evaluate

146   emotion overtly (the emotional stimuli are used as backgrounds) may have allowed emotional

147   responses in the laboratory setting to more closely imitate life experiences.

148   The hypotheses were based on the work of Zsido et al. (2020b), namely, that arousal could

149   modulate the strength of the motor interference effect. Specifically, at the medium arousal level,

150   the mean RTs in the negative valence condition should be longer than those in the neutral and

151   positive valence conditions because negative valence background stimuli could distract attention

152   from the Go/NoGo signals at the medium arousal level. In contrast, high arousal stimuli might

153   divert attentional resources to the background targets, which may enhance perceptual

154   representation of negative valence targets. Participants might suppress their prepared responses

155   more strongly because many threatening details could be analyzed by the increased attentional

156   resources in the high arousal and negative valence condition. Therefore, a larger effect size (mean

157   RT in the negative valence condition minus those in the neutral and positive valence conditions)

158   should emerge at the high arousal level compared with the medium arousal level. For ERPs,

159   according to Liu et al. (2017), who suggested that the valence factor could significantly contribute

160   to the P3 amplitudes, more positive P3 amplitudes should emerge in the negative valence condition

161   than in the neutral and positive valence conditions at the medium arousal level. Moreover, the

162   differences in the P3 amplitudes between the negative and neutral valence conditions and those

163   between the negative and positive valence conditions should be larger at the high arousal level

164   than the medium arousal level.

165   **2 Method**

166   **2.1 Participants**

167   To obtain robust results, 76 right-handed subjects were recruited to participate in the

168   experiment. Note that the number of subjects was more than that of a prior simple size estimation

169   (7 subjects) with a large effect size ($f = 0.4$) and 0.95 statistical power. Subjects No. 6 and No. 11

170   were excluded from the data analysis because of a reference channel error. The remaining 74

171   subjects (thirty males), ranging in age from 18 to 26 years (mean age = 21.91), were included in

172   the data analysis. All participants had normal or corrected-to-normal visual acuity. They also

173   reported an absence of neurological disorders. They provided written informed consent before

174   participating the experiment and were compensated with RMB 50 while finishing the experiment.

175   The experiment was approved by the Medical Ethics Committee at Northwest University.

2.2 Materials and apparatus

Left or right hand with a partial forearm pictures (subtending a visual angle 13° horizontally and 11° vertically) were used as primes, which aimed to activate a corresponding directional response readiness (Liu, Cao, Chen, & Wang, 2017). To imitate a spatially matched grasping situation, primes were presented 2° to the left or right of the fixation point. Centrally presented targets were combined pictures with a Go/NoGo signal (yellow capital letters "M" or "W" subtending a visual angle 2° horizontally and 2° vertically) superimposed on the center of an emotional picture (the size of raw pictures was adjusted to a visual angle 12° horizontally and 9° vertically). Emotional pictures were selected from the IAPS (Lang et al., 2005) with the following criteria: 1) touchable stimuli were selected as targets to interact with the motor preparations induced by priming stimuli and 2) all of the selected stimuli belonged to one category (i.e., animal) to exclude stimulus categories as a confounding factor. Accordingly, we selected 18 animal pictures (Table 1) as backgrounds with systematically manipulated valence and arousal levels (Table 2). Two two-way analyses of variances (ANOVAs), as a function of valence and arousal, were separately performed for the valence and arousal scores. Analysis of the valence scores revealed a significant main effect of valence [F (2, 12) = 65.94, p < 0.001, η^2_p = 0.92], together with an insignificant main effect of arousal [F (1, 12) = 0.001, p = 0.99, η^2_p = 0.001] and insignificant interaction [F (2, 12) = 0.04, p = 0.97, η^2_p = 0.006]. Moreover, analysis of the arousal scores revealed a significant main effect of arousal [F (1, 12) = 42.13, p < 0.001, η^2_p = 0.78], together with an insignificant main effect of valence [F (2, 12) = 0.67, p = 0.53, η^2_p = 0.10] and insignificant interaction [F (2, 12) = 0.08, p = 0.92, η^2_p = 0.01]. The results suggested that both valence and arousal levels were systematically manipulated, with equivalent valence ratings between medium and high arousal levels and equivalent arousal ratings among negative, positive

199   and neutral valence levels.

200   [Please insert Tables 1 and 2 about here]

201   Data were recorded as previously described in Liu et al. (2017). Specifically, stimulus

202   presentation was driven by an E-Prime software (version 2.0, Psychology Software Tools, Inc.

203   Pittsburgh, PA, USA) on a standard PC linked to a 17- inch CRT monitor (60-Hz refresh rate).

204   Electroencephalogram (EEG) data were recorded by a NeuroScan system (NeuroScan, Inc.). A

205   Neuroscan Synamp 2 amplifier with a 64 Ag/AgCl electrode cap mounted according to an

206   extended international 10–20 system was used to continuously record EEG data.

207   **2.3 Procedure**

208   To reduce eye fatigue, all stimuli were presented on a black background. Each trial was

209   initiated from a 300-ms fixation cross to alert participants to concentrate on the screen. Then, a

210   300-ms blank screen, a 200-ms left- or right-hand prime, another 50-ms blank screen, and a 1000-

211   ms target were successively presented. Note that the target display was terminated if the response

212   was executed within 1,000 ms. The intertrial interval was randomized within 1,400-1,600 ms.

213   The participants were seated in front of a laboratory table in a dimly lit chamber. A bracket

214   fixed on the table held their chin to maintain central eye fixation and to fix a computer screen

215   placed 60 cm in front of their eyes throughout the experiment. They were instructed to respond

216   according to the Go/NoGo signal ("M" or "W"), which was superimposed on the emotional

217   pictures. Specifically, they were instructed to prepare a left- or right-hand response that

218   corresponded to the handedness of the prime and not to execute the response until a Go signal

219   appeared. Half of the participants were asked to execute the prepared response as fast and

220   accurately as possible whenever the letter "M" (Go) emerged and to withhold the prepared

221   response when presented with the letter "W" (Nogo). The response rule was counterbalanced in

222 the other half of the participants, with the letter "W" as a Go signal and the letter "M" as a NoGo

223 signal. The participants were instructed to execute a left-hand response by pressing the "F" key

224 using the index finger of their left hand and to execute a right-hand response by pressing the "J"

225 key using the index finger of their right hand on an English keyboard. In contrast, when a NoGo

226 signal appeared, the participants were instructed to withhold the prepared response.

227   The design manipulated valence (negative, neutral and positive), arousal (medium versus

228 high) and Go/NoGo factor (Go versus NoGo). The formal task contained 1152 trials, which

229 included 3 levels of valence × 2 levels of arousal × 2 levels of Go/NoGo × 96 repetitions. In each

230 condition, left or right handedness of the prime was assigned in equal proportions. At the

231 beginning, a 12-trial practice was performed. The formal task would begin unless the participant

232 correctly answered over 11-trials in the practice phase. Each block contained 128 trials. The

233 participants could take a rest between the blocks until they were ready for the next block.

234 **2.4 EEG recording and processing**

235   The EEG data were recorded with the signals bandpass-filtered at 0.05-100 Hz and

236 referenced to the tip of the nose. To ensure signal quality, the impedance of the electrodes was

237 maintained at less than 5 kΩ throughout the experiment. The sampling rate was 500 Hz. The

238 recorded EEG data were preprocessed using the EEGLAB toolbox (Delorme & Makeig, 2004)

239 according to the following steps: (1) The continuous EEG data were resampled at 250 Hz. (2) The

240 resampled EEG data were high-pass filtered at 0.1 Hz and low-pass filtered at 30 Hz. (3) The EEG

241 data were segmented and time-locked to the target onset. The duration of each epoch was 3,000

242 ms with a baseline of 1,000 ms before the target onset. (4) The epoched data were corrected using

243 the mean amplitude of the baseline. (5) The behavioral data were merged into the epoched data,

244 and the incorrect trials were deleted. (6) Bad channels were deleted. (7) The epoched data

245 contaminated by eye blinks and eye movements were corrected using the independent component

246 analysis (ICA) algorithm (Delorme & Makeig, 2004). (8) The deleted channels were interpolated

247 using the EEGLAB toolbox. (9) The epochs were re-referenced to the mean of the bilateral mastoid

248 electrodes, and (10) the epochs with large artifacts were detected by eye and manually deleted.

249 Automatic artifact detection was then performed with deletion of the trials containing amplitudes

250 less than -100 µV or more than 100 µV. Consequently, 2.5 % of the epochs were rejected as

251 contaminated during preprocessing across all subjects and conditions. The mean number of

252 artifact-free trials obtained for each condition stabilized between 93 and 94, which ensured a valid

253 trial amount for each condition.

254   Before the final averaging, the preprocessed data were resegmented and initiated from 300

255 ms before and 900 ms after the target onset. A flat time window (-300 to -200 ms before the target

256 onset) was selected as a baseline to correct the new epochs. Then, the extracted average waveforms

257 for each participant and condition were used to calculate the grand-average waveforms.

258 **2.5 Statistical analysis**

259 **2.5.1 Behavioral data**

260   Mean RTs and mean error rates for each condition were averaged separately for each

261 participant. Note that only the RTs for correct responses in Go trials were involved in the RT

262 analysis. Before the analysis, Kolmogorov-Smirnov tests of normality were performed on RTs and

263 error rates for each condition. The results indicated that mean RTs were normally distributed for

264 all conditions. Accordingly, the mean RTs were analyzed by a two-way repeated-measures

265 ANOVA as a function of valence (negative, neutral and positive) and arousal (medium versus

266 high). However, the Kolmogorov-Smirnov tests indicated that the mean error rates deviated from

267 normality for all conditions (ps < 0.01). Accordingly, logarithmic mean correct rates (because 0

268   cannot be log-transformed, we used correct rates instead of error rates) were analyzed by a three-

269   way repeated-measures ANOVA as a function of valence (negative, neutral and positive), arousal

270   (medium versus high) and Go/NoGo factor (Go versus NoGo).

271   **2.5.2 ERP data**

272   To utilize more channel signals, the centroparietal scalp regions of interest (SROIs, the

273   average of the C5, C3, C1, Cz, C2, C4, C6, CP5, CP3, CP1, CPz, CP2, CP4, CP6, P5, P3, P1, Pz,

274   P2, P4 and P6 electrodes) were defined according to the topographic maps (more details are

275   presented in Figure 1), where the electrodes were maximally activated. The dependent variables

276   comprised centroparietal P3 amplitudes, which were calculated based on the mean amplitude

277   between 300 and 500 ms for Go and that between 400 and 600 ms for NoGo trials. Note that only

278   P3 amplitudes were used as an ERP index because Liu et al. (2017) identified that the neural

279   processing of the motor interference effect from dangerous objects is reflected by the amplitudes

280   of the late component (i.e., P3 amplitudes) rather than by those of the early (P1 and N1) and middle

281   (P2 and N2) latency components. The independent variables were valence (negative, neutral and

282   positive), arousal (medium versus high), and Go/NoGo factor (Go versus NoGo). Kolmogorov-

283   Smirnov tests of normality were also performed on P3 amplitudes in each condition. The results

284   indicated that distributions of P3 amplitudes did not deviate from normality. Accordingly, a three-

285   way repeated-measures ANOVA was used to analyze the effects of the independent variables. The

286   degrees of freedom of the *F*-ratio were corrected using the Greenhouse-Geisser method, and

287   multiple comparisons were adjusted by the Bonferroni method in the analyses. The effect sizes are

288   presented as partial eta-squared values (η^2_p) for the ANOVA and as *Cohen's d*s for the *t*-tests.

289   [Please insert Figure 1 about here]

290   **3 Results**

3.1 Behavioral results

291

292   The analysis of RTs revealed significant main effects of valence [F (2, 146) = 50.50, $p <$

293   0.001, $\eta^2_p = 0.41$] and arousal [F (1, 73) = 22.01, $p < 0.001$, $\eta^2_p = 0.23$], together with a significant

294   two-way interaction between valence and arousal [F (2, 146) = 39.05, $p < 0.001$, $\eta^2_p = 0.35$] (Figure

295   2). Subsequent one-way ANOVAs indicated significant main effects of valence at both high [F (2,

296   146) = 77.59, $p < 0.001$, $\eta^2_p = 0.52$] and medium [F (2, 146) = 16.91, $p < 0.001$, $\eta^2_p = 0.19$] arousal

297   levels. *Post hoc* tests with Bonferroni correction indicated that at the high arousal level, RTs for

298   the negative (492 ± 54 ms; $p < 0.001$, *Cohen's d* = 1.19) and positive valence (492 ± 51 ms; $p <$

299   0.001, *Cohen's d* = 1.31) conditions were slower than those for the neutral valence condition (474

300   ± 53 ms), and the difference between the negative and positive valence conditions did not reach

301   significance (p = 1.00, *Cohen's d* = 0.01). In contrast, at the medium arousal level, responses for

302   the negative valence condition (496 ± 52 ms) were slower than those for the positive (486 ± 53

303   ms; $p < 0.001$, *Cohen's d* = 0.64) and neutral valence (488 ± 50 ms; $p < 0.001$, *Cohen's d* = 0.47)

304   conditions, and the difference between the positive and neutral valence conditions did not reach

305   significance (p = 0.76, *Cohen's d* = 0.13).

306   [Please insert Figure 2 about here]

307   Regarding error rates (Figure 3), the analysis of log-transformed correct rates revealed

308   significant main effects of valence [F (2, 146) = 4.93, p = 0.01, $\eta^2_p = 0.06$] and arousal [F (1, 73)

309   = 5.04, p = 0.03, $\eta^2_p = 0.07$]. Furthermore, a significant two-way interaction between valence and

310   arousal [F (2, 146) = 3.65, p = 0.03, $\eta^2_p = 0.05$] together with a significant three-way interaction

311   among valence, arousal and Go/NoGo factor [F (2, 146) = 5.03, p = 0.009, $\eta^2_p = 0.06$] was

312   identified. Analysis of the simple effect of the significant three-way interaction revealed a

313   significant two-way interaction between valence and arousal in Go trials [F (2, 146) = 7.00, p =

314   0.02, $\eta^2{}_p$ = 0.09]. Subsequent one-way ANOVAs indicated a nonsignificant main effect of valence

315   at the high arousal level [F (2, 146) = 0.39, p = 0.65, $\eta^2{}_p$ = 0.005]. However, the main effect of

316   valence reached significance at the medium arousal level [F (2, 146) = 7.54, p = 0.001, $\eta^2{}_p$ = 0.09].

317   The *post hoc* analysis indicated that response errors for the negative valence condition (1.72 ± 2.40

318   %) were more than those for the positive (1.04 ± 1.49 %; p = 0.003, *Cohen's d* = 0.41) and neutral

319   valence (1.11 ± 1.85 %; p = 0.02, *Cohen's d* = 0.34) conditions, and the difference between the

320   positive and neutral valence conditions did not reach significance (p = 1.00, *Cohen's d* = 0.05). In

321   contrast, analysis of the simple effect indicated significant main effects of valence [F (2, 146) =

322   4.57, p = 0.01, $\eta^2{}_p$ = 0.06] and arousal [F (1, 73) = 7.40, p = 0.008, $\eta^2{}_p$ = 0.09] in NoGo trials. The

323   *post hoc* analysis of valence indicated that response errors for the positive (1.19 ± 1.24 %; p =

324   0.04, *Cohen's d* = 0.30) and negative (1.20 ± 1.29 %; p = 0.057, *Cohen's d* = 0.28) valence

325   conditions were more and nearly more than those for the neutral valence condition (0.82 ± 1.09

326   %), respectively. The *post hoc* analysis of arousal indicated that response errors for the high arousal

327   condition (0.91 ± 1.03 %) were less than those for the medium arousal condition (1.23 ± 1.17 %).

328   [Please insert Figure 3 about here]

329   **3.2 ERP results**

330   Grand averages of target-locked ERPs are presented in Figure 4. The three-way repeated-

331   measures ANOVA results of the centroparietal P3 amplitudes revealed insignificant main effects

332   of valence [F (2, 146) = 2.32, p = 0.10, $\eta^2{}_p$ = 0.03], arousal [F (1, 73) = 1.75, p = 0.19, $\eta^2{}_p$ = 0.02]

333   and Go/NoGo factors [F (1, 73) = 3.21, p = 0.08, $\eta^2{}_p$ = 0.04]. The two-way interaction between

334   valence and arousal reached significance [F (2, 146) = 18.55, p < 0.001, $\eta^2{}_p$ = 0.20]. However, the

335   two-way interaction between valence and Go/NoGo [F (2, 146) = 2.34, p = 0.10, $\eta^2{}_p$ = 0.03] and

336   that between arousal and Go/NoGo [F (1, 73) = 0.75, p = 0.39, $\eta^2{}_p$ = 0.01], together with the three-

337 way interaction among all factors [F (2, 146) = 2.84, p = 0.06, η^2_p = 0.04], did not reach

338 significance. To assess the valence effect on different arousal levels, we performed two one-way

339 ANOVAs as a function of valence at the high and medium arousal levels. Specifically, at the

340 medium arousal level, the main effect of valence reached significance [F (2, 146) = 4.41, p = 0.01,

341 η^2_p = 0.06]. *Post hoc* tests with Bonferroni correction indicated that the P3 amplitudes for the

342 positive valence (2.81 ± 2.71 µV; p = 0.04, *Cohen's d* = 0.30) and neutral valence (2.81 ± 3.03

343 µV; p = 0.03, *Cohen's d* = 0.31) conditions were more positive than those for the negative valence

344 condition (2.53 ± 2.87 µV), and the difference between the positive and neutral valence conditions

345 did not reach significance (p = 1.00, *Cohen's d* = 0.003). At the high arousal level, the main effect

346 of valence reached significance [F (2, 146) = 18.43, p < 0.001, η^2_p = 0.20]. *Post hoc* tests with

347 Bonferroni correction indicated that the P3 amplitude for the negative valence condition (3.11 ±

348 2.87 µV) was more positive than that for the neutral valence (2.77 ± 2.72 µV; p = 0.004, *Cohen's*

349 *d* = 0.38) and positive valence (2.52 ± 2.77 µV; p < 0.001, *Cohen's d* = 0.70) conditions. Moreover,

350 the P3 amplitude for the neutral valence condition was more positive than that for the positive

351 valence condition (p = 0.03, *Cohen's d* = 0.32).

352   [Please insert Figure 4 about here]

353 **4 Discussion**

354 **4.1 Overview of the study**

355   This study investigated whether different arousal levels (medium versus high) could

356 modulate the motor interference effect from dangerous objects. The design adopted a motor

357 priming paradigm mixed with a Go/NoGo task, which was consistent with Liu et al. (2017), and

358 further manipulated the valence and arousal of target stimuli referred to Zsido et al. (2020b). The

359 target stimuli were selected from the IAPS with a yellow capital letter "M" or "W" superimposed

360   on them as a Go or NoGo signal. Participants were instructed to prepare the ipsilateral hand

361   responses that corresponded to the handedness of the prime and to decide to execute the prepared

362   responses or not according to the Go/NoGo signals.

363   The hypotheses proposed a modulation effect of different arousal levels on valence factor.

364   Specifically, the motor interference effect should emerge at the medium arousal level with the

365   responses in the negative valence condition executing slower than those in the neutral and positive

366   valence conditions. In contrast, at the high arousal level, the strength of the motor interference

367   effect should increase compared with the medium arousal level. The ERP results predicted more

368   positive P3 amplitudes in the negative valence condition than in the neutral and positive valence

369   conditions at the medium arousal level. Moreover, the differences in the P3 amplitudes between

370   the negative and neutral valence conditions and those between the negative and positive valence

371   conditions should be larger at the high arousal level than the medium arousal level.

372   The behavioral results of RTs revealed a significant motor interference effect with longer

373   RTs for the negative valence condition than for the neutral and positive valence conditions at the

374   medium arousal level. The results supported the hypothesis that the motor interference effect

375   originated from negative valence rather than the emotional attribute (either negative or positive

376   valence) of the target stimuli. Specifically, only negative background stimuli could distract

377   attention from the main Go/NoGo task at the medium arousal level. At the high arousal level, a

378   significant motor interference effect was also observed with longer RTs for the negative valence

379   condition than for the neutral valence condition. Moreover, the effect size (mean RTs of the

380   negative valence condition minus that of the neutral valence condition) was examined by the two-

381   way interaction between valence (negative versus neutral) and arousal (medium versus high) in

382   Go trials. The results revealed a significant two-way interaction [F (1, 73) = 20.50, p < 0.001, η^2_p

383   = 0.22], which supports the hypothesis that the effect size of the motor interference effect at the

384   high arousal level (19 ms) is significantly larger than that at the medium arousal level (8 ms). The

385   results support the hypothesis that high arousal stimuli distract many attentional resources from

386   processing the background targets, which may enhance threatening details implied in the negative

387   valence targets. Responses are interfered more strongly in the negative valence condition at the

388   high arousal level than the medium arousal level. However, the difference in RTs between the

389   negative and positive valence conditions did not reach significance, which violates the hypothesis

390   and might suggest that both the negative and positive background stimuli distract attention from

391   the Go/NoGo signals at the high arousal level. The violation of the hypothesis was discussed

392   together with the ERP results in the following paragraphs.

393   The ERP results present a deeper investigation of the motor interference effect. At the high

394   arousal level, more positive P3 amplitudes emerged in the negative valence condition than the

395   neutral valence condition. As the centroparietal P3 amplitude reflects attentional resource

396   allocation (Isreal et al., 1980), the results support the hypothesis that many attentional resources

397   are assigned to the negative valence condition. Because responding to the Go/NoGo signal is a

398   simple task, remnant attentional resources could be allocated to the background stimuli. This

399   would enhance the processing of the threatening details implied in the negative valence targets,

400   enabling the more dangerous targets. As a more negative valence stimulus may elicit a deeper

401   activation of the aversive motivational system (Lang et al., 1990, 2000), the strength of the motor

402   interference effect could be increased. However, at the medium arousal level, less positive P3

403   amplitudes emerged in the negative valence condition than the neutral valence condition.

404   Assuming that consistent attentional resources are consumed by the Go/NoGo signals, fewer

405   attentional resources could be allocated to the negative valence background stimuli at the medium

406   arousal level than those at the high arousal level, enabling the negative valence targets to be less

407   dangerous; thus, the strength of the motor interference effect could be decreased.

408   The positive valence was included in the experimental design to exclude an alternative

409   explanation of whether the motor interference effect originates from the emotionality of the

410   background stimuli. Similar result patterns were expected between the positive and negative

411   valence conditions according to this hypothesis. Although identical RTs were observed between

412   the negative and positive valence conditions at the high arousal level, the P3 amplitudes

413   significantly differed. The ERP results indicated that fewer attentional resources were assigned to

414   the positive valence stimuli than to the negative valence stimuli at the high arousal level. A possible

415   reason was proposed based on the valence-arousal conflict theory (Feng et al., 2012; Robinson et

416   al., 2004). The theory suggested that negative valence stimuli evoke the aversive motivational

417   system at a high arousal level. Additionally, subjects might have been more sensitive to the

418   negative valence than the positive valence stimuli, which decreased the P3 amplitude of the

419   positive valence condition. Moreover, the positive valence stimuli force subjects to approach the

420   stimuli (Feng et al., 2012; Robinson et al., 2004). Thus, a conflict exists between high arousal

421   elicited aversive motivation and positive valence evoked approach motivation, which might delay

422   the responses to the positive valence stimuli at the high arousal level. The explanation was also

423   supported by the results at the medium arousal level. According to the valence-arousal conflict

424   theory, the appetitive motivational system will gradually replace the aversive motivational system

425   to dominate emotional cognitive processing along with lower arousal levels. Subjects might be

426   more sensitive to the positive valence than the negative valence stimuli, which increased the P3

427   amplitude of the positive valence condition at the medium arousal level. When the motivational

428   tendency is congruent between appetitive motivation elicited by medium arousal and approach

429 motivation evoked by positive valence, responses to the positive valence stimuli are accelerated

430 and become close to the neutral valence stimuli at a medium arousal level because the conflict

431 diminishes in the positive valence and medium arousal condition.

432   The valence-arousal conflict theory could also provide an alternative explanation to the

433 delayed responses and the less positive P3 amplitudes in the negative valence condition compared

434 with those in the neutral valence condition at the medium arousal level. As the appetitive

435 motivational system gradually replaces the aversive motivational system along with lower arousal

436 levels, subjects might be less sensitive to the negative valence stimuli than the neutral and positive

437 valence stimuli, which decreased the P3 amplitude of the negative valence condition at the medium

438 arousal level. Moreover, the motivational tendency is incongruent between appetitive motivation

439 elicited by medium arousal and aversive motivation evoked by negative valence, which might

440 delay the responses to the negative valence stimuli at the medium arousal level. The validation of

441 this alternative explanation requires further investigation.

442   Note that error rates are not discussed because 1) they are insensitive to the variations of

443 valence and arousal levels. Few errors are made in the simple Go/NoGo task (the mean error rates

444 for each condition were less than 1.72 %), which may have caused a ceiling effect; and 2) analyses

445 of the error rates showed only small to medium effect sizes, which might signal false-positive

446 results.

447 **4.2 Relationship between the current study and the study by Liu et al. (2017)**

448   The current study was conducted to clarify whether different arousal levels (medium versus

449 high) could modulate the motor interference effect. We hypothesized that arousal levels could

450 modulate valence effect on the behavioral and ERP results. The results revealed a larger motor

451 interference effect at the high arousal level than that at the medium arousal level. Moreover, the

452 centroparietal P3 amplitudes were more positive in the negative valence condition than the neutral

453 valence condition at the high arousal level. Nevertheless, the results of the centroparietal P3

454 amplitudes were reversed at the medium arousal level. The results expand on those obtained by

455 Liu et al. (2017) by demonstrating that the more positive parietal P3 amplitudes in the dangerous

456 condition than those in the safe condition likely emerged because the dangerous targets not only

457 activated an aversive motivational system (elicited by a negative valence level) but also enhanced

458 the strength of the activation by their high arousal attributes. Only in this manner could the parietal

459 P3 amplitudes be more positive in the dangerous condition than the safe condition in the study by

460 Liu et al. (2017).

461   Analysis of the centroparietal P3 amplitudes did not reveal significant interactions with the

462 Go/NoGo factor. The results suggest that valence and arousal information is processed regardless

463 of whether the prepared responses were executed (Go trials) or not (NoGo trials). The results are

464 inconsistent with those of Liu et al. (2017), who found a significant dangerous effect (i.e., a more

465 positive parietal P3 amplitude in dangerous conditions than in safe conditions) only when the

466 prepared responses were executed (Go trials). In the NoGo trials, the dangerous effect diminished.

467 The reasons for the different results between the two studies might be due to different perceptual

468 attributes of the background stimuli. Specifically, the colorful animal pictures adopted in the

469 current study are perceptually richer than the gray modern pictures adopted by Liu et al. (2017).

470 The former pictures might reflect possible experiences in daily life, which enables subjects to be

471 more sensitive to the valence and arousal information of the background picture in both the Go

472 and NoGo trials.

473 **4.3 Difference between the study by Zsido et al. (2020b) and the current study**

474   The current study manipulated valence and arousal factors in accordance with the study by

475   Zsido et al. (2020b), identical result patterns were observed at the medium arousal level that

476   responses were delayed when facing a negative valence compared with a neutral valence

477   background stimulus. However, the results differed at the high arousal level. The enlarged RT

478   differnece between the negative and neutral valence conditions at the high arousal level, observed

479   in the current study, however diminished in Zisdo et al. (2020b). The reason for the discrepancy

480   might attribute to the different difficulties of the main task. Specifically, searching for numbers in

481   a matrix required more attentional resources compared with the Go/NoGo task. Increased

482   attentional resources elicited by the high arousal background stimuli could be assigned to the

483   searching numbers task in priority, which improved performance on the main task. In contrast,

484   discriminating the Go/NoGo signals only required a few attentional resources, and the remaining

485   resources could be assigned to the background stimuli, which enhanced the processing of

486   threatening details implied in the negative valence stimuli. Thus, the motor interference effect was

487   enhanced at the high arousal level in the current study.

488   **4.4 Limitations**

489   Although the difference in the arousal scores between the medium (mean = 4.67) and high

490   arousal (mean = 5.68) levels reached significance, the difference was relatively small compared

491   with that in Zsido et al. (2020b) because the arousal levels were matched among negative, neutral

492   and positive valences in the animal category of the background stimuli. The results revealed a

493   significant modulation effect of the arousal factor, which verified the effectiveness of the

494   manipulation in distinguishing the medium and high arousal levels. However, we believe that the

495   arousal effect could be more salient if the design increased the difference between the medium and

496   high arousal level. This is a limitation of the current study and should be avoided in further

497   research.

498   **5 Conclusion**

499   In summary, the current study investigated whether the arousal of target stimuli could

500   modulate the motor interference effect. The behavioral results revealed a significant motor

501   interference effect (mean RTs in the negative valence condition minus those in the neutral valence

502   condition) at the medium arousal level, and the effect size increased at the high arousal level. The

503   results support the hypothesis that the motor interference effect could be modulated by different

504   arousal levels of the stimuli with an increment of the motor interference effect along with a higher

505   arousal level. The results indicate that negative valence stimuli may interfere with the prime

506   elicited motor preparation more strongly at the high arousal level than at the medium arousal level.

507   The underlying cognitive processes are reflected by the results of the centroparietal P3 amplitudes,

508   which indicate that the effect size of the motor interference effect increased because subjects are

509   more sensitive to the negative valence stimuli at the high arousal level than at the medium arousal

510   level, and the activation of the aversive motivational system increased with increasing arousal

511   level. Furthermore, the motor interference effect is related to the negative valence rather than

512   emotionality of the target stimuli because different result patterns emerged between the positive

513   and negative valence conditions. We attempt to relate the findings of the current study to safety

514   management; specifically, increasing the arousal of dangerous stimuli could activate the aversive

515   motivational system. Workers may be more sensitive to dangerous elements in machines when

516   these elements are presented at a high arousal level (e.g., painting bold colors on dangerous

517   elements). Thus, dangerous elements inducing a high state of arousal may increase the motor

518   interference effect, which in turn reduces work-related accidents because responses to dangerous

519   elements have been inhibited.

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Figure 1

Topographic plots of the P3 components.

Grand-average topographic plots were calculated based on the mean amplitude in the 300- to 500-ms time window for the Go trials and in the 400- to 600-ms time window for the NoGo trials as a function of valence (negative, positive and neutral) and arousal (medium and high).

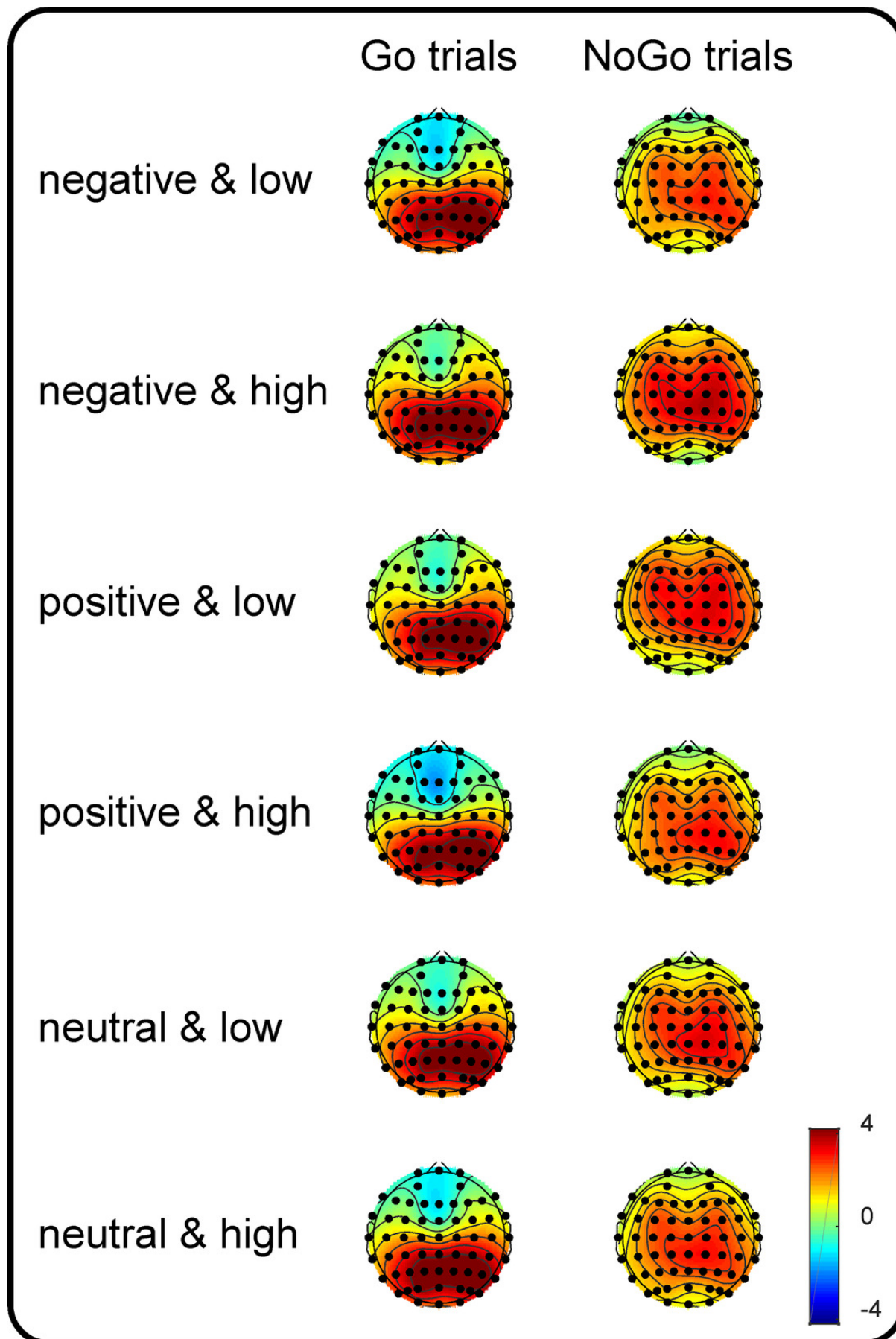



Figure 2

Results of the reaction times.

The figure presents the mean reaction times as a function of valence (negative, positive and neutral) and arousal (medium and high) in Go trials.

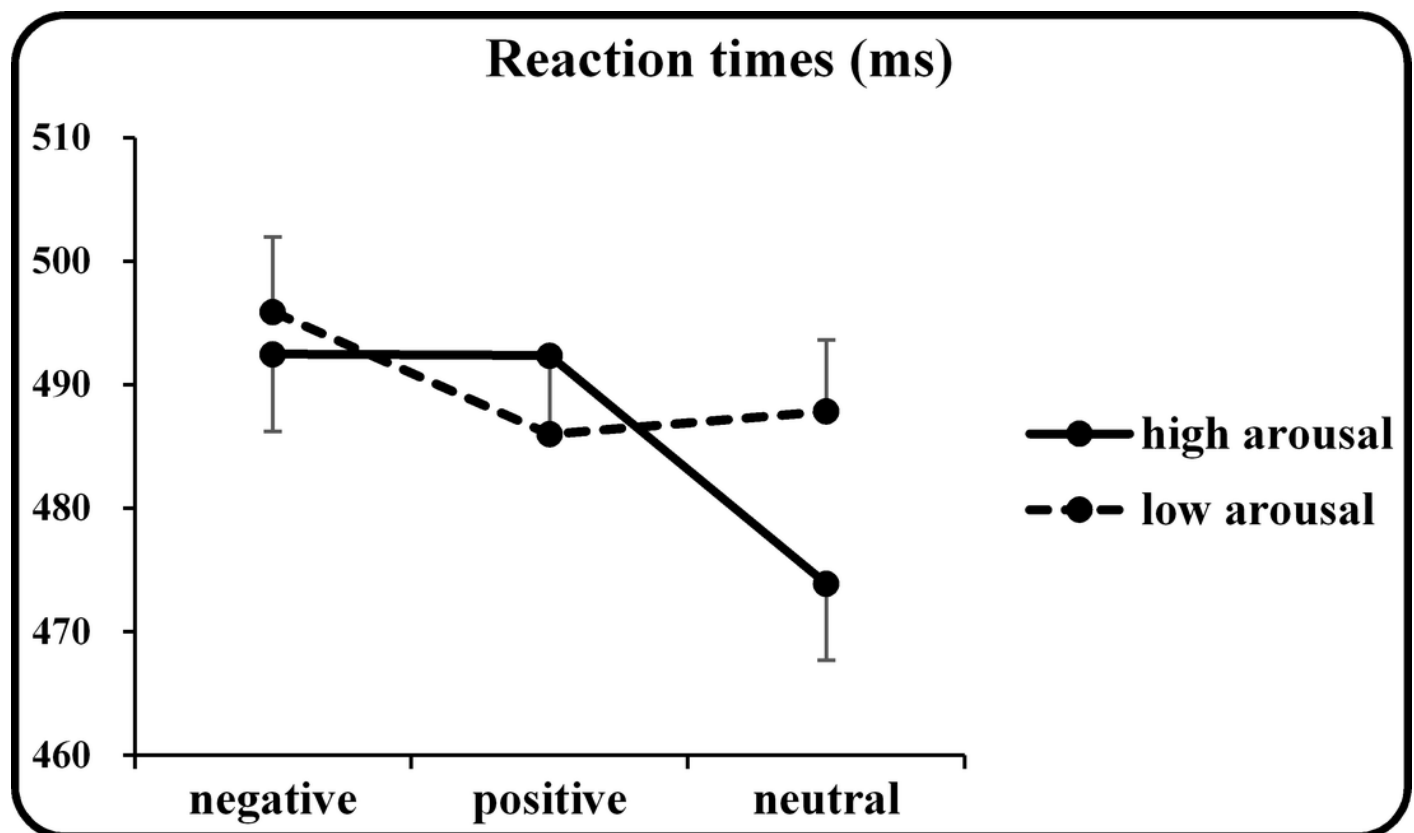



Figure 3

Results of the error rates.

The figure presents the mean error rates as a function of valence (negative, positive and neutral), arousal (medium and high) and Go/NoGo factor (Go and NoGo).

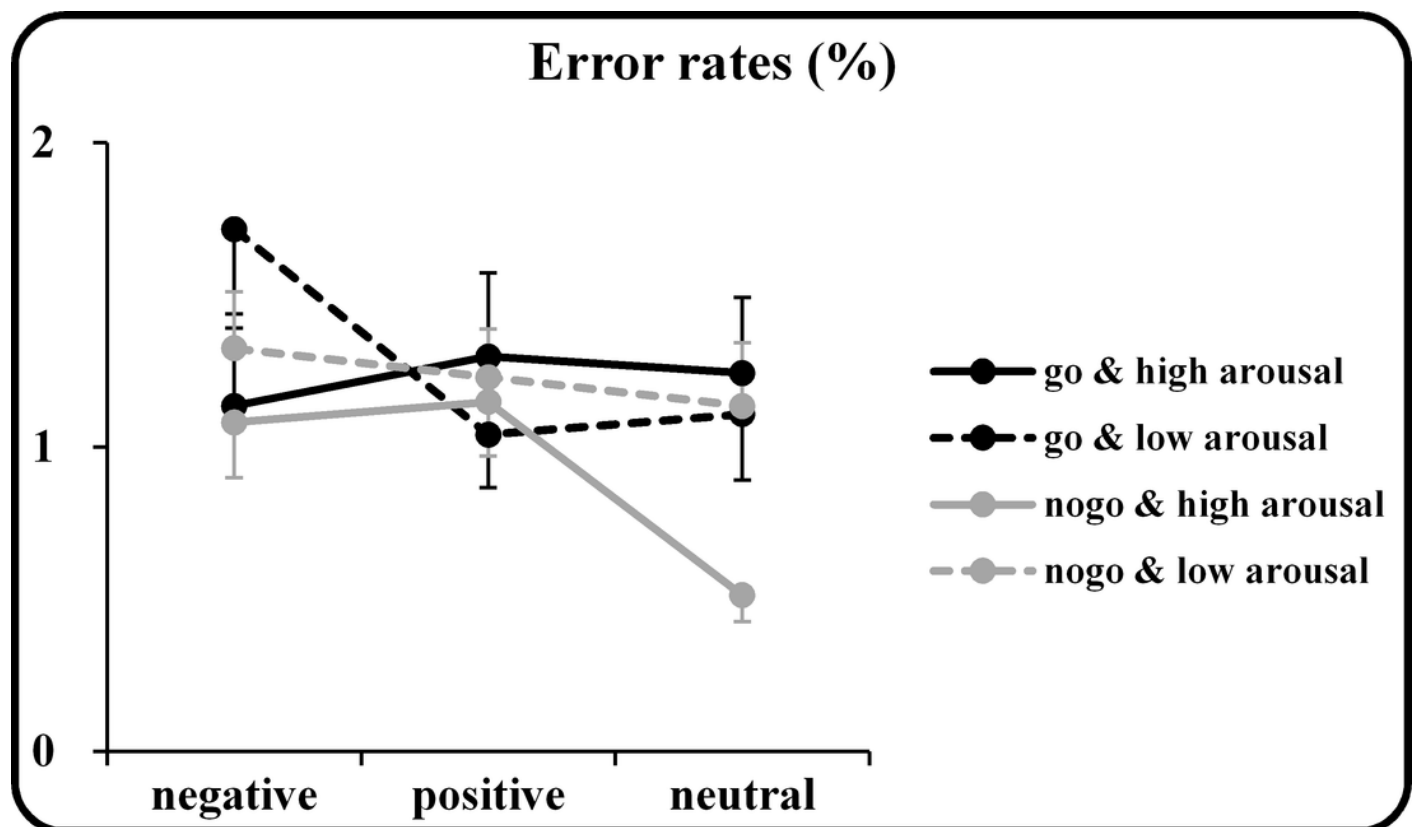
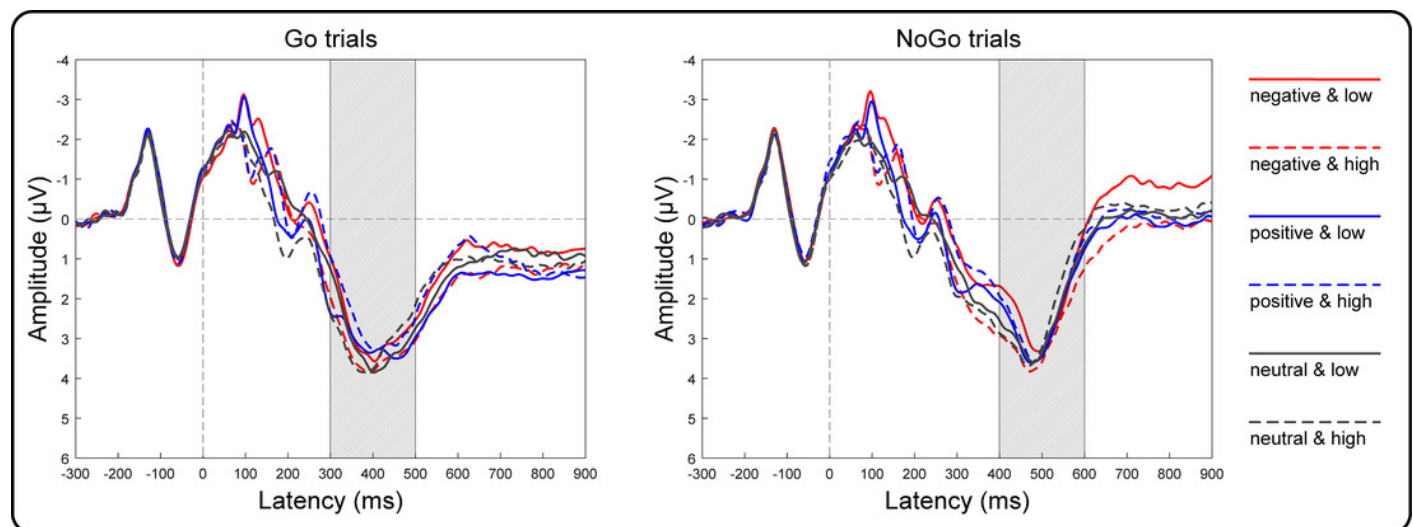



Figure 4

Grand-average target-locked ERPs of the P3 components.

Grand-average target-locked ERPs for Go and NoGo trials were separately presented as a function of valence (negative, positive and neutral) and arousal (medium and high) at the centroparietal area (the average of the C5, C3, C1, Cz, C2, C4, C6, CP5, CP3, CP1, CPz, CP2, CP4, CP6, P5, P3, P1, Pz, P2, P4 and P6 electrodes). The rectangles filled with oblique lines indicate the analyzed time windows for the P3 amplitudes.

IAPS codes for target pictures in each valence and arousal level.

	Negative valence	Neutral valence	Positive valence
Low arousal	1230 (Spider)	1121 (Lizard)	1463 (Kittens)
	1270 (Roach)	1313 (Frog)	1540 (Cat)
	1275 (Roaches)	1947 (Octopus)	1590 (Horse)
High arousal	1019 (Snake)	1560 (Hawk)	1650 (Jaguar)
	1205 (Spider)	1640 (Coyote)	1710 (Puppies)
	1301 (Dog)	1726 (Tiger)	1720 (Lion)

Means and standard deviations of valence and arousal scores as a function of valence and arousal. The raw scores are derived from Table 1 in Lang et al. (2005).

	Negative valence		Neutral valence		Positive valence	
	valence scores	arousal scores	valence scores	arousal scores	valence scores	arousal scores
Low arousal	3.69 (0.40)	4.81 (0.04)	5.76 (0.10)	4.52 (0.27)	7.26 (0.17)	4.69 (0.13)
High arousal	3.77 (0.16)	5.78 (0.01)	5.68 (0.78)	5.62 (0.56)	7.26 (0.94)	5.65 (0.50)