Three Simulated Goalball Games in the Same Day Cause Central Fatigue and Can Impair Game Technical Performance

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2   **game technical performance**

3

4   **Abstract**

5   The purpose of this study was to investigate the effects of three simulated goalball games on

6   neuromuscular, physiological, perceptual and technical parameters. Ten male players

7   underwent assessments before and immediately after each game. Heart rate was recorded at rest

8   and during all games that were entirely filmed for further technical performance analysis.

9   Exercise significantly decreased knee extensor muscles peak force and percentage of voluntary

10   activation after the second and third games, indicating the presence of central fatigue. Heart

11   rate responses remained predominantly in a range equivalent to moderate activity intensity in

12   all games. In addition, perceptual parameters were associated with reduced frequency of throws

13   and density of actions. These findings suggest significant implications for the management of

14   physical training, game strategy during a competition and fixture change from three to two

15   games per day.

16   **Keywords:** Disability sport; muscle fatigue; twitch interpolation; heart rate; game analysis.

17

18   **Introduction**

19   Goalball is a sport in increasing popularity already practiced by athletes with visual disabilities

20   in more than 90 countries on all continents (IBSA, 2021). Played at the Paralympic Games, this

21   is a sport without territorial invasion where three players from each team, completely

22   blindfolded, carry out a cycle of attacks and defences in order to score goals and are guided by

23   the tactile stimulus coming from the goal posts and embossed lines demarcated in a court with

24   dimensions of 18m x 9m, as well as through the sound stimulus from the bells inside the ball.

25   (Morato et al., 2012). Although somewhat scarce, publications on goalball point to evidence

26   indicating that the regular practice of this sport by people with visual disabilities (VD) provides

27   numerous advantages in terms of health-related aspects, such as improved balance, reduced

28   body fat and increased level of physical fitness (Alves et al., 2020). However, the literature on

29   assessing the physical fitness of individuals with VD is relatively limited and indicates the need

30   for innovative studies that aid in the evolution of this sport (Petrigna et al., 2020).

31   A match consists of two periods of 12 min and may finish earlier if one of the teams

32   opens an advantage of ten goals on the scoreboard (IBSA, 2021). However, due to constant

33   stoppages, the game can last over 60% longer than the scheduled 24 min (IBSA Goalball, n.d.).

34   The total playing time may vary according to the possibilities provided by the rules: official

35   stoppages (e.g., noise, equipment check, clarification), penalties, timeouts, substitutions, court

36   cleaning, among others. Moreover, due to the fact that the rules allow the same team to play up

37   to three games per day, it is common that in goalball competitions the same team plays more

38   than one game in the same day on consecutive days, which may require a team to remain in the

39   competition environment for up to 8 consecutive hours (IBSA, 2021). Although the amount of

40   recovery actions during a game is relatively large, which may explain the low blood lactate

41   concentrations previously reported (Alves et al., 2018), goalball has shown to demand from

42   players a considerable level of cardiovascular (Ikeda et al., 2019; Theophilos et al., 2005) and

43   cognitive effort (Eddy & Mellalieu, 2003; Powis, 2018). This may be exacerbated by a scenario

44   of three games on the same day and, consequently, lead to the development of muscle fatigue.

45   Muscle fatigue corresponds to a reduction in the capacity of the involved muscles to

46   generate force, which is typically caused by motor tasks performed for long periods of time,

47   leading to a decrease in voluntary activation (Enoka & Duchateau, 2008). Isometric maximal

48   voluntary contractions (IMVC) (Cairns et al., 2005) and percentage of voluntary activation

49   (VA) through the Twitch Interpolation (TI) technique are standardized methods that allow the

50   verification of impairments in contractile function (peripheral fatigue) and/or in the ability of

51   the central nervous system to activate the muscle (central fatigue) (Gandevia, 2001). In addition,

52   decline in maximum strength and incidence of central fatigue are accentuated by the duration

53   of activity (Martin et al., 2010), as demonstrated in intermittent sports lasting more than 90 min,

54   such as tennis, (Girard et al., 2008) soccer (Brownstein et al., 2017) and a day of table tennis

55   competition (Le Mansec et al., 2017). As reported by Gandevia (2001) and Enoka and

56   Duchateau (2008), the incidence of central fatigue is susceptible to impair muscle performance

57   in high-intensity actions, in addition to limiting tolerance and motivation to perform the effort.

58   Researchers have noted that match-related fatigue impaired specific tennis actions such as the

59   speed of service and accuracy of strikes (Rota et al., 2014), besides taking up to 48 h to recover

60   in soccer players (Brownstein et al., 2017). In the case of goalball, lower limbs explosive

61   strength and sprint performance are essential for faster balls because players must be able to

62   accelerate and decelerate quickly from a short distance to perform the throw (Goulart-Siqueira

63   et al., 2019). Therefore, it seems particularly relevant to investigate match-related fatigue in the

64   knee extensor muscles due to the possible detrimental effect of fatigue in determinant goalball

65   actions sustained by this muscle group.

66   In addition, heart rate (HR) analysis and systematic video observation can provide

67   meaningful information about exertion in goalball games. Scientists have demonstrated that

68   time played with HR above 85% of the maximum heart rate can exceed 40% (Ikeda et al., 2019;

69   Theophilos et al., 2005), which demonstrates the intense cardiovascular demand prompted by

70   the game. Furthermore, systematic video analysis makes it possible to verify fluctuations in

71   performance based on the frequency of the offensive and defensive goalball actions (Morato et

72   al., 2017). These elements constitute the game technical performance (GTP), which is

73   susceptible to be affected according to the ability to maintain the effort during a game (Alves

74   et al., 2018), because increases in recovery time and decreases in density of actions over the

75   course of a competition day may indicate a reduction in the athlete's participation in games due

76   to muscle fatigue.

77   Therefore, the aims of the present study were to: (i) examine the neuromuscular fatigue

78   responses to three goalball games played on the same day; (ii) examine the associated activity

79   profile and physiological responses and; (iii) investigate the relationship between

80   neuromuscular, physiological, perceptual and technical parameters of the games. The first

81   hypothesis of the study is that three simulated goalball games on the same day may induce a

82   significant reduction in the strength of knee extensor muscles due to central alterations. Our

83   second hypothesis is that the neuromuscular, physiological and perceptual variables will

84   significantly correlate with GTP parameters.

85

86   **Method**

87   *Participants*

88   Ten male players (37 ± 9 years; 90.3 ± 18.1 kg; 1.75 ± 0.1 m) competing in the state

89   championship in 2019, with no history of muscle disorders, participated in the study. Players

90   trained ≥ 3 times/week for ≥ 150 min, and their experience in the sport was 5 ± 3 years.

91   Furthermore, three players included previous experience with the Brazil national under-19

92   Goalball team in international competitions. Seven players were classified as B1 (visual acuity

93   less than LogMAR 2.6), one player as B2 (visual acuity ranging from LogMAR 1.5 to 2.6

94   (inclusive) and/or visual field restricted to a diameter less than 10 degrees) and two players as

95   B3 (visual acuity ranging from LogMAR 1.4 to 1.0 (inclusive) and/or visual field restricted to

96   a diameter less than 40 degrees) (IBSA, 2021). All procedures were approved by the Human

97   Research Ethics Committee of the local University (nº XXXXX) and were conducted according

98   to the Helsinki declaration. Informed consent was obtained from all participants included in the

99   study.

100

101   *Procedures*

102   The evaluations were carried out during the competition period and took place in a sports court

103   with all the necessary specifications for the practice of goalball. A familiarization routine took

104   place for two consecutive days before the assessments simulating the procedures. On the day

105   of the assessments, the procedures started in the morning, lasting 5 hr. The experimental design

106   (Figure 1) corresponded to a game system where each participant played three 40-min efforts

107   with 30-min of passive rest between each effort. The participants' order of entry on court

108   occurred in a random and staggered way to allow the assessments before the first and

109   immediately after each game of RPE, blood lactate concentration ([La⁻]), and neuromuscular

110   parameters through IMVC and TI (~5 min per participant at each moment). In addition, HR

111   was recorded throughout the whole period of games and all actions were entirely filmed by two

112   digital cameras positioned at specific locations on the court for later video analyses to determine

113   GTP parameters.

114

115   [Figure 1 near here]

116

117   *Neuromuscular assessments*

118   Force data acquisition was performed through knee extension IMVC, and VA was quantified

119   using the TI. IMVC and TI are both valid and reliable measures classically adopted to describe

120   fatigue. Place et al. (2007) reported high levels of absolute reliability with an Intraclass

121   correlation coefficient (ICC) of 0.90 and a coefficient of variation (CV) of 3.5% for quadriceps

122   IMVC torque, as well as a CV of 3.1% for VA and 1.2% for central activation ratio with a

123   typical error lower than 5%.

124   All assessment was performed against a load cell measuring up to 200 kg (CSR-1T, MK

125   Controle®, São Paulo, Brazil) and the data acquisition was done in a Labview 2015

126   environment (National Instruments®). Signals were obtained at a sampling rate of 1000 Hz and

127   digitally filtered through a fourth order Butterworth filter with a cut-off frequency of 15 Hz,

128   assumed after the analysis of signal residues. IMVC peak force (F_{PEAK}) was assumed to

129   represent the average of 100 ms during the force plateau. Participants were positioned on a

130   custom-made ergometer designed for this test. They remained with the trunk attached to the

131   chair, with the hips and knees flexed at 80º and 90º, respectively, and firmly attached to the seat

132   by two crossed belts at chest height and at waist level. The player's preferred leg was attached

133   to the equipment approximately 3 cm above the lateral malleolus using a velcro tape attached

134   to a metal wire attached to the load cell.

135   Double electrical pulses (doublets) (100 Hz – 1 ms pulse duration, 10 ms interval

136   between pulses) were applied to the most sensitive sites of the femoral triangle (cathode) and

137   gluteal fold (anode) by a high-voltage electrical stimulator (Bioestimulador 200 V peak-to-

138   peak–Insight–Ribeirão Preto– SP–Brazil) through carbon rubber electrodes (5 x 7 cm, CF3200

139   ValuTrode® Self-Adhesive Electrodes). The intensity of the stimulation threshold was

140   previously determined through IMVC by applying consecutive incremental doublets (10 mA

141   increments) to the relaxed muscle up to the participant's voluntary sensation of discomfort or

142   until determining an intensity at which even with the increase in intensity there was no increase

143   in the torque produced by the relaxed muscle (Girard et al., 2013). The maximum electric

144   current reached was recorded and the intensity of stimulation during the TI was set at 110% to

145   guarantee supramaximal stimulations (Scaglioni & Martin, 2009).

146   Players performed two IMVC lasting 5 s separated by 60 s, with double electrical pulses

147   application at 2-3 s [IMVC superimposition – Superimposed Twitch (SIT)] and 3 s after IMVC

148   [relaxed muscle – Peak Twitch (PT)]. The increase in SIT is associated with central fatigue

149   patterns (Kooistra et al., 2008) whereas the decrease in PT is evidence of peripheral fatigue

150   (Gandevia, 2001). VA was calculated as VA = [1 - (SIT × (strength level at the time of

151   stimulation/peak force (F_{PEAK})) / PT)] × 100 (Neyroud et al., 2014). IMVC with the highest

152   strength value during attempts were recorded to determine the neuromuscular parameters

153   (F_{PEAK}, SIT, PT and VA).

154

155   *Blood lactate concentration evaluation*

156   Blood samples [La^-] from the earlobe (25 μL) were collected before and immediately after each

157   game, deposited in tubes with sodium fluoride (1%) and analysed using a YSI 2300 STAT

158   electrochemical lactimeter (Yellow Springs, OH, USA).

159

160   *Heart rate monitoring*

161   HR was recorded beat-by-beat at rest and continuously over the three simulated games with a

162   heart rate monitor (Polar Team; Polar®, Kempele, Finland) and later transmitted to the

163   computer via a proprietary interface (IR interface; Polar ®, Kempele, Finland). In a recent

164   study, Hernando et al. (2018) validated the Polar® heart rate measurement system to collect

165   heart rate and heart rate variability data in humans during exercise and showed a high

166   correlation coefficient between mean heart rate and the power of exercise low-frequency (r =

167   0.89) as well as ICC > 0.9.

168   The mean heart rate (HR_{MEAN}) and the highest HR value ($HR_{MAXGAME}$) recorded in each

169   game were retained for analyses. The maximum heart rate (HR_{MAX}) was considered the highest

170   HR obtained at the end of an incremental test specific to goalball (Gulick & Malone, 2011)

171   previously undertaken by the players, as this value was higher than the $HR_{MAXGAME}$ obtained in

172   the three simulated games. The relative time was determined in three intensity zones based on

173   the recommendations of the American College of Sports Medicine (2010): sub-aerobic activity

174   or low activity (< 65% of HR_{MAX}), aerobic zone or moderate activity (65 - 85% HR_{MAX}) and

175   above threshold or very vigorous activity (> 85% HR_{MAX}).

176

177   *Rating of perceived exertion*

178   RPE determination was carried out verbally by the CR-10 scale adapted by Foster et al. (2001).

179   In their mini review article, Haddad et al. (2017) present evidence from several studies which

180   confirmed that CR-10 scale modified by Foster et al. (2001) is a valid and reliable method, led

181   by a reported ICC > 0.8 and its strong correlations with selected objective methods in different

182   types of physical exercise and sports, regardless of gender, age group and skill level.

183

184   *Simulated goalball games and game technical performance*

185   The games protocol consisted of an uninterrupted game system in which each participant played

186   three subsequent 40 min efforts, which already considered the stoppages provided for by the

187   rules (e.g., penalties, substitutions, court cleaning), with 30 min of passive rest between efforts.

188   Playing time of 40 min was adopted because this is the average duration of official goalball

189   games (IBSA Goalball, n.d.). Regarding the 30-min interval, we estimated that this corresponds

190   to the minimum recovery interval on a day of goalball competition if one takes into account

191   that, according to the event table, the match that takes place between two matches of a same

192   team finishes quickly due to a difference of 10 goals on the scoreboard, requiring the subsequent

193   game to initiate in 5 min (IBSA, 2021). Therefore, considering the effort-pause ratio and the

194   density of the game (Alves et al., 2018), the aforementioned setting was sought to stimulate

195   exertion through the most reasonable possible proximity to the real context.

196   The order of entry into the court of the evaluated players was randomly defined and took

197   place in a staggered way, allowing all participants to be evaluated immediately after playing

198   their respective 40 min efforts to ensure that the game remained in a high intensity, evaluations

199   occurred in the correct periods and to minimize the chance of restoring muscle homeostasis.

200   Time on the court was individually timed for each evaluated player, replaced when completing

201   40 min by the participant in the sequence, or by a staff, when the 30-min interval had not yet

202   been finished. All assessment equipment was placed next to the court, close to the team's bench

203   area.

204   GTP was adopted to quantify the offensive and defensive actions of the participants in

205   each effort. In order to preserve game's validity and stimulate high competitiveness, no specific

206   requirements that could influence the situation, context or positional variables were demanded.

207   All official rules were applied, and the entire period of games was filmed by two GoPro HERO

208   3+ cameras (Woodman Labs Inc., USA) adjusted to a frequency of 60 Hz in full HD, totalling

209   4 hr of footage. The cameras were positioned at the highest point of the gymnasium bleachers,

210   attached to metal structures, in order to frame the entire court.

211   Two researchers analysed and registered GTP through systematic video observation in

212   a specific software (Kinovea 0.8.25). Considering the three measurement moments for each

213   participant, the technical measures included the following set of analysis criteria: frequency of

214   throws, defensive actions and recovery time (seconds) between each action (throw or defence).

215   The researchers agreed that all actions in which the player moved towards the ball, independent

216   on touching it, would be considered as defence. The density of actions (sum of throws and

217   defences per minute) was also calculated at each moment. GTP indicators were selected

218   according to the offensive and defensive principles that constitute goalball self-organization

219   (Morato et al., 2017).

220   Reliability of GTP responses was assessed using the first 50 min of the footage (20% of

221   the sample), analysed twice, at different times (15 days apart) by two observers, a goalball

222   coach and an experienced researcher in the observational video analysis. The Kappa index was

223   used for categorical variables (Fleiss et al., 2013) and was higher than 0.8 for the actions

224   analysed for both intra-observer and inter-observer reliability. The ICC was adopted for

225   numerical variables (Hopkins, 2000) and was higher than 0.9 for intra and inter-observer in

226   recovery times.

227

228   *Statistical analysis*

229   The sample size was calculated by using predicted effect size of -1.32 provided by Milioni et

230   al. (2016) for changes in the peak force associated with the Twitch Interpolation technique in

231   knee extension IMVC measured before and after a futsal match. We used the G*power 3.1

232   software (Dusseldorf, Germany) that had revealed that eight participants would provide 95%

233   power to detect differences at an α-level of 0.05. Therefore, for this study 10 players were

234   recruited considering a possible sample loss of 20% throughout the experiment, which did not

235   occur.

236   Statistical analyses were performed using the JASP software version 0.12.2

237   (Amsterdam, the Netherlands). A Bayesian statistical approach was used to provide

238   probabilistic statements, as it offers a useful alternative with regard to the interpretation of the

239   relative support of a null model against an alternative model (Wagenmakers, Love, et al., 2018).

240   According to Wagenmakers, Marsman, et al. (2018), although both p values and Bayes factors

241   generally reach similar conclusions, there are several advantages of Bayesian inference over

242   classical inference. For instance, Bayes factors not only allow the quantification of evidence,

243   but also the continuous monitoring as data accumulates without the need to identify the intent

244   with which the data was collected (Wagenmakers, Marsman, et al., 2018). The authors also

245   explain that from a Bayesian approach it is possible to quantify evidence that the data provide

246   for the null hypotheses (H_0) vs. the alternative hypotheses (H_1), to quantify evidence in favour

247   of H_0, in addition to not being strongly biased against H_0 (Wagenmakers, Marsman, et al.,

248   2018).

249   Initially, the normality of data distribution was confirmed by the Shapiro Wilk test. The

250   data were analysed by one-way analysis of variance (ANOVA) and Pearson's correlation. The

251   Bayesian ANOVA was adopted to compare the differences between neuromuscular variables

252   (F_{PEAK}, SIT, PT and VA), RPE, [La⁻] and HR_{MEAN} in the moments before, after games 1, 2 and

253   3, and between $HR_{MAXGAME}$ and GTP variables (throws, defences, recovery and density) in

254   games 1, 2 and 3. The Bayes factor (BF) was calculated for all variables employing the fixed

255   effects of the r scale predefined by JASP, prior width of 0.5 for the prior distribution. Pearson's

256   Bayesian correlations were used to verify possible associations between neuromuscular,

257   physiological, perceptual and GTP variables. A prior beta pre-defined by JASP with width 1

258   was used, which assigns a prior probability equal to all the correlation values between -1 and

259   1. For the comparison of the registered heart rates, the 40 min recorded for each participant in

260   each game were used.

261   The BF calculates the probability that H_0 or H_1 is true from the present data. If a

262   significant Bayes factor favourable to H_1 (BF_{10}) was identified, a post-hoc (Westfall et al.,

263   1997) was performed. Evidence for the alternative hypothesis (H_1) was set as $BF_{10} > 1$ and

264   evidence for null hypothesis (H_0) was set as $BF_{10} < 1/3$. BF_{10} was reported to indicate the

265   strength of the evidence for each analysis (within and between) and interpreted as *anecdotal*

266   ($BF_{10} = 1\text{-}3$), *moderate* ($BF_{10} = 3\text{-}10$), *strong* ($BF_{10} = 10\text{-}30$), *very strong* ($BF_{10} = 30\text{-}100$) and

267   *extreme* ($BF_{10} > 100$) when favouring the alternative hypothesis; or *anecdotal* ($BF_{10} = 1\text{-}0.33$),

268   *moderate* ($BF_{10} = 0.33\text{-}0.01$), *strong* ($BF_{10} = 0.01\text{-}0.03$), *very strong* ($BF_{10} = 0.03\text{-}0.01$) and

269   *extreme* ($BF_{10} < 0.01$) when favouring the null hypothesis (Wagenmakers, Love, et al., 2018).

270   For each ANOVA, the *partial eta squared (η^2)* was calculated. For all comparisons, we also

271   calculated the Cohen's d. Effect size limit values were $d > 0.2$ (small), > 0.5 (medium), and $>$

272   0.8 (large); $\eta^2 > .01$ (small), $> .06$ (medium), and $> .15$ (large; Cohen 1988).

273

274 **Results**

275 The means, standard deviation (SD) and BF_{10} related to the differences between the moments

276 pre, games 1, 2 and 3 for the neuromuscular, physiological, perceptual and game technical

277 performance variables are shown in Table 1.

278

279   [Table 1 near here]

280

281   Bayesian ANOVA reported evidence for H_1 for the neuromuscular variables F_{PEAK}

282 (BF_{10} = 1.28, *anecdotal*, η^2 = .19) and VA (BF_{10} = 1.01, *anecdotal*, η^2 = .17). The significant

283 decrease in the strength of IMVC is demonstrated by F_{PEAK} in the comparison between the

284 moments pre vs game 2 (BF_{10} = 4.5, *moderate*, d = 0.94) and pre vs game 3 (BF_{10} = 2.6,

285 *anecdotal*, d = 0.81), and for central factors through the significant decrease in VA in the

286 comparison between pre vs game 2 (BF_{10} = 3.2, *moderate*, d = 0.86) and pre vs game 3 (BF_{10}

287 = 1.5, *anecdotal*, d = 0.68). The post-hoc test also pointed to differences with medium and large

288 effect sizes that occurred in RPE between pre vs game 1 (BF_{10} = 710.80, *extreme*, d = 2.79),

289 pre vs game 2 (BF_{10} = 599.25, *extreme*, d = 2.74) and pre vs game 3 (BF_{10} = 5003.66, *extreme*,

290 d = 3.37); [La⁻] between pre vs game 1 (BF_{10} = 4.9, *moderate*, d = 1.33), pre vs game 2 (BF_{10}

291 = 4.8, *moderate*, d = 1.33), pre vs game 3 (BF_{10} = 1.2, *anecdotal*, d = 0.88) and game 1 vs game

292 3 (BF_{10} = 0.73, *anecdotal for H_0*, d = 0.62); HR_{MEAN} between pre vs game 1 (BF_{10} = 56,591.73,

293 *extreme*, d = 4.87), pre vs game 2 (BF_{10} = 629,929.79, *extreme*, d = 5.47) and pre vs game 3

294 (BF_{10} = 555,197.35, *extreme*, d = 5.42); frequency of throws between game 1 vs game 2 (BF_{10}

295 = 0.68, *anecdotal for H_0*, d = 0.56); and frequency of defences between game 1 vs game 2 (BF_{10}

296 = 0.65, *anecdotal for H_0*, d = 0.53).

297   The HR_{MAX} obtained in the incremental test was 190 ± 18 bpm. In all games, HR_{MEAN}

298   remained in the range between 130 and 140 bpm, equivalent to an average intensity in games

299   of 71 ± 2% of HR_{MAX} and 79 ± 3% of $HR_{MAXGAME}$. It is observed that in the three games the

300   highest percentage of time identified is in the range < 130 bpm (Figure 2). Regarding the

301   percentages established in different zones of intensity in relation to the HR_{MAX} of each

302   participant, the following average values were obtained:

303   • *Low activity*: the time spent below 65% of HR_{MAX} was 21 ± 9.4% of playing time;

304   • *Moderate activity*: the time spent between 65 and 85% of HR_{MAX} was 74.6 ± 9.8% of

305   playing time;

306   • *Very vigorous activity*: the time spent above 85% of HR_{MAX} was 4.4 ± 0.8% of playing

307   time.

308

309   [Figure 2 near here]

310

311   Evidence for H_1 was also identified in the comparisons between the time spent at each

312   intensity (BF_{10} = 1.061e +8, *extreme, η^2 = .67*) (Figure 3). The post-hoc test showed *extreme*

313   evidence in the comparison between the relative time spent in the intensity between 65 and 85%

314   of HR_{MAX} and the intensities < 65% (BF_{10} = 2458.8, *d* = 2.03) as well as > 85% (BF_{10} = 1.419e

315   +8, *d* = 3.80), and *anecdotal* evidence between < 65% and > 85% (BF_{10} = 2.5, *d* = 0.85).

316

317   [Figure 3 near here]

318

319   The Bayesian correlation reported that RPE was positively correlated with HR_{MEAN}, r =

320   0.77 (BF_{10} = 285512.66, *extreme*), and negatively with GTP variables, as is the case of the

321   frequency of throws, r = -0.58 (BF_{10} = 48.66, *very strong*), and density of actions, r = -0.53

322   (BF_{10} = 17, *strong*). $HR_{MAXGAME}$ presented a negative correlation with recovery time, r = -0.63

323   (BF_{10} = 66.99, *very strong*), and positive with density of actions, r = 0.55 (BF_{10} = 13.12, *strong*).

324   A complete list of correlations is shown in Table 2.

325

326   [Table 2 near here]

327

328   **Discussion**

329   The aims of the study were to examine the neuromuscular responses of three consecutive

330   simulated goalball games, the activity profile by monitoring GTP, heart rate and lactate, and

331   the correlation between neuromuscular, physiological, perceptual and GTP parameters. To the

332   best of our knowledge, this is the first study that evaluated neuromuscular parameters in a

333   sample of goalball players and the main results were: (i) IMVC strength of knee extensor

334   muscles and VA decreased significantly after the second and third games, indicating the

335   presence of central fatigue; (ii) HR response remained predominantly in a range equivalent to

336   moderate activity intensity in all games; and (iii) the RPE is associated with reduced frequency

337   of throws and density of actions. Collectively, these data partly confirm the study's hypotheses

338   that stimulus provoked by three subsequent goalball games cause central fatigue and that some

339   dependent variables would significantly correlate with performance parameters. Consequently,

340   it is possible that from the second game on, players experiencing central fatigue present a

341   worsening of performance with consequent lower participation in the determinant actions of

342   the game in addition to the greater need for recovery between goalball games in a competition

343   day.

344   One of our main findings was the occurrence of central fatigue on the second and third

345   games. The magnitude of fatigue change observed after the second game, with a large effect

346   size for F_{PEAK} ($d = 0.94$) and VA ($d = 0.86$), is in line with what was demonstrated by Le Mansec

347   et al. (2017) due to the substantial number of matches during a simulated table tennis

348   competition, as IMVC strength reduced by 11% and VA by 13%. Moreover, these findings are

349   also similar to the stimulus caused by a competitive 90-min soccer game, which revealed a 14%

350   reduction in IMVC and 7% in VA (Brownstein et al., 2017), as well as a simulated 150-min

351   tennis match, in which IMVC decreased by 13% and the VA by 11% (Girard et al., 2008).

352   Hence, this strongly suggests that goalball coaches should ensure that strength and specific

353   endurance training routines are included in the training plans in order to reduce the decrease of

354   muscle function mediated by central fatigue by improving players' physical fitness.

355   The average recovery time between the determinant goalball technical actions greater

356   than 30 s (Table 1) may explain the low [La$^-$] after games. Blood lactate concentration is one

357   of the metabolic factors that can affect muscle contraction and fatigue as it increases with

358   exercise intensity (Wan et al., 2017). However, despite the large effect sizes related to its

359   significant increase after each game compared to basal values, [La$^-$] in all matches was lower

360   than 4 mM (Table 1) as previously demonstrated (Alves et al., 2018; Theophilos et al., 2005).

361   It may be explained by the fast execution time of throws and defences (less than 2 s) as well as

362   the dependence of the density of actions on the alactic metabolism due to its importance for a

363   higher frequency of actions per unit of time during games (Alves et al., 2018). In addition, the

364   observed recovery periods may explain the predominance of heart rate that indicates moderate

365   intensity (Figure 3).

366   Both HR_{MEAN} and the activity profile identified from the HR_{MAX} percentages were

367   different from those previously recorded (Ikeda et al., 2019; Theophilos et al., 2005). Regarding

368   the activity profile, the lowest percentage of time in very vigorous activity may be associated

369   with the method used to estimate HR_{MAX}. In relative terms, we adopted the highest HR obtained

370   at the end of an incremental test specific to goalball as a reference, whereas Theophilos et al.

371   (2005) considered the peak heart rate recorded during the games as HR_{MAX}. In fact, the

372    $HR_{MAXGAME}$ was ~8% lower than the HR_{MAX} obtained in the incremental test in our study,

373   suggesting that these authors could have underestimated the actual players HR_{MAX} and,

374   consequently, identified very vigorous intensity in 40% of the time (Theophilos et al., 2005),

375   whereas we identified a predominance of intensity between 65 and 85% of HR_{MAX} with large

376   effect sizes in comparison with intensities < 65% ($d = 2.03$) and > 85% ($d = 3.80$). Moreover,

377   the difference in HR_{MEAN} may be related to playing time, which in the present study was 40

378   min, closer to the proper context of goalball, while in the study by Ikeda et al. (2019), who

379   observed a HR_{MEAN} of 155 ± 5 bpm, it was exactly 24 min (2 x 12 min), probably stimulating

380   shorter intervals between actions and a consequent increase in cardiovascular demand. Hence,

381   the more extended duration of the games in our investigation may be associated with a decrease

382   in intensity to maintain performance, a crucial aspect for the proportion of central fatigue

383   experienced (Martin et al., 2010).

384   In this study, the reduction in VA presented a significant difference with large and

385   medium effect sizes after the second and third games, respectfully, allowing extrapolation of

386   results to future research. Neuromuscular fatigue of central origin caused by intermittent sports

387   of prolonged duration, such as tennis (Girard et al., 2008; Rota et al., 2014) and soccer

388   (Brownstein et al., 2017), has shown to impair determinant technical actions as well as to

389   require a long recovery period. When investigating the effect of a simulated tennis match lasting

390   four sets of 40 min, Rota et al. (2014) identified considerable reductions in speed and accuracy

391   of service, and decreases in accuracy and consistency of strokes. Furthermore, Brownstein et

392   al. (2017) show evidence that soccer match-related fatigue may allow more than 48 hr to

393   recover. It is important to highlight that soccer matches are likely more demanding than

394   goalball, as players can cover more than 10,000 m and perform a frequency of very high

395   intensity runs over 170 in a game (Bradley et al., 2010). Goalball is a sport with no territorial

396   invasion in which elite players present a frequency of recovery actions higher than the sum of

397   attack and defensive actions (Alves et al., 2018). On the other hand, tournaments often require

398   teams to play the up to three games per day, requiring players to stay in the competition

399   environment for up to 8 hours, even on consecutive days (IBSA, 2021). Therefore, it is possible

400   to infer that after three goalball games in one day, players are not sufficiently recovered for a

401   second day of competition, which may result in an impaired performance. However, this

402   possibility needs to be further investigated.

403   Muscle strength represents an essential factor for successful goalball shooting (Morato

404   et al., 2017). However, despite the occurrence of neuromuscular fatigue, significant correlations

405   were not observed between neuromuscular variables and other parameters analysed. The non-

406   significant correlations with perceptual, physiological and performance variables can be

407   explained by the fact that although the incidence of neuromuscular fatigue is likely to cause a

408   worsening in the quality of game technical actions, as observed in other sports (Rota et al.,

409   2014), the number of actions may not have been affected, thus mitigating the physiological

410   stress by decreasing shooting speed, for example. Consequently, we recommend future studies

411   evaluate shooting speed and/or the success in the execution of defences in goalball games

412   together with neuromuscular assessments, due to the possible deterioration in the quality of

413   technical actions even if this does not affect their quantity.

414   Significant inverse correlations were observed between perceptual and physiological

415   variables with GTP variables, demonstrating that exertion related to three subsequent simulated

416   goalball games is associated with impaired technical performance. The increase in $HR_{MAXGAME}$

417   is proportional to the decrease in recovery time between actions, while the density of actions

418   decreases as RPE increases, indicating that players experiencing fatigue tend to participate less

419   in the game. This is illustrated by the non-significant decrease with medium effect sizes in the

420   frequency of throws ($d = 0.56$) and defences ($d = 0.53$) in the second match compared to the

first. The frequency of determinant technical actions is in line with the ~35 throws and ~67

defensive actions previously demonstrated by Alves et al. (2018) when investigating Brazil's

elite players. It is essential to highlight that the decrease in the frequency of defensive actions

is related to the non-execution of the defensive principles (Morato et al., 2017) by the athletes

positioned next to the ball's target sector. Consequently, the defensive coverage as an aid to the

teammate to whom the thrown ball was intended is likely to decrease throughout the games,

increasing the opponent's chances to score goals.

In addition, we observed that while RPE and [La$^-$] did not significantly correlate,

probably due to long recovery intervals between actions (Table 1) that may have optimized

[La$^-$] removal, RPE and HR$_{MEAN}$ revealed a large positive correlation. The fact that both are

measures used to monitor the internal load and pointed in the same direction through their

concomitant increase may be associated with evidence that indicates the increase in HR is

proportional to cognitive effort (Sadler & Woody, 2006). In fact, athletes with visual disabilities

perform an intense cognitive work during sports practice to achieve psychological results in

various contexts of training and competition (Eddy & Mellalieu, 2003), especially from

auditory information that enable them to identify the location of teammates, opponents and

what is happening in the game (Powis, 2018). Therefore, goalball coaches could include

exercises that, through auditory stimuli, improve players' ability to discriminate and utilize

environmental information to increase the efficiency of reaction time, decision making and

maintenance of attention during the game.

To counteract the potential deleterious effects of central fatigue in a competition with

three goalball games on the same day, we suggest that the International Blind Sports Federation

(IBSA) check the possibility of updating the goalball regulation to reduce the maximum amount

of games per day from three to two. While this cannot be achieved, coaches are provided with

a few possible options. It is recommended during competition to carry out an attack rotation

446   system, that is, the three players on the court take turns performing the throws to preserve

447   themselves for the subsequent games. In addition, coaches may instruct their players to focus

448   the target of their attacks on just one opponent, thus being able to exacerbate fatigue in this

449   player who, consequently, could be more susceptible to conceding goals. Finally, during a

450   tournament of several matches for a limited time, the team can be modified at each game by the

451   coaches, an option made easier when the complete squad of players (in championships: six) has

452   similar goalball skills, so as not to impair team performance.

453   Some limitations should be noted. Firstly, the verification of neuromuscular fatigue in

454   the upper limbs was not performed due to the limitations in the application of the TI technique

455   in this muscle group (Norberto et al., 2020). However, the handgrip dynamometry (Gunha et

456   al., 2020) could have been adopted. Secondly, the study was conducted with simulated games,

457   which could have influenced the intensity of the game for the reason that individual

458   performance in team sports is affected by teammates and opponents (Carron & Chelladurai,

459   2016). Furthermore, the results are limited to men; the neuromuscular assessments could have

460   increased muscle fatigue to some extent; and, although the correlations indicated some

461   interesting relationships, they are insufficient to infer causation. Despite these limitations, the

462   results are innovative for the field of goalball and may provide a valid basis for further research.

463

Conclusions

465   In conclusion, the dispute of three subsequent simulated goalball games resulted in the

466   reduction of muscle strength mediated by central fatigue from the second match. In addition to

467   requiring a considerably long recovery time, the incidence of central fatigue may be responsible

468   for impairing performance in key technical actions. Therefore, the results may have important

469   implications both for the improvement of the players' physical fitness and strategies during the

470   competition to delay fatigue, as well as for the reduction of the maximum number of matches

471   per day from three to two games.

472

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607

608   **Table 1.** Comparison of baseline and simulated games by Bayesian ANOVA. Data presented

609   as mean ± SD (N = 10).

Variable	Pre	Game 1	Game 2	Game 3	BF $_{10}$	Qualitative interpretation
F_{PEAK} (N)	401.90 ± 132.54	403.62 ± 113.48	359.02 ± 79.78	374.10 ± 79.04	1.28	*Anecdotal*
SIT (N)	18.43 ± 18.08	23.92 ± 24.45	39.96 ± 41.37	32.54 ± 40.57	0.36	*Anecdotal for H_0*
PT (N)	101.81 ± 38.90	103.14 ± 36.32	103.77 ± 35.83	101.49 ± 30.66	0.18	*Moderate for H_0*
VA (%)	84.23 ± 12.67	80.70 ± 13.57	73.06 ± 20.08	77.61 ± 16.87	1.01	*Anecdotal*
RPE (AU)	0.70 ± 1.34	5.90 ± 2.28	6.30 ± 2.31	7.10 ± 2.13	147721.53	*Extreme*
[La⁻] (mM)	1.80 ± 0.41	3.61 ± 1.98	3.29 ± 1.61	2.61 ± 1.34	1.87	*Anecdotal*
HR_{MEAN} (bpm)	76 ± 8	131 ± 14	137 ± 14	138 ± 15	3,677e +9	*Extreme*
$HR_{MAXGAME}$ (bpm)	-	172 ± 22	166 ± 14	174 ± 28	0.29	*Moderate for H_0*
Throws (actions)	-	25 ± 10	22 ± 10	20 ± 8	0.34	*Anecdotal for H_0*
Defences (actions)	-	70 ± 23	58 ± 30	54 ± 34	0.34	*Anecdotal for H_0*
Recovery (sec)	-	31.38 ± 11.48	35.36 ± 12.27	33.99 ± 15.67	0.25	*Moderate for H_0*
Density (number.time⁻¹)	-	2.37 ± 0.70	2.12 ± 0.96	2.16 ± 1.01	0.24	*Moderate for H_0*

610   *F_{PEAK}: IMVC peak force; SIT: amplitude of the superimposed twitch; PT: amplitude of the peak*
611   *twitch; VA: percentage of voluntary activation; RPE: rating of perceived exertion; [La⁻]: blood*
612   *lactate concentration; HR_{MEAN}: mean heart rate; $HR_{MAXGAME}$: peak heart rate registered in the*
613   *game; Throws: frequency of actions; Defences: frequency of actions; Recovery: time in seconds*
614   *between each action; Density: sum of throws and defences per minute; BF_{10}: Bayes factor*
615   *favourable to H_1; N: newton; AU: arbitrary units; mM: milimolar; bpm: beats per minute.*
616

617 **Table 2.** Bayesian correlations between neuromuscular, physiological, RPE and game technical

618 performance variables (N = 10).

Variable		[La⁻]	HR$_{MEAN}$	HR$_{MAXGAME}$	RPE	TH	DE	RE	DS
F$_{PEAK}$	r	0.18	-0.06	0.15	0.02	0.25	0.21	-0.27	0.31
	BF$_{10}$	0.36	0.23	0.32	0.21	0.50	0.41	0.56	0.77
SIT	r	-0.12	0.25	0.02	0.07	-0.25	-0.20	0.13	-0.25
	BF$_{10}$	0.26	0.55	0.26	0.23	0.51	0.38	0.29	0.50
PT	r	-0.09	0.20	0.17	0.14	-0.19	0.12	-0.06	0.02
	BF$_{10}$	0.24	0.39	0.34	0.28	0.36	0.29	0.25	0.24
VA	r	0.06	-0.19	-0.01	-0.01	0.16	0.24	-0.16	0.26
	BF$_{10}$	0.22	0.38	0.26	0.21	0.32	0.47	0.32	0.55
[La⁻]	r	—	0.30	0.03	0.43	-0.04	-0.25	0.10	-0.16
	BF$_{10}$	—	0.94	0.25	7.22	0.23	0.52	0.26	0.32
HR$_{MEAN}$	r		—	0.54*	0.77***	-0.14	0.28	-0.30	0.17
	BF$_{10}$		—	11.09	285512.66	0.30	0.58	0.70	0.34
HR$_{MAXGAME}$	r			—	-0.21	0.31	0.42	-0.63**	0.55*
	BF$_{10}$			—	0.41	0.75	2.16	66.99	13.12
RPE	r				—	-0.58**	-0.49	0.46	-0.53*
	BF$_{10}$				—	48.66	8.65	5.19	17.00

619 *Note: * BF$_{10}$ > 10, ** BF$_{10}$ > 30, *** BF$_{10}$ > 100. IMVC peak force; SIT: amplitude of the*
620 *superimposed twitch; PT: amplitude of the peak twitch; VA: percentage of voluntary activation;*
621 *RPE: rating of perceived exertion; [La⁻]: blood lactate concentration; HR$_{MEAN}$: mean heart*
622 *rate; HR$_{MAXGAME}$: peak heart rate registered in the game; TH: throws; DE: defences; RE:*
623 *recovery; DE: density.*

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629   **Figure legends**

630

631   **Figure 1.** Organizational chart of the simulated goalball games evaluations. Order of collection

632   of baseline and post-game procedures: 1) RPE; 2) blood collection [La$^-$]; 3) IMVC/TI.

633

634   **Figure 2.** Percentages of time spent in different heart rate ranges during games 1, 2 and 3. The

635   first line immediately below the bar graph refers to the heart rate ranges. The remaining lines

636   refer to the percentages of time spent in each heart rate range.

637

638   **Figure 3.** Percentages of time spent in low activity ($< 65\%$ HR$_{MAX}$), moderate activity ($65 -$

639   85% HR$_{MAX}$) and very vigorous activity ($> 85\%$ HR$_{MAX}$) during games 1, 2 and 3. The first line

640   immediately below the bar graph refers to the heart rate zones. The remaining lines refer to the

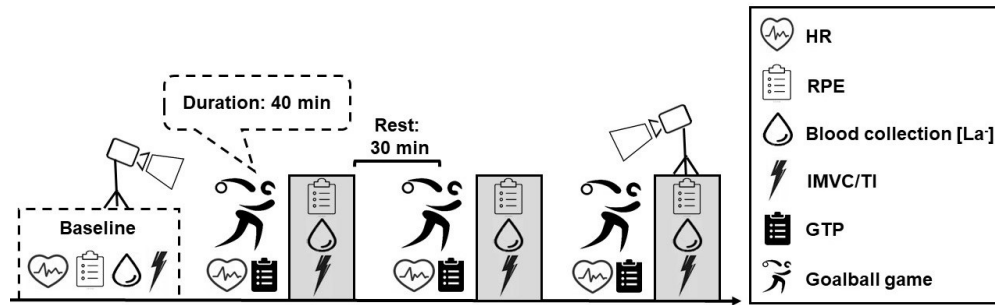641   percentages of time spent in each heart rate zone.

Figure 1. Organizational chart of the simulated goalball games evaluations. Order of collection of baseline and post-game procedures: 1) RPE; 2) blood collection [La-]; 3) IMVC/TI.
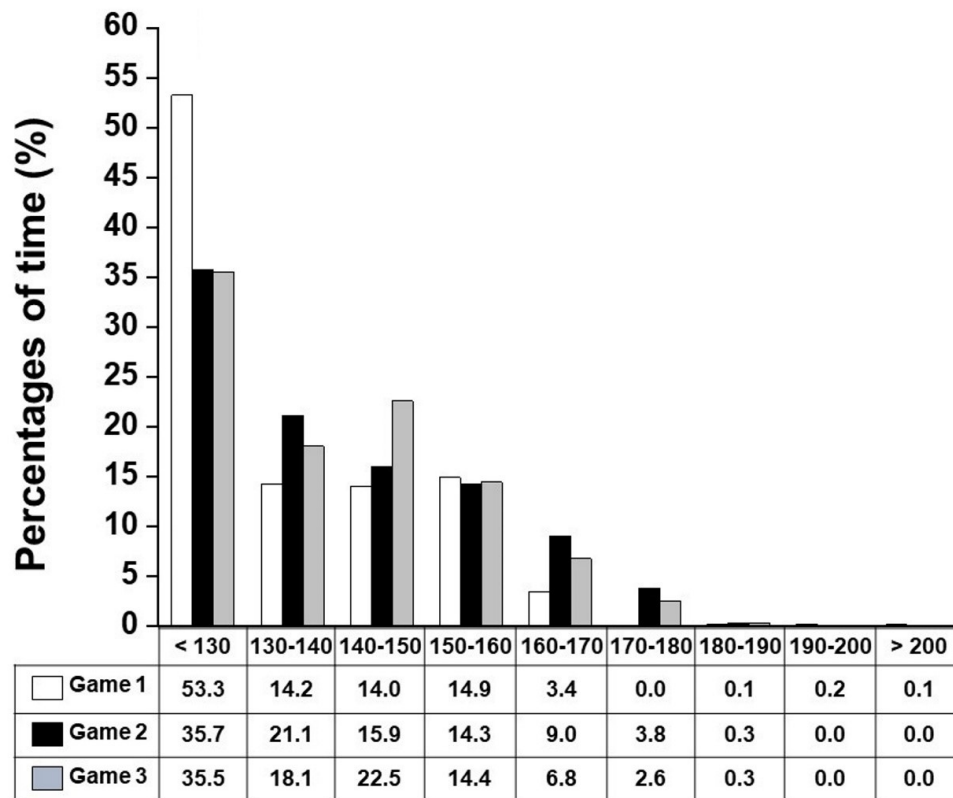
108x34mm (300 x 300 DPI)

Figure 2. Percentages of time spent in different heart rate ranges during games 1, 2 and 3. The first line immediately below the bar graph refers to the heart rate ranges. The remaining lines refer to the percentages of time spent in each heart rate range.

146x120mm (220 x 220 DPI)

	< 65%	65 – 85%	> 85%
☐ Game 1	31.8	63.3	4.9
■ Game 2	15.2	79.9	4.9
▨ Game 3	15.9	80.7	3.5

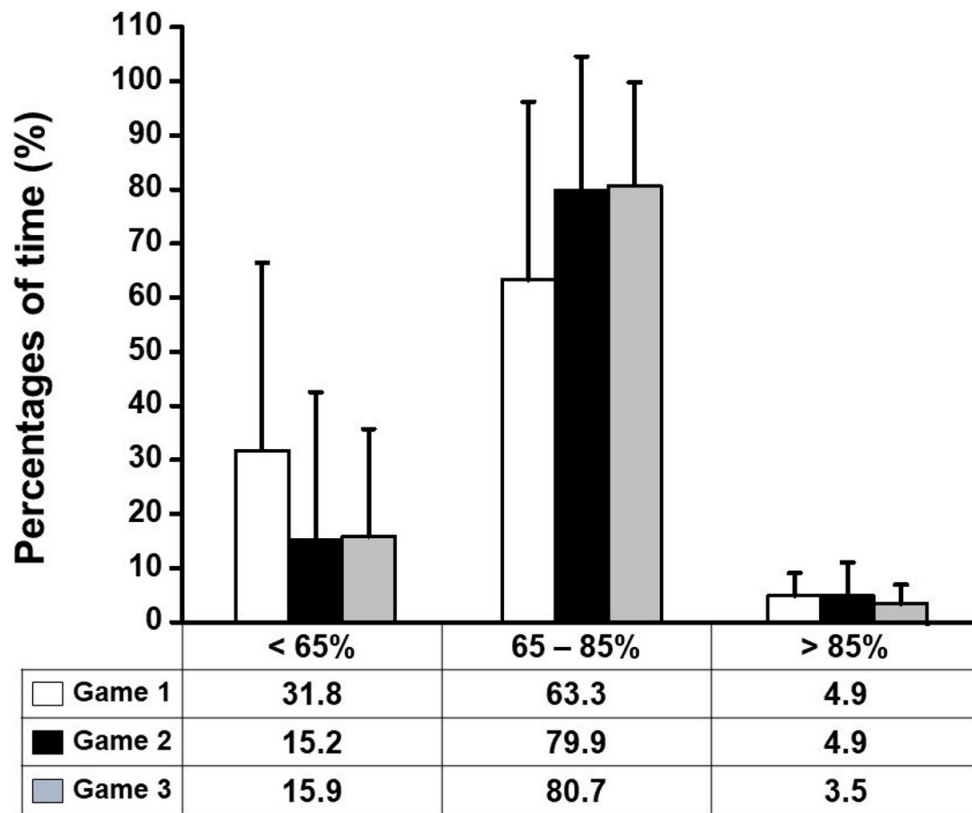Figure 3. Percentages of time spent in low activity (< 65% HRMAX), moderate activity (65 - 85% HRMAX) and very vigorous activity (> 85% HRMAX) during games 1, 2 and 3. The first line immediately below the bar graph refers to the heart rate zones. The remaining lines refer to the percentages of time spent in each heart rate zone.

144x119mm (220 x 220 DPI)