Postural control in girls with adolescent idiopathic scoliosis while wearing a Chêneau brace or performing active self-correction: A pilot study

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Abstract

Background. It is known that adolescent idiopathic scoliosis (AIS) is often accompanied by balance deficits. This reciprocal relationship must be taken into account when prescribing new therapeutic modalities because these may differently affect postural control, interacting with therapy and influencing its results.

Objective. The purpose was to compare postural control in girls with AIS while wearing the Chêneau brace (BRA) or performing active self-correction (ASC) with their postural control in a quiet comfortable stance.

Methods. Nine subjects were evaluated on a force plate in three series of two 20-s quiet standing trials with eyes open or closed; three blocks were randomly arranged: normal quiet stance (QST), quiet stance with BRA, and quiet stance with ASC. On the basis of centre-of-pressure (COP) recordings, the spatial and temporal COP parameters were computed.

29   **Results and Discussion.** Performing ASC was associated with a significant backward excursion

30   of the COP mean position with eyes open and closed (ES = 0.56 and 0.65, respectively; p <

31   0.05). This excursion was accompanied by an increase in the COP fractal dimension (ES = 1.05

32   and 0.98; p < 0.05) and frequency (ES = 0.78; p = 0.10 and ES = 1.14; p < 0.05) in the

33   mediolateral (ML) plane. Finally, both therapeutic modalities decreased COP sample entropy

34   with eyes closed in the anteroposterior (AP) plane. Wearing BRA resulted in ES = 1.45 (p <

35   0.05) while performing ASC in ES = 0.76 (p = 0.13).

36   **Conclusion.** The observed changes in the fractal dimension (complexity) and frequency caused

37   by ASC account for better adaptability of patients to environmental demands and for their

38   adequate resources of available postural strategies in the ML plane. These changes in sway

39   structure were accompanied by a significant (around 25 mm) backward excursion of the mean

40   COP position. However, this improvement was achieved at the cost of lower automaticity, i.e.

41   higher attentional involvement in postural control in the AP plane. Wearing BRA may have an

42   undesirable effect on some aspects of body balance.

43

Introduction

45   Adolescent idiopathic scoliosis (AIS) is one of the common spinal deformities observed during

46   adolescence, affecting 2–4% of individuals aged 10–16 years (Hawasli, Hullar & Dorward,

47   2015). AIS can introduce wide-ranging dysfunction in important bodily systems and organs

48   (Simoneau et al., 2006; Wang et al., 2011; Weinstein et al., 2008). Research in the recent decade

49   has attempted to determine if AIS patients show proprioceptive and somatosensory impairment.

50   Several studies on AIS prognosis have reported abnormal somatosensory function, balance

51   control, and proprioception (Guo et al., 2006). Numerous researchers present that standing

52   balance assessments show greater postural instability in AIS patients compared with age-

53   matched controls (Gaudreault et al., 2005; Karimi, Kavyani & Kamali, 2016; Chow et al., 2006).

54   The cited literature suggests that young patients with scoliosis are more susceptible than healthy

55   individuals to external perturbations and have greater difficulty in righting the body after

56   disturbed balance (Karimi, Kavyani & Kamali, 2016).

57   The underlying cause of impaired postural control is considered multifactorial albeit

58   strongly associated with vestibular dysfunction and defects in certain structures of the central

59   nervous system (Hawasli, Hullar & Dorward, 2015; Gauchard et al., 2001; Byl et al., 1997). As

60   the medial vestibulospinal tract controls the axial muscles (Pialasse et al., 2013), changes in the

61   brain stem or sensorimotor cortex during the critical preadolescent and adolescent period of

62   growth can impair sensorimotor integration and therefore lead to inappropriate trunk muscle

63   activities, spine deformation, and greater instability. Hence, it is hypothesized that reduced

64   balance control in AIS patients may be caused by either impaired vestibular information transfer

65   or sensorimotor processing (Shi et al., 2013).

66   Two of the most common non-operative treatments prescribed for AIS are physiotherapy

67   via active self-correction (ASC) and orthotic braces (Coillard et al., 2003; d'Amato, Griggs &

68   McCoy, 2001; Katz & Durrani, 2001). ASC is a series of movements of realignment as a whole

69   that the patients autonomously perform in order to reduce the scoliotic curves. This exercise has

70   to be implemented as much as possible in three dimensions, which sometimes makes the ASC

71   movement not easy to be understood and also not easy to be completed by the patient (Pizzetti et

72   al., 2010). Bracing is generally recommended for skeletally immature patients with Cobb angles

73   of 25–45° so as to halt further progressive curvature and provide passive correction (Chow,

74   Leung & Holmes, 2007). Within the group of rigid Thoraco-Lumbo-Sacral Orthoses (TLSO), the

75   Chêneau brace (BRA) is most widely used in Poland (Zaborowska-Sapeta et al., 2011).

76   However, the clinical effects of bracing on postural balance in the AIS-afflicted population have

77   only been addressed by a few studies, which report inconsistent findings. In the available

78   literature, there is evidence that a bracing intervention can improve postural stability and balance

79   in the sitting position (Smith & Emans, 1992). One investigation confirmed that bracing did not

80   impede stability or balance during upright stance on a solid surface but significantly increased

81   the centre-of-pressure (COP) sway area, displacement, and mediolateral amplitude in patients

82   standing on an unstable surface (Chow, Leung & Holmes, 2007). Other studies have reported no

83   significant clinical effects, among others, no changes in COP displacement or sway area, after a

84   4-month application of the Boston bracing system compared with controls (Sadeghi et al., 2008).

85   Instead, greater postural stiffness in the anteroposterior direction and reduced mediolateral

86   balance control were observed. Another study demonstrated improved postural balance after 4

87   months of bracing in young AIS patients (Paolucci et al., 2013; Khanali et al., 2015).

88   A significant issue is that the vast majority of studies have focused solely on the effects

89   of BRA-induced alignment on postural control whereas few have addressed autocorrective-based

90   approaches (three-dimensional ASC). The diagnostic and therapeutic recommendations

91   published by the Society on Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT)

92   show consensus on the use of autocorrection exercises and the efficacy of this intervention

93   (Negrini et al., 2018). To the authors' knowledge, there are no studies that have evaluated the

94   effects of ASC (autocorrection). Therefore, the aim of this study was to compare postural control

95   in girls with AIS while wearing BRA or performing ASC with their postural control in a quiet

96   comfortable stance. We hypothesized better efficacy of ASC in supporting postural control.

97

98   **Materials & Methods**

99   *Participants*

100   Nine post-menarche female AIS patients aged 11–16 years (age: 14 ± 1.48 years, weight: 47.71 ±

101   5.61 kg, height: 161.5 ± 8.81 cm, Cobb angle: 35.6 ± 8.9°) from a local therapeutic rehabilitation

102   centre participated in the study. All subjects had normal vision. Individual patient characteristics

103   including scoliotic curvature details are presented in Table 1. The inclusion criteria for the

104   participants were diagnosis of AIS by an independent physician and receiving conservative

105   treatment: BRA and physiotherapeutic scoliosis-specific exercises (PSSE) recommended by

106   SOSORT (Negrini et al., 2018). Excluded were patients with history of spine surgery,

107   musculoskeletal or neurological disease, or any spinal pathology not comorbid with AIS. All

108   participants received brace treatment for a minimum of 2 months (3.56 ± 1.42 months) with a

109   dosage of 20 hours/day; the brace was removed for personal hygiene, exercise, or delineated rest

110   periods. Each BRA was custom designed for three-dimensional curve correction by an

111   experienced orthotics specialist. Figures 1 and 2 illustrate an exemplary BRA used in the study.

112   All patients knew their own ASC movements which reduced scoliotic curves. These included

113   different types of movements: (1) controlled self-elongation, having regard to the sagittal plane;

114   (2) correction of the primary curve in the frontal plane; (3) correction of contiguous curves in the

115   frontal plane; (4) correction of the primary curve in the horizontal plane.

116   Written informed consent was obtained from all participants and their parent(s) or legal

117   guardian(s). The study goals, procedures, and methods were explained in full, and the subjects

118   were informed that they could withdraw at any time. The study was approved by the Senate

119   Research Ethics Committee at the University School of Physical Education in Wroclaw, Poland

120   (the approval number: 35/2016).

121

122   [Table 1]

123   [Figure 1]

124   [Figure 2]

125

126   ***Methods***

127   All procedures were performed in laboratory conditions. Postural control was assessed barefoot

128   on a Kistler force platform (Kistler 9281CA, Winterthur, Switzerland). Two-dimensional

129   horizontal coordinates of the COP data were recorded for 20 s at a sampling frequency of 100

130   Hz. Three bipedal quiet standing trials were performed: (1) QST- normal quiet stance: standing

131   upright with a neutral and comfortable stance with arms relaxed at the sides; (2) ASC: standing

132   upright with autocorrection; on the 'correction' command, the participant performed ASC; and

133   (3) BRA: standing upright wearing BRA.

134   Each trial was performed in eyes-open and eyes-closed conditions. The foot position (5

135   cm apart) was standardized on the surface to ensure repeatability across trials and participants.

136   Task order was counterbalanced with 1 min of rest provided after each trial in order to minimize

137   the effects of fatigue or hysteresis (Chow et al., 2007). The participants were instructed to stand

138   as motionless as possible. Data acquisition began when the subject signalled they were ready.

139   Relevant COP outcome measures were determined separately for the mediolateral (ML) and the

140   anteroposterior (AP) direction. These were:

141

142   • COP SD [mm] – standard deviation of COP displacement from mean COP;

143   • COP sway range [mm] – difference between the maximum and minimum value of the

144   COP;

145   • COP mean [mm] – mean value of the COP position;

146   • COP mean velocity [mm/s] – COP excursion divided by trial time;

147   • COP fractal dimension – a non-linear dynamic parameter of COP where the greater the

148   fractal dimension, the better the postural system adapts to changes;

149   • COP sample entropy – a non-linear dynamic parameter of COP where greater entropy

150   (higher COP irregularity) suggests less attentional resources devoted to balance

151   maintenance (greater automaticity);

152   •   COP frequency [Hz] – frequency of COP, indicative of the involvement of the neural

153   system in postural regulation.

154

155   *Statistical Analysis*

156   Data were processed with the Statistica 12.0 software package (StatSoft, USA). The data met the

157   criteria of normal distribution for all parameters of COP measures. Thus, to evaluate the possible

158   effects and interactions of vision (eyes open, eyes closed) and posture (quiet standing, ASC,

159   BRA), a 2×3 repeated analysis of variance (ANOVA) was conducted for all parameters of the

160   COP in the ML and the AP planes separately. To assess differences between the three groups, the

161   post-hoc Fisher's least significant difference (LSD) test was used. The level of significance was

162   set at $p < 0.05$. Effect size (ES) was calculated to determine the effects of ASC and BRA on

163   postural control compared with quiet standing. An effect size of 0.3 is a small effect, 0.5 is a

164   moderate effect, and 0.8 is a strong effect.

165

166   **Results**

167   In the AP plane, the COP mean position showed the main effect of posture ($F[2, 16] = 3.73$; $p =$

168   0.0047). The LSD test pointed at a significant backward shift of the COP mean position in both

169   eyes open ($p = 0.004$) and eyes closed ($p = 0.0002$) (Fig. 3). The traditional measures of the COP

170   dispersion displayed the main effects of vision in the AP plane for COP variability ($F[1, 8] =$

171   17.78; $p = 0.003$), range ($F[1, 8] = 18.33$; $p = 0.0003$), and velocity ($F[1, 8] = 9.57$; $p = 0.001$).

172   Eyes closure increased the values of these three latter parameters. In addition, there was a vision

173   $\times$ posture interaction ($F[2, 16] = 3.89$; $p = 0.042$) for range only, which arose because brace

174   differently affected this parameter: the range increased during eyes closed ($p = 0.003$) and

175   remained unchanged during eyes open. The COP sample entropy in the AP plane displayed the

176   main effect of vision ($F[1, 8] = 6.87$; $p = 0.031$), indicating lower values with eyes closed. Post-

177   hoc analysis revealed that using a brace resulted in a significantly lower ($p = 0.02$) sample

178   entropy during eyes closed (Fig. 4). Interestingly, there were no differences between ASC and

179   quiet standing.

180   In the ML plane, the results of ANOVA proved the main effect of posture on the COP

181   fractal dimension ($F[2, 16] = 6.05$; $p = 0.011$) and sway frequency ($F[2, 16] = 10.7$; $p = 0.001$).

182   The post-hoc LSD test indicated the highest values of the COP fractal dimension during ASC

183 with eyes open (p = 0.01) and eyes closed (p = 0.03) compared with the brace and quiet standing

184 (Fig. 5). The post-hoc analysis of frequency did not reveal significant changes (Fig. 6).

185   The means (SD) of all dependent variables including effect size values over 0.5 are

186 shown in Table 2.

187

188 [Table 2]

189 [Figure 3]

190 [Figure 4]

191 [Figure 5]

192 [Figure 6]

193

194 **Discussion**

195 The purpose of this study was to compare postural control in girls with AIS while wearing BRA

196 or performing ASC with their postural control in a quiet comfortable stance. In view of the

197 fundamental difference between the two therapeutic approaches, i.e. BRA and ASC, we

198 hypothesized better efficacy of ASC in supporting postural control. This prediction was mainly

199 based on the expected releasing degrees of freedom and facilitating exploratory function by ASC

200 as opposed to biomechanical constraints imposed by the brace, rendering the hip and trunk joints

201 practically inflexible. On the other hand, releasing degrees of freedom has been suggested as an

202 important characteristic of motor learning, which is necessary when exploring solutions for a

203 novel task (Sternad, 2018).

204   To find the effects of the investigated postures on the possible preferential use of

205 different sensory afferents, we examined the subjects with the manipulation of visual input. Such

206 an experimental protocol provides unique opportunities to reveal how sensory and motor signals

207 are integrated to control the upright body (Paillard, Bizid & Dupui, 2007; Kabbaligere et al.,

208 2017; Rasman et al., 2018). However, the results failed to find any interactions between the

209 postural condition and vision in any of the sway indices. This means that changes in postural

210 control between ASC and BRA observed in this study cannot be explained by differential effects

211 of the investigated postures on the quality of sensory inputs. Instead, they must have been caused

212 by some enhancement in sensory integration and internal representation of verticality. The latter

213 proposition is consistent with some other studies on AIS (Gauchard et al., 2000; Simoneau et al.,

214   2006; Catanzariti et al., 2014), as well as on stroke or vestibular pathology (Pérennou et al.,

215   2008; Borel et al., 2008).

216   In contrast to the weak interactions, there were strong main effects of vision on several

217   postural indices. Eyes closure deteriorated postural performance, as evidenced by the increased

218   COP variability and mean velocity. The same manipulation decreased COP entropy, indicating

219   the need for more conscious and less automatic postural control with occluded vision.

220   Additionally, eyes closure resulted in an increased COP frequency, suggesting that a higher rate

221   of the exploratory sway function is required when some of the normally available sensory inputs

222   are suppressed. The results of these manipulations add to our understanding of the differing

223   effects of BRA and ASC on the COP parameters in patients with AIS.

224   With regard to the specific results of this study, aimed at comparing the role of BRA and

225   ASC in postural control, four findings seem of particular value. First, ASC resulted in a

226   significant backward shift of the COP mean position on a hard surface in both visual conditions.

227   This is equivalent to a very similar mean backward shift of the body centre of mass. Second, this

228   shift was accompanied by an increase in the ML fractal dimension and frequency. Third, both

229   therapeutic modalities increased sway amplitude only in the AP plane with eyes closed.

230   Furthermore, in the AP plane with eyes closed, sway entropy decreased with BRA and to a lesser

231   extent with ASC.

232   Mean COP position is seldom computed and analysed except in subjects standing at

233   heights (Carpenter et al., 2001) and in older persons (Jbabdi, Boissy & Hamel, 2008), where fear

234   of falling significantly contributes to increasing the distance between the limits of stability and

235   the COP mean position. The fact of ignoring this index in the majority of studies probably

236   indicates a high consistency in adopting this position regardless of various sensory manipulations

237   and accounts for a presence of a strong set-point used by the central nervous system in

238   controlling erect stance. Therefore, in our subjects, this backward shift of the mean COP position

239   that resulted from the ASC posture must be interpreted as a relevant adjustment in postural

240   control. By virtue of the unexpected emergence and its impressive magnitude only, the backward

241   displacement of the COP cannot be instantly classified as a beneficial modification of posture.

242   Importantly, however, this modification was accompanied by an increase in the COP fractal

243   dimension and frequency, which manifest advantageous changes in the postural control system.

244   The fractal dimension is regarded as a measure of complexity of the investigated time-series and,

245 within some limits, its higher values account for improvements in the overall postural strategies

246 and in the better adaptability to novel postural challenges, in particular. A higher COP

247 complexity reflects the ability of the central nervous system to use a variety of postural strategies

248 to maintain stable stance (Cone, Goble & Rhea, 2017).

249   As documented by Cone, Goble & Rhea (2017), balance training that focused at a better

250 sensory reweighting resulted in an increased complexity of sway. In the same vein, Casabona et

251 al. (2016) showed a larger fractal dimension in ballet dancers than in non-dancers and concluded

252 that this difference might indicate a rearrangement of sensory integration and motor adaptation

253 necessary to meet the particular demands of selected ballet performances. This is in line with our

254 understanding of the results of this study. Lower values of complexity found in AIS in habitual

255 postures and while wearing braces may indicate the presence of biomechanical (and also

256 psychological) constraints impeding the selection of sensorimotor strategies which might lead to

257 optimal postural behaviour. The situation was quite different after the patients learned to

258 adequately use the ASC posture. The mechanically and habitually imposed constraints were, at

259 least partially, removed, as reflected by larger sway complexity, which indicated an improved

260 activity of the sensorimotor system in the integrating available sensory inputs and of its capacity

261 to perform the exploratory function.

262   It is important to point out that in contrast to the apparent gain in the organization of the

263 ASC postural control in the ML plane, the respective changes in the AP plane revealed an

264 unexpected outcome. While using ASC with eyes closed, our patients decreased sway entropy,

265 which reflected more attention invested in postural corrections, characteristic of conscious or

266 deliberate involvement into this process. By doing so, they constrained the normal automatic

267 mode of operation and this interaction resulted in decreased postural performance, which was

268 manifested by increases in sway variability. Although these changes in COP entropy are much

269 lesser than those caused by BRA in the same condition, they may account for some problems

270 that the AIS patients experienced in maintaining the backward shift associated with the new body

271 alignment while performing ASC. Although these undesirable reactions occurred only in trials

272 with eyes closed, when limited sensory input made postural control more challenging, their

273 presence may be associated with a suboptimal design of the self-corrected posture or inadequate

274 adherence of subjects to the rules established by therapists. Such questions have seldom, if ever,

275 been asked in relation to postural performance of subjects with AIS. The results of this study

276   suggest that a regular application of posturography in AIS patients may help answer these

277   questions and shed light on how to improve the treatment of this disease.

278   The main limitation of this pilot study is a small number of participants, which may have

279   concealed significant changes in postural performance brought about by BRA or ASC. Thus, in

280   addition to statistical significance, we also focused on the magnitude of effect sizes when

281   interpreting the study results. Nevertheless, the subsequent conclusions should be regarded with

282   caution unless confirmed by a replication study with an adequate sample size. The results of this

283   study may provide support as the input data for sample size calculation.

284   The second limitation concerns the lack of postural control assessment at some

285   intermediate points between the ASC practice and bracing onset and the final test. The large

286   backward shift of the mean COP position did not, most likely, occur during this final test but

287   rather resulted from a continuous process of postural adjustments. One can only speculate that

288   the latter modification of the gravity line alignment tends to optimize its position as a set-point

289   for controlling erect stance. Owing to its direct relationship to poor posture in scoliosis, further

290   research on this issue is warranted. Along the same lines, the investigation into the acute effects

291   of new braces or postures on body stability may be helpful in clinical practice, facilitating the

292   trade-off between body alignment and postural control.

293

Conclusions

295   This study compared postural control in girls with AIS while wearing BRA or performing ASC

296   with their postural control in a quiet comfortable stance. We predicted better control during self-

297   correction because its studious and diligent character seems to promote the exploratory function

298   of postural sway, necessary in exploiting new strategies, as opposed to constraints imposed by

299   the brace. Our hypothesis was confirmed by the increase in the COP complexity and frequency

300   in the ML plane while performing active self-correcting movements in comparison with habitual

301   standing. Such changes in complexity and frequency are supposed to account for better

302   adaptability of patients to environmental demands and for their adequate resources of available

303   postural strategies. However, this apparent improvement was achieved at the cost of lower

304   automaticity, i.e. higher attentional involvement in postural control in the AP plane. Notably, the

305   observed changes in sway were accompanied by a significant (around 25 mm) backward shift of

306 the mean COP position, which, we believe, may indicate a relevant adjustment in postural

307 control.

308

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Anthropometric and scoliotic curvature characteristics of the participants.

No.	Sex	Age [years]	Body mass [kg]	Body height [cm]	Risser sign	AIS curve type	Cobb angle [°]	Apex
1	Female	14	45.6	163.5	3	Right thoracic/left lumbar	30/32	T8/L2
2	Female	14	53.5	169	3.5	Right thoracic/left lumbar	28/40	T8/L2
3	Female	12.5	52.2	163.5	3.5	Right thoracic/left lumbar	16/25	T7/L1
4	Female	15	51.8	170.5	2	Right thoracic/left lumbar	18/35	T9/L3
5	Female	15	53.1	171.5	3	Right thoracic/left lumbar	37/20	T8/L1
6	Female	16	48.8	158	4	Right thoracic/left lumbar	32/30	T8/L1
7	Female	14.5	40.8	153	1.5	Right thoracic/left lumbar	55/20	T7/L1
8	Female	11	38	144.5	1	Right thoracic/left lumbar	26/20	T8/L1
9	Female	14	45.6	160	3	Right thoracic/left lumbar	38/18	T9/L3

Mean ± SD in AP and ML COP outcome measures for posture trials

* significant difference at $p < 0.05$

† ES > 0.5 ; †† ES> 0.8

Direction	Variable	Eyes open			Eyes closed		
		Quiet standing	Active self-correction	Chêneau brace	Quiet standing	Active self-correction	Chêneau brace
Anteroposterior	COP SD [mm]	3.89 ± 1.30	4.09 ± 1.87	3.92 ± 1.36	3.97 ± 1.46	**5.93 ± 3.06*††**	**6.25 ± 2.8*1††**
	COP sway range [mm]	18.96 ± 5.61	19.07 ± 9.12	17.50 ± 5.54	19.73 ± 8.86	26.88 ± 12.80	30.23 ± 12.85
	COP mean velocity [mm/s]	12.12 ± 2.11	13.14 ± 3.71	11.58 ± 2.26	14.60 ± 3.83	17.32 ± 6.43	15.86 ± 4.23
	COP frequency [Hz]	0.30 ± 0.11	0.32 ± 0.07	0.29 ± 0.18	0.40 ± 0.13	0.39 ± 0.12	0.37 ± 0.19
	COP fractal dimension	1.43 ± 0.06	1.43 ± 0.03	1.41±0.07	1.45 ± 0.05	1.44 ± 0.05	1.43 ± 0.05
	COP sample entropy	1.23 ± 0.26	1.27 ± 0.28	1.18 ± 0.27	1.30 ± 0.26	**1.10 ± 0.29*†**	**0.95 ± 0.22*††**
	COP mean [mm]	24.89 ± 28.81	43.1 ± 35.2†	23.1 ± 26.1	16.28 ± 25.87	**43.86± 51.24*†**	16.68 ± 23.77
Mediolateral	COP SD [mm]	3.33 ± 1.33	3.11 ± 1.40	3.26 ± 1.32	3.81 ± 1.96	3.96 ± 1.84	3.65 ± 1.48
	COP sway range [mm]	16.52 ± 6.35	16.65 ± 7.54	15.88 ± 4.89	18.51 ± 9.69	19.74 ± 8.46	18.31 ± 8.01
	COP mean velocity [mm/s]	9.35 ± 2.76	11.13 ± 4.42	9.25 ± 2.11	11.14 ± 5.47	13.91 ± 5.27	11.15 ± 4.02
	COP frequency [Hz]	0.33 ± 0.11	**0.42 ± 0.12*†**	0.39 ± 0.14	0.35 ± 0.11	**0.47 ± 0.10*††**	0.39 ± 0.08
	COP fractal dimension	1.43 ± 0.06	**1.48 ± 0.03*††**	1.40 ± 0.06	1.44 ± 0.06	**1.49 ± 0.04*††**	1.45 ± 0.02
	COP sample entropy	1.06 ± 0.34	1.22 ± 0.22	1.07 ± 0.31	1.03 ± 0.30	1.09 ± 0.22	1.05 ± 0.18
	COP mean [mm]	-4.26 ± 13.28	-3.9 ± 16.0	-1.26 ± 8.37	-4.32 ± 10.94	-0.15 ± 9.32	-2.03 ± 11.00

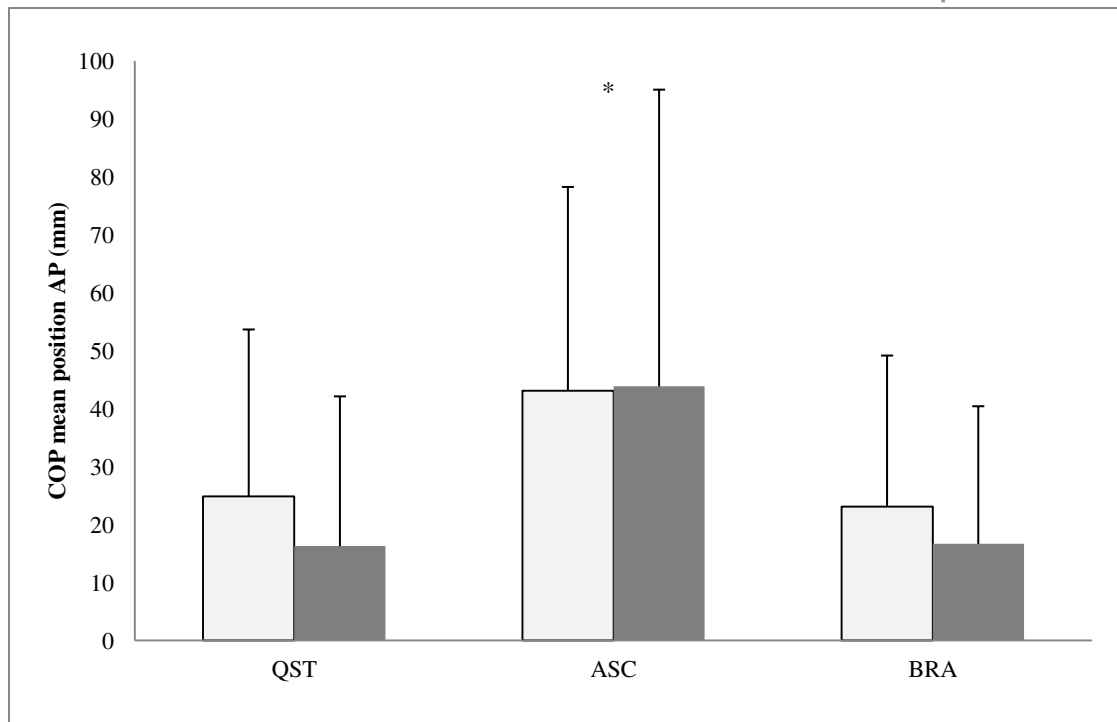
Figure 1

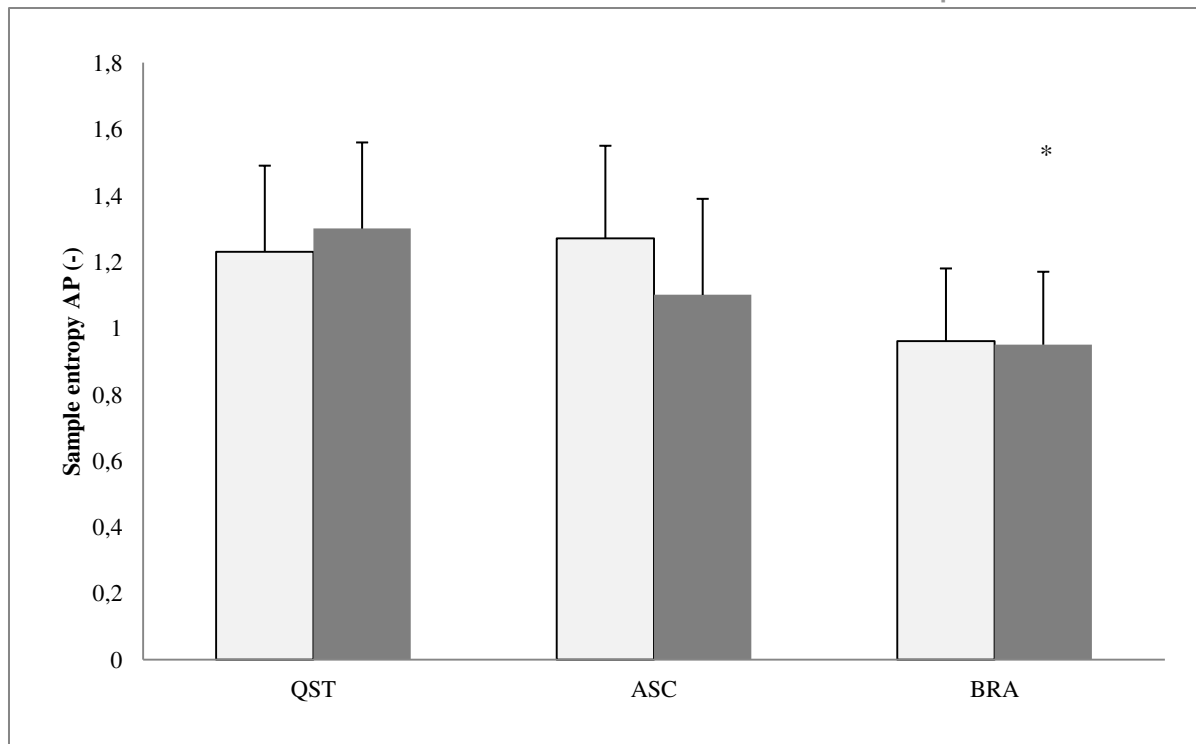
The Chêneau brace used in this study (back).

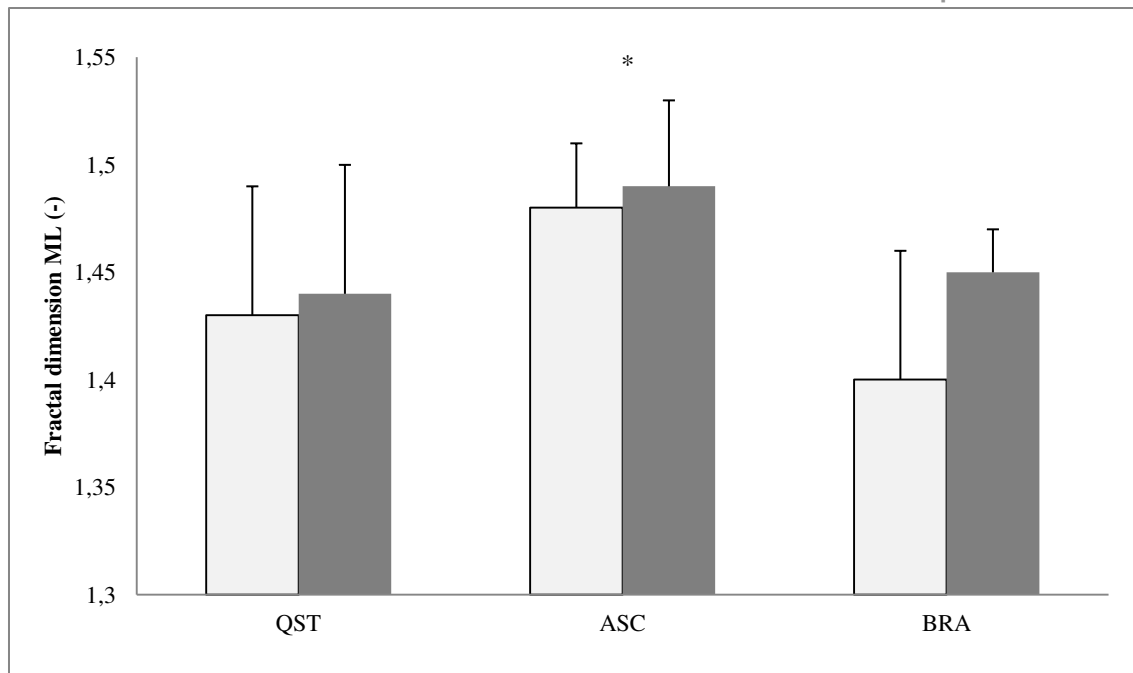
Figure 2

The Chêneau brace used in this study (front).

Mean (SD) values of COP mean position in the AP plane in the backward directions.

QST- quiet standing; ASC- active self-correction; BRA- Chêneau brace. White column- Eyes open; Shaded column- Eyes closed. Asterisks indicate a significant (p <0.05) post hoc difference with respect to QST.

Mean (SD) values of Samle entropy in the AP plane.

QST- quite standing; ASC- active self-correction; BRA- Chêneau brace. White column- Eyes open; Shaded column- Eyes closed. Asterisks indicate a significant (p <0.05) post hoc difference with respect to QST

Mean (SD) values of COP fractal dimension in the ML plane.

QST- quiet standing; ASC- active self-correction; BRA- Chêneau brace. White column- Eyes open; Shaded column-Eyes closed. Asterisks indicate a significant (p <0.05) post hoc difference with respect to QST

Mean (SD) values of COP frequency in the ML plane.

QST- quite standing; ASC- active self-correction; BRA- Chêneau brace. White column- Eyes open; Shaded column- Eyes closed.