Selective enhancement of attentional networks in college table tennis athletes: a preliminary investigation

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The purpose of the study was to investigate the characteristics of the attentional network in college table tennis athletes. A total of 65 college students categorized as table tennis athlete group or non-athlete group participated in the study. All participants completed the attentional network test (ANT) which measured the alerting, orienting and executive control networks. The results showed a significant difference between the athlete and non-athlete group for executive control network ($p < 0.01$), while no differences were observed for alerting ($p > 0.05$) or orienting ($p > 0.05$) networks. These results combined suggest that college table tennis athletes exhibited selectively enhanced executive control of attentional networks.

1   **Selective Enhancement of Attentional Networks in College Table Tennis**

2   **Athletes: A Preliminary Investigation**

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11   **Abstract**

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13   athletes. A total of 65 college students categorized as table tennis athletes or non-athletes participated in the

14   study. All participants completed the attentional network test (ANT) which measured the alerting, orienting

15   and executive control networks. The results showed a significant difference between the athlete and non-

16   athlete group for executive control network ($p < 0.01$), while no differences were observed for alerting ($p > 0.05$)

17   or orienting ($p > 0.05$) networks. These results combined suggest that college table tennis athletes exhibited

18   selectively enhanced executive control of attentional networks.

19   **1 Introduction**

20   The ability to selectively focus on the relevant information while ignoring irrelevant information is a basic

21   function of our brain to ensure that we can interact with the environment effectively. This ability requires

22   attention, which is a core function of cognitive system and regulates other cognitive functions such as memory

23   and language (Posner & Petersen, 1990). More specifically, attention plays an important role in sports (Williams

24   & Davids, 1999). Obviously, it is crucial for most athletes to choose the important information to process in an

25   extreme short period of time in a competition context (Allard, Brawley, Deakin, & Elliot, 1989). And it would

26   be difficult to achieve any goals for athletes with easily disturbed attention. Thus, it is reasonable to speculate

27   that the sport-specific attentional function may develop better in athletes, relative to non-athletes. However, it is

28   still unclear whether the athletes may have a better general attentional function (Voss, Kramer, Basak, Prakash,

29   & Roberts, 2010). So the present study focused on the transfer of sport-specific attentional function to general

30   attentional function. Indeed, several studies have already focused on the possible relationship between athlete

31   experience and general attentional function in a laboratory setting (Enns & Richards, 1997; Memmert, 2009;

32   Memmert, Simons, & Grimme, 2009; Nougier, Azemar, Stein, & Ripoll, 1992). However, these kind of studies

33   yielded mixed results due to variation in laboratory attentional tasks (Voss et al., 2010). The attentional network

34   test (ANT) developed by Fan et al. (2002) is one of the most dominant attention paradigms and seems to be

35   appropriate for this kind of study (Fan, McCandliss, Sommer, Raz, & Posner, 2002). It is a short and simple

36   computerized task that measures the attentional networks independently. The task was based on the well-known

37   attention network theory proposed by Posner and Petersen (Petersen & Posner, 2012; Posner & Petersen, 1990).

38   According to this theory, the attention system could be divided into three different networks: alerting network,

39   orienting network and executive control network. Each of them representing a set of certain attentional functions

40   and little overlap between the three networks was revealed by a neuroimaging analysis (Fan, McCandliss,

41   Fossella, Flombaum, & Posner, 2005). The alerting network is related to maintenance of certain levels of arousal

42   and sustained vigilance, the orienting network allows selection of information from multiple sensory inputs, and

43   the executive control network is related to the ability to monitor and resolve conflict (Petersen & Posner, 2012;

44   Posner & Petersen, 1990).

45   Although few studies have explored the three attentional networks of athletes in one experiment using the

46   ANT, there is some evidence showing the characteristics of alerting, orientation or executive control in athletes

47   in different studies. The alerting and orientation ability of athletes is mainly measured by the spatial cueing

48   paradigm (Posner & Fan, 2008). For example, Enns and Richards (1997) used different cue-target intervals to

49   investigate the alerting effect. The results revealed that athletes sustained a high level of alertness over the longest

50   cue-target interval (Enns & Richards, 1997). Cereatti et al. (2009) observed athletes outperform non-athletes on

51   the voluntary orientation of attention (Cereatti, Casella, Manganelli, & Pesce, 2009). Studies have also

52   demonstrated athletes to exhibit higher proficiency on tasks testing executive function (Jacobson & Matthaeus;

53   2014; Vestberg, Gustafson, Maurex, Ingvar, & Petrovic, 2012; Verburgh, Scherder, van Lange, & Oosterlaan,

54   2014). For example, Jocobson and Matthaeus (2014) revealed that athletes performed better than non-athletes

55   on a problem solving as well as an inhibition task, suggesting that athletes achieved better executive control

56   ability.

57   This study was designed to investigate the association between sports training experiences and the

58   modulation of attentional network functions. It could, to some extent, answer a basic question in brain plasticity

59   research whether an individual's experience can affect the attentional process. Athletes are one of the most

60   suitable models to investigate this question because of their unique experience. Compared with non-athletes,

61   most of them trained with larger amount regularly for several years. Although it seems that previous studies have

62   already focused on this topic for decades, the present study and these studies differ in many aspects. Firstly,

63   athletes from one of the typical open-skilled sports, table tennis, served as the athlete group in this study. Previous

64   studies mainly explored the attentional function of athletes from closed-skill sports (e.g. swimming, running)

65   rather than athletes from open-skilled sports (e.g. tennis, table tennis) (Voss et al., 2010). Compared to closed-

66   skill sports, open-skill sports require individuals to invest higher cognitive effort in the unpredictable

67   environment which may serve as cognitive training to enhance the attention skill (Tang & Posner, 2009). It has

68   been shown that open-skill athletes are more flexible in visual attention, decision making, inhibition, and

69   working memory, compared to closed-skill athletes (Voss et al., 2010; Wang et al., 2013; Heppe, Kohler,

70   Fleddermann, & Zentgraf, 2016). Secondly, the attentional network test (ANT) was adopted in this study to

71   evaluate the efficiencies of the three attention networks in one experiment, it is more efficient than the battery

72   of attention test mainly used in previous studies because the ANT requires only about 15 min to complete, and

there are very little overlaps among the three networks. It has been widely used in certain clinical populations, however few studies have investigated the differences between athletes and non-athletes on the ANT. To the best of our knowledge, this is the first study to investigate the characteristics of table tennis athlete's attentional networks with the ANT.

The present study aimed to investigate the characteristics of the attentional network in college table tennis athletes using the ANT. Although previous studies have indicated that chronic exercise (Pérez, Padilla, Parmentier, & Andrés, 2013) and acute exercise (Chang, Pesce, Chiang, Kuo, & Fong, 2015) improve the performance on ANT in non-athletes, this was the first study to our knowledge to adopt table tennis athletes as the participants. There are three reasons for choosing table tennis athletes as the participants. Firstly, table tennis is one of the fastest ball sports and the response window dictated by the ball speed is very brief. The table tennis athletes have to use advanced cues to decide what response is required as soon as possible (Padulo et al., 2015), and therefore, they would develop superior alerting and orienting ability. Secondly, table tennis is a highly developed tactical skill, involving creativity, concentration, competitiveness, apprehension, self-regulation, and will power (Raab, Masters, & Maxwell, 2005). Table tennis athletes compete in a dynamically changing, unpredictable, and externally-paced environment which may lead to better executive control ability. Thirdly, table tennis is one of the most popular sports in China. Table tennis athletes are trained systematically and have a high competition level, so they are the perfect samples to investigate the relationship between athlete training experience and attentional function. Based on the results of previews studies which focused on the three networks of attention separately, it was hypothesized that athletes would perform better on the alerting, orientation and executive network than non-athletes.

2 Method

2.1 Participants

A total of 65 individuals categorized as athletes or non-athletes participated in the study. They were recruited through advertisements posted in the campus of Shanghai University of Sport. The athlete group was composed of 31 table tennis players (mean age = 21.9, ranging from 19 to 25, 11 females) whom satisfied all of the following criteria: (1) had 5 or more years of professional training experience, (2) qualified as the National Player at Second Grade or above, (3) trained more than three times a week in the last 2 years, (4) trained for 2 or more hours each time. The non-athlete group was composed of 35 students (mean age =21.9, ranging from 19 to 25, 14 females) majoring in psychology or kinesiology. The non-athlete group matched the athlete group in age and education, but they had no experience of playing table tennis, nor any experience of athlete training. The non-athlete group had a moderate physical activity level which was measured by the Taiwan version of the International Physical Activity Questionnaire (IPAQ) (Liou, Jwo, Yao, Chiang, & Huang, 2008). All the participants were right-handed and had normal or corrected to normal visual acuity. No individuals reported having a history of neurological or psychiatric disorder. Written informed consent was obtained from each participant prior to the study. All participants received a payment of approximately $10 for taking part in the experiment. Table 1 shows the main characteristics of the subjects. This study was approved by the Ethics

109   Committee of the Shanghai University of Sport (No. 2015014).

110   **2.2 Attention network test**

111   Attention network test (ANT) was designed to assess the function of the three different attention networks
112   (Fan et al., 2002). A fixation cross was presented in the center of a computer screen at the onset of each trial.
113   After a random interval of 400 to 1600ms, cues would present in one of the four possible conditions: no cue,
114   center cue (the fixation cross was replaced by an asterisk), double cue (two asterisks were respectively displayed
115   above and below the fixation cross), or spatial cue (an asterisk were displayed either above or below the fixation
116   cross). The cues remained visible for 100ms. The presentation of asterisks provided temporal information about
117   the appearance of target stimuli. The asterisk in the spatial cue condition provided additional information about
118   the location of target stimuli. The spatial cues were always valid. The fixation cross was displayed alone for
119   400ms after the disappearance of cue. Then a target stimulus was presented above or below the fixation cross
120   according to the indication of the previous cue. The target stimulus consisted of five horizontally arranged arrows
121   or lines. Participants were required to press the corresponding key to indicate the direction of the central target
122   arrow. The other four arrows or lines served as flankers in the task with three possible conditions: congruent
123   condition (arrows pointed in the same direction as the central arrow), incongruent condition (arrows pointed in
124   the opposite direction of the central arrow), or neutral condition (lines with no direction information). The target
125   stimulus remained on the screen until the participant responded or for 1700ms if no answer was given.
126   The participants were instructed to concentrate on the fixation cross throughout the task. A numeric
127   keyboard was placed in front of the participant and the participant was required to lightly put his left hand index
128   finger on key "1" and right hand index finger on key "3". Once target stimuli were presented, participants were
129   instructed to respond as fast and accurately as possible by pressing the key "1" for left directed central target
130   arrow and pressing the key "3" when the direction was right.
131   Four blocks were included in this test. Each block contained 48 trials based on the combination of four cues
132   conditions (no cue, center cue, double cue, and spatial cue), three flankers' conditions (congruent, incongruent,
133   and neutral), two directions (left or right directed target arrow) and two locations (target displayed above or
134   below the fixation cross). Each trial was presented only once in a block. The stimuli were presented and the data
135   were recorded using Psychtoolbox (Brainard, 1997) (see Fig.1).
136   The three components of attentional network were computed as follows: no cue RTs versus double cue RTs
137   for alerting, central cue RTs versus spatial cue RTs for orienting and congruent flankers RTs versus incongruent
138   flankers RTs for executive network.

139
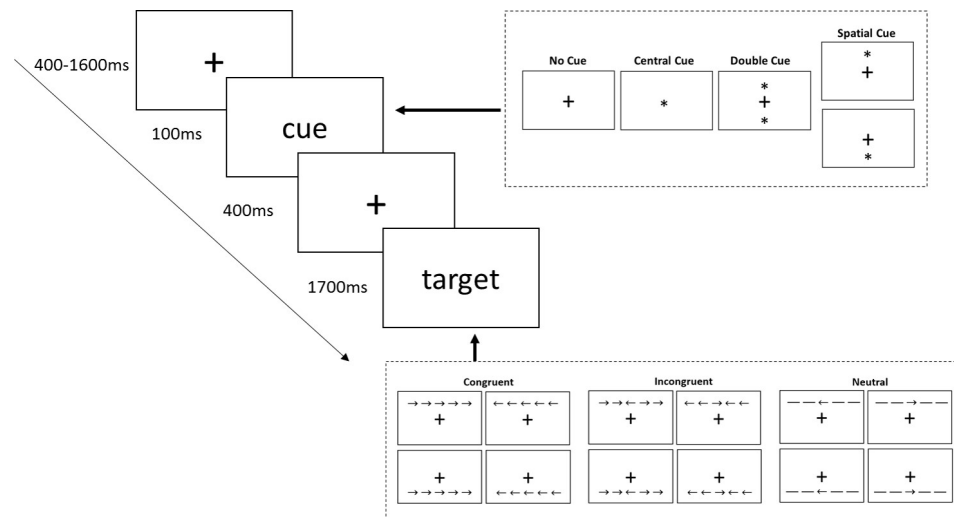
140   **Fig. 1 Stimuli and experimental paradigm of Attention Network Test (ANT)**

141   **2.3 Procedure**

142   As a requirement of the advertisements, all the participants had to contact the researchers by telephone first.
143   A survey about the demographic data of participants was conducted during the call. Athlete participants were
144   further asked about their training experiences. Participants who met the criteria (see 2.1 Participants) were
145   invited to our laboratory on another day to participate in the experiment. They were instructed to abstain from
146   alcohol for 24 hours and from caffeine-containing substances for 12 hours before the experiment.

147   After arriving at the laboratory, participants were asked to sign an informed consent form and were assessed
148   by the Taiwan version of the International Physical Activity Questionnaire (IPAQ). Then the purpose of the
149   study and the instruction of ANT were introduced to them in written form. After participants reported
150   understanding the instructions, they performed the ANT task individually in a dimly lit and quiet room. At first,
151   they had to perform a practice block with 24 random trials. If their response accuracy reached 80%, they could
152   perform their next 4 experimental blocks of 48 trials in each; otherwise, they would perform another practice
153   block until their accuracy reached 80%. Participants were allowed to rest between each block, and they could
154   start the next block by pressing any keys once they felt adequately rested. Completing the whole task required
155   about 17 minutes, including both practice and experimental blocks.

156

157   **2.4 Design and statistical analysis**

158   A mixed factors design was adopted in the study. The athlete and non-athlete group was a between-subjects
159   variable, the cue type (no cue, central cue, double cue and spatial cue) and flankers type (neutral, congruent,
160   incongruent) were within-subject variables. The dependent variables were response times (RTs) and accuracy
161   rates. They were analyzed with a 2 (group) ×4（cue type）× 3（flanker type）mixed-design ANOVA.

162   A t-test between athlete and non-athlete groups was carried out in order to explore the effect of athlete

163   experience on each component of attentional network.

3 Results

3.1 Participant characteristics

166   No significant differences were observed in age ($F_{(1, 63)}$ =0.00, p =0.98), height ($F_{(1, 63)}$ =3.29, p =0.07),
167   weight ($F_{(1, 63)}$ =2.92, p =0.09), BMI ($F_{(1, 63)}$ =0.64, p =0.43), average reaction time ($F_{(1, 63)}$ =1.53, p =0.22) and
168   accuracy rate ($F_{(1, 63)}$ =0.25, p =0.62), and as expected, a significant difference was observed in physical activity
169   level (overall score on IPAQ) ($F_{(1, 63)}$ =4.29, p <0.05) of the two groups (see Table.1).

170   **Table.1 The main characteristics of the subjects in different groups**

	athlete group(n=31)	non-athlete group(n=34)
Female	11	14
Age(yr)	21.90±1.72	21.91±1.80
Height(cm)	1.73±0.08	1.69±0.10
Weight(kg)	65.18±9.38	61.13±9.67
BMI(kg/m^2)	21.69±1.72	21.32±1.95
IPAQ(METs/week)		
Vigorous(METs/week)	3587.09±2372.72	2037.65±5109.58
Moderate(METs/week)	1597.42±1659.15	927.06±1386.74
Walking(METs/week)	1448.47±1763.65	1297.68±1261.23
Overall(METs/week)	6632.99±3808.16	4262.38±5229.69*
Reaction time(ms)	474.33±48.86	487.25±34.56
Accuracy(%)	96.69±1.92	96.92±1.82

171   Note. BMI=body mass index, IPAQ=International Physical Activity Questionnaire, METs=metabolic
172   equivalents.

3.2 Mean RTs

174   For the RTs analysis, the wrong trials or the trials which were 3 standard deviations from the individual
175   mean were excluded in order to exclude the extreme data, and the proportion of excluded data was 1.5%.
176   Results showed a significant main effect of cue type ($F_{(3, 189)}$ =147.56, p <0.01, η_p^2 =0.70), the RTs were the
177   longest in the no cue condition, and the shortest in the spatial cue condition. A significant main effect also
178   observed in flanker type ($F_{(2, 126)}$ =373.52, p <0.01, η_p^2 =0.86). The RTs were longer in the incongruent
179   condition than in the congruent or neutral condition. Furthermore, there were significant interactions between
180   flanker type and cue type ($F_{(6, 378)}$ =6.95, p <0.01, η_p^2 =0.10), group and flanker type ($F_{(2, 126)}$ =5.90, p <0.01,
181   η_p^2 =0.09). The interaction contrasts for flanker type and cue type revealed significant differences between the
182   congruent and incongruent conditions, incongruent conditions and neutral conditions under all cue conditions,
183   no significant differences were observed between congruent and neutral conditions under all cue conditions. The

184 interaction contrast for the group and flanker type revealed significant differences between the groups under
185 incongruent condition, no significant differences were observed between the groups under congruent and neutral
186 conditions. There were no significant main effect of group ($F_{(1, 63)}$ =1.53, p =0.22, η_p^2 =0.02), group × cue type
187 ($F_{(3, 189)}$ =0.51, p =0.68, η_p^2 =0.01) or group × cue type × flanker type ($F_{(6, 378)}$ =0.60, p =0.73, η_p^2 =0.01)
188 interaction. The description data of the mean RTs and standard deviations of athlete and non-athlete group
189 according to the cue and flanker type are shown in Table.2.

190 **Table.2 Mean RTs (ms) and standard deviations of athlete and non-athlete group according to cue and**
191 **flanker type**

|	Congruent		Incongruent		Neutral	
	Athlete	Non-athlete	Athlete	Non-athlete	Athlete	Non-athlete
No cue	478.5±50.9	488.1±37.2	529.4±55.9	551.1±42.2	479.9±53.4	489.3±41.3
Central cue	456.9±48.9	462.1±36.8	517.6±62.2	534.5±43.8	455.6±47.4	464.9±40.6
Double cue	460.8±50.1	464.4±39.3	515.5±55.8	539.6±43.0	456.0±49.6	463.9±41.3
Spatial cue	434.6±52.9	445.5±36.1	472.4±51.4	500.8±43.3	434.5±48.4	442.8±37.0

192

3.3 Accuracy

194   For the accuracy analysis, significant main effects of cue type ($F_{(3, 189)}$ =9.72, p <0.01, η_p^2 =0.13), and
195 flanker type ($F_{(2, 126)}$ =48.29, p <0.01, η_p^2 =0.43) were revealed. Furthermore, there were significant interactions
196 between flanker type and cue type ($F_{(6, 378)}$ =4.80, p <0.01, η_p^2 =0.07). Interaction contrast revealed significant
197 differences between the congruent and incongruent conditions, incongruent conditions and neutral conditions
198 under all cue conditions, no significant differences were observed between congruent and neutral conditions
199 under all cue conditions. There were no significant main effect of group ($F_{(1, 63)}$ =0.25, p =0.62, η_p^2 =0.00),
200 group and flanker type ($F_{(2, 126)}$ =1.60, p =0.21, η_p^2 =0.02), group × cue type ($F_{(3, 189)}$ =0.87, p =0.50, η_p^2 =0.01)
201 or group × cue type × flanker type ($F_{(6, 378)}$ =1.66, p =0.13, η_p^2 =0.01) interaction. The descriptive data of the
202 mean accuracy and standard deviations of athlete and non-athlete group according to the cue and flanker type
203 are shown in Table.3.

204 **Table.3 Mean accuracy (%) and standard deviations of athlete and non-athlete group according to cue**
205 **and flanker type**

	Congruent		Incongruent		Neutral	
	Athlete	Non-athlete	Athlete	Non-athlete	Athlete	Non-athlete
No cue	97.0±4.5	97.8±5.3	93.1±5.9	92.3±6.7	97.4±4.2	98.3±2.8
Central cue	98.8±2.5	98.7±3.0	90.9±9.0	93.2±7.4	98.0±3.0	98.9±2.4
Double cue	99.4±1.9	97.2±4.9	92.5±8.3	94.7±5.4	98.2±2.9	97.4±3.8
Spatial cue	99.6±1.6	98.0±4.3	96.6±4.8	97.4±5.4	98.8±3.0	99.1±2.2

206

3.4 Differences of athletes and non-athletes on the 3 components of attentional network

Independent samples t-tests were carried out for each component of the attentional system (alerting, orienting, and executive networks). Results showed a significant difference between athlete and non-athlete group on executive network ($t_{(63)} = 2.78$, $p < 0.01$), while no differences were observed on alerting ($t_{(63)} = 0.36$, $p = 0.72$) or orientation ($t_{(63)} = -1.13$, $p = 0.27$) networks (see Fig.2).
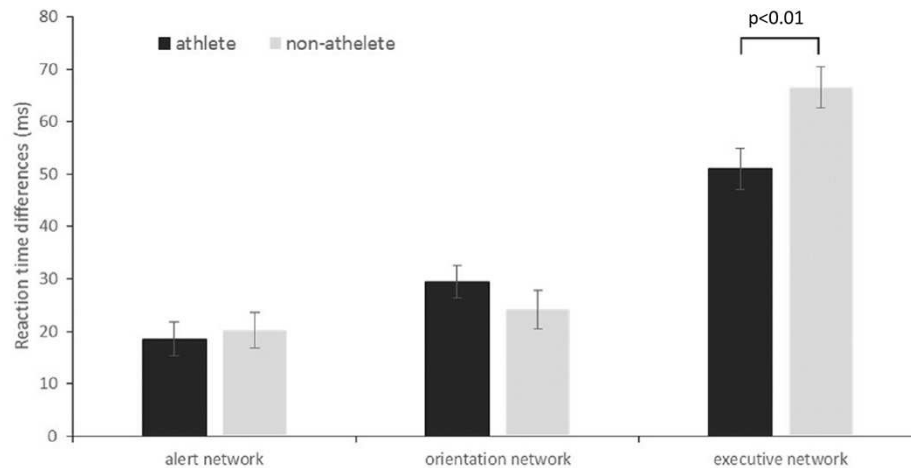
Fig.2 Reaction time differences that reflect the efficiency of the three attentional networks of athlete and non-athlete group (mean±SE). The smaller differences on executive network and the larger differences on alerting and orientation network indicate a better function.

4 Discussion

The aim of the present study was to investigate the relationship between sports training experience and the attentional network using the ANT. Our results showed that the athlete group received a higher score than the non-athlete group on the executive network component, which is consistent with previous findings that have confirmed a positive correlation between executive control and athletic ability (Jacobson & Matthaeus, 2014; Vestberg et al., 2012). A possible reason for the superior executive network function of athletes may be mainly due to the cognitive benefit of physical activity. Also, it has been proposed that exercises performed in the cognitively challenged environment are more effective to induce neural and cognitive benefits than exercise alone (Fabel et al., 2009). Table tennis athletes train and compete in the kind of enrichment environment that includes both physical and mental challenges. However, the present study cannot infer a causal relationship between athletic experience and attentional network function. It is possible that individuals who develop strong executive control skills are more likely to become athletes. Vestberg et al. (2012) suggest that individuals with high executive control ability become athletes more often and the ability further improved with training. It is speculated that the observed differences in attentional network may, at least in part, result from athletic participation.

231   The alerting and orientation of attention are especially important for athletes because they have to keep
232   alerted all the time and orientate their attention quickly to the relevant information in the sporting context.
233   However, the efficiency of the alerting and orientation networks tested by ANT did not differ in athletes and
234   non-athletes in the present study. These results were inconsistent with previous findings, which have revealed
235   that athletes practicing open-skilled sports showed superior ability on the alerting and voluntary orientation of
236   attention than their counterbalanced controlled non-athlete group (Enns & Richards, 1997; Nougier, Azemar,
237   Stein, & Ripoll, 1992). Both of these studies measured the alerting effect by testing more than one stimulus onset
238   asynchrony (SOA) between cue and target, and the orienting effect was measured by comparing the reaction
239   time difference between target stimuli at attended and unattended locations. However, the efficiency of alerting
240   and orientation network tested by ANT were equivalent in athletes and non-athletes in the present study. This is
241   consistent with the meta-analysis by Voss et al. (2010). They found the effects of athlete experience were small
242   and not statistically significant ($g=.17$; $p>.05$) in attentional cuing paradigm which is similar to the alerting and
243   orienting network tests of the ANT in the present study. A possible reason for the inconsistency may be mainly
244   due to the different experimental paradigms. The ANT used in this study is a relative simple task, and the
245   response times for the measurement of orienting might have been affected by a ceiling effect. Also, the
246   participants in the non-athlete group seemed to participate in regular physical exercise which could improve their
247   cognitive function (Voss, Nagamatsu, Liu-Ambrose, & Kramer, 2011).
248   The selective enhancement of the executive control network in athletes is similar to previous studies focused
249   on the effect of chronic exercise or acute exercise on alerting, orientation, and executive control using a similar
250   version of the ANT. Pérez et al. (2014) found a difference between active and passive participants on the
251   executive network while no differences were observed on the alerting and orientation network. Along the same
252   line, Chang et al. (2015) found that rather than eliciting general improvement, a single bout of acute exercise
253   selectively enhanced executive control of attention.
254   The present study also revealed a significant interaction between flanker type and cue type, suggesting that
255   the orientation cue was most effective when conflict resolution was required, while the alerting cue failed to
256   increase the efficiency of executive control. It mirrored the pattern of interactions obtained in an earlier study
257   with adults using the ANT (Fan et al., 2002). The interaction between group and flanker type was consistent with
258   the result that athletes were more efficient on the executive network.
259   Some limitations existed in the present study. Firstly, the cross-sectional design revealed a possible
260   relationship between athletic experience and the attentional network, but it can hardly conclude a causal
261   relationship. Longitudinal studies are needed in the future. Also, all the athlete participants in the study were
262   qualified as the National Player at Second Grade. Athletes in different sport levels (e.g. elite and novice) should
263   be enrolled in a future study to specify the relationship between attentional network and expertise in sports.

264   **Conclusion**

265   In conclusion, college table tennis athletes exhibited selective enhancement of execution control of
266   attentional networks while no differences between athletes and non-athletes were observed in the alerting and
267   orientation networks. It suggests the existence of certain association between sports training experiences and the
268   modulation of the executive control network.

269 **Reference**

270 Allard, F., Brawley, L. R., Deakin, J., & Elliot, F. (1989). The effect of exercise on visual attention performance. Human
271   Performance, 2(2), 131-145.

272 Brainard, D. H. (1997). The Psychophysics Toolbox. Spatial Vision, 10(4), 433-436.

273 Cereatti, L., Casella, R., Manganelli, M., & Pesce, C. (2009). Visual attention in adolescents: Facilitating effects of
274   sport expertise and acute physical exercise. Psychology of Sport & Exercise, 10(1), 136-145.

275 Chang, Y. K., Pesce, C., Chiang, Y. T., Kuo, C. Y., & Fong, D. Y. (2015). Antecedent acute cycling exercise affects
276   attention control: An ERP study using attention network test. Frontiers in Human Neuroscience, 9, 156.

277 Enns, J. T., & Richards, J. C. (1997). Visual Attentional Orienting in Developing Hockey Players. Journal of Experimental
278   Child Psychology, 64(2), 255-275.

279 Fabel, K., Wolf, S. A., Ehninger, D., Babu, H., Leal-Galicia, P., & Kempermann, G. (2009). Additive effects of physical
280   exercise and environmental enrichment on adult hippocampal neurogenesis in mice. Frontiers in Neuroscience,
281   3, 1-7.

282 Fan, J., McCandliss, B. D., Fossella, J., Flombaum, J. I., & Posner, M. I. (2005). The activation of attentional networks.
283   Neuroimage, 26(2), 471-479. doi: 10.1016/j.neuroimage.2005.02.004

284 Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of
285   attentional networks. Journal of cognitive neuroscience, 14(3), 340-347. doi: 10.1162/089892902317361886

286 Heppe, H., Kohler, A., Fleddermann, M. T., & Zentgraf, K. (2016). The Relationship between Expertise in Sports,
287   Visuospatial, and Basic Cognitive Skills. Frontiers in Psychology, 7, 904. doi: 10.3389/fpsyg.2016.00904

288 Jacobson, J., & Matthaeus, L. (2014). Athletics and executive functioning: How athletic participation and sport type
289   correlate with cognitive performance. Psychology of Sport & Exercise, 15(5), 521-527.

290 Liou, Y. M., Jwo, C. J., Yao, K. G., Chiang, L. C., & Huang, L. H. (2008). Selection of appropriate Chinese terms to
291   represent intensity and types of physical activity terms for use in the Taiwan version of IPAQ. Journal of Nursing
292   Research, 16(4), 252-263.

293 Memmert, D. (2009). Pay attention! A review of visual attentional expertise in sport. Parasitology Today, 2(12), 360-
294   361.

295 Memmert, D., Simons, D. J., & Grimme, T. (2009). The relationship between visual attention and expertise in sports.
296   Psychology of Sport & Exercise, 10(1), 146-151.

297 Nougier, V., Azemar, G., Stein, J. F., & Ripoll, H. (1992). Covert orienting to central visual cues and sport practice
298   relations in the development of visual attention. Journal of Experimental Child Psychology, 54(3), 315–333.

299 Padulo, J., Pizzolato, F., Tosi, R. S., Migliaccio, G. M., Attene, G., Curcio, R., & Moura, Z. A. (2015). Task complexity
300   reveals expertise of table tennis players. Journal of Sports Medicine & Physical Fitness, 56(1-2), 149-156.

301 Pérez, L., Padilla, C., Parmentier, F. B., & Andrés, P. (2013). The Effects of Chronic Exercise on Attentional Networks.
302   Plos One, 9(7), e101478.

303 Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. Annual Review of
304   Neuroscience, 35, 73.

305 Posner, M. I., & Petersen, S. E. (1990). The Attention System of the Human Brain. Annual Review of Neuroscience,
306   13(1), 25-42.

307 Posner, M. I., & Fan, J. (2008). Attention as an organ system. Topics in integrative neuroscience, 31-61.

308 Raab, M., Masters, R. S. W., & Maxwell, J. P. (2005). Improving the 'how' and 'what' decisions of elite table tennis
309   players. Human Movement Science, 24(3), 326-344.
310 Tang, Y. Y., & Posner, M. I. (2009). Attention training and attention state training. Trends in cognitive sciences, 13(5),
311   222-227. doi: 10.1016/j.tics.2009.01.009
312 Verburgh, L., Scherder, E. J., van Lange, P. A., & Oosterlaan, J. (2014). Executive functioning in highly talented soccer
313   players. Plos One, 9(3), e91254. doi: 10.1371/journal.pone.0091254
314 Vestberg, T., Gustafson, R., Maurex, L., Ingvar, M., & Petrovic, P. (2012). Executive functions predict the success of
315   top-soccer players. Plos one, 7(4), e34731.
316 Voss, M. W., Kramer, A. F., Basak, C., Prakash, R. S., & Roberts, B. (2010). Are expert athletes 'expert' in the cognitive
317   laboratory? A meta-analytic review of cognition and sport expertise. Applied Cognitive Psychology, 24(6), 812-
318   826.
319 Voss, M. W., Nagamatsu, L. S., Liu-Ambrose, T., & Kramer, A. F. (2011). Exercise, brain, and cognition across the life
320   span. Journal of Applied Physiology, 111(5), 1505-1513.
321 Wang, C. H., Chang, C. C., Liang, Y. M., Shih, C. M., Chiu, W. S., Tseng, P., ... & Juan, C. H. (2013). Open vs. closed skill
322   sports and the modulation of inhibitory control. PloS one, 8(2), e55773.
323 Williams, A. M., & Davids, K. (1999). Visual perception and action in sport. E&FN Spon.
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Figure 1

Stimuli and experimental paradigm of Attention Network Test (ANT)
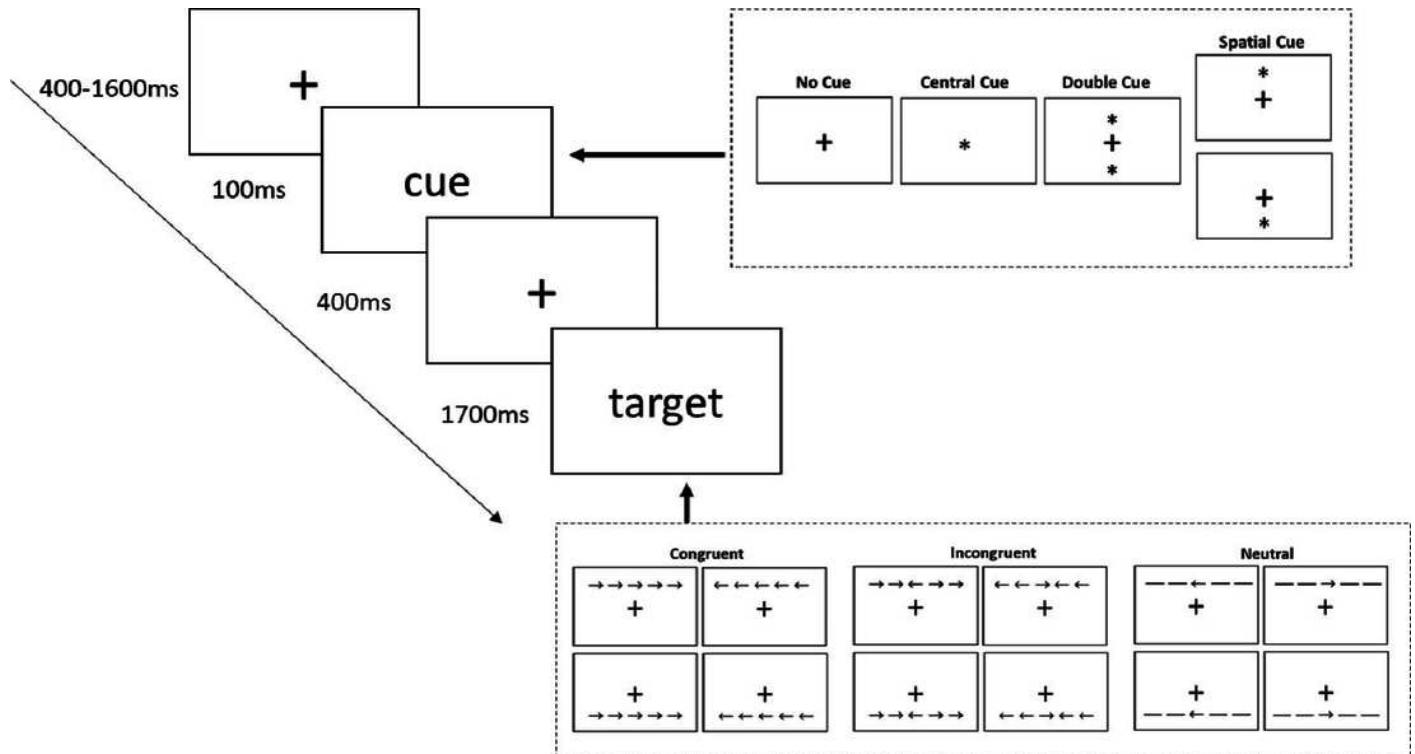
Table 1(on next page)

The main characteristics of the subjects in different groups

1   **Table.1 The main characteristics of the subjects in different groups**
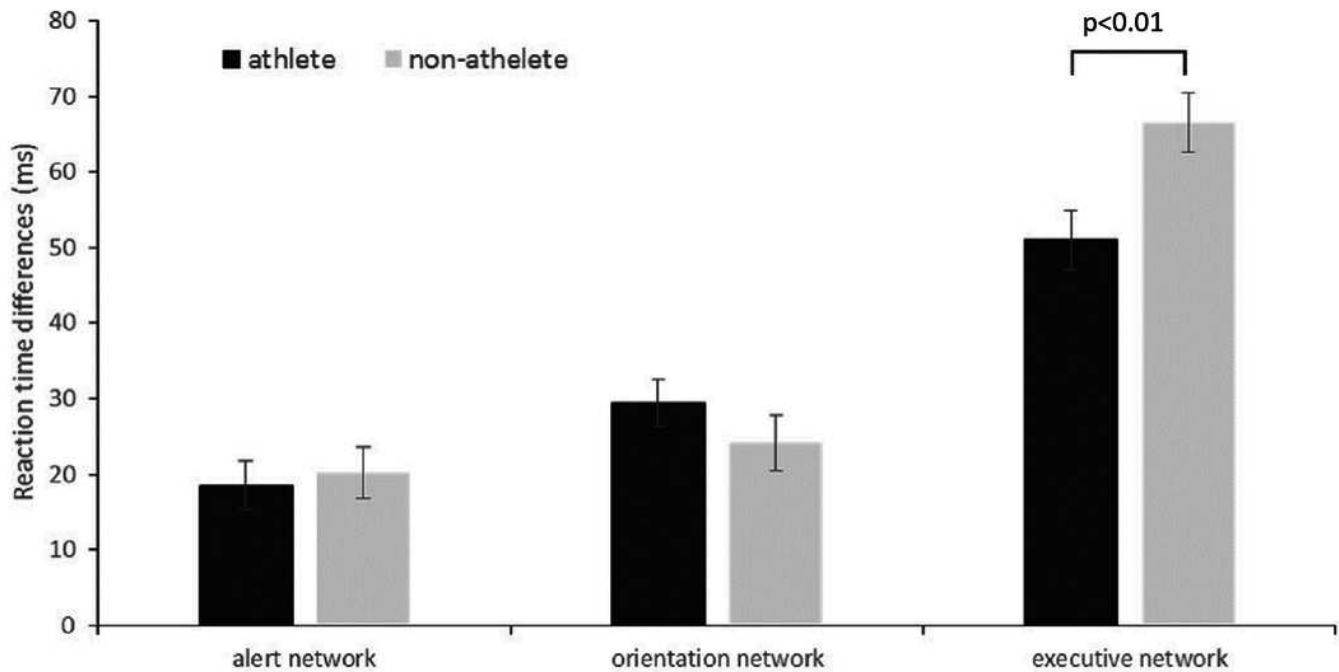
	athlete group(n=31)	non-athlete group(n=34)
Female	11	14
Age(yr)	21.90±1.72	21.91±1.80
Height(cm)	1.73±0.08	1.69±0.10
Weight(kg)	65.18±9.38	61.13±9.67
BMI(kg/m^2)	21.69±1.72	21.32±1.95
IPAQ(METs/week)		
Vigorous(METs/week)	3587.09±2372.72	2037.65±5109.58
Moderate(METs/week)	1597.42±1659.15	927.06±1386.74
Walking(METs/week)	1448.47±1763.65	1297.68±1261.23
Overall(METs/week)	6632.99±3808.16	4262.38±5229.69*
Reaction time(ms)	474.33±48.86	487.25±34.56
Accuracy(%)	96.69±1.92	96.92±1.82

2   Note. BMI=body mass index, IPAQ=International Physical Activity Questionnaire, METs=metabolic

3   equivalents.

4

Figure 2

Reaction time differences that reflect the efficiency of the three attentional networks of athlete and non-athlete group.

Table 2(on next page)

Mean RTs (ms) and standard deviations of athlete and non-athlete group according to cue and flanker type

1 **Table.2 Mean RTs (ms) and standard deviations of athlete and non-athlete group according to cue and**

2 **flanker type**

	Congruent		Incongruent		Neutral	
	Athlete	Non-athlete	Athlete	Non-athlete	Athlete	Non-athlete
No cue	478.5±50.9	488.1±37.2	529.4±55.9	551.1±42.2	479.9±53.4	489.3±41.3
Central cue	456.9±48.9	462.1±36.8	517.6±62.2	534.5±43.8	455.6±47.4	464.9±40.6
Double cue	460.8±50.1	464.4±39.3	515.5±55.8	539.6±43.0	456.0±49.6	463.9±41.3
Spatial cue	434.6±52.9	445.5±36.1	472.4±51.4	500.8±43.3	434.5±48.4	442.8±37.0

3

Table 3(on next page)

Mean accuracy (%) and standard deviations of athlete and non-athlete group according to cue and flanker type

1 **Table.3 Mean accuracy (%) and standard deviations of athlete and non-athlete group according to cue**
2 **and flanker type**

	Congruent		Incongruent		Neutral	
	Athlete	Non-athlete	Athlete	Non-athlete	Athlete	Non-athlete
No cue	97.0±4.5	97.8±5.3	93.1±5.9	92.3±6.7	97.4±4.2	98.3±2.8
Central cue	98.8±2.5	98.7±3.0	90.9±9.0	93.2±7.4	98.0±3.0	98.9±2.4
Double cue	99.4±1.9	97.2±4.9	92.5±8.3	94.7±5.4	98.2±2.9	97.4±3.8
Spatial cue	99.6±1.6	98.0±4.3	96.6±4.8	97.4±5.4	98.8±3.0	99.1±2.2

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