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

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1 **Three simulated goalball games in the same day cause central fatigue and can impair**
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 (n° 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 80° and 90°, 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 $VA = [1 - (SIT \times (\text{strength level at the time of}$
151 $\text{stimulation/peak force (F}_{PEAK})) / PT)] \times 100$ (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 μ L) 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 ($BF_{10} = 1-3$), *moderate* ($BF_{10} = 3-10$), *strong* ($BF_{10} = 10-30$), *very strong* ($BF_{10} = 30-100$) and
267 *extreme* ($BF_{10} > 100$) when favouring the alternative hypothesis; or *anecdotal* ($BF_{10} = 1-0.33$),
268 *moderate* ($BF_{10} = 0.33-0.01$), *strong* ($BF_{10} = 0.01-0.03$), *very strong* ($BF_{10} = 0.03-0.01$) 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*, $\eta^2 = .19$) and VA ($BF_{10} = 1.01$, *anecdotal*, $\eta^2 = .17$). 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 $71 \pm 2\%$ of HR_{MAX} and $79 \pm 3\%$ 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 $21 \pm 9.4\%$ of playing time;
- 304 • *Moderate activity*: the time spent between 65 and 85% of HR_{MAX} was $74.6 \pm 9.8\%$ of
305 playing time;
- 306 • *Very vigorous activity*: the time spent above 85% of HR_{MAX} was $4.4 \pm 0.8\%$ 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*, $\eta^2 = .67$) (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

421 first. The frequency of determinant technical actions is in line with the ~35 throws and ~67
422 defensive actions previously demonstrated by Alves et al. (2018) when investigating Brazil's
423 elite players. It is essential to highlight that the decrease in the frequency of defensive actions
424 is related to the non-execution of the defensive principles (Morato et al., 2017) by the athletes
425 positioned next to the ball's target sector. Consequently, the defensive coverage as an aid to the
426 teammate to whom the thrown ball was intended is likely to decrease throughout the games,
427 increasing the opponent's chances to score goals.

428 In addition, we observed that while RPE and $[La^-]$ did not significantly correlate,
429 probably due to long recovery intervals between actions (Table 1) that may have optimized
430 $[La^-]$ removal, RPE and HR_{MEAN} revealed a large positive correlation. The fact that both are
431 measures used to monitor the internal load and pointed in the same direction through their
432 concomitant increase may be associated with evidence that indicates the increase in HR is
433 proportional to cognitive effort (Sadler & Woody, 2006). In fact, athletes with visual disabilities
434 perform an intense cognitive work during sports practice to achieve psychological results in
435 various contexts of training and competition (Eddy & Mellalieu, 2003), especially from
436 auditory information that enable them to identify the location of teammates, opponents and
437 what is happening in the game (Powis, 2018). Therefore, goalball coaches could include
438 exercises that, through auditory stimuli, improve players' ability to discriminate and utilize
439 environmental information to increase the efficiency of reaction time, decision making and
440 maintenance of attention during the game.

441 To counteract the potential deleterious effects of central fatigue in a competition with
442 three goalball games on the same day, we suggest that the International Blind Sports Federation
443 (IBSA) check the possibility of updating the goalball regulation to reduce the maximum amount
444 of games per day from three to two. While this cannot be achieved, coaches are provided with
445 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

464 **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 \pm SD (N = 10).

Variable	Pre	Game 1	Game 2	Game 3	BF ₁₀	Qualitative interpretation
F _{PEAK} (N)	401.90 \pm 132.54	403.62 \pm 113.48	359.02 \pm 79.78	374.10 \pm 79.04	1.28	<i>Anecdotal</i>
SIT (N)	18.43 \pm 18.08	23.92 \pm 24.45	39.96 \pm 41.37	32.54 \pm 40.57	0.36	<i>Anecdotal for H₀</i>
PT (N)	101.81 \pm 38.90	103.14 \pm 36.32	103.77 \pm 35.83	101.49 \pm 30.66	0.18	<i>Moderate for H₀</i>
VA (%)	84.23 \pm 12.67	80.70 \pm 13.57	73.06 \pm 20.08	77.61 \pm 16.87	1.01	<i>Anecdotal</i>
RPE (AU)	0.70 \pm 1.34	5.90 \pm 2.28	6.30 \pm 2.31	7.10 \pm 2.13	147721.53	<i>Extreme</i>
[La ⁻] (mM)	1.80 \pm 0.41	3.61 \pm 1.98	3.29 \pm 1.61	2.61 \pm 1.34	1.87	<i>Anecdotal</i>
HR _{MEAN} (bpm)	76 \pm 8	131 \pm 14	137 \pm 14	138 \pm 15	3,677e+9	<i>Extreme</i>
HR _{MAXGAME} (bpm)	-	172 \pm 22	166 \pm 14	174 \pm 28	0.29	<i>Moderate for H₀</i>
Throws (actions)	-	25 \pm 10	22 \pm 10	20 \pm 8	0.34	<i>Anecdotal for H₀</i>
Defences (actions)	-	70 \pm 23	58 \pm 30	54 \pm 34	0.34	<i>Anecdotal for H₀</i>
Recovery (sec)	-	31.38 \pm 11.48	35.36 \pm 12.27	33.99 \pm 15.67	0.25	<i>Moderate for H₀</i>
Density (number.time ⁻¹)	-	2.37 \pm 0.70	2.12 \pm 0.96	2.16 \pm 1.01	0.24	<i>Moderate for H₀</i>

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; BF₁₀: Bayes factor*
 615 *favourable to H₁; 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	—	—	—	—	—	-0.49	0.46	-0.53*
	BF ₁₀	—	—	—	—	0.58**	48.66	8.65	5.19

619 *Note: * BF₁₀ > 10, ** BF₁₀ > 30, *** BF₁₀ > 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.

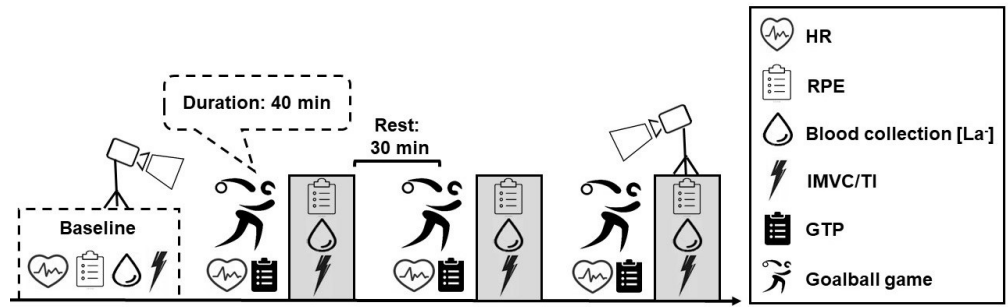


Figure 1. Organizational chart of the simulated goalball games evaluations. Order of collection of baseline and post-game procedures: 1) RPE; 2) blood collection [La-]; 3) IMVC/TI.

108x34mm (300 x 300 DPI)

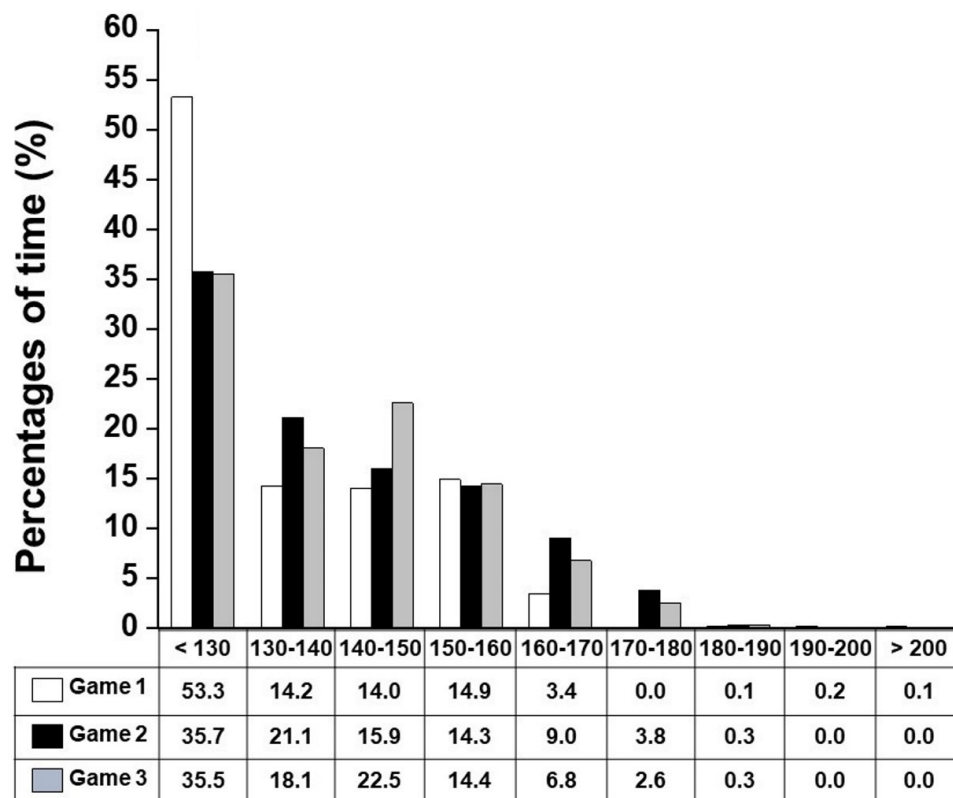


Figure 2. Percentages of time spent in different heart rate ranges during games 1, 2 and 3. The first line immediately below the bar graph refers to the heart rate ranges. The remaining lines refer to the percentages of time spent in each heart rate range.

146x120mm (220 x 220 DPI)

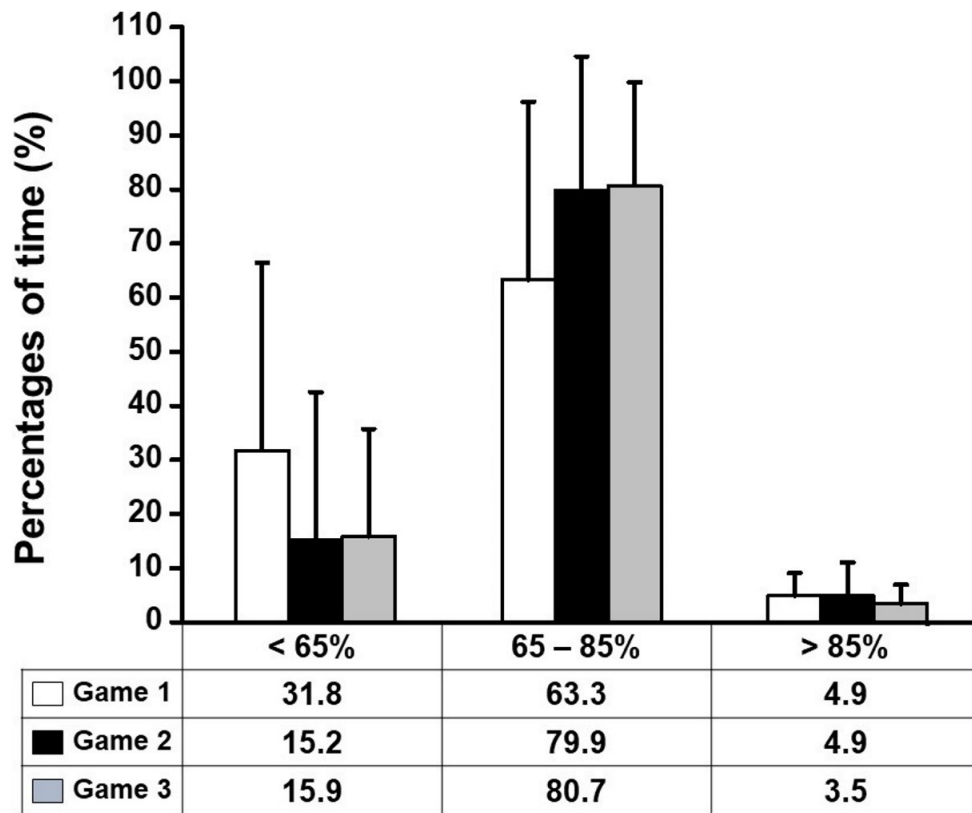


Figure 3. Percentages of time spent in low activity (< 65% HRMAX), moderate activity (65 - 85% HRMAX) and very vigorous activity (> 85% HRMAX) during games 1, 2 and 3. The first line immediately below the bar graph refers to the heart rate zones. The remaining lines refer to the percentages of time spent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

144x119mm (220 x 220 DPI)