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**Affective priming enhances gaze cueing effect**

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1 **Abstract**

2 Other's gaze direction triggers a reflexive shift of attention known as the gaze cueing  
3 effect. Fearful facial expressions are further reported to enhance the gaze cueing effect,  
4 but it remains unclear whether this facilitative effect is specific to gaze cues or the result  
5 of more general increase in attentional resources due to affective arousal.

6 We examined the effects of affective priming on the cueing effects of gaze and arrow  
7 stimuli in the Posner cueing task. Participants were primed with two types of briefly  
8 presented affective stimuli (neutral, threatening), and the target location was cued  
9 either by an arrow or a gaze cue in a neutral face. Gaze cues were preceded by the same  
10 face with its eyes closed or directed to the viewer. Study 1 (n = 26) assessed the cueing  
11 effect using manual key press, and Study 2 (n = 30) employed gaze-contingent eye  
12 tracking techniques to assess the cueing effect using time to first fixate the cued target  
13 location. Both studies found that threatening priming significantly enhanced the cueing  
14 effects of eye gaze but not arrow stimuli. The results therefore suggest that affective  
15 priming does not facilitate general attentional orienting, but the facilitation is more  
16 specific to social cues such as eye gaze.

17 Key words: Gaze cueing; Eye contact; Affective priming; Posner cueing task

18

19 **Public significance statement**

20 Gaze cueing has been one of the major topics in experimental psychology. However,  
21 only a limited number of studies have been reported on the affective mechanisms  
22 which could influence this social phenomenon. Our empirical studies provide a  
23 convincing case that affective priming selectively facilitates attentional orienting to  
24 social cues such as eye gaze, contributing theoretical advances of researches in social  
25 attention and cognition.

26

27 **Introduction**

28 Direction of eye gaze is a crucial signal for human social interaction and  
29 communication, and can be used to infer mental states such as attention, perception, and  
30 intention (Frith & Frith, 2007). Several studies have found that humans shift their  
31 attention in response to another person's gaze direction, even when eye gaze direction is  
32 not informative or when participants were instructed to ignore or attend to the opposite  
33 direction of eye gaze (Driver et al., 1999; Friesen & Kingstone, 1998, 2003; Friesen et al.,  
34 2004; Hietanen, 1999; Kingstone et al., 2000; Ristic et al., 2002). This demonstrates that  
35 the shift of attention toward the direction of another person's gaze (i.e., the gaze cueing  
36 effect) may be reflexive.

37           As Frischen et al. (2007) summarised, previous studies have reported that facial  
38 cues, such as facial expressions depicted in the stimuli, can modulate the gaze cueing  
39 effect in humans. For instance, compared to neutral faces, the gaze cueing effect was  
40 larger for fearful but not happy faces suggesting fearful facial expressions can enhance  
41 attentional orienting in response to eye gaze (Tipples, 2006; Mathews et al., 2003).  
42 Pecchinenda et al. (2008) examined gaze cueing effects for disgusted, fearful, happy, and  
43 neutral faces. They showed that negative facial expressions (disgusted and fearful) have  
44 stronger cueing effects than happy or neutral faces when participants  
45 performed/engaged in affective judgments during the task. Kuhn and Tipples (2011)  
46 found identical levels of cueing effects between fearful and happy faces when searching  
47 for a pleasant target. When searching for a threatening target, the gaze cueing effect  
48 was stronger for fearful faces than happy faces.  
49 Thus, it was suggested that contextual factors such as the target item affect the influence  
50 of facial expressions on gaze cueing effects. From a theoretical perspective, Mathews et  
51 al. (2003) argued that an enhanced gaze cueing effect followed by a presentation of  
52 fearful expression may provide a significant advantage to an individual. Specifically, the  
53 combination of averted gaze and a fearful facial expression may facilitate orienting to  
54 the source of a potential threat, which requires immediate detection for one's safety.

55 It is widely known that animals automatically respond to a threatening stimulus  
56 (e.g., fight or flight response; Roelofs, 2017). Aston-Jones et al. (1999) proposed that  
57 animals tend to be more responsive and sensitive to changes in external stimuli, with  
58 high levels of arousal in threatening situations. Relatedly, it has been proposed that the  
59 attentional state can be regulated by changes in physiological arousal (Reynolds et al.,  
60 2013). For instance, heart rate response, which is an index of arousal state, is associated  
61 with the participants' looking durations on the stimuli (Courage et al., 2006).

62 Perception of fearful faces could induce an emotional experience of fear (Hariri &  
63 Holmes, 2006; Hariri et al., 2002; Lau et al., 2009; Pine et al., 2005), as well as the  
64 perception of threat (Mogg et al., 2007; Stein et al., 2009). For example, several  
65 neuroimaging studies demonstrated that perception of fearful faces activates the  
66 amygdala, a subcortical structure that plays a vital role in experiencing fear  
67 (Felmingham et al., 2010; Hariri & Holmes, 2006; Hariri et al., 2002). Since the  
68 amygdala is involved in physiological arousal (Adolphs, 2003; Pfaff et al., 2008) and  
69 individuals experiencing a fearful emotional state exhibit high levels of arousal (Globisch  
70 et al., 1999), these studies support the view that perception of fearful expression induces  
71 heightened arousal, possibly as a result of the induced experience of fear. Thus,  
72 modulation of fearful expressions on gaze cueing may be mediated by high levels of

73 arousal induced by the threatening stimuli.

74 Previous studies compared the cueing effects between gaze and arrow cues. Overall,  
75 studies often show identical levels of cueing effects (Tipples, 2002; Kuhn & Kingstone,  
76 2009). On the other hand, some studies found increased difficulties in inhibiting gaze  
77 cues compared to arrow cues (Friesen et al., 2004), suggesting functional differences  
78 between gaze cues and arrow cues. Functional differences between gaze and arrow cues  
79 may be due to differences in social significance. It has been argued that directional cues  
80 with social significance may drive the modulation of reflexive shifts in spatial attention  
81 (Kingstone et al., 2003). Gaze cues would have more social significance than arrow cues,  
82 thus it may be difficult to inhibit gaze cues compared to arrow cues. Also, if the social  
83 significance of cues affected reflexive shifts in spatial attention, gaze cues preceded by  
84 direct gaze might have stronger cueing effects than gaze cues preceded by closed eyes.  
85 Direct gaze is one of the most important signals to engage communicative partners  
86 (Senju & Johnson, 2009). Neurophysiological studies have shown that direct gaze  
87 increased amygdala activation and physiological arousal, suggesting direct gaze  
88 modulates attentional states (Adolphs, 2009; Helminen et al. 2011). It has been argued  
89 that gaze direction preceded by direct gaze modulates neurophysiological state because  
90 other's gaze direction will play a critical role in the detection of potential threat sources

91 in social situations (Richeson et al., 2008). Gaze cues preceded by direct gaze would have  
92 more social significance than gaze cues preceded by closed eyes.

93 In previous studies on gaze cueing, the use of affective stimuli was limited to facial  
94 expressions, which makes it impossible to dissociate whether the effect is a response to  
95 the communicative signal conveyed by fearful facial expressions or due to general  
96 affective arousal induced by the fearful faces. Moreover, it is not clear whether the  
97 influence of affective stimuli is general to attentional orienting, or specific to social  
98 attention such as gaze cueing. To address this issue, we used non-facial threatening  
99 stimuli, which can elicit affective responses in both central and autonomic nervous  
100 systems consistent with fear arousal even when the stimuli are presented subliminally  
101 (Hedger et al., 2015). For example, subliminal threatening stimuli increase amygdala  
102 activity (Morris et al., 1999) and autonomic skin conductance responses (Esteves et al.,  
103 1994) even in the absence of awareness of the stimuli. The use of brief presentation of  
104 (non-facial) threatening stimuli as affective priming allows us to compare the effect of  
105 affective priming on eye gaze cueing, as well as attentional cueing for non-social  
106 directional cues such as an arrowhead.

107 In the current study, we introduced three types of cueing stimuli (arrow, eye gaze  
108 followed by closed eyes, or eye gaze followed by direct gaze) that were presented after a



109 brief presentation of affective priming images (neutral or threatening). There were two  
110 conditions of cue validity with the same probability (valid, *i.e.* the target appeared in the  
111 cued location, or invalid, *i.e.* the target appeared in the direction opposite to the cue) to  
112 examine cueing effects of eye gaze and arrow stimuli in a Posner cueing task. In this  
113 task, spatial cueing facilitates stimulus detection at the cued location relative to uncued  
114 locations (Posner, 1980). There were three alternative hypotheses. Firstly, if affective  
115 priming influences general attentional orienting in the cueing task, it is predicted that  
116 affective priming will shorten response time irrespective of the validity or social nature  
117 of cue. As Aston-Jones et al. (1999) suggested, participants will be sensitive and  
118 responsive to external stimulus change and show rapid response to the target regardless  
119 of cueing direction, if they have high levels of arousal after threatening priming. Secondly,  
120 if affective priming increases attention for socially relevant cues only, it is predicted that  
121 response times will be shorter for congruent gaze cues only, and longer for incongruent  
122 gaze cues due to the increased difficulty of shifting away from the gaze cue. Finally,  
123 according to the threat-related hypothesis, only gaze cues followed by direct gaze will  
124 result in decreased response times for congruent gaze cues and increased response times  
125 for incongruent gaze cues. As Mathews et al. (2003) suggested, gaze direction of another  
126 person can be an important source of threat perception. Also, some studies have

127 suggested that eye contact directly activates arousal systems in the brain including  
128 amygdala (Hood et al., 2003; Adolphs, 2009), and direct gaze plays a critical role in the  
129 detection of potential threat sources (Richeson et al., 2008). It was predicted that cueing  
130 effects would be larger when the gaze cue was following a period of direct gaze compared  
131 to closed eyes.

## 132 **Study 1**

### 133 **Method**

#### 134 **Participants**

135 A total of 26 adults (of which 12 were female) participated in Study 1. The experiment  
136 was conducted in Japan. The mean age was 22.0 years (range: 19–29 years, Standard  
137 Deviation (SD) = 2.68 years). We estimated the required sample size as follows. The main  
138 effects of cue validity for gaze and arrow cues in a similar study by Blai et al. (2017) had  
139 effect sizes of  $\eta_p^2 = .53$ . To obtain a desired statistical power of .90 for main effects, with  
140 an alpha value of .05, a minimum sample size of 12 individuals was required. Another  
141 study examined affective priming effects during a Stroop task with 14 adult participants  
142 with sufficient effect sizes of affective priming ( $\eta_p^2 = .95$ ; Hart et al., 2010). We recruited  
143 a larger number of participants than estimated from power analysis to account for  
144 possible inflation of effect sizes due to a small number of participants included in some

145 of the previous studies. Using the effect size from the current study ( $\eta^2 = .226$ ), we  
146 conducted a *post-hoc* power analysis with G\*Power (Erdfelder et al., 1996). The result  
147 indicated that with the present sample we have achieved above 95% power with alpha  
148 at .05 to find three-way interaction between affective priming, type of cueing sequence,  
149 and validity. All participants had normal or corrected-to-normal vision. The  
150 experimental protocol was approved by the Research Ethics Review Board of the  
151 Department of Psychology, Kyoto University, Kyoto, Japan. The participants provided  
152 written informed consent before they participated in this study.

153

#### 154 **Apparatus**

155 The experiment was performed using PsychoPy 1.90.1 (Peirce, 2007) on an EPSON  
156 Endeavor MR-8000 PC with a BenQ GW2470H 23.8-inch LCD monitor (60 Hz refresh  
157 rate). The participants were seated at a distance of approximately 60 cm from the  
158 monitor. Reaction times (RT) and accuracy were measured on the basis of their keyboard  
159 responses.

#### 160 **Stimuli**

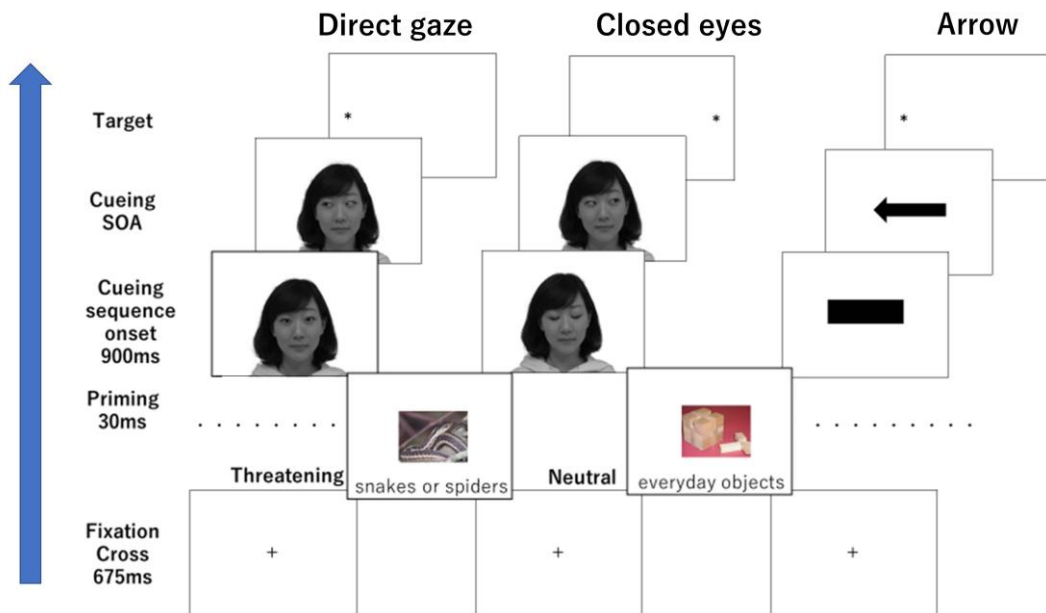
161 All trials were preceded by a fixation cross placed at the screen center (about 3°). For  
162 the affective priming stimuli, threatening (36 snakes, 36 spiders) and neutral stimuli (72

163 everyday objects) were selected from the Geneva Affective PicturE Database (GAPED)  
164 (Dan-Glauser & Scherer, 2011), which is available for use in non-commercial research  
165 projects. The GAPED has been employed previously for a subliminal visual priming  
166 study (Maureira et al., 2015), and priming stimuli were presented in the center of the  
167 screen (6° in height and 8° in width).

168 For the facial stimuli, we used images of two different adult female faces. In a pilot  
169 study, these female faces were perceived to be equally attractive. Gaze cues were  
170 preceded by the same face with its eyes closed (eyes closed condition) or directed (direct  
171 gaze condition) to the viewer. For the cueing stimuli, the faces were presented with eyes  
172 gazing either at the left or right side. All faces were presented in greyscale and measured  
173 approximately 16° in height and 10° in width.

174 The arrow cueing stimulus was preceded by a black horizontal line (arrow condition).  
175 The arrow cues were black arrows that pointed to the left or right, and measured about  
176 3° in height and 9° in width.

177 The target stimulus, presented after the cueing stimuli, was an asterisk  
178 (approximately 1° ) positioned on the left or right side of the screen at 15° eccentricity  
179 from the fixation point.



180

181 Figure 1. Sequence of events for each of the three cueing sequence conditions (*Direct*

182 *gaze, Closed eyes, Arrow*) SOA: stimulus onset asynchrony

183

184 **Procedure**

185 The experiment consisted of three types of cueing sequence: arrow cueing preceded by

186 a black horizontal line (arrow condition), gaze cueing preceded by closed eyes (closed eyes

187 condition), and gaze cueing preceded by direct gaze (direct gaze condition). A task

188 consisted of four practice trials (without affective priming) followed by 144 experimental

189 trials. The number of trials was selected to retain the effects of affective priming (72

190 trials with affective priming and 72 trials with neutral priming), as it has been shown

191 that repeated subliminal exposure to affective stimuli leads to habituation in 72 trials

192 (Dijksterhuis & Smith, 2002), which could reduce effect sizes with a larger number of  
193 trials. Three within-participant factors were fully crossed in the experiment: affective  
194 priming (threatening, neutral), type of cueing sequence (arrow, closed eyes, direct gaze),  
195 and cue validity (valid, invalid). All combinations of stimuli were presented in a random  
196 order and with equal probability.

197 In each trial, a fixation cross was centrally displayed for 675 ms, followed by an  
198 affective priming stimulus presented for 30 ms (see Figure 1). The presentation time was  
199 decided so that the visual stimulus cannot reach visual consciousness. In previous  
200 studies, physiological and behavioural threat responses were observed with ~30 ms  
201 presentation durations, and it has been suggested that these responses are concomitants  
202 of “unconscious” processing (Carlson et al., 2009; Morris et al., 1999). After the affective  
203 priming image (threatening or neutral), a cueing sequence (arrow, closed eyes, or direct  
204 gaze) was started and a black horizontal line, closed eyes, or direct gaze was presented  
205 for 900 ms, followed by a cueing stimulus (arrow or eye gaze) pointing either to the right  
206 or to the left, presented for either 100, 300, or 700 ms. It was emphasized during the  
207 instruction that the direction of the cueing stimuli was not relevant to the target position.  
208 The target was presented immediately after the offset of the cueing stimuli. Participants  
209 were required to press, as quickly as possible, the “Z” key when the target appeared on

210 the left and the “M” key when the target appeared on the right. The target was displayed  
211 until the participant responded. After recording the participants’ responses, they were  
212 given feedback, which was displayed for 500 ms (“O” represented a correct response, and  
213 “X” represented an incorrect response).

## 214 **Data Analysis**

215 The mean accuracy was 99.65% (SD = 0.56). There were only 12 trials with incorrect  
216 responses, so these were excluded from the analyses. Since the number of incorrect  
217 responses was so small, we did not compare accuracy across conditions. Furthermore,  
218 almost all participants responded correctly in all the trials. RTs above and below 2.5 SDs  
219 from the individual mean for each condition were excluded, which was 1.6% of all trials.

220 For the analysis of response time, we used individual mean response times for each  
221 condition, affective priming (threatening, neutral), type of cueing sequence (arrow, closed  
222 eyes, direct gaze), and validity (valid, invalid) as independent variables. The values for  
223 skewness and kurtosis between -2 and +2 are considered acceptable to assume normal  
224 univariate distribution (George & Mallery, 2010). The distributions of RTs for each  
225 condition showed the skewness and kurtosis within the range of normal distribution  
226 (skewness range: 0.35 ~ 1.48; kurtosis range: -.881 ~ 1.94).

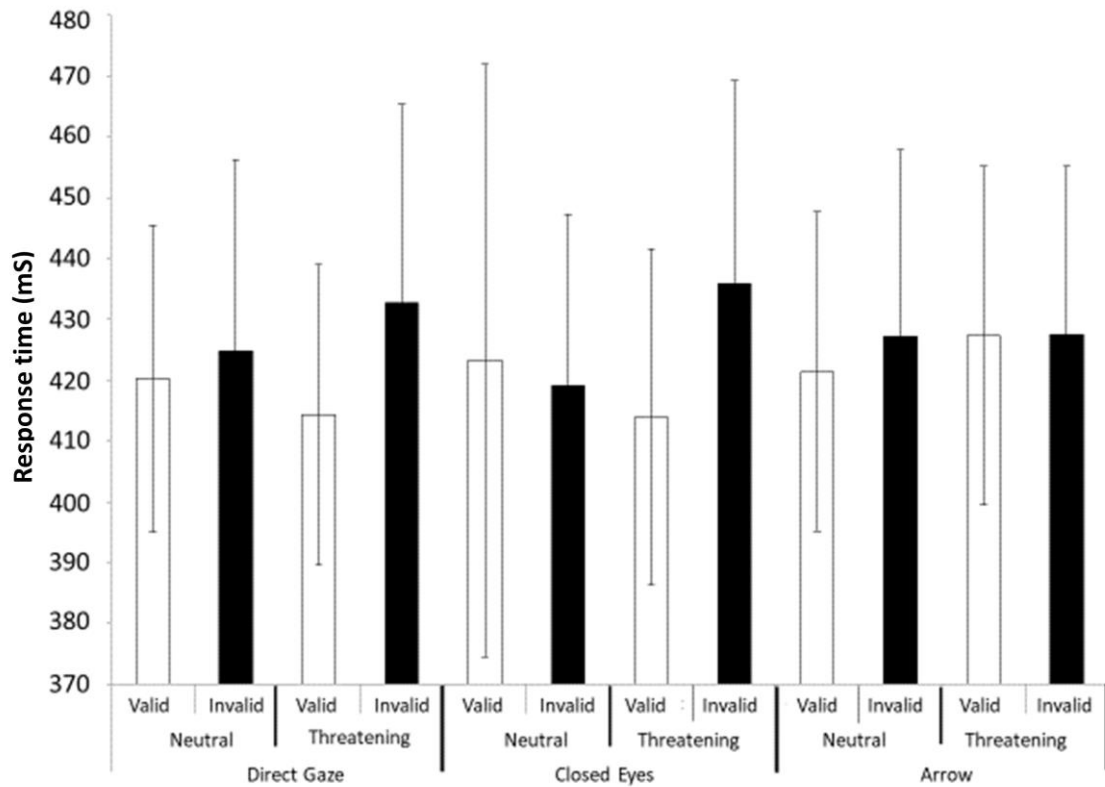
## 227 **Results**

228 Figure 2 shows the mean manual RTs in each condition.

229 An ANOVA revealed a significant three-way interaction between affective priming,  
230 type of cueing sequence, and validity ( $F(2, 50) = 3.506, p = .046, \eta_p^2 = .226$ ). No other  
231 interactions reached significance (validity  $\times$  cueing sequence:  $F(2, 50) = 1.422, p = .261,$   
232  $\eta_p^2 = .106$ ; priming  $\times$  cueing sequence:  $F(2, 50) = .1092, p = .352, \eta_p^2 = .083$ ; priming  $\times$   
233 validity:  $F(2, 50) = 0.337, p = .567, \eta_p^2 = .013$ ). There was a significant main effect of  
234 validity ( $F(1, 25) = 7.478, p = .011, \eta_p^2 = .230$ ; Valid mean RT = 414.28 ms vs. Invalid  
235 mean RT = 428.71 ms). No other main effects approached significance (priming:  $F(1, 25)$   
236  $= 3.286, p = .082, \eta_p^2 = .116$ ; Neutral mean RT = 418.86 ms vs. Threatening mean RT =  
237 424.13 ms; cueing sequence:  $F(2, 50) = 2.200, p = .133, \eta_p^2 = .155$ ; Direct gaze mean RT =  
238 421.14 ms, Closed eyes mean RT = 417.80 ms, Arrow mean RT = 425.56ms). To explore  
239 the three-way interaction more, a series of Bonferroni-corrected follow-up pairwise  
240 comparisons were performed.

241





242

243 Figure 2. Mean manual RTs as a function of cueing sequence (direct gaze, closed eyes,  
 244 and arrow), affective priming (neutral, threatening), and cue validity (valid, invalid).

245 Error bars show standard deviations.

246

247 Firstly, to examine how affective priming influenced attentional orienting, we  
 248 compared each priming condition across the conditions in the cueing sequence and  
 249 validity factors with Bonferroni-corrected post-hoc analyses. For valid cue trials,  
 250 threatening priming stimuli induced faster response times than neutral stimuli within  
 251 the direct gaze condition ( $p = .021$ ,  $\eta_p^2 = .196$ ). Similarly, for invalid cue trials,

252 threatening priming stimuli showed longer response times than neutral stimuli within  
253 the closed eyes condition ( $p = .012$ ,  $\eta_p^2 = .226$ ). There were no significant differences  
254 between neutral and threatening conditions within the arrow condition (valid:  $p = .106$ ,  
255  $\eta_p^2 = .101$ ; invalid:  $p = .945$ ,  $\eta_p^2 = .000$ ). Thus, affective priming with threatening stimuli  
256 affected attentional orienting only in the direct gaze and closed eyes conditions.

257 Secondly, another series of Bonferroni-corrected post-hoc analyses examined the  
258 simple main effect of cue validity within each condition of the affective priming and  
259 cueing sequence factors. For threatening priming stimuli, direct gaze and closed eyes  
260 conditions showed significant effects of validity (i.e. cueing effect) in the closed eyes ( $p$   
261  $= .002$ ,  $\eta_p^2 = .324$ ) and the direct gaze ( $p = .010$ ,  $\eta_p^2 = .235$ ) conditions, but not in the  
262 arrow condition ( $p = .663$ ,  $\eta_p^2 = .008$ ). By contrast, for neutral priming stimuli, the effect  
263 of validity was not significant in any of the cueing sequence conditions (closed eyes:  $p$   
264  $= .319$ ,  $\eta_p^2 = .040$ ; direct gaze:  $p = .190$ ,  $\eta_p^2 = .068$ ), although it is worth noting that arrow  
265 cueing showed a marginal, but still not significant, effect (arrow:  $p = .095$ ,  $\eta_p^2 = .107$ ).

266 Finally, we compared RTs for each cueing sequence condition across the conditions in  
267 the affective priming and validity factors, but this did not reach significance apart from  
268 the difference with shorter RTs in the closed eyes and direct gaze than arrow conditions  
269 for valid threatening priming stimuli (closed eyes:  $p = .012$ ; direct gaze:  $p = .011$ ).

270 **Comparing cueing effects**

271 To probe the effects of affective priming on cueing effects, we calculated the mean  
272 cueing effect (mean invalid RT minus mean valid RT) for each priming and cueing  
273 sequence, and conducted an ANOVA with affective priming and type of cueing  
274 sequence. There was a significant main effect of affective priming ( $F(1, 25) = 6.946$ ,  $p$   
275  $= .014$ ,  $\eta_p^2 = .217$ ; Neutral mean cueing effect = 6.273 ms vs. Threatening mean cueing  
276 effect = 16.513 ms). No main effect of cue approached significance ( $F(1, 25) = 1.249$ ,  
277  $p = .296$ ,  $\eta_p^2 = .048$ ). A significant interaction between affective priming and type of  
278 cueing was found ( $F(2, 50) = 5.564$ ,  $p = .007$ ,  $\eta_p^2 = .182$ ).

279 Series of Bonferroni-corrected post-hoc analyses showed that threatening priming  
280 enhanced cueing effects than neutral priming in the closed eyes ( $p = .001$ ,  $\eta_p^2 = .346$ ;  
281 Neutral mean cueing effect = 0.622 ms vs. Threatening mean cueing effect = 22.791 ms)  
282 and the direct gaze ( $p = .026$ ,  $\eta_p^2 = .183$ ; Neutral mean cueing effect = 7.832 ms vs.  
283 Threatening mean cueing effect = 23.802 ms) conditions, but not in the arrow condition  
284 ( $p = .305$ ,  $\eta_p^2 = .042$ ; Neutral mean cueing effect = 10.364 ms vs. Threatening mean  
285 cueing effect = 2.947 ms). Thus, affective priming with threatening stimuli increased  
286 cueing effects only in the direct gaze and closed eyes conditions.

287

288        **Discussion**

289            This study tested whether affective priming enhances the cueing effect in general or  
290        only for gaze cues. As predicted, the results suggest that affective priming only enhances  
291        a cueing effect for gaze stimuli, but not arrow stimuli. However, we did not observe the  
292        predicted differences in gaze cueing effect between the direct gaze and closed eyes  
293        conditions. Only the direct gaze condition revealed a consistent trend for both neutral  
294        and threatening priming stimuli, with shorter response times for valid compared to  
295        invalid cue trials. This is consistent with the claim that direct gaze can modulate  
296        attentional orienting to gaze cues, though our initial prediction on the effect of direct  
297        gaze could not be fully supported.

298            The results in Study 1 did not show significant cueing effects after neural priming,  
299        nor did arrow cues show cueing effects in the threatening condition. Although it is  
300        unclear why the cueing effects in these conditions could not be replicated cueing effects  
301        in these conditions, particularly for arrow cues, one could argue that relatively lower  
302        saliency of cues used in the current study, compared to other studies which found  
303        significant gaze and arrow cueing effects, may have contributed to less robust cueing  
304        effects. We used the images of real faces for gaze cueing and the arrows with one  
305        arrowhead for arrow cueing. Previous studies used pictures of schematic faces and

306 double arrowheads (Tipples, 2002; Kuhn & Benson, 2007; Kuhn & Kingstone, 2009).  
307 Another possibility was that the behavioural measurement used in this study, namely  
308 manual response time in a localization task, may not have been sensitive enough to  
309 detect cueing effects in some conditions. This issue was explored in Study 2 as described  
310 below.

311 Study 1 measured participants' reaction times using manual key presses to assess  
312 attentional orienting in the Posner cueing task (Posner & Cohen, 1984). In Study 2, we  
313 aimed to replicate Study 1 with an oculomotor measurement, namely the latency of overt  
314 orienting, mainly because this measurement showed larger effect sizes and better  
315 reliability in previous studies (Friesen & Kingstone, 2003; Smith & Casteau, 2019). It  
316 has been shown that emotions and mood states influence the spatiotemporal course of  
317 overt attention (Kaspar et al., 2013). We used eye tracking techniques to measure overt  
318 shifts of attention (gaze-dependent shifts in attention) in a reliable and unobtrusive  
319 manner (Kaspar et al., 2015).

320

## 321 **Study 2**

322 In Study 2, we examined how affective priming influences orienting time, i.e. the  
323 time to first fixations to targets (Van Rooijen et al., 2018), in a gaze-contingent Posner

324 cueing task. We replicated the experimental paradigm used in Study 1 except for (a) the  
325 measurement of overt orienting with eye tracking techniques instead of the  
326 measurement of covert orienting with manual key press, and (b) the use of gaze-  
327 contingent stimulus control. The details of these changes are described below.

## 328 **Method**

### 329 **Participants**

330 A total of 30 adults (of which 22 were female) participated in Study 2. The experiment  
331 was conducted in the UK and Japan. The mean age was 22.76 years (range: 19–30 years,  
332 SD = 4.43 years). All participants had normal vision or wore contact lenses to correct  
333 their vision. The number of participants in this study is greater than the sample size in  
334 many previous studies of gaze cueing (e.g., Driver et al., 1999; Jones et al., 2009).  
335 Hietanen and Leppanen (2003) have previously shown that findings for gaze cueing in  
336 samples of this size generalize to much larger samples. Using the effect size from the  
337 current study ( $\eta_p^2 = .214$ ), we conducted a *post-hoc* power analysis in G\*Power  
338 (Erdfelder et al., 1996). The result indicated that with the present sample we have  
339 achieved above 95% power with alpha at .05 to find three-way interaction between  
340 affective priming, cueing sequence, and validity. Informed consent was obtained from  
341 participants before the study was conducted. The experimental protocol was approved

342 by the Research Ethics Review Board of the Department of Psychology, Kyoto University,  
343 Kyoto, Japan, and Department of Psychology, Birkbeck, University of London, London,  
344 UK. The participants provided written informed consent before they participated in this  
345 study.

346

### 347 **Apparatus**

348 The experiment was controlled through MatLab (R2013a, MathWorks) using the  
349 Psychophysics toolbox (Version 3) on a Tobii TX300 eye tracker (Tobii Technology,  
350 Sweden; screen resolution: 1920 x 1080; refresh rate: 60Hz) at a sampling rate of 120 Hz.

351 The participants were seated at a distance of approximately 60 cm from the monitor.

352 Positions of left and right eye centres were calculated. Fixation was defined as gaze  
353 recorded within a 50 pixel diameter for a minimum of 50 ms. Saccadic RTs were coded  
354 as the time to first fixate target stimuli after target presentation onset (gaze RT).

### 355 **Stimuli**

356 The cueing and affective priming stimuli were the same as those of Study 1. To allow for  
357 gaze-contingent targets, we used a red circle (120-pixel diameter, 2°) as the target  
358 stimulus positioned on the left or right of the screen at approximately 13° eccentricity  
359 from the fixation point.

360       **Procedure**

361       It was emphasized during the instruction that the direction of the cueing stimuli was not  
362       relevant to the target position. Also, participants were asked to fixate the centre of the  
363       screen until the target appears. We excluded extremely short gaze RTs (RTs less than  
364       100ms) for the analysis to account for instances when participants had shifted their eyes  
365       in the expected target location in advance. The presentation of the visual stimuli followed  
366       the same paradigm as Study 1. Participants were seated at a distance of approximately  
367       60 cm from the monitor, and a five-point calibration was conducted prior to recording.

368       A task consisted of four practice trials (without affective priming) followed by 144  
369       experimental trials. Three within-participant factors were fully crossed in the  
370       experiment: affective priming (threatening, neutral), type of cueing sequence (arrow,  
371       closed eyes, direct gaze), and cue validity (valid, invalid). All combinations of stimuli  
372       were presented in a random order and with equal probability.

373       On each trial, a fixation point was centrally displayed for 1.5s, followed by the brief  
374       presentation of an affective priming stimulus (30 ms). After the affective priming  
375       stimulus, a cueing sequence (arrow, closed eyes, or direct gaze) was started and a black  
376       horizontal line, closed eyes, or direct gaze was presented (900 ms), followed by a cueing  
377       stimulus, pointing either left or right, for either 100, 300, or 400 ms. The changes in the



378 SOAs from Study 1 were introduced based on Kuhn et al. (2010), who have shown that  
379 a shorter SOA of less than 600 ms has stronger cueing effects in eye tracking paradigms.  
380 Given the non-significance of cueing effects in some conditions in Study 1, we shortened  
381 the range of SOA with the aim of improving the effect sizes. A target circle then appeared  
382 immediately after the offset of the cueing stimuli, positioned on the left or right of the  
383 screen at approximately 13° eccentricity from the fixation point. Participants were  
384 instructed to look at the target circle as quickly as possible and maintain fixation until  
385 the target circle disappeared. The target was presented until the participant responded  
386 (by looking at the target circle for at least 100ms). After the participant looked at the  
387 target, the target circle disappeared and a fixation point was contingently presented in  
388 the center of the screen.

### 389 **Data Analysis**

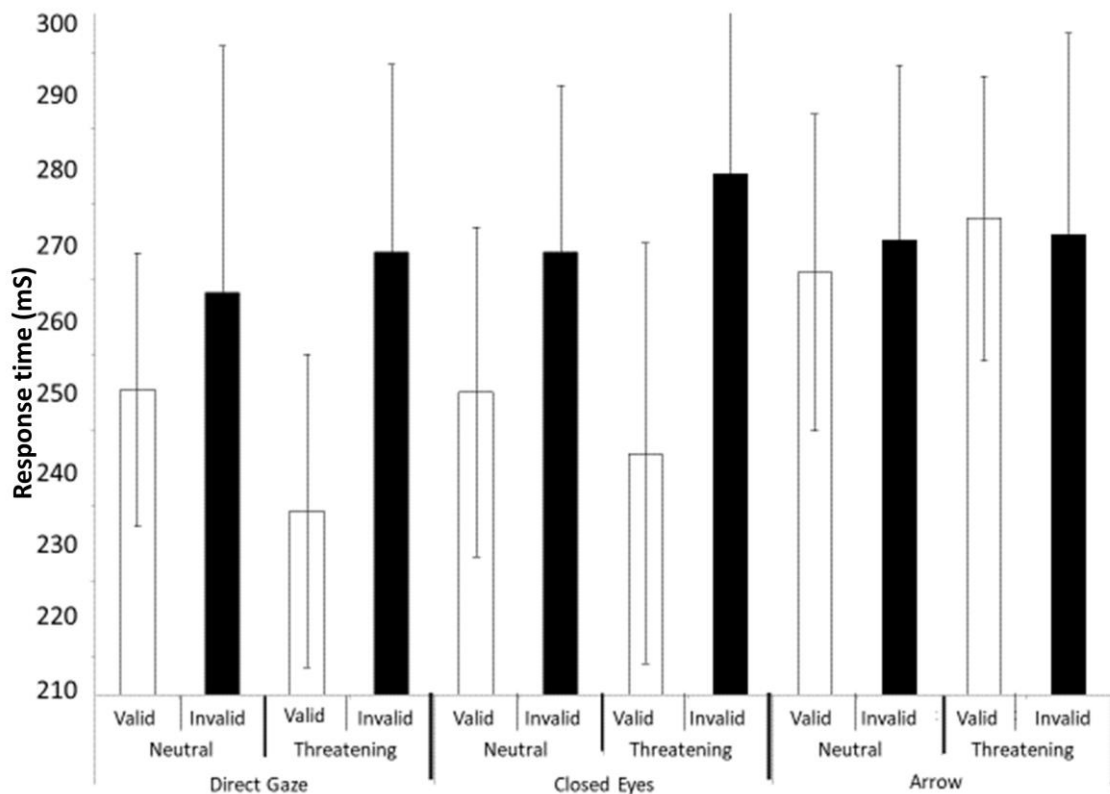
390 Gaze RTs less than 100ms and RTs above and below 2.5 SDs from the individual mean  
391 for each condition were excluded, which was 4.3% of all trials.

392 For the analysis of gaze RTs, we used the individual mean time to first fixations to the  
393 target circle for each condition, affective priming (threatening, neutral), type of cueing  
394 sequence (arrow, closed eyes, direct gaze) and validity (valid, invalid) as independent  
395 variables. The distributions of RTs for each condition mostly showed the skewness and

396 kurtosis within the range characteristic of a normal distribution (skewness range:  $-.01 \sim$   
397  $1.59$ ; kurtosis range:  $-1.13 \sim 2.03$ ).

## 398 **Results**

399 Figure 3 shows the mean gaze RTs in each condition. An ANOVA revealed a significant  
400 three-way interaction between affective priming, cueing sequence, and validity ( $F(2, 58)$   
401  $= 3.817, p = .034, \eta_p^2 = .214$ ). The interaction between priming and cue validity was also  
402 significant ( $F(2, 58) = 4.697, p = .039, \eta_p^2 = .139$ ). No other interactions reached  
403 significance (validity  $\times$  cueing sequence:  $F(2, 58) = 2.938, p = .069, \eta_p^2 = .173$ ; priming  $\times$   
404 cueing sequence:  $F(2, 58) = 0.166, p = .848, \eta_p^2 = .012$ ). There was a significant main  
405 effect of validity ( $F(1, 29) = 23.795, p < .001, \eta_p^2 = .477$ ; Valid mean RT =  $247.96$  ms vs.  
406 Invalid mean RT =  $269.73$  ms) and cueing sequence ( $F(2, 58) = 4.248, p < .024, \eta_p^2 = .233$ ;  
407 Direct gaze mean RT =  $252.24$  ms, Closed eyes mean RT =  $259.69$  ms, Arrow mean RT =  
408  $264.59$  ms), but no significant main effect of priming was observed ( $F(1, 29) = 0.046, p$   
409  $= .831, \eta_p^2 = .002$ ; Neutral mean RT =  $259.11$  ms vs. Threatening mean RT =  $258.58$  ms).  
410



411

412

413 Figure 3. Mean gaze RTs as a function of cueing sequence (direct gaze, closed eyes, and

414 arrow), affective priming (neutral, threatening), and cue validity (valid, invalid). Error

415 bars show standard deviations.

416 Firstly, to examine how affective priming influences attentional orienting, we

417 compared each priming condition across the conditions in the cueing sequence and

418 validity factors with Bonferroni-corrected post-hoc analyses. For valid cue trials,

419 threatening affective priming resulted in faster response times than neutral priming

420 stimuli, which was significant only in the direct gaze condition ( $p = .032$ ,  $\eta_p^2 = .149$ ), but

421 not in the closed eyes ( $p = .202$ ,  $\eta_p^2 = .055$ ) or arrow ( $p = .246$ ,  $\eta_p^2 = .046$ ) conditions. In  
422 the invalid condition, threatening affective priming resulted in slower response times  
423 than neutral priming stimuli, which was only significant in the closed eyes condition ( $p$   
424  $= .037$ ,  $\eta_p^2 = .141$ ) but not in the direct gaze ( $p = .609$ ,  $\eta_p^2 = .009$ ) or arrow ( $p = .696$ ,  $\eta_p^2$   
425  $= .005$ ) conditions. To summarize, affective priming enhanced gaze cueing effects both in  
426 the closed eyes and direct gaze conditions. There was no influence of affective priming  
427 on arrow cueing effects.

428 Secondly, to clarify effects of cue validity, Bonferroni-corrected post-hoc analyses  
429 compared the effect of validity across conditions in the priming and cueing sequence  
430 factors. This revealed that threatening priming induced significant cueing effects (*i.e.*  
431 valid < invalid) in the closed eyes ( $p < .001$ ,  $\eta_p^2 = .454$ ) and direct gaze ( $p < .001$ ,  $\eta_p^2$   
432  $= .456$ ) conditions, but not in the arrow condition ( $p = .241$ ,  $\eta_p^2 = .046$ ). For neutral  
433 priming, the cueing effect was significant in the closed eyes condition ( $p = .004$ ,  $\eta_p^2 = .257$ )  
434 and arrow ( $p = .013$ ,  $\eta_p^2 = .194$ ) conditions, but there was a marginal cueing effect in the  
435 direct gaze ( $p = .0974$ ,  $\eta_p^2 = .092$ ).

436 Finally, we compared each cueing sequence condition across conditions of the affective  
437 priming and validity factors. A significant difference in gaze RTs was only found between  
438 the direct gaze and arrow conditions for threatening priming and valid cue trials ( $p$

439 = .004).

#### 440 **Comparing cueing effects**

441 To probe the effects of affective priming on cueing effects, we calculated the mean  
442 cueing effect (mean invalid RT minus mean valid RT) for each priming and cueing  
443 sequence, and conducted an ANOVA with affective priming and type of cueing  
444 sequence. There was a significant main effect of affective priming ( $F(1, 29) = 8.185$ ,  $p$   
445  $= .008$ ,  $\eta_p^2 = .220$ ; Neutral mean cueing effect = 14.414 ms vs. Threatening mean cueing  
446 effect = 26.911 ms). No main effect of cue approached significance ( $F(1, 29) = 3.183$ ,  
447  $p = .052$ ,  $\eta_p^2 = .099$ ). A significant interaction between affective priming and type of  
448 cueing was found ( $F(2, 58) = 5.230$ ,  $p = .008$ ,  $\eta_p^2 = .153$ ).

449 Series of Bonferroni-corrected post-hoc analyses showed that threatening priming  
450 enhanced cueing effects than neutral priming in the closed eyes ( $p = .009$ ,  $\eta_p^2 = .210$ ;  
451 Neutral mean cueing effect = 18.704 ms vs. Threatening mean cueing effect = 37.234 ms)  
452 and the direct gaze ( $p = .009$ ,  $\eta_p^2 = .211$ ; Neutral mean cueing effect = 11.758 ms vs.  
453 Threatening mean cueing effect = 36.057 ms) conditions, but not in the arrow condition  
454 ( $p = .347$ ,  $\eta_p^2 = .031$ ; Neutral mean cueing effect = 12.779 ms vs. Threatening mean cueing  
455 effect = 7.441 ms). Thus, affective priming with threatening stimuli increased cueing  
456 effects only in the direct gaze and closed eyes conditions.

457 After threatening priming, the gaze cueing effects were larger than the arrow cueing  
458 effect (Closed eyes = 37.234 vs. Arrow = 7.411;  $p = .008$ ,  $\eta_p^2 = .208$ ; Direct gaze = 36.057  
459 vs. Arrow;  $p = .006$ ,  $\eta_p^2 = .228$ ).

## 460 **Discussion**

461 Study 2 was conducted to assess the effects of affective priming on the gaze cueing  
462 effect by measuring time to first fixate targets using gaze-contingent eye tracking.  
463 Consistent with the results of Study 1, affective priming enhanced the effects of eye gaze  
464 cueing but not arrow cueing. Thus, we replicated the effect of affective priming on  
465 orienting to eye gaze cues, as also found in Study 1. Against predictions, however, the  
466 direct gaze condition again did not show larger cueing effects than the other conditions.  
467 The replication of the key findings reported in Study 1 supports the robustness of the  
468 present results.

469 In Study 2, we found significant cueing effects following neutral priming in closed  
470 eyes condition and most crucially in arrow condition, as well as a marginal cueing effect  
471 in direct gaze condition. These cueing effects after neutral priming negate a possible  
472 claim that the arrow cues used in the current study cannot elicit cueing effect in any  
473 condition, and corroborate our argument that affective priming enhanced gaze cueing  
474 effects but not arrow cueing effects.

475

476 **General discussion**

477       In Studies 1 and 2, affective threatening priming consistently enhanced the gaze  
478 cueing effect, but did not influence the attentional orienting to the direction of arrow  
479 cues. These results thus support the hypothesis that affective priming preferentially  
480 facilitates social attention. However, gaze cueing preceded by direct gaze did not elicit a  
481 larger cueing effect than the other cueing sequence conditions, and our hypothesis that  
482 direct gaze would further facilitate the gaze cueing effect could therefore not be  
483 supported.

484       It has been shown that the levels of cueing effects are identical for arrows and gaze  
485 both in covert and overt orienting tasks (Tipples, 2002; Kuhn & Kingstone, 2009).  
486 Consistently, we did not find significant differences in cueing effects between arrow and  
487 gaze cues after neutral priming. The identical levels of cueing effects for gaze and arrow  
488 cues have also been suggested in event-related-potentials (ERP) studies. For example,  
489 effects of validity on the P1 and N1 amplitudes have been shown for targets preceded by  
490 gaze and arrow cues (Eimer, 1997; Schuller & Rossion, 2001). Hietanen et al. (2008) have  
491 compared the ERPs triggered by the targets preceded by gaze and arrow cues, and they  
492 showed similar patterns of P1 and N1 responses for the targets preceded by gaze and

493 arrow cues although amplitudes were different between cue types. It was suggested that  
494 gaze and arrow cues have similar effects of attention orienting on the processing of  
495 incoming visual information. Also, fMRI studies have reported overlap in brain  
496 activation during automatic orienting to gaze and arrow cues (Hietanen, et al., 2006;  
497 Sato et al., 2009). It has been suggested that the superior temporal sulcus (STS) could  
498 be involved in automatic attentional orienting towards the cued direction, regardless of  
499 the type of attention-triggering stimulus (Sato et al., 2009). Generally, gaze and arrow  
500 cues have identical levels of cueing effects on automatic attentional orienting and  
501 overlapping brain regions processing attention-triggering stimuli.

502         However, for the affective priming effects observed in the current study, there are  
503 several possible mechanisms which can account for the relationship between affective  
504 priming and gaze cueing effects. Firstly, it is possible that gaze cues are processed as  
505 emotional stimuli, even though it only shows a 'neutral' facial expression (Lee et al.,  
506 2008). As a result, enhanced amygdala activity, which is known to occur following  
507 affective priming, might mediate enhanced processing of gaze cues as an emotional  
508 stimulus (Adolphs et al., 2001; Anderson & Phelps, 2001; Hamann, 2001). By contrast,  
509 affective priming may not affect arrow cueing since arrows do not represent emotional  
510 stimuli.



511           Secondly, an enhanced response to gaze cues in the threatening priming condition  
512   may be related to the detection of a threat since the gaze direction of another person can  
513   be an important source of threat perception (Mathews et al., 2003). It might reflect the  
514   proposed differences between the strength in social relevance, given proposals that eyes  
515   are 'biological' stimuli but arrows are not (Birmingham & Kingstone, 2009). Thus,  
516   induced fearful experience through affective priming could facilitate fight or flight  
517   responses, which subsequently facilitated sensitivity to gaze cues. By contrast, arrows  
518   do not constitute such ecologically valid signals for threat detection.

519           We highlight that these interpretations are not mutually exclusive, and actually  
520   share the common assumption that affective priming and gaze cueing share similar  
521   neural mechanisms or serve similar functions. This position is consistent with evidence  
522   from neuropsychological findings. For instance, studies of split-brain patients have  
523   revealed that the reflexive gaze cueing effect is lateralized to the cortical mechanisms  
524   involved in face/gaze processing (Kingstone et al., 2000; Friesen & Kingstone, 2003). In  
525   addition, a split-brain patient exhibited no lateralization of reflexive orienting to arrows  
526   (Ristic et al., 2002). The neural substrates for attentional orientation to cues are  
527   considered to be different for nonbiological cues and gaze cues. Altogether, the evidence  
528   points to a possibility that emotional processing and gaze cueing share overlapping

529 neural substrates (Adolphs, 2002), which can subserve the proposed functional overlap  
530 and the observed relationship between affective priming and gaze cueing in the current  
531 study.

532       Also, we acknowledge that motor preparation, as well as attentional shift, could have  
533 contributed to the cueing effect observed in the current studies. It has been argued that  
534 the direction of cues induces motor preparation to respond to the target (Brown et al.,  
535 2011). An electrophysiological study of the Posner paradigm has shown that delayed  
536 offset of motor-readiness potentials such as the late positive complex (LPC) is associated  
537 with long RTs, suggesting a longer response selection stage in conditions in which the  
538 cue and the target were spatially incompatible (Perchet & Garcia-Larrea, 2000). Thus,  
539 it would be possible that enhanced cueing effects after affective priming could include  
540 enhanced motor preparation. As the current study cannot fully dissociate the effects of  
541 affective priming between attention orienting and motor preparation, further studies  
542 with stricter control and possibly the utilization of brain imaging techniques will be  
543 required to identify the mechanisms underlying the influence of affective priming on  
544 gaze cueing effects.

545       We hypothesized that cueing effects would be more enhanced when the gaze cue  
546 followed a period of direct gaze than closed eyes, but results did not fully support our

547 hypothesis. Some studies have reported larger gaze cueing effects after direct gaze than  
548 non-direct gaze (Bristow et al., 2007; Xu et al., 2018). One possibility is that direct gaze  
549 drew attention to the eye area itself, and not to the peripheral areas, thereby weakening  
550 the gaze cueing effect. For example, Senju and Hasegawa (2005) showed that, compared  
551 to averted gaze or closed eyes, response time to a peripheral target was delayed after  
552 presenting direct gaze in the center of a screen. Similarly, Conty et al. (2010) showed  
553 that the cognitive processing for stimuli in non-facial areas can be disturbed when the  
554 facial stimuli showed direct gaze. Thus, direct gaze can draw attention to the eye region,  
555 at the cost of the efficiency to process the surrounding area, under some experimental  
556 contexts. This could contribute to the observed lack of stronger cueing effects for direct  
557 gaze cuing sequence than other conditions.

558 We also acknowledge that we did not observe significant cueing effects for arrow  
559 stimuli in threatening priming conditions. This could be specific to the condition in our  
560 experiment, in which arrow (and gaze) cues always followed affective priming, or the  
561 specific types of arrow cues used in our study. Further studies will need to establish the  
562 robustness and generalisability of affective priming effects on the arrow cueing.

563 Another remained question is the difference in the way priming enhanced gaze  
564 cueing effects for direct gaze and closed eyes conditions. Affective priming decreased RTs

565 for valid gaze cueing in direct gaze condition, while increased RTs for invalid gaze cueing  
566 in closed eyes condition. Importantly, both effects eventually lead to the enhanced cueing  
567 effects (i.e. the difference RTs between valid and invalid cues) of the gaze cue. Previous  
568 studies on cueing effects have mainly focused on the differences in RTs between valid  
569 and invalid trials (see a review, Frischen et al., 2007), and are not particularly  
570 informative to interpret the current finding. It is still possible that there are different  
571 mechanisms of affective attention preceded by direct gaze and closed eyes. A possible  
572 direction for further exploration would be to compare RTs for each SOA, which  
573 unfortunately is not feasible in the current study. As discussed above, the current study  
574 used a comparatively small number of trials per condition to avoid possible habituation,  
575 which would make it difficult to compare the difference of SOA with sufficient power. In  
576 addition, due to the small number of trials per condition, we adopted first fixation time  
577 to the target for analysis in Study 2 rather than a more narrowly defined ‘saccade’ which  
578 would require a stricter definition of speed and amplitude. This measurement is used in  
579 wider participant populations such as infants and young children, which could  
580 compensate for smaller trial numbers and noisier gaze data (e.g., Van Rooijen, Junge, &  
581 Kemner, 2018). However, we also acknowledge that this measurement limits our  
582 interpretation of the oculomotor or attentional mechanisms underlying the current

583 finding. Future studies using between-subject designs, which would allow for  
584 incorporating more trials per condition without risking habituation, will help to identify  
585 priming effects on gaze cueing and clarify attentional mechanisms.

586 To conclude, the results of the current studies suggest that the effects of affective  
587 priming on gaze cueing may not be based on general attention/arousal system but are  
588 related to social or emotional processing. The different cueing effects of gaze and arrow  
589 cues may reflect differences in the neural substrates of attentional orientation to  
590 biological and nonbiological cues. Future research would benefit from investigating the  
591 neural substrates that underlie social attention and emotional processing, which seem  
592 to show functional overlap.

593

#### 594 **Author's contributions**

595 MI designed the study, conducted data collection, analysed data and wrote the initial  
596 draft of the manuscript. MI and JH programmed the experimental paradigm. All authors  
597 have contributed to interpretation, critically reviewed the manuscript, approved the  
598 final version of the manuscript, and agree to be accountable for all aspects of the work  
599 in ensuring that questions related to the accuracy or integrity of any part of the work  
600 are appropriately investigated and resolved.

601 **Data accessibility**

602 The data sets generated and analysed during the current study are available from  
603 the corresponding author upon reasonable request.

604 **Conflict of interests**

605 Authors have no conflicts of interest.

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610

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