The interplay between cognitive tasks and vision for upright posture balance in adolescents

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Background. The control of an upright stance in humans is important in medicine, psychology, and physiology. The maintenance of upright stance balance depends not only on sensory information from proprioceptive, vestibular, cutaneous, and visual sources but also on cognitive resources. The present study investigated the effects of cognitive tasks while standing with eyes open on upright stance balance in adolescents. We hypothesized that performing a cognitive task while standing with eyes open would increase body sway among these adolescents and that the upright posture would thus become less stable.

Methods. A static balance assessment system comprising a force platform connected to a computer was used to evaluate the stability of the upright stance among 21 healthy adolescents under six conditions: no cognitive task, a relatively easy cognitive task, or the same cognitive task made more difficult, with each task being performed while the eyes were open and again while the eyes were closed. The participants performed mental calculations as fast as possible by subtracting either 3 or 18 from a random three-digit number continuously, for the simple cognitive task or the difficult cognitive task, respectively. Each calculation was completed within 10 s. The evaluation indexes used to measure upright posture stability were the root mean square (RMS) of the total body sway in the mediolateral and anteroposterior directions, the mean velocity (MV) value of the total body sway, and the Romberg quotient (RQ) of these values.

Results. The RMS ($p < 0.01$) and MV ($p < 0.01$) values of the upright posture sway were lower when participants performed no cognitive task and their eyes were open than when their eyes were closed. When their eyes were open, compared with no cognitive task, the values of the measures evaluating upright posture sway were higher, meaning the stance was less stable, while performing either the simple or the more difficult cognitive task (RMS: simple task, $p < 0.01$; difficult task, $p < 0.05$; MV: simple task, $p < 0.01$; difficult task, $p < 0.01$) although no significant differences were detected for the RMS or MV values between the simple and more difficult cognitive tasks. The RQs for both the RMS and the total MV values of the upright posture sway during performance of the difficult cognitive task were significantly lower than when the participants performed no task.

Conclusion. Performance of a cognitive task significantly reduced the upright posture balance in adolescents during eyes open although increased task difficulty did not show a greater effect. The interference between the performance of a cognitive task and the visual control of an upright stance may be attributable in part to cognitive and visual processing streams competing for common central resources, consistent with the Multiple Resource Theory of information processing.

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Abstract:

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Results. The RMS ($p < 0.01$) and MV ($p < 0.01$) values of the upright posture sway were lower when participants performed no cognitive task and their eyes were open than when their eyes were closed. When their eyes were open, compared with no cognitive task, the values of the measures evaluating upright posture sway were higher, meaning the stance was less stable, while performing either the simple or the more difficult cognitive task (RMS: simple task, $p < 0.01$; difficult task, $p < 0.05$; MV: simple task, $p < 0.01$; difficult task, $p < 0.01$) although no significant differences were detected for the RMS or MV values between the simple and more difficult cognitive tasks. The RQs for both the RMS and the total MV values of the upright

55   posture sway during performance of the difficult cognitive task were significantly lower than

56   when the participants performed no task.

57   **Conclusion.** Performance of a cognitive task significantly reduced the upright posture balance in

58   adolescents during eyes open although increased task difficulty did not show a greater effect.

59   The interference between the performance of a cognitive task and the visual control of an upright

60   stance may be attributable in part to cognitive and visual processing streams competing for

61   common central resources, consistent with the Multiple Resource Theory of information

62   processing.

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64   **Keywords:** adolescent; upright posture; cognitive task; visual control; dual task

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94 **1 Introduction**

95   Upright walking is arguably considered uniquely human. Controlling posture stability is

96 considered the premise and basis of other kinds of action behaviors. Thus, understanding posture

97 control to maintain an upright stance among humans is an important issue in modern medicine,

98 psychology, and physiology (*Ren et al., 2010*). Recent studies have concluded that balance

99 maintenance in the upright body position is not entirely automated. It not only depends on

100 sensory information from proprioceptive, vestibular, cutaneous, and visual sources (*Ceyte et al.,*

101 *2014; Lakhani & Mansfield, 2015; Manor et al., 2010*), but also requires a large amount of

102 cognitive resources (*Chong et al., 2010; Polskaia et al., 2015*). Some studies have found that

103 when processing cognitive tasks in a constantly changing environment, upright posture control

104 systems regulate the body's postural sway through complex interactions of somatosensory, visual,

105 and vestibular sensory feedback networks with the musculoskeletal systems (*Manor et al., 2010;*

106 *Muelas Perez et al., 2014*). Therefore, the modulation of cognitive tasks on the visual control of

107 upright posture has attracted the attention of researchers.

108   The interaction between cognitive tasks and vision adjusts the stability of the upright

109 posture. One study found that performing a cognitive task while standing with closed eyes

110 increases body sway (*Donker et al., 2007*). According to the Multiple Resource Theory of

111 information processing (*Wickens, 1980*), the interference between the performance of a cognitive

112 task and the visual control of an upright stance may be attributable to cognitive and visual

113 processing streams competing for common central resources (*Fraizer & Mitra, 2008*). Therefore,

114 the effects of cognitive tasks on the stability of upright posture differ under visual and non-visual

115 conditions. Recent evidence supports this theory, showing that performance of cognitive tasks

116 inhibit visual processing during upright posture control (*Ren et al., 2010*). However, it remains

117 unclear whether the difficulty of the cognitive task plays a key role, that is, whether there is a

118 difference between the modulation that occurs during performance of a simple cognitive task or

119 of a more difficult cognitive task, in the visual control of upright posture.

120 Measuring the ability to balance is an important index for evaluating body function, and

121 having proper balance is of substantial significance for numerous actions, for example, to

122 prevent injuries from falls and improve sports skills among people of all ages. In adolescents,

123 proper balance is important to promote growth and development, in general and to develop

124 mechanical skills, including those used in sports. To provide additional evidence in support of

125 the information processing Multiple Resource Theory, the present study investigated the effects

126 of varying the difficulty of a cognitive task while standing with eyes open on the upright posture

127 balance among adolescents. Because, according to the theory, competition for limited

128 information processing resources will impair processing of specific sensory channels, we

129 hypothesized that performing a cognitive task while standing with eyes open would increase

130 body sway among these adolescents and that the upright posture would become less stable.

131

132 **2 Materials and Methods**

133 2.1 Participants

134 In total, 21 healthy adolescents from the same high school (10 males and 11 females) aged

135 16–19 years were selected who met the study criteria. Their mean age was 17.81 ± 1.12 years old,

136 their mean height was 167.4 ± 6.52 cm, and their mean weight was 58.43 ± 10.06 kg. All

137 participants were healthy, with no brain, nerve, or muscle disorders and had normal or corrected-

138 to-normal vision. The study protocol was approved by the ethics committee of Anqing Normal

139 University (Ethical Application Ref: ANU201112). Participants, or their guardians for

140 adolescents younger than 18 years, were informed of the experimental details and signed

141 informed consents prior to beginning the study.

142

143 2.2 Experimental design

144 The experiment used a within-subjects 3 × 2 factorial design. The first factor was the visual

145 condition, and it was divided into two levels: eyes open and eyes closed. The second factor was

146   performance of a cognitive task, and it was divided into three levels: no cognitive task, a simple

147   cognitive task, and a difficult cognitive task.

148   The upright posture balance was evaluated using two indicators, namely, the root mean

149   square (RMS) of the body sway in the mediolateral (ML) and anteroposterior (AP) directions and

150   the mean velocity (MV) of the total body sway, as well as the Romberg quotient (RQ) of these

151   two indicators. The RMS and MV values are the two most commonly used indicators for

152   evaluating the stability of upright posture. The RQ was calculated as the ratio of the indicator

153   values (RMS or MV) measured when the eyes were open versus when they were closed (*van*

154   *Parys & Njiokiktjien, 1976*). Higher RQ values indicate a greater role for vision in posture

155   control.

156

157   2.3 Experimental equipment and materials

158   The experimental equipment was a human static balance assessment system—a force

159   platform connected to a computer, called a dynamometer—developed by the Hefei Institute of

160   Intellectual Science of the Chinese Academy of Sciences. The system has a high-precision five-

161   dimensional force sensor, high-precision amplifier circuit, and 16-bit A and D sampling cards.

162   The system collects, processes, and analyzes changes in the center of the pressure of the static

163   upright posture of the human body and presents the analyzed data as intuitive graphics and

164   curves. A computer (Windows 7, CPU 3.0 GHZ, display 19 inches, resolution 1280 × 720 pixels,

165   refresh frequency 100 Hz) was connected to the dynamometer to control the experimental flow

166   and to record experimental data online. The computer was also connected to the pressure-sensing

167   devices to enable an integrated perception of the somatic balance and the real-time recording of

168   the motion graphics.

169

170   2.4 Experimental tasks

171   For the main task, the participants were required to stand quietly on the dynamometer,

172   maintaining their balance in an upright posture with a minimum of body sway either with their

173   eyes open or closed, as requested by the investigator. During the upright posture balance test, the

174   participants were asked to stand as still as possible on the force platform with their feet together

175   (one foot touching the other), with their arms relaxed by their sides, and to look at the visual

176   target on the wall in front of them.

177   For the secondary task, participants were required to stand on the dynamometer and to

178   maintain their balance in an upright posture with their eyes open or closed while performing the

179   assigned cognitive task. The cognitive task comprised a relatively simple or more difficult

180   mental calculation. At the beginning of the experiment, the investigator gave the participant a

181   randomly selected three-digit number, such as 423. The participant subtracted either 3 (for the

182   simple cognitive task) or 18 (for the more difficult cognitive task) from the three-digit number

183   continuously as fast as possible. The participants performed the mental calculations and gave

184   oral reports as quickly and accurately as possible within 10 s for each task. If the participant

185   made an error, the correct value was immediately provided, and the participant continued the

186   mental calculations using the corrected value until the end of the task. For each condition, if the

187   number of reported errors during a cognitive task exceeded three, the participant was required to

188   repeat the task.

189   To perform the visual and non-visual portions of the experiments, the participants stood in

190   the laboratory 2 m from a white wall that had a target (a black circle with a diameter of 4 cm)

191   drawn on the wall at approximately eye level. During the visual control component of the

192   experiment, the participants stared at the target, and during the non-visual control component, the

193   participants closed their eyes.

194   Before the formal experiment began, we conducted a pilot study with 8 participants (none

195   of whom participated in the formal experiment). The participants completed the two mental

196   calculation tasks as described above. The results of a one-way analysis of variance (ANOVA) of

197   the correct number of mental calculations in 10 s for each task condition indicated that the

198   difference in difficulty between the two tasks was substantial and significant ($F_{(1,15)} = 269.73$, p

199   < 0.001), indicating that the difficulty levels of the cognitive tasks met our experimental

200 requirements.

201

202 2.5 Experimental procedures

203   The experiment was conducted in a university physical fitness promotion experimental

204 center. The laboratory was quiet, and the environment was comfortable. Before the experiment,

205 all participants were informed of the task requirements.

206   For balance assessment of the upright posture, each participant prepared according to the

207 instructions presented by the computer and began the formal experiments. For the eyes open or

208 closed variable, all the participants completed the upright posture stability test under three

209 conditions: no cognitive task, the simple cognitive task, and the difficult cognitive task. Thus,

210 there were six conditions: (1) no cognitive task with eyes open, (2) no cognitive task with eyes

211 closed, (3) simple cognitive task with eyes open, (4) simple cognitive task with eyes closed, (5)

212 difficult cognitive task with eyes open, and (6) difficult cognitive task with eyes closed. These

213 six conditions were randomly presented to the participants. One balance trial was performed for

214 each of the six conditions. The experimental time for each condition was 10 s, and the rest time

215 between each test condition was 2 min. All experiments were conducted at approximately the

216 same time each day (after 2:00 PM) to minimize the differences in individual biological rhythms.

217

218 2.6 Statistical analysis

219   A two-way repeated measures ANOVA was conducted to evaluate the effects of cognitive

220 task and visual control on the RMS and MV values of the upright posture movement trajectory.

221 Paired t tests with Bonferroni corrections for multiple comparisons were used for post hoc tests if

222 the results of the ANOVA showed significant main effects or interactions. In addition, a one-way

223 ANOVA was used to investigate the differences in RQ values when participants performed no

224 cognitive task, the simple cognitive task, and the relatively more difficult cognitive task.

225   SPSS software, version 17.0, was used for all statistical analyses. The threshold for

226 statistical significance was $\alpha < 0.05$. Values are represented herein as the mean ± standard error

227 (SE).

228

3 Results

230 3.1 RMS of upright posture sway in adolescents

231   Figure 1 shows the mean and SE of RMS values of upright posture sway for participants

232 under the six experimental conditions. For upright posture sway in the ML direction, the repeated

233 measures ANOVA results showed that the main effects of both the visual ($F_{(1,20)} = 9.86$, $p =$

234 0.005), and cognitive ($F_{(2,40)} = 17.01$, $p < 0.001$) factors were significant, as was their interaction

235 ($F_{(2,40)} = 3.5$, $p = 0.04$). The post hoc analysis showed that the upright posture sway amplitude

236 when participants performed no cognitive task was smaller with the eyes open than with the eyes

237 closed ($p < 0.01$). When participants had their eyes open, their sway amplitude was significantly

238 smaller when they performed no cognitive task than when they performed either the simple

239 cognitive task ($p < 0.01$) or the more difficult cognitive task ($p < 0.05$); however, there was no

240 significant difference detected in sway amplitude between the simple or the more difficult

241 cognitive task. That is, increasing task difficulty did not further increase sway amplitude.

242   For the upright posture sway in the AP direction, although the main effect of the cognitive

243 factor was significant ($F_{(2,40)} = 7.48$, $p = 0.002$), neither the main effect of the visual factor ($F_{(1,20)}$

244 $= 1.55$, $p = 0.227$) nor the interaction between these two factors was significant ($F_{(2,40)} = 2.23$, p

245 $= 0.143$).

246

247 3.2 MV of upright posture sway in adolescents

248   Figure 2 shows the change in the MV values of upright posture total sway for the

249 participants under the six experimental conditions. The repeated measures ANOVA results

250 showed that the main effects of the cognitive ($F_{(2,40)} = 14.27$, $p < 0.001$) and visual ($F_{(1,20)} = 6.02$,

251 $p = 0.023$) factors were significant, and their interaction was also significant ($F_{(2,40)} = 3.23$, $p =$

252 0.045). The post hoc test results indicated that the MV value was smaller with the eyes open than

253 with the eyes closed while participants performed no cognitive task ($p < 0.01$). With the eyes

254   open, the MV value of the upright posture sway was smaller when participants did not perform a

255   cognitive task than when they performed the simple ($p < 0.01$) or the more difficult cognitive

256   task ($p < 0.01$); however, there was no significant difference in the MV values of the upright

257   posture sway between the simple and more difficult cognitive tasks.

258

259   3.3 RQ of upright posture sway in adolescents

260   We compared the RQs for the RMS and the MV values for upright posture sway under the

261   different task conditions (Fig. 3). The results showed that the RQ for the RMS value was

262   significantly higher when participants performed no cognitive task than when they performed the

263   more difficult cognitive task only for upright posture sway in the ML direction ($F_{(2,60)} = 3.63$, $p =$

264   0.01). The RQ for the total MV value was significantly higher when participants performed no

265   cognitive task than when they performed the difficult cognitive task ($F_{(2,60)} = 2.81$, $p = 0.022$).

266

267   **4 Discussion**

268   4.1 Visual control of upright posture balance

269   The RMS values for the ML direction and the total MV values for the upright posture sway

270   showed that while adolescents performed no cognitive task, their upright stance was more stable

271   when their eyes remained open than when their eyes were closed, indicating that vision affected

272   the control of upright posture balance in these adolescents. Thus, the results of this portion of our

273   study support previous findings on the importance of vision in upright posture control (*Lakhani*

274   *& Mansfield, 2015; Muelas Perez et al., 2014*). In contrast to our results for the ML direction,

275   the RMS values in the AP direction were not affected by our experimental manipulations. The

276   front and rear of the feet are supported by the forefoot and the heel, respectively. Thus, the sway

277   of an upright posture in the AP direction is not easily affected by the presence or absence of

278   vision, and the upright posture remains relatively stable.

279   The control of upright posture balance depends on visual information. For example, studies

280   have shown that when the visual field is limited or visual movement feedback is reduced, the

281 amplitude of the upright posture sway increases, and conversely, when the visual field or

282 movement feedback is no longer limited, the sway amplitude is reduced (*Anna et al., 2002;*

283 *Muelas Perez et al., 2014*). However, the maintenance of upright posture balance is a complex,

284 multidimensional process, depending not only on visual information but also on other sensory

285 information, such as proprioceptive, vestibular, and skin sensations (*Manor et al., 2010*). Indeed,

286 other factors may also affect the processing of visual information for maintaining an upright

287 stance and further research is needed to fully understand all of these factors.

288

289 4.2 Effect of cognitive tasks on upright posture

290   The main effect of cognitive factor was found to be significant for open eyes in the analysis

291 of RMS values for the ML and AP directions and for the MV of total body sway of the upright

292 posture in adolescents. This result is consistent with those of some previous studies showing that

293 cognitive processing plays an important role in upright posture control and supports the view that

294 cognitive factors affect the balance control of the upright stance (*Lajoie et al., 2017; Polskaia et*

295 *al., 2015*). However, the results of other studies are not consistent with those or with our results.

296 For example, a few studies among young adults found that the upright posture sway increased

297 (*Ceyte et al., 2014; Polskaia et al., 2015*), decreased (*Stins et al., 2011*), or was not altered

298 (*Yardley et al., 1999*) in young adults during the execution of cognitive tasks; even when the

299 complexity of the cognitive task was increased, their results remained unchanged. This apparent

300 lack of consistent experimental evidence may be attributable to many factors, such as the

301 processing needs of the specific cognitive task (*Fraizer & Mitra, 2008*), the difficulty of the

302 postural task (*Barra et al., 2006*), and the use of reinforcement strategies (*Stins et al., 2011*).

303 Thus, the performance of cognitive tasks may interact with other factors to influence upright

304 posture balance.

305

306 4.3 The interplay between cognitive tasks and vision for upright posture

307   Visual function, cognitive function, and stability control of the upright posture among

308 humans are not independent systems. Donker et al. (2007) found that processing cognitive tasks

309 while standing with closed eyes increases body sway. Ren et al. (2010) examined the effects of

310 cognitive tasks on the visual control of upright posture and found that performance of cognitive

311 tasks inhibited visual processing for the control of upright posture. Similar to those two studies,

312 our findings also supported the view that interactions between visual processing and cognitive

313 task performance influenced upright posture control. Sway amplitude was larger during

314 performance of a cognitive task than when no cognitive task was being performed when the eyes

315 remained open, indicating that cognitive task processing reduces the role of vision in upright

316 posture control. Because previous studies of maintaining upright posture control while

317 performing cognitive tasks have indicated that the mental subtraction task increases body sway

318 among the participants (*Donker et al., 2007; Ren et al., 2010*), we used both a relatively simple

319 and a more difficult level of that task in the present study. The analysis of the RQ for the RMS

320 values of the upright posture sway in the ML direction showed that the RQ with no cognitive

321 task was higher than that for the more difficult cognitive task. These results further demonstrated

322 that the role of vision in upright posture control was reduced during cognitive processing.

323   A current theoretical explanation of the control of upright posture balance is the Multiple

324 Resources Theory of information processing; this theory holds that the interference between

325 cognitive task performance and upright posture control is attributable to the competition for a

326 common central pool of processing resources (*Ren et al., 2010; Riley et al., 2012*). On the basis

327 of this theory, we speculated that cognitive task performance would affect visual control of

328 upright posture balance. Our results showed that when the participants' eyes were open, the

329 upright posture sway while performing either the simple or the more difficult cognitive task was

330 greater than that while not performing a cognitive task. Thus, our results support the Multiple

331 Resources Theory of information processing. Owing to limited information processing resources,

332 the ability to maintain upright posture balance will compete with cognitive tasks and with vision

333 for central processing resources, resulting in an increase in the amplitude of the upright posture

334 sway.

335   Upright posture balance has been used to evaluate physical function among adolescents;

336 indeed it has become an important indicator in the monitoring of physical fitness in adolescents.

337 However, the use of this measure as indicator is not ideal. The maintenance of balance in an

338 upright stance or during walking is a complex and multidimensional process requiring higher

339 levels of motor control and cognitive flexibility to cope with balance threats (*Buchman et al.,*

340 *2011*). Therefore, it may be too simplistic to suggest that determining the ability of an adolescent

341 to balance in an upright stance is a good measure of their physical fitness without

342 comprehensively evaluating their stability under the interference of other factors, such as their

343 simultaneous performance of cognitive tasks. Furthermore, for balance training of young people,

344 the addition of interfering factors should be considered to improve the training effectiveness.

345   In summary, while processing cognitive tasks, the role of vision in the upright posture

346 control of adolescents is significantly reduced, which indicates that visual function, cognitive

347 function, and human upright posture stability control are not independent systems. These

348 findings further support the view that upright posture control requires multisensory channel

349 processing.

350

351 **5 Conclusions**

352   The performance of a cognitive task while standing with eyes open reduced the upright

353 posture balance in adolescents although this posture control was not further reduced by the

354 simultaneous processing of a more difficult cognitive task. The interference between cognitive

355 task performance and visual control of stance may be attributable in part to the competition

356 between cognitive and visual processing for common and limited central processing resources.

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Figure 1

Figure 1 RMS of upright posture sway in adolescents under various experimental conditions.

*p < 0.05; **p < 0.01; RMS, root mean square.

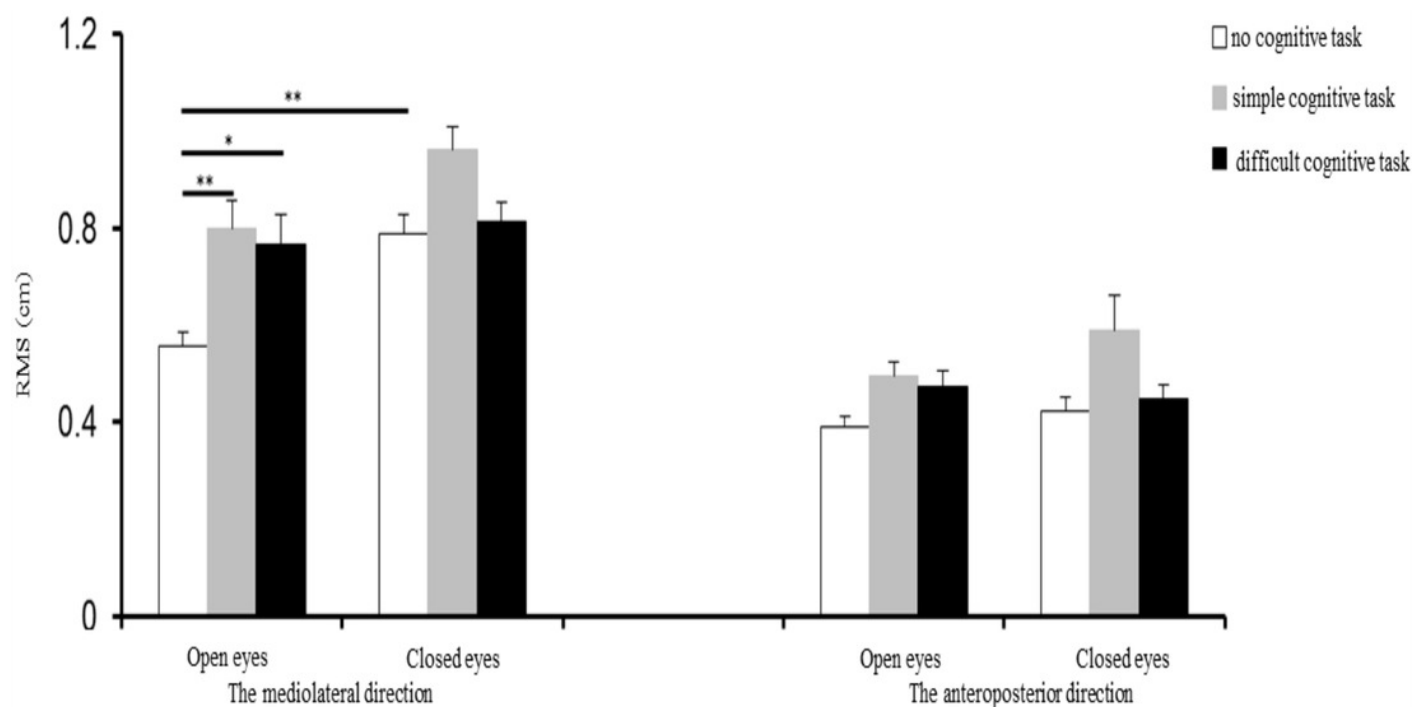



Figure 2

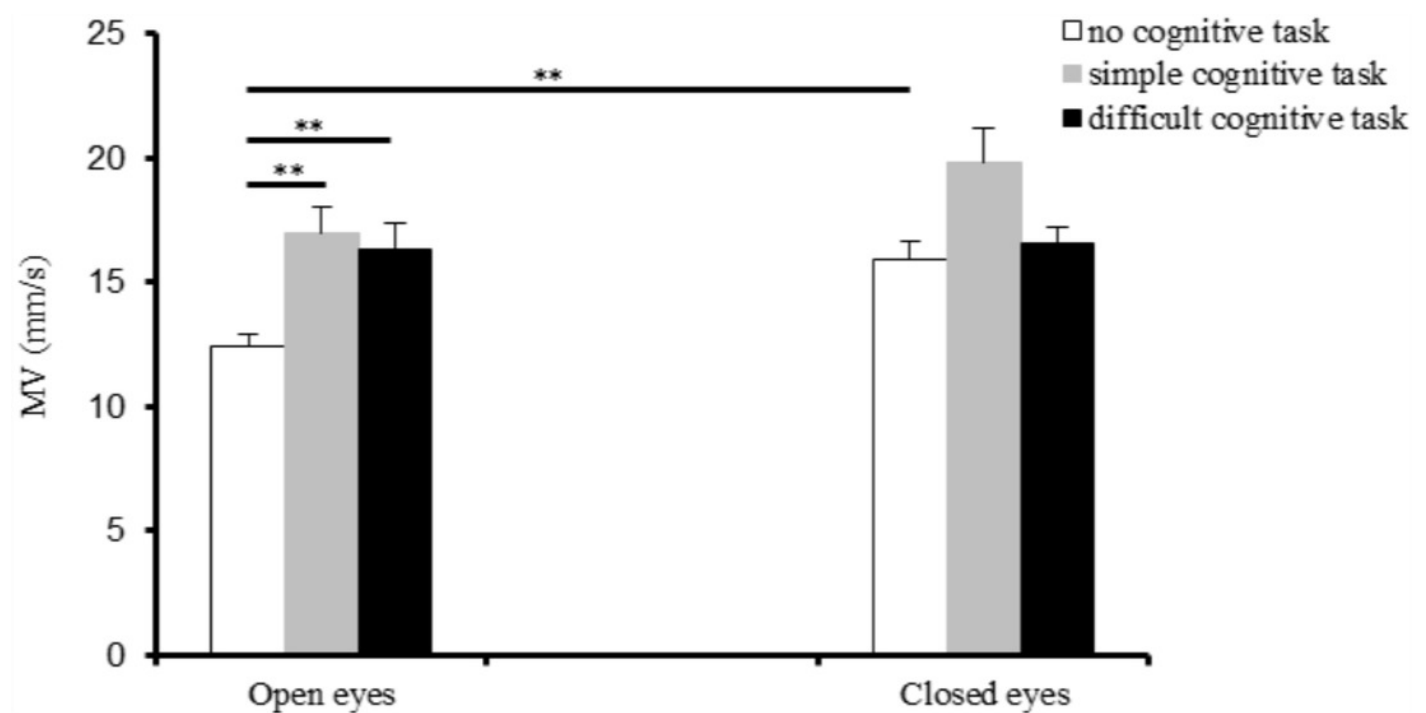
Figure 2 Mean Velocity (MV) of upright posture sway in adolescents under various experimental conditions.

**$p < 0.01$

Figure 3

Figure 3 Romberg Quotient (RQ) of upright posture sway in adolescents under various experimental conditions.

**p < 0.01