Motor expertise affects the unconscious processing of geometric forms

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Background. The unconscious processing of information is an important skill used by competitive athletes to handle the rapidly changing movements of opponents and equipment. Previous studies have shown that unconscious information processing among athletes is better than that among non-athletes in the sports-specific domain. However, it is not yet clear whether athletes also show superior unconscious information processing in the general cognitive domain.

Methods. Twenty-five competitive table tennis players (athletes) and 26 aged-matched non-athletic college students (non-athlete controls) were recruited for this study. Participants first performed a masked priming task that used geometric shapes as primes and targets to examine unconscious information processing in the general cognitive domain. As a control, participants then completed a prime identification task to determine whether they could consciously detect the priming geometric forms. Reaction times and error rates were analyzed to examine whether motor expertise influenced unconscious information processing in the general domain. In addition, we also selected the 19 athletes and 17 non-athletes, all of them have participated in the present study with general stimuli, as well as our previous study with sport-specific stimuli. The strength of the unconscious response priming effect was analyzed to examine whether the effect of motor expertise on unconscious processing could be transferred from a sports-specific domain to a general domain.

Results. The use of signal detection analyses for the performance of participants to identify the masked primes indicated that neither athletes nor non-athletes could consciously perceive the priming stimuli. Two-way repeated-measures analyses of variance followed by simple effects analyses of the results of the masked priming task indicated that athletes responded faster and committed fewer errors when the priming stimulus was congruent with the target stimulus than when the stimuli were incongruent. These results indicated a significant unconscious response priming effect of geometric forms among athletes. By contrast, non-athletes did not respond faster or commit fewer errors for congruent vs. incongruent conditions. No significant difference was detected between athletes and non-athletes in error rates for congruent trials, but athletes committed significantly more errors than non-athletes on incongruent trials. Besides, the strength of the unconscious response priming effect that athletes showed is higher than in non-athletes both in the present study with general stimuli and in our previous study with sport-specific stimuli.

Conclusion. The results indicated that motor expertise facilitated the unconscious processing of geometric forms, suggesting that the influence of motor expertise on unconscious information processing occurs not only for the sports-specific domain but also for the general cognitive domain.

1   **Motor expertise affects the unconscious processing of geometric forms**

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12   ## 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 information processing among athletes is better

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

17   athletes also show superior unconscious information processing 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 information processing in the general cognitive domain. As a control, participants

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

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

24   motor expertise influenced unconscious information processing in the general domain. In

25   addition, we also selected the 19 athletes and 17 non-athletes, all of them have participated in the

26 present study with general stimuli, as well as our previous study with sport-specific stimuli. The

27 strength of the unconscious response priming effect was analyzed to examine whether the effect

28 of motor expertise on unconscious processing could be transferred from a sports-specific domain

29 to a general domain.

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

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

32 priming stimuli. Two-way repeated-measures analyses of variance followed by simple effects

33 analyses of the results of the masked priming task indicated that athletes responded faster and

34 committed fewer errors when the priming stimulus was congruent with the target stimulus than

35 when the stimuli were incongruent. These results indicated a significant unconscious response

36 priming effect of geometric forms among athletes. By contrast, non-athletes did not respond

37 faster or commit fewer errors for congruent vs. incongruent conditions. No significant difference

38 was detected between athletes and non-athletes in error rates for congruent trials, but athletes

39 committed significantly more errors than non-athletes on incongruent trials. Besides, the strength

40 of the unconscious response priming effect that athletes showed is higher than in non-athletes

41 both in the present study with general stimuli and in our previous study with sport-specific

42 stimuli.

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

44 geometric forms, suggesting that the influence of motor expertise on unconscious information

45 processing occurs not only for the sports-specific domain but also for the general cognitive

46 domain.

47 **1. Introduction**

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

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

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

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

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

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

54 to study unconscious information processing is the masked priming task (Kiefer, 2012; Kiefer &

55 Martens, 2010). The unconscious response priming effect is considered an indirect measure to

56 evaluate the processing of the masked primes (Ansorge, Kunde, & Kiefer, 2014). The theory of

57 direct parameter specification (DPS, Neumann, 1990; Neumann & Klotz, 1994) could be used to

58 explain the unconscious response priming effect. According to this account, once an action plan

59 is established, sensory information could specify response parameters without conscious

60 perception as a meditating stage. In the case of the masked priming paradigm, researchers have

61 proved the specification of response parameters by the masked prime through EEG (Leuthold &

62 Kopp, 1988; Minelli, Marzi, & Girelli, 2007) and fMRI (Dehanen et.al 1998; Dostilio & Garraux,

63 2011; Ulrich & Kiefer, 2016). As a consequence, if the prime shape activates the same response

64 with the target, the response times and error rates would be reduced. By contrast, if the prime

65 shape activates the different response with the target, the response times and error rates would be

66 increased.

67   Previous studies have suggested that long periods of practice are required for unconscious or

68 implicit learning (Lewicki, Czyzewska, & Hoffman, 1987; Wulf & Schmidt, 1997).With the

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

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

71 show superior unconscious information processing owing to their extensive specialized training

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

73 whether athletes also show superior unconscious information processing in the general domain is

74 still unknown. Recent studies have suggested that expertise or practice may be an important

75 prerequisite for unconscious information processing (Heinemann, Kiesel, Pohl, & Kunde, 2010;

76 Kiesel, Kunde, Pohl, Berner, & Hoffmann, 2009; Reuss, Kiesel, Pohl, & Kunde, 2015). Athletes

77 are considered experienced individuals because of the extensive motor expertise they have

78 accumulated during their years of training (Guo, Li, & Yu, 2017; Voss, Kramer, Basak, Prakash,

79   & Roberts, 2010). Additionally, unconscious information processing is an important skill that

80   enables athletes to deal with rapidly changing movement information (Gueldenpenning, Koester,

81   Kunde, Weigelt, & Schack, 2011; Kibele, 2006). Hence, researchers are beginning to investigate

82   the relationship between motor expertise and unconscious information processing. For example,

83   using the masked priming task, Meng et al. (2019) investigated unconscious information

84   processing among table tennis players with circles with the notch. The stimuli were designed

85   based on the characteristic of table tennis and a theoretical model of long-time object memory-

86   the type-token model. They believed that the circle provided outline information for the table

87   tennis, and the notch orientation provided direction information of the hitting point for the table

88   tennis (Guo et al., 2017; Guo, Li, Lu, & Gu, 2019). Their results showed that table tennis players

89   unconsciously perceive visuospatial information and show significant unconscious response

90   priming effect, whereas the control nonathletic college students did not. Gueldenpenning et al.

91   (2015) also examined the unconscious processing of complex movements by using a similar

92   method. They found that compared with novices, athletes involved in martial arts training were

93   able to distinguish feint and non-feint actions unconsciously and to initiate a faster motor

94   response. Some researchers have suggested that the high perceptual sensitivity and the

95   perceptual-motor common representations among athletes may well explain their superiority in

96   unconscious information processing (Gueldenpenning et al., 2011). However, the stimuli that

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

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

99   general domain has not been systematically investigated.

100   The present study aimed to examine whether motor expertise facilitates unconscious

101   information processing in a general masked priming task that uses stimuli unrelated to sports.

102   Thus, we recruited a group of competitive table tennis players and a group of aged-matched

103   college students without specific motor expertise to perform a masked priming task and a control

104   prime visibility task. We hypothesized that both athletes and non-athletes would respond faster

105   and commit fewer errors on trials in which prime and target stimuli were congruent than when

106   they were incongruent, displaying a significant unconscious response priming effect. We further

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

108   stronger than that in non-athletes.

109   **2. Materials and Methods**

110

111   **2.1 Participants**

112   To find an interaction between expertise and response congruency in line with Meng et al.

113   (2019), we calculated the sample size by Gpower3.1 (α=0.05, power = 0.80, effect size = 0.19).

114   The result showed that a minimum of 40 participants was required. Twenty-five

115   age-matched competitive table tennis players (9 females; mean age, 20.44 years with a range of

116   18-23 years) and 26 college students (10 females; mean age, 19.85 years with a range of 18-22

117   years) were recruited for this study. The competitive table tennis players were considered

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

119   recruited from Chinese Table Tennis College, Shanghai University of Sport. All of them had

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

121   experience of 7.96 years. The non-athletes were recruited from the School of Economics and

122   Management, Shanghai University of Sport, had no practical experience with any sports. All

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

124   or neurologic illness. All participants provided written informed consent before starting the

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

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

127   **2.2 Stimuli and equipment**

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

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

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

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

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

133   vertically) from a viewing distance of 60 cm.

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

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

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

137   **2.3 Procedure and tasks**

138   **2.3.1 Masked priming task**

139   During the experiment, the experimenter strictly adhered to the rules and maintained a neutral

140   attitude. Participants were instructed to respond to the geometric form of the target stimuli as

141   soon as possible under the premise of ensuring the correct response by pressing the appropriately

142   assigned key on a computer keyboard. An image of a circle or a diamond was assigned to the ''f''

143   key, and an image of an ellipsoid or a square was assigned to the ''j'' key. The reaction was

144   counterbalanced across participants; that is, half the participants followed the aforementioned

145   stimulus-response key assignment, and the remaining participants followed the opposite

146   stimulus-response key assignment.

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

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

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

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

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

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

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

154   1500 ms.

155   *(Insert Figure 1 about here)*

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

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

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

159   target included geometric forms belonging to the same response category, and incongruent, for

160   which the prime and target included geometric forms belonging to the different response

161   category. Within each block, half the trials were congruent, and the remaining trials were

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

163   varied across trials to avoid the repetition response priming effect.

164   **2.3.2 Prime identification control task**

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

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

167   priming task. This measure is conducted in an interview. The sequence and content of questions

168   are as following: (1) In addition to the fixation, two random line patterns, and clear geometry

169   forms, what else did you see? (2) Did you see any flashing stimulus between the two random line

170   patterns? (3) What was the flashing do you think? (4)Was the flashing you saw a geometric form?

171   (5) What was the flashing geometry form? In addition, the participants performed an objective

172   measure of prime identification. Apart from 24 practice trials, the prime identification task

173   included 64 trials (32 congruent trials and 32 incongruent trials). Participants were informed of

174   the existence of the prime. The prime identification task procedure was identical to the masked

175   priming task in that participants were asked to respond to the geometric form of the primes with

176   the same stimulus-response key assignment as was used for the priming task. There was no time

177   pressure for participants in the prime identification task. Participants were required to make their

178   best guess when they were unable to determine the form of the primes.

179   **2.4 Statistical analysis**

180   **2.4.1 Identification rates**

181   We used the statistic d' as a signal detection measure to assess prime visibility. Consistent with

182   the work of Green and Swets (1966), the present study considered a correct response to the target

183   stimulus on a congruent trial a hit and an erroneous response to the target stimulus on an

184   incongruent trial a false alarm (Kiefer & Martens, 2010). The hit rates and false-alarm rates were

185   calculated for each participant, and the identification rate d' was calculated from each

186   participant's hit and false-alarm rates.

187   To obtain an objective measure of the ability to identify the geometric prime form presented

188   between the two masks, one-sample t-tests were performed to determine whether the

189   identification performances of athletes and non-athletes were distributed around the level of

190   chance, that is, at 50% (which is indicated by $d' = 0$). We then compared the identification rates

191   (d') between athletes and non-athletes through independent t-tests. The Bayes Factor was

192   employed to evaluate the null-hypothesis (a Cauchy distribution (scale = 0.707) as prior to one-

193   sample t-test). To rule out that any unconscious response priming effect observed among athletes

194   correlated with prime visibility, Pearson's correlation between the identification rate d' and the

195   size of the unconscious response priming effect was performed for the group of athletes.

196   **2.4.2 Reaction times and response errors**

197   To minimize errors caused by incorrect and extreme values, incorrect and missed trials

198   (17.52%) and reaction times (RTs) that deviated by more or less than three standard deviations

199   (0.83%) were removed from further analysis. The mean RT of the correct responses and the

200   mean error rates (ERs) were calculated for each participant and each experimental condition.

201   Two-way repeated-measures analyses of variance (ANOVAs) were used to examine the mean

202   RTs and ERs, with the within-subjects factor being response congruency (congruent vs.

203   incongruent) and the between-subjects factor being expertise (athletes vs. non-athletes).

2.4.3 The strength of the unconscious response priming effect

To better illustrate whether the effect of motor expertise on unconscious processing could be transferred from a sports-specific domain to a general domain, we, firstly, selected the 19 athletes (6 females; mean age, 20.63 years with a range of 18-23 years) and 17 non-athletes (5 females; mean age, 20.06 years with a range of 18-22 years), all of them have participated in the present study with general stimuli, as well as the previous study with sport-specific stimuli. Then, the strength of the unconscious response priming effect (the reaction time on incongruent trials minus the reaction time on congruent trials) was calculated for each participant and each experimental condition. Two-way repeated-measures analyses of variance (ANOVAs) were used to examine the strength of the unconscious response priming effect, with the within-subject factor being stimulation type (general stimuli vs. sport-specific stimuli) and the between-subjects factor being expertise (athletes vs. non-athletes).

3. Results

3.1 Prime visibility

During the subjective measurement, 10 athletes and 7 non-athletes reported that they saw some images between the random lines patterns, but the exact content of the images was unknown. Additionally, four athletes and two non-athletes reported that they saw some regular forms, but it was not clear what the forms were. The other participants didn't perceive any image except the fixation, random lines patterns, and clear geometry.

The signal detection analysis on the performance of participants to identify the masked primes indicated that for athletes d' was 0.14, which did not deviate significantly from zero ($t_{(24)} = 0.97$, $p = 0.341$). In addition, for non-athletes, d' was 0.06, which also did not differ significantly from zero ($t_{(25)} = 0.81$, $p = 0.425$). Furthermore, no significant difference was found between the d' values of athletes and non-athletes ($t_{(49)} = 0.48$, $p = 0.636$). These results indicated that neither athletes nor non-athletes could consciously perceive the masked primes.

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

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

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

232   response priming effect did not correlate with each other (r(25) = −0.19, p = 0.377), suggesting

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

234   of the masked primes.

235   **3.2 Reaction times and response errors**

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

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

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

239   0.15). A simple effects analysis of the interaction showed that athletes responded faster on

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

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

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

243   9.56 ms; incongruent, 501.41 ± 8.82 ms; p = 0.734). In addition, the main effect of expertise did

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

245   *(Insert Figure 2 about here)*

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

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

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

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

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

251   incongruent, 26.36% ± 2.08%; p = 0.001). By contrast, there was no significance difference in

252   ERs between congruent and incongruent trials for non-athletes (congruent, 14.27% ± 1.56%;

253 incongruent, 16.00% ± 2.04%; $p = 0.572$). For expertise, athletes committed more errors than

254 non-athletes on incongruent trials (athletes, 26.36% ± 2.08%; non-athletes, 16.00% ± 2.04%; $p =$

255 0.00), but not on congruent trials (athletes, 13.00% ± 1.59%; non-athletes, 14.27% ± 1.56%%; p

256 $= 0.315$). However, the main effect of expertise did not reach significance ($F_{(1,49)} = 3.94$; $p =$

257 0.053; $\eta_p^2 = 0.07$) (Fig. 3).

258 *(Insert Figure 3 about here)*

259 **3.3 The strength of the unconscious response priming effect**

260 The results of a two-way repeated-measures ANOVA examining the strength of the

261 unconscious response priming effect revealed a significant main effect of expertise ($F_{(1,34)} =$

262 12.58; $p = 0.001$; $\eta_p^2 = 0.27$). The strength of the unconscious response priming effect that

263 athletes showed is higher than non-athletes (athletes, 15.13 ± 2.65 ms; non-athletes, 1.46 ±

264 2.80 ms). The main effect of stimulation type did not reach statistical significance ($F_{(1,34)} = 0.05$;

265 $p = 0.818$; $\eta_p^2 = 0.00$). The interaction between expertise and stimulation type did not reach

266 statistical significance ($F_{(1,34)} = 1.51$; $p = 0.228$; $\eta_p^2 = 0.04$) (Fig. 4).

267 *(Insert Figure 4 about here)*

268 **4. Discussion**

269 Although unconscious information processing among athletes is reportedly better than that of

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

271 show superior unconscious information processing in the general domain. Thus, to determine

272 whether motor expertise is associated with unconscious information processing in the general

273 domain, we compared the performance on a masked priming task that used geometric forms as

274 prime and target stimuli in a group of competitive table tennis players who had extensive motor

275 expertise with that of a group of college students who had no specific motor expertise. Our

276   primary results showed that athletes responded faster and committed fewer errors on trials in

277   which the prime and target stimuli were congruent (i.e., required the same response) than on

278   trials in which they were incongruent. By contrast, there was no significant difference in reaction

279   times or error rates between congruent and incongruent trials for non-athletes. Moreover, athletes

280   showed significant unconscious response priming effect both in the masked priming task with

281   general stimuli and the masked priming task with sport-specific stimuli.

282   Athletes showed a significant unconscious response priming effect, and suggesting that

283   athletes exhibited superior unconscious information processing. This finding is consistent with

284   the results of a previous study that has shown that motor expertise promotes unconscious

285   response inhibition in the general cognitive domain (You et al., 2018). We speculate that this

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

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

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

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

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

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

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

293   With such time pressure, the decisions made by competitive athletes are usually without any

294   explicit evaluation of the perceived information (Raab & Johnson, 2008; Williams & Ward,

295   2007). Table tennis is an open skills sport in which athletes are required to react in a dynamically

296   changing environment, and likely because of their years of training, these athletes show more

297   unconscious behaviors compared with non-athletes (Wang et al., 2013; Yu, Chan, Chau, & Fu,

298   2017). Besides, we further found that the strength of the unconscious response priming effect

299   among athletes was not affected by stimulation type, suggesting that the effect of motor expertise

300   on unconscious processing can be transferred from a sports-specific domain to a general domain.

301   The masked priming paradigm used in the present study closely replicated the time pressure of

302   an open skills sport and was favorable for the performance of the athletes.

303   Schütz-Bosbach and Prinz (2007) have suggested that perceptual sensitivity is a prerequisite

304   for unconscious processing. We selected geometric forms as prime and target stimuli because

305   they are considered well-known to most people (Kiesel et al., 2009). Thus, we believed that both

306   athletes and non-athletes would show high perceptual sensitivity to these geometric forms.

307   However, our results showed that only athletes exhibited a significant unconscious response

308   priming effect whereas the non-athletes did not. This result was in line with Guo et al. (2017),

309   which found that whether it was sport-specific stimuli or general stimuli, table tennis players had

310   better performance in perceptual observation and motion control compared to non-athletes.

311   According to the results of the present study and previous research, we speculated that athletes

312   may have higher perceptual sensitivity to geometric forms in comparison with non-athletes. In

313   order to accurately judge the flight trajectory of the ball, spinning and land point, table tennis

314   players may rely heavily on visual imagery system, where the athletes processed movement

315   information through image coding, during daily training and competition. So it may be the case

316   that athletes with extensive special training showed higher perceptual sensitivity to the sport-

317   specific stimuli and general geometric forms compared to non-athletes.

318   In fast-ball sports, the perception-action coupling capacities may play a critical role in motor

319   expertise (Ranganathan, & Carlton, 2007), and these capacities are not limited to sport-specific

320   scenarios, which can also differentiate athletes and non-athletes in general cognitive tasks

321   (Mallek, Benguigui, Dicks, & Thouvarecq, 2017). In the present study,   compared with the

322   number of words used as prime and target stimuli in previous studies (Martens, Ansorge, &

323   Kiefer, 2011; Ulrich, Adams, & Kiefer, 2014), the number of geometric forms used in the

324   present study was small, and each geometric shape had a unique physical feature. Participants

325   can store the geometric forms and their corresponding reactions in their working memory, and

326   then form a stimulus-reaction connection between the stimuli and reactions (Kiesel, Kunde, Poh,

327   & Hoffmann, 2006; Wang, Huo, & Wang, 2012). The present results indicated that the

328   performance of athletes was significantly influenced by the presentation of the geometric forms

329   despite their perception being unconscious, whereas the performance of non-athletes was not

330   affected by the presence of geometric forms. This result may be because athletes established an

331   unconscious association between the stimuli and motor responses, whereas the non-athletes did

332   not. Thus, the motor reactions of the athletes would be facilitated or disrupted by the

333   unconsciously perceived primes. In other words, the unconsciously perceived geometric shapes

334   could have activated the previously established stimulus-response assignment and triggered a

335   motor response when the prime and target were congruent. The response to the target would be

336   facilitated because it was pre-activated by the prime. By contrast, when the prime and target

337   stimuli required a different response (i.e., were incongruent), the response to the target would be

338   interfered because the pre-activated response was inconsistent with the required target response.

339   Athletes need to timely inhabit the incorrect motor response tendency, retrieving the appropriate

340   stimulus-response assignment. Hence, athletes responded faster and committed fewer errors on

341   congruent trials than on incongruent trials. In the present study, athletes could learn the rules

342   faster and better than non-athletes. Then a stable unconscious connection between the stimuli and

343   motor response was established. By contrast, this connection was not stable in non-athletes and

344   did not reach to an automatic level. Thus, the stimuli presented below the threshold of

345   consciousness didn't influence on the performance of non-athletes. Although there was no

346   unconscious response priming effect for non-athletes, the results of error rates showed that non-

347   athletes committed more errors on incongruent trials in comparison with that on congruent trials,

348   which displayed a tendency for a similar result with athletes. An aposteriori sample size based on

349   the effect sizes of error rates was calculated in Gpower3.1, the result showed that a minimum of

350   80 participants was needed with $\alpha=0.05$, power $= 0.80$, effect size $= 0.32$. In order to find an

351   equivalent main effect of response congruency, more non-athletes would be needed in future

352   studies. Also, we found that the error rates among athletes were higher than those among non-

353   athletes on incongruent trials, suggesting that the conflict that was unconsciously perceived by

354   athletes was stronger than non-athletes. Moreover, the influence of the geometric forms

355   presented unconsciously mainly on the incongruent trials.

356   Our results showed that non-athletes did not exhibit a significant unconscious response

357   priming effect. However, this finding was inconsistent with previous studies (Klotz & Neumann,

358   1999; Neumann & Klotz, 1994; Ulrich & Kiefer, 2016). For instance, the study of Klotz and

359   Neumann (1999) who found a significant unconscious response priming effect among normal

360   subjects also used geometric stimuli, suggested that motor activation could be trigged without

361   conscious discrimination. We speculated that the reason for the inconsistent results between us

362   and Klotz and Neumann (1999) might be the task difficulty. For one aspect, only two geometric

363   forms were used in the study of Klotz and Neumann (1999), resulting in the possible prime-

364   target combinations were fewer than our current study. For another aspect, participants made a

365   response according to the spatial position of the target (e.g., if the target on the right, participants

366   made a response by pressing the right bottom). Thus, we believed that the task in the present

367   study was more difficult than the study of Klotz and Neumann (1999). This is in line with the

368   study of Kibele (2001, 2006) who thought that unconscious information processing was

369   obstructed in complex tasks. Similarly, to study the neural signature of the unconscious response

370   priming effect, Ulrich and Kiefer (2016) recruited college students to participant in a masked

371   priming task that also used geometric forms. They found that the difference between congruent

372   and incongruent trials was significant in RT, the RT range is 569-593 ms. In contrast, the

373   difference was not significant in ER because of slow decisions. In the present study, the RT

374   range is 500-501 ms, indicating that non-athletes focused on the current task and made the rapid

375   response. So, it is possible that non-athletes would show an unconscious response priming effect

376   if they made slower responses and committed fewer errors that is comparable to Ulrich and

377   Kiefer (2016). Although participants were normal subjects in both studies, the reaction strategies

378   of these two groups might be different. Compared with the different results and based on the

379   previous researches we speculated that the group difference might also be responsible for the

380   inconsistent results. Notably, the researcher found that individual difference or group difference

381   was an important factor in unconscious rewards (Braver, Cole, & Yarkoni, 2010; Capa &

382   Bouquet, 2018) and unconscious response conflict (Van Gaal, Scholte, Lamme, Fahrenfort, &

383   Ridderinkhof, 2011). Future studies could systematically explore the effect of individual

384   differences or group differences on unconscious information processing both in the general and

385   sport-specific domain.

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

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

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

389   information processing in the general domain. This finding suggests that the influence of motor

390   expertise on unconscious information processing is transferable from the sports-specific domain

391   to the general cognitive domain.

392   **5. Limitations**

393   The present study had some limitations. Firstly, participants might feel too difficult to

394   complete the task with full effort during the objective threshold measurement in the assessment

395   of whether or not participants consciously perceived the prime. Thus, subjective threshold

396   measurements such as the 5-point Likert scale should be considered in the future study because it

397   can contribute to a more enhanced data precision in comparison to the interview in the prime

398   identification task. Secondly, the athletes played table tennis, which is an open skills sport. In

399   order to better identify the facilitation of motor expertise on unconscious information processing

400   in the general cognitive domain, athletes who play closed skills sports should also be recruited in

401   future studies. Thirdly, although the present study described the influence of motor expertise on

402   the unconscious executive control of the general domain on a behavior level, the neural signature

403   of this phenomenon remains unclear and warrants future exploration.

404   **6. Conclusions**

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

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

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

408

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542

Figure 1

The masked priming task

Trial sequence of the masked priming task.
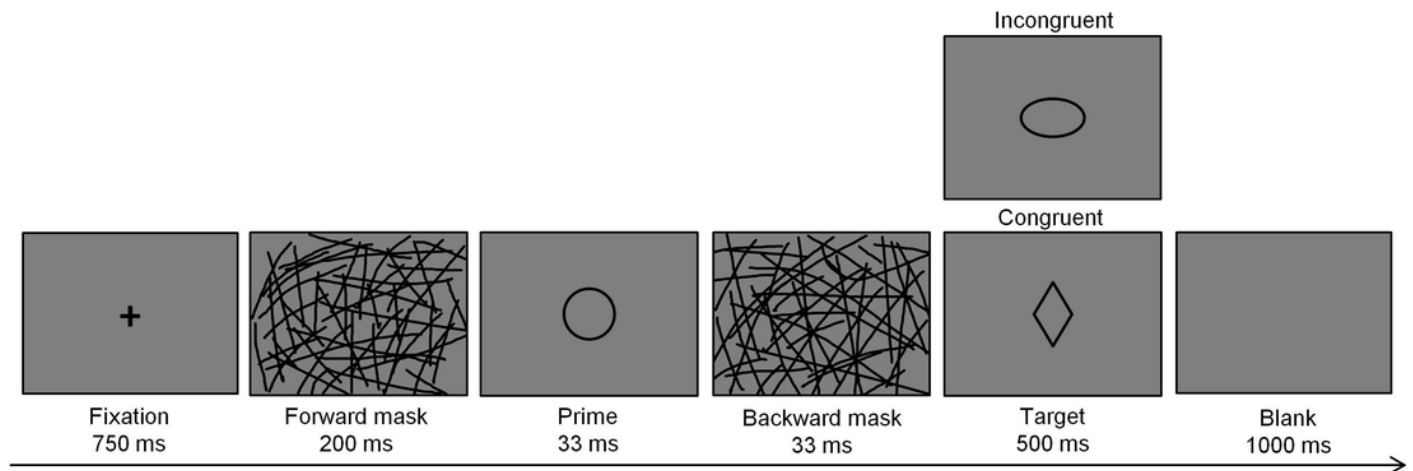
Figure 2

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.
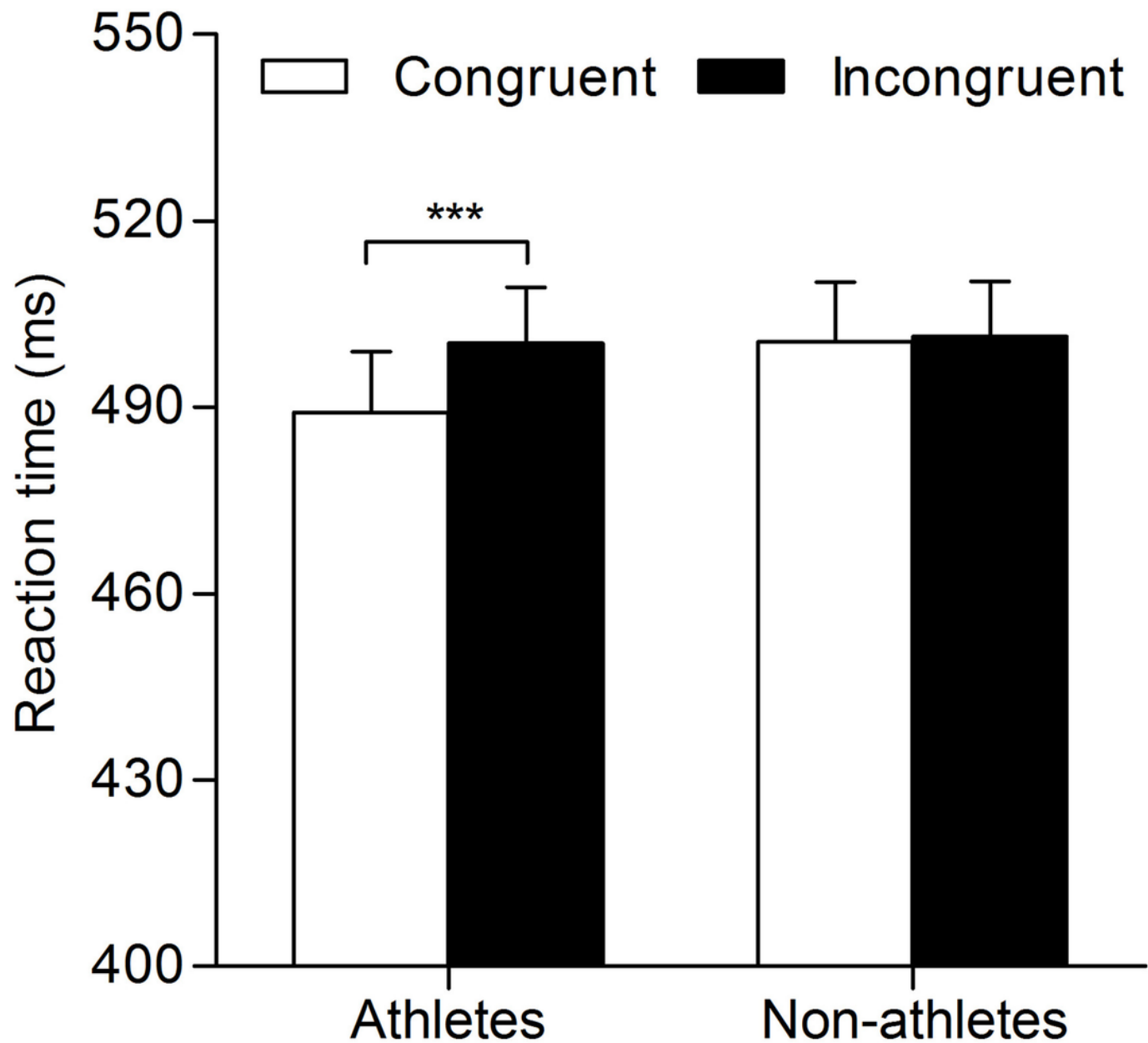
Figure 3

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.
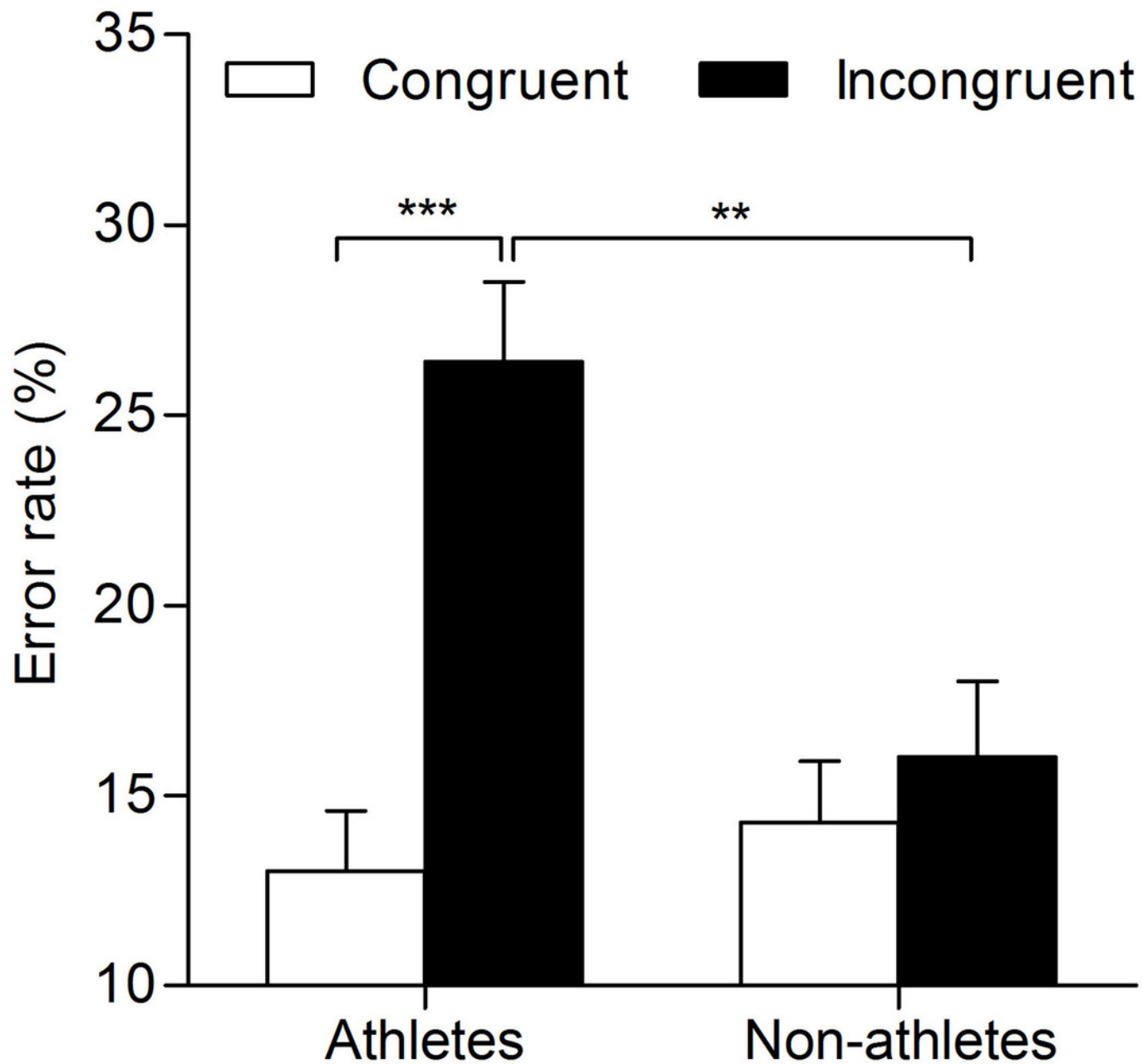
Figure 4

Mean strength of unconscious response priming effect in the masked priming task with general stimuli and sport-specific stimuli for athletes and non-athletes.

The vertical bars represent mean strength of unconscious response priming effect as a function of stimulation type and expertise. White bars represent the strength of unconscious response priming effect of general stimuli, and black bars represent the strength of unconscious response priming effect of sport-specific stimuli.