Motor expertise affects the unconscious processing of geometric forms

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Abstract

13   **Background.** The unconscious processing of information is an important skill used by

14   competitive athletes to handle the rapidly changing movements of opponents and equipment.

15   Previous studies have shown that unconscious executive control among athletes is better than

16   that among non-athletes in the sports-specific domain. However, it is not yet clear whether

17   athletes also show superior unconscious executive control in the general cognitive domain.

18   **Methods.** Twenty-five competitive table tennis players (athletes) and 26 aged-matched non-

19   athletic college students (non-athlete controls) were recruited for this study. Participants first

20   performed a masked priming task that used geometric shapes as primes and targets to examine

21   unconscious executive control in the general cognitive domain. As a control, participants then

22   completed a prime identification task to determine whether they could consciously detect the

23   priming geometric forms. Reaction times and error rates were analyzed to examine whether

24   motor expertise influenced unconscious processing in the general domain.

25   **Results.** The use of signal detection analyses for the performance of participants to identify the

26   masked primes indicated that neither athletes nor non-athletes could consciously perceive the

27   priming stimuli ($p > 0.05$ for both groups). Two-way repeated-measures analyses of variance

28   followed by simple effects analyses of the results of the masked priming task indicated that

29   athletes responded faster (mean ± standard error: congruent, 489.15 ± 9.75 ms; incongruent,

30   500.33 ± 8.99 ms; $p < 0.001$) and committed fewer errors (congruent, 13.00% ± 1.59%;

31   incongruent, 26.36% ± 2.08%; $p < 0.001$) when the priming stimulus was congruent with the

32   target stimulus than when the stimuli were incongruent. These results indicated a significant

33   unconscious response priming effect of geometric forms among athletes. By contrast, non-

34   athletes did not respond faster or commit fewer errors for congruent vs. incongruent conditions.

35   No significant difference was detected between athletes and non-athletes in overall reaction

36   times and error rates for congruent trials, but athletes committed significantly more errors than

37   non-athletes on incongruent trials ($p < 0.01$).

38   **Conclusion.** The results indicated that motor expertise facilitated the unconscious processing of

39   geometric forms, suggesting that the influence of motor expertise on unconscious executive

40   control occurs not only for the sports-specific domain but also for the general cognitive domain.

41   **1. Introduction**

42   Previous studies have shown that behavior can be influenced by visual stimuli that are not

43   consciously perceived; that is, individuals can encode information that lies below their threshold

44   for conscious awareness (Ortells, Kiefer, Castillo, Megias, & Morillas, 2016; Tseng et al., 2016;

45   Zovko & Kiefer, 2013). In competitive sports, athletes, especially those engaged in sports that

46   require open skills, process movement information unconsciously most of the time because of

47   the limited time available before the athletes must react (Kibele, 2006). A widely used paradigm

48   to study unconscious processing in executive control is the masked priming task (Kiefer, 2012;

49   Kiefer & Martens, 2010). The unconscious response priming effect is considered an indirect

50   measure to evaluate processing of the masked primes (Ansorge, Kunde, & Kiefer, 2014). With

51   the masked priming paradigm, recent studies found that athletes exhibit stronger unconscious

52   response priming effects than non-athletes in a sport-specific domain, suggesting that athletes

53   show superior unconscious executive control owing to their extensive specialized training

54   (Gueldenpenning, Braun, Machlitt, & Schack, 2015; Meng, Li, You, & Xie, 2019). However,

55   whether athletes also show superior unconscious executive control in the general domain is still

56   unknown.

57   Recent studies have suggested that expertise or practice may be an important prerequisite for

58   unconscious processing (Heinemann, Kiesel, Pohl, & Kunde, 2010; Kiesel, Kunde, Pohl, Berner,

59   & Hoffmann, 2009; Reuss, Kiesel, Pohl, & Kunde, 2015). Athletes are considered experienced

60   individuals because of the extensive motor expertise they have accumulated during their years of

61   training (Guo, Li, & Yu, 2017; Voss, Kramer, Basak, Prakash, & Roberts, 2010). Additionally,

62   unconscious executive control is an important skill that enables athletes to deal with rapidly

63   changing movement information (Gueldenpenning, Koester, Kunde, Weigelt, & Schack, 2011;

64   Kibele, 2006). Hence, researchers are beginning to investigate the relationship between motor

65   expertise and unconscious executive control. For example, using the masked priming task, Meng

66   et al. (2019) investigated unconscious executive control in table tennis players. Their results

67   showed that table tennis players unconsciously perceive visuospatial information and show

68   significant unconscious response priming effect, whereas the control nonathletic college students

69   did not. Gueldenpenning et al. (2015) also examined unconscious processing of complex

70   movements by using a similar method. They found that compared with novices, athletes involved

71   in martial arts training were able to distinguish feint and non-feint actions unconsciously and to

72   initiate a faster motor response. Some researchers have suggested that the high perceptual

73   sensitivity and the perceptual-motor common representations among athletes may well explain

74   their superiority in unconscious processing (Gueldenpenning et al., 2011). However, the stimuli

75   that were used in these aforementioned studies are associated with the sports-specific domain.

76   Whether the effect of motor expertise can be transferred from a sports-specific domain to a

77   general domain has not been systematically investigated.

78   A study conducted by You et al. (2018) using a general masked go/no-go task to examine

79   motor expertise and unconscious response inhibition found that table tennis athletes have

80   superior unconscious response inhibition compared with non-athletes. That study provided initial

81   evidence that the superiority of unconscious executive control performance in athletes may not

82   be confined to the sport-specific domain. However, unconscious response inhibition is only one

83   subprocess of unconscious executive control. Other subprocesses, such as updating

84   representations in working memory and switching between tasks or mental sets (Miyake et al.,

85   2000), should also be considered before it is known whether athletes compared with non-athletes

86   show superior unconscious executive control in the general domain.

87   The present study aimed to examine whether motor expertise facilitates unconscious executive

88   control in a general masked priming task that uses stimuli unrelated to sports. Thus, we recruited

89   a group of competitive table tennis players and a group of aged-matched college students without

90   a specific motor expertise to perform a masked priming task and a control prime visibility task.

91   We hypothesized that both athletes and non-athletes would respond faster and commit fewer

92   errors on trials in which prime and target stimuli were congruent than when they were

93   incongruent, displaying a significant unconscious response priming effect. We further

94   hypothesized that the strength of this unconscious response priming effect in athletes would be

95   stronger than that in non-athletes.

96   **2. Materials and Methods**

97

98   **2.1 Participants**

99   Twenty-five age-matched competitive table tennis players (9 females; mean age, 20.44 years

100   with a range of 18-23 years) and 26 college students (10 females; mean age, 19.85 years with a

101   range of 18-22 years) were recruited for this study. The competitive table tennis players were

102   considered athletes, and the college students were considered non-athlete controls. All athletes

103   had obtained the first or second level of the national standard, with a mean table tennis training

104   experience of 7.96 years. The non-athletes had no practical experience with any sports. All

105   participants were right-handed, had normal or corrected-to-normal vision, and had no psychiatric

106   or neurologic illness. All participants provided written informed consent prior to starting the

107   experiment and received financial compensation after finishing the experiment. This study

108   received approval from the Ethics Committee of Shanghai University of Sport (No. 2018025).

109   **2.2 Stimuli and equipment**

110   On the basis of previous studies (Ulrich & Kiefer, 2016; Zovko & Kiefer, 2013), we selected

111   images of four black geometric forms (circle, diamond, ellipsoid, and square) as primes and

112   targets. Two images that contained many randomly oriented lines were designed as masks. The

113   stimuli (including masks) were presented on a gray background (RGB values of 128,128, and

114   128) with a size of 7×7 cm and had a subtended visual angle of 6.69° (horizontally and

115   vertically) from a viewing distance of 60 cm.

116   A Dell computer with a 16-inch VGA display (frequency 60 Hz, resolution 1024×768) was

117   used for stimulus presentation. The E-prime 2.0 software package (Psychology Software Tools,

118   Pittsburgh, PA, USA) was used for response sampling.

119   **2.3 Procedure and tasks**

120   **2.3.1 Masked priming task**

121   Participants were instructed to respond to the geometric form of the target stimuli as quickly

122   and accurately as possible by pressing the appropriately assigned key on a computer keyboard.

123   An image of a circle or a diamond was assigned to the ''f'' key, and an image of an ellipsoid or a

124   square was assigned to the ''j'' key. The reaction was counterbalanced across participants; that is,

125   half the participants followed the aforementioned stimulus-response key assignment, and the

126   remaining participants followed the opposite stimulus-response key assignment.

127   The sequence of each trial in the masked priming task is shown in Fig. 1 and is described as

128   follows: (1) a fixation cross appeared for 750 ms; (2) a forward mask (i.e., an image containing

129   many randomly oriented lines) appeared for 200 ms; (3) the priming stimulus appeared for 33 ms;

130   (4) a backward mask (i.e., another image containing many randomly oriented lines that differed

131   from the forward mask) appeared for 33 ms; (5) the target stimulus appeared for 500 ms; (6) a

132   blank screen appeared for 1000 ms. Participants were required to report their decision (i.e., press

133   the appropriate key) within 1500 ms. The interval between trials varied randomly from 1000 to

134   1500 ms.

135   *(Insert Figure 1 about here)*

136   All participants were given 24 practice trials before the formal experiment began. The masked

137   priming task followed and included four blocks of 168 total trials. The relationship between the

138   prime and target allowed for two experimental conditions: congruent, for which the prime and

139   target had same response, and incongruent, for which the prime and target had a different

140   response. Within each block, half the trials were congruent, and the remaining trials were

141   incongruent. The four geometric forms appeared equally often as primes and targets and were

142   varied across trials to avoid repetition response priming effect.

143   **2.3.2 Prime identification control task**

144   To assess whether or not participants consciously perceived the prime, they participated in a

145   task that provided a subjective measure of conscious awareness after finishing the masked

146   priming task. For this measure, all participants were verbally asked whether they were aware of

147   the primes that were presented before the targets. In addition, the participants performed an

148   objective measure of prime identification. The prime identification task procedure was identical

149   to the masked priming task in that participants were asked to respond to the geometric form of

150   the primes with the same stimulus-response key assignment as was used for the priming task.

151   However, response accuracy was stressed over response speed. Participants were required to

152   make their best guess when they were unable to determine the form of the primes.

153 2.4 Statistical analysis

154 2.4.1 Reaction times and response errors

155 To minimize errors caused by incorrect and extreme values, incorrect and missed trials
156 (17.52%) and reaction times (RTs) that deviated by more or less than three standard deviations
157 (0.83%) were removed from further analysis. The mean RT of the correct responses and the
158 mean error rates (ERs) were calculated for each participant and each experimental condition.
159 Two-way repeated-measures analyses of variance (ANOVAs) were used to examine the mean
160 RTs and ERs, with the within-subjects factor being response congruency (congruent vs.
161 incongruent) and the between-subjects factor being expertise (athletes vs. non-athletes).

162 2.4.2 Identification rates

163 We used the statistic d' as a signal detection measure to assess prime visibility. Consistent with
164 the work of Green and Swets (1966), the present study considered a correct response to the target
165 stimulus on a congruent trial a hit and an erroneous response to the target stimulus on an
166 incongruent trial a false alarm (Kiefer & Martens, 2010). The hit rates and false-alarm rates were
167 calculated for each participant, and the identification rate d' was calculated from each
168 participant's hit and false-alarm rates.
169 In order to obtain an objective measure of the ability to identify the geometric prime form
170 presented between the two masks, one sample t-tests were performed to determine whether the
171 identification performances of athletes and non-athletes were distributed around the level of
172 chance, that is, at 50% (which is indicated by $d' = 0$). We then compared the identification rates
173 (d') between athletes and non-athletes through independent t-tests. To rule out that any
174 unconscious response priming effect observed among athletes correlated with prime visibility,
175 Pearson's correlation between the identification rate d' and the size of the unconscious response
176 priming effect was performed for the group of athletes.

177 **3. Results**

178 **3.1 Reaction times and response errors**

179 The results of a two-way repeated-measures ANOVA examining RTs revealed a significant

180 main effect of response congruency ($F_{(1,49)} = 11.44$; $p = 0.001$; $\eta_p^2 = 0.19$). The interaction

181 between expertise and response congruency was also significant ($F_{(1,49)} = 8.43$; $p = 0.006$; $\eta_p^2 = $

182 0.15). A simple effects analysis of the interaction showed that athletes responded faster on

183 congruent trials than on incongruent trials (mean ± standard error: congruent, 489.15 ± 9.75 ms;

184 incongruent, 500.33 ± 8.99 ms; $p = 0.00$). By contrast, there was no significant difference in

185 reaction times between congruent and incongruent trials for non-athletes (congruent, 500.56 ±

186 9.56 ms; incongruent, 501.41 ± 8.82 ms; $p = 0.734$). In addition, the main effect of expertise did

187 not reach statistical significance ($F_{(1,49)} = 0.23$; $p = 0.633$; $\eta_p^2 = 0.01$) (Fig. 2).

188 *(Insert Figure 2 about here)*

189 An analogous two-way repeated-measures ANOVA on ERs revealed a significant main effect

190 of response congruency ($F_{(1,49)} = 38.39$; $p = 0.00$; $\eta_p^2 = 0.44$). The interaction between expertise

191 and response congruency was also significant ($F_{(1,49)} = 22.80$; $p = 0.00$; $\eta_p^2 = 0.32$). For response

192 congruency, the simple effects analysis of the interaction showed that athletes committed fewer

193 errors on congruent trials than on incongruent trials (congruent, 13.00% ± 1.59%; incongruent,

194 26.36% ± 2.08%; $p = 0.001$). By contrast, there was no significance difference in ERs between

195 congruent and incongruent trials for non-athletes (congruent, 14.27% ± 1.56%; incongruent,

196 16.00% ± 2.04%; $p = 0.572$). For expertise, athletes committed more errors than non-athletes on

197 incongruent trials (athletes, 26.36% ± 2.08%; non-athletes, 16.00% ± 2.04%; $p = 0.00$), but not

198 on congruent trials (athletes, 13.00% ± 1.59%; non-athletes, 14.27% ± 1.56%%; $p = 0.315$).

199 However, the main effect of expertise did not reach significance ($F_{(1,49)} = 3.94$; $p = 0.053$; $\eta_p^2 = $

200 0.07) (Fig. 3).

201 *(Insert Figure 3 about here)*

202 **3.2** Prime visibility

203   The signal detection analysis on the performance of participants to identify the masked primes

204 indicated that for athletes d' was 0.14, which did not deviate significantly from zero ($t_{(24)} = 0.97$,

205 $p = 0.341$). In addition, for non-athletes, d' was 0.06, which also did not differ significantly from

206 zero ($t_{(25)} = 0.81$, $p = 0.425$). Furthermore, no significant difference was found between the d'

207 values of athletes and non-athletes ($t_{(49)} = 0.48$, $p = 0.636$). These results indicated that neither

208 athletes nor non-athletes could consciously perceive the masked primes.

209   The distribution of the identification rates d' (Kolmogorov-Smirnov = 0.14, $p = 0.20$) and the

210 size of the unconscious response priming effect (Kolmogorov-Smirnov = 0.10, $p = 0.20$) for

211 athletes were normal. For athletes, the identification rates d' and the size of the unconscious

212 response priming effect did not correlate with each other ($r(25) = -0.19$, $p = 0.377$), suggesting

213 that the unconscious response priming effect of the athletes was not the result of their awareness

214 of the masked primes.

215 **4. Discussion**

216   Although unconscious executive control among athletes is reportedly better than that of non-

217 athletes in the sports-specific domain, it has not been fully shown whether athletes also show

218 superior unconscious executive control in the general domain. Thus, to determine whether motor

219 expertise is associated with unconscious executive control in the general domain, we compared

220 the performance on a masked priming task that used geometric forms as prime and target stimuli

221 in a group of competitive table tennis players who had extensive motor expertise with that of a

222 group of college students who had no specific motor expertise. Our primary results showed that

223 athletes responded faster and committed fewer errors on trials in which the prime and target

224 stimuli were congruent (i.e., required the same response) than on trials in which they were

225 incongruent. By contrast, there was no significant difference in reaction times or errors rates

226 between congruent and incongruent trials for non-athletes.

227   Athletes showed a significant unconscious response priming effect, consistent with the results

228 of a previous study that has shown that motor expertise promotes unconscious processing in the

229 general cognitive domain (You et al., 2018). Schütz-Bosbach and Prinz (2007) have suggested

230 that perceptual sensitivity is a prerequisite for unconscious processing. We selected geometric

231 forms as prime and target stimuli because they are considered well-known to most people (Kiesel

232 et al., 2009). Thus, we believed that both athletes and non-athletes would show high perceptual

233 sensitivity to these geometric forms. However, our results showed that only athletes exhibited a

234 significant unconscious response priming effect; the non-athletes did not. We speculate that this

235 result is because the motor expertise possessed by athletes facilitates unconscious information

236 processing. A characteristic of competitive sports is that they require rapid and changeable

237 responses. Given the Olympic motto "faster, higher, and stronger" (Coubertin, 2008) incentive,

238 competitive sports, especially open skills sports, have developed so that the movement speed of

239 athletes and sports equipment exceeds the perception threshold of individuals most of time. For

240 example, in table tennis, the ball speeds may be up to 144-180 km/h, and the contact time

241 between the ball and the racket is only approximately 0.01 s (Bootsma & Van Wieringen, 1990).

242 With such time pressure, the decisions made by competitive athletes are usually intuitive and

243 without any explicit evaluation of the perceived information (Raab & Johnson, 2008; Williams &

244 Ward, 2007). Table tennis is an open skills sport in which athletes are required to react in a

245 dynamically changing environment, and likely because of their years of training, these athletes

246 show more unconscious behaviors compared with non-athletes (Wang et al., 2013; Yu, Chan,

247 Chau, & Fu, 2017). The masked priming paradigm used in present study closely replicated the

248 time pressure of an open skills sport and was favorable for the performance of the athletes.

249   Compared with the number of words used as prime and target stimuli in previous studies

250 (Martens, Ansorge, & Kiefer, 2011; Ulrich, Adams, & Kiefer, 2014), the number of geometric

251 forms used in present study was small. In addition, each geometric shape had a unique physical

252 feature. Participants can store the geometric forms and their corresponding reactions in their

253   working memory, and then form a stimulus-reaction connection between the stimuli and

254   reactions (Kiesel, Kunde, Poh, & Hoffmann, 2006; P. Wang, Huo, & Wang, 2012). The present

255   results indicated that the performance of athletes was significantly influenced by the presentation

256   of the geometric forms despite their perception being unconscious, whereas the performance of

257   non-athletes was not affected by the presentation of geometric forms. This result may be because

258   athletes established an unconscious association between the stimuli and motor responses during

259   the practice experiments, whereas the non-athletes did not. Thus, the motor reactions of the

260   athletes would be facilitated or disrupted by the unconsciously perceived primes. In other words,

261   the unconsciously perceived geometric shapes could have activated the previously established

262   stimulus-response assignment and triggered a motor response when the prime and target were

263   congruent. The response to the target would be facilitated because it was pre-activated by the

264   prime. By contrast, when the prime and target stimuli required a different response (i.e., were

265   incongruent), the response to the target would have been interfered because the pre-activated

266   response was inconsistent with the required target response. Athletes need to timely inhabit the

267   incorrect motor response tendency, retrieving the appropriate stimulus-response assignment.

268   Hence, athletes responded faster and committed fewer errors on congruent trials than on

269   incongruent trials. Although there was a tendency for a similar result among non-athletes, the

270   difference was not statistically significant. The results indicated, to some extent, that non-athletes

271   appeared to sense a conflict between an incongruent prime and target, but compared with athletes,

272   the conflict felt by non-athletes was substantially smaller. Owing to lack of a stable connection

273   between the stimuli and motor reactions in non-athletes, the geometric forms presented

274   unconsciously did not influence their performance. Thus, no significant unconscious response

275   priming effect was found among non-athletes. This finding explains why the ERs among athletes

276   were higher than those among non-athletes on incongruent trials.

277   Our results showed that non-athletes exhibited no significant unconscious response priming

278   effect. However, this finding was inconsistent with that of a previous study   (Ulrich & Kiefer,

279   2016). To study the neural signature of the unconscious response priming effect, Ulrich and

280 Kiefer (2016) recruited college students to participant in a masked priming task that also used

281 geometric forms, their results showed that the participants exhibited a significant unconscious

282 response priming effect. We speculate that the lack of sufficient practice for the college students

283 in our study may have led to the different results. Previous studies have suggested that long

284 periods of practice are required for unconscious or implicit learning (Lewicki, Czyzewska, &

285 Hoffman, 1987; Wulf & Schmidt, 1997). In the present study, participants were allowed 24

286 practice trials, whereas in the Ulrich and Kiefer (2016) study, participants were given up to 32

287 practice trials. Given the more limited practice allowed in our study, athletes could master the

288 rules faster and better than non-athletes and then could establish a stable unconscious connection

289 between the stimuli and motor response. By contrast, this connection was not stable in non-

290 athletes and had not reached an automatic level. Thus, the stimuli presented below the threshold

291 of consciousness had no influence on the performance of non-athletes.

292   Our findings, together with the results from previous studies, not only add further evidence to

293 support that expertise is an important determinant of unconscious processing but also provide

294 preliminary evidence that, compared with non-athletes, athletes exhibit superior unconscious

295 processing of executive control in the general domain. This finding suggests that the influence of

296 motor expertise on unconscious executive control is transferable from the sports-specific domain

297 to the general cognitive domain.

298 **5. Limitations**

299   The present study had some limitations. First, we did not detect a significant unconscious

300 response priming effect among non-athletes in the masked priming task; as suggested above, this

301 result may have been due to a lack of practice on the task prior to the formal experiment.

302 Allowing more practice should be a consideration for future studies. Second, the sample size of

303 participants, especially female participants, in the present study was small. To reduce the effect

304 of individual differences, the number of participants should be increased in future studies. Third,

305 the athletes played table tennis, which is an open skills sport. In order to better identify the

306   facilitation of motor expertise on unconscious executive control in the general cognitive domain,

307   athletes who play closed skills sports should also be recruited in future studies. Finally, although

308   the present study described the influence of motor expertise on the unconscious executive control

309   of the general domain on a behavior level, the neural signature of this phenomenon remains

310   unclear and warrants future exploration.

311   **6. Conclusions**

312   The findings of our study provide evidence that motor expertise facilitates the unconscious

313   processing of geometric forms, indicating that the influence of motor expertise on unconscious

314   executive control is not just sports-specific but can be transferred to the general cognitive domain.

315

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410

Figure 1

The masked priming task

Trial sequence of the masked priming task.
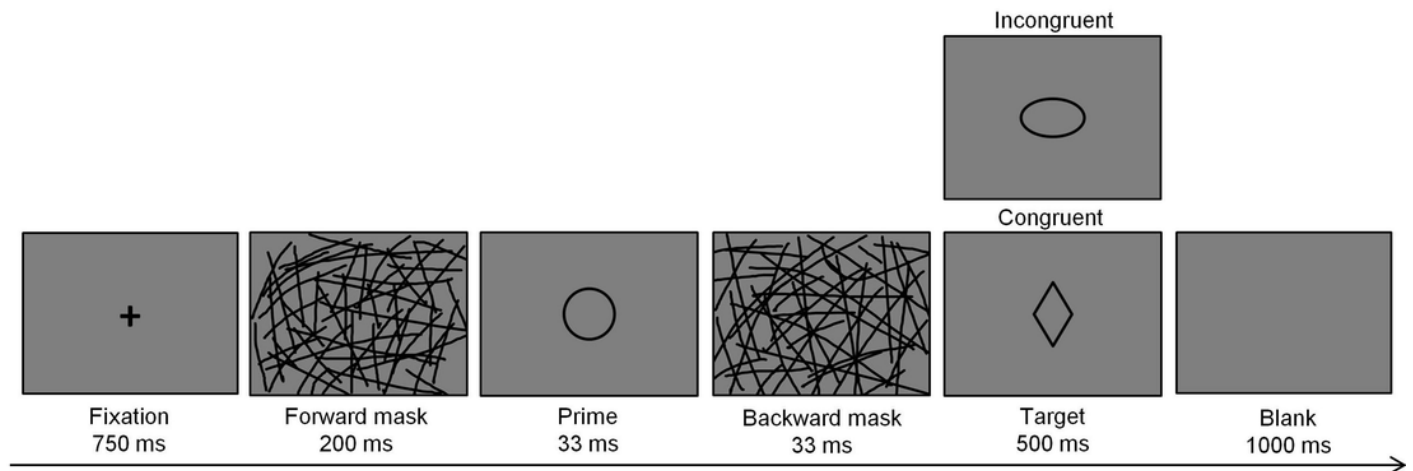
Figure 2

Mean reaction times for trials with correct responses in the masked priming task for athletes and non-athletes.

The vertical bars represent mean reaction times as a function of response congruency and expertise. White bars represent reaction times of congruent responses, and black bars represent reaction times of incongruent responses. Error bars indicate standard error of mean; ***$p < 0.001$ for the indicated comparison.

[object Object]Manuscript to be reviewed
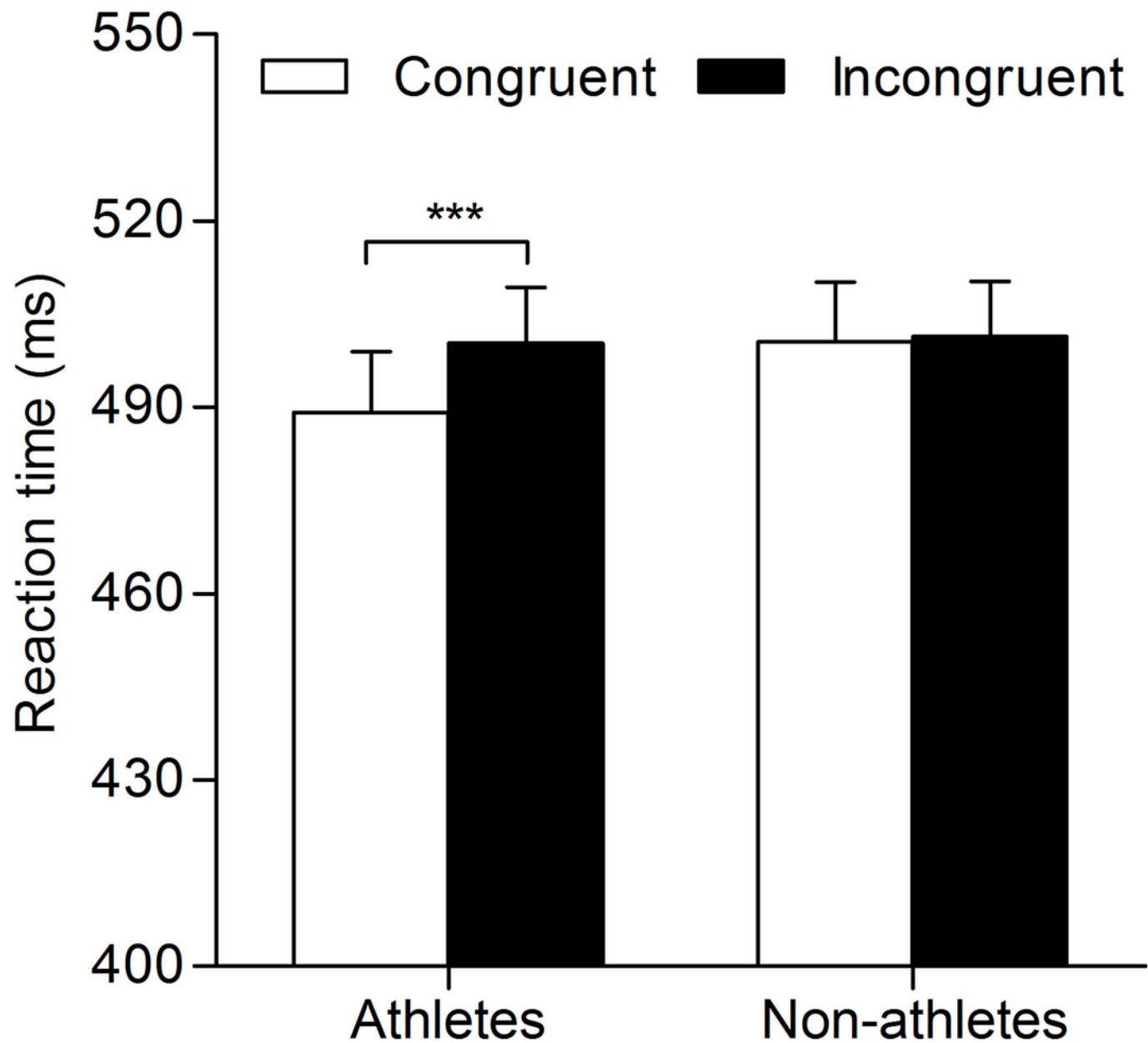
Figure 3

Mean error rates for athletes and non-athletes in the masked priming task for athletes and non-athletes.

The vertical bars represent mean error rates as a function of response congruency and expertise. White bars represent error rates of congruent responses, and black bars represent error rates of incongruent responses. Error bars indicate standard error of mean; **$p < 0.01$, ***$p < 0.001$ for the indicated comparisons.