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

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Three simulated goalball games in the same day cause central fatigue and can impair game technical performance

Abstract

The purpose of this study was to investigate the effects of three simulated goalball games on neuromuscular, physiological, perceptual and technical parameters. Ten male players underwent assessments before and immediately after each game. Heart rate was recorded at rest and during all games that were entirely filmed for further technical performance analysis. Exercise significantly decreased knee extensor muscles peak force and percentage of voluntary activation after the second and third games, indicating the presence of central fatigue. Heart rate responses remained predominantly in a range equivalent to moderate activity intensity in all games. In addition, perceptual parameters were associated with reduced frequency of throws and density of actions. These findings suggest significant implications for the management of physical training, game strategy during a competition and fixture change from three to two games per day.

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

Introduction

Goalball is a sport in increasing popularity already practiced by athletes with visual disabilities in more than 90 countries on all continents (IBSA, 2021). Played at the Paralympic Games, this is a sport without territorial invasion where three players from each team, completely blindfolded, carry out a cycle of attacks and defences in order to score goals and are guided by the tactile stimulus coming from the goal posts and embossed lines demarcated in a court with dimensions of 18m x 9m, as well as through the sound stimulus from the bells inside the ball.

(Morato et al., 2012). Although somewhat scarce, publications on goalball point to evidence indicating that the regular practice of this sport by people with visual disabilities (VD) provides numerous advantages in terms of health-related aspects, such as improved balance, reduced body fat and increased level of physical fitness (Alves et al., 2020). However, the literature on assessing the physical fitness of individuals with VD is relatively limited and indicates the need for innovative studies that aid in the evolution of this sport (Petrigna et al., 2020).

A match consists of two periods of 12 min and may finish earlier if one of the teams opens an advantage of ten goals on the scoreboard (IBSA, 2021). However, due to constant stoppages, the game can last over 60% longer than the scheduled 24 min (IBSA Goalball, n.d.). The total playing time may vary according to the possibilities provided by the rules: official stoppages (e.g., noise, equipment check, clarification), penalties, timeouts, substitutions, court cleaning, among others. Moreover, due to the fact that the rules allow the same team to play up to three games per day, it is common that in goalball competitions the same team plays more than one game in the same day on consecutive days, which may require a team to remain in the competition environment for up to 8 consecutive hours (IBSA, 2021). Although the amount of recovery actions during a game is relatively large, which may explain the low blood lactate concentrations previously reported (Alves et al., 2018), goalball has shown to demand from players a considerable level of cardiovascular (Ikeda et al., 2019; Theophilos et al., 2005) and cognitive effort (Eddy & Mellalieu, 2003; Powis, 2018). This may be exacerbated by a scenario of three games on the same day and, consequently, lead to the development of muscle fatigue.

Muscle fatigue corresponds to a reduction in the capacity of the involved muscles to generate force, which is typically caused by motor tasks performed for long periods of time, leading to a decrease in voluntary activation (Enoka & Duchateau, 2008). Isometric maximal voluntary contractions (IMVC) (Cairns et al., 2005) and percentage of voluntary activation (VA) through the Twitch Interpolation (TI) technique are standardized methods that allow the verification of impairments in contractile function (peripheral fatigue) and/or in the ability of the central nervous system to activate the muscle (central fatigue) (Gandevia, 2001). In addition, decline in maximum strength and incidence of central fatigue are accentuated by the duration of activity (Martin et al., 2010), as demonstrated in intermittent sports lasting more than 90 min, such as tennis, (Girard et al., 2008) soccer (Brownstein et al., 2017) and a day of table tennis competition (Le Mansec et al., 2017). As reported by Gandevia (2001) and Enoka and Duchateau (2008), the incidence of central fatigue is susceptible to impair muscle performance in high-intensity actions, in addition to limiting tolerance and motivation to perform the effort. Researchers have noted that match-related fatigue impaired specific tennis actions such as the speed of service and accuracy of strikes (Rota et al., 2014), besides taking up to 48 h to recover in soccer players (Brownstein et al., 2017). In the case of goalball, lower limbs explosive strength and sprint performance are essential for faster balls because players must be able to accelerate and decelerate quickly from a short distance to perform the throw (Goulart-Siqueira et al., 2019). Therefore, it seems particularly relevant to investigate match-related fatigue in the knee extensor muscles due to the possible detrimental effect of fatigue in determinant goalball actions sustained by this muscle group.

In addition, heart rate (HR) analysis and systematic video observation can provide meaningful information about exertion in goalball games. Scientists have demonstrated that time played with HR above 85% of the maximum heart rate can exceed 40% (Ikeda et al., 2019; Theophilos et al., 2005), which demonstrates the intense cardiovascular demand prompted by the game. Furthermore, systematic video analysis makes it possible to verify fluctuations in performance based on the frequency of the offensive and defensive goalball actions (Morato et al., 2017). These elements constitute the game technical performance (GTP), which is susceptible to be affected according to the ability to maintain the effort during a game (Alves et al., 2018), because increases in recovery time and decreases in density of actions over the course of a competition day may indicate a reduction in the athlete's participation in games due to muscle fatigue.

Therefore, the aims of the present study were to: (i) examine the neuromuscular fatigue responses to three goalball games played on the same day; (ii) examine the associated activity profile and physiological responses and; (iii) investigate the relationship between neuromuscular, physiological, perceptual and technical parameters of the games. The first hypothesis of the study is that three simulated goalball games on the same day may induce a significant reduction in the strength of knee extensor muscles due to central alterations. Our second hypothesis is that the neuromuscular, physiological and perceptual variables will significantly correlate with GTP parameters.

Method

Participants

Ten male players (37 ± 9 years; 90.3 ± 18.1 kg; 1.75 ± 0.1 m) competing in the state championship in 2019, with no history of muscle disorders, participated in the study. Players trained ≥ 3 times/week for ≥ 150 min, and their experience in the sport was 5 ± 3 years. Furthermore, three players included previous experience with the Brazil national under-19 Goalball team in international competitions. Seven players were classified as B1 (visual acuity less than LogMAR 2.6), one player as B2 (visual acuity ranging from LogMAR 1.5 to 2.6 (inclusive) and/or visual field restricted to a diameter less than 10 degrees) and two players as B3 (visual acuity ranging from LogMAR 1.4 to 1.0 (inclusive) and/or visual field restricted to a diameter less than 40 degrees) (IBSA, 2021). All procedures were approved by the Human Research Ethics Committee of the local University (nº XXXXX) and were conducted according to the Helsinki declaration. Informed consent was obtained from all participants included in the study.

Procedures

The evaluations were carried out during the competition period and took place in a sports court with all the necessary specifications for the practice of goalball. A familiarization routine took place for two consecutive days before the assessments simulating the procedures. On the day of the assessments, the procedures started in the morning, lasting 5 hr. The experimental design (Figure 1) corresponded to a game system where each participant played three 40-min efforts with 30-min of passive rest between each effort. The participants' order of entry on court occurred in a random and staggered way to allow the assessments before the first and immediately after each game of RPE, blood lactate concentration ([La^-]), and neuromuscular parameters through IMVC and TI (~5 min per participant at each moment). In addition, HR was recorded throughout the whole period of games and all actions were entirely filmed by two digital cameras positioned at specific locations on the court for later video analyses to determine GTP parameters.

[Figure 1 near here]

Neuromuscular assessments

Force data acquisition was performed through knee extension IMVC, and VA was quantified using the TI. IMVC and TI are both valid and reliable measures classically adopted to describe fatigue. Place et al. (2007) reported high levels of absolute reliability with an Intraclass correlation coefficient (ICC) of 0.90 and a coefficient of variation (CV) of 3.5% for quadriceps IMVC torque, as well as a CV of 3.1% for VA and 1.2% for central activation ratio with a typical error lower than 5%.

All assessment was performed against a load cell measuring up to 200 kg (CSR-1T, MK Controle®, São Paulo, Brazil) and the data acquisition was done in a Labview 2015 environment (National Instruments®). Signals were obtained at a sampling rate of 1000 Hz and digitally filtered through a fourth order Butterworth filter with a cut-off frequency of 15 Hz, assumed after the analysis of signal residues. IMVC peak force (F_{PEAK}) was assumed to represent the average of 100 ms during the force plateau. Participants were positioned on a custom-made ergometer designed for this test. They remained with the trunk attached to the chair, with the hips and knees flexed at 80º and 90º, respectively, and firmly attached to the seat by two crossed belts at chest height and at waist level. The player's preferred leg was attached to the equipment approximately 3 cm above the lateral malleolus using a velcro tape attached to a metal wire attached to the load cell.

Double electrical pulses (doublets) (100 Hz – 1 ms pulse duration, 10 ms interval between pulses) were applied to the most sensitive sites of the femoral triangle (cathode) and gluteal fold (anode) by a high-voltage electrical stimulator (Bioestimulador 200 V peak-to-peak–Insight–Ribeirão Preto– SP–Brazil) through carbon rubber electrodes (5 x 7 cm, CF3200 ValuTrode® Self-Adhesive Electrodes). The intensity of the stimulation threshold was previously determined through IMVC by applying consecutive incremental doublets (10 mA increments) to the relaxed muscle up to the participant's voluntary sensation of discomfort or until determining an intensity at which even with the increase in intensity there was no increase in the torque produced by the relaxed muscle (Girard et al., 2013). The maximum electric current reached was recorded and the intensity of stimulation during the TI was set at 110% to guarantee supramaximal stimulations (Scaglioni & Martin, 2009).

Players performed two IMVC lasting 5 s separated by 60 s, with double electrical pulses application at 2-3 s [IMVC superimposition – Superimposed Twitch (SIT)] and 3 s after IMVC [relaxed muscle – Peak Twitch (PT)]. The increase in SIT is associated with central fatigue patterns (Kooistra et al., 2008) whereas the decrease in PT is evidence of peripheral fatigue (Gandevia, 2001). VA was calculated as VA = [1 - (SIT × (strength level at the time of stimulation/peak force (F_{PEAK})) / PT)] × 100 (Neyroud et al., 2014). IMVC with the highest strength value during attempts were recorded to determine the neuromuscular parameters (F_{PEAK}, SIT, PT and VA).

Blood lactate concentration evaluation

Blood samples [La^-] from the earlobe (25 µL) were collected before and immediately after each game, deposited in tubes with sodium fluoride (1%) and analysed using a YSI 2300 STAT electrochemical lactimeter (Yellow Springs, OH, USA).

Heart rate monitoring

HR was recorded beat-by-beat at rest and continuously over the three simulated games with a heart rate monitor (Polar Team; Polar®, Kempele, Finland) and later transmitted to the computer via a proprietary interface (IR interface; Polar ®, Kempele, Finland). In a recent study, Hernando et al. (2018) validated the Polar® heart rate measurement system to collect heart rate and heart rate variability data in humans during exercise and showed a high correlation coefficient between mean heart rate and the power of exercise low-frequency (r = 0.89) as well as ICC > 0.9.

The mean heart rate (HR_{MEAN}) and the highest HR value ($HR_{MAXGAME}$) recorded in each game were retained for analyses. The maximum heart rate (HR_{MAX}) was considered the highest HR obtained at the end of an incremental test specific to goalball (Gulick & Malone, 2011) previously undertaken by the players, as this value was higher than the $HR_{MAXGAME}$ obtained in the three simulated games. The relative time was determined in three intensity zones based on the recommendations of the American College of Sports Medicine (2010): sub-aerobic activity or low activity (< 65% of HR_{MAX}), aerobic zone or moderate activity (65 - 85% HR_{MAX}) and above threshold or very vigorous activity (> 85% HR_{MAX}).

Rating of perceived exertion

RPE determination was carried out verbally by the CR-10 scale adapted by Foster et al. (2001). In their mini review article, Haddad et al. (2017) present evidence from several studies which confirmed that CR-10 scale modified by Foster et al. (2001) is a valid and reliable method, led by a reported ICC > 0.8 and its strong correlations with selected objective methods in different types of physical exercise and sports, regardless of gender, age group and skill level.

Simulated goalball games and game technical performance

The games protocol consisted of an uninterrupted game system in which each participant played three subsequent 40 min efforts, which already considered the stoppages provided for by the rules (e.g., penalties, substitutions, court cleaning), with 30 min of passive rest between efforts. Playing time of 40 min was adopted because this is the average duration of official goalball games (IBSA Goalball, n.d.). Regarding the 30-min interval, we estimated that this corresponds to the minimum recovery interval on a day of goalball competition if one takes into account that, according to the event table, the match that takes place between two matches of a same team finishes quickly due to a difference of 10 goals on the scoreboard, requiring the subsequent game to initiate in 5 min (IBSA, 2021). Therefore, considering the effort-pause ratio and the density of the game (Alves et al., 2018), the aforementioned setting was sought to stimulate exertion through the most reasonable possible proximity to the real context.

The order of entry into the court of the evaluated players was randomly defined and took place in a staggered way, allowing all participants to be evaluated immediately after playing their respective 40 min efforts to ensure that the game remained in a high intensity, evaluations occurred in the correct periods and to minimize the chance of restoring muscle homeostasis. Time on the court was individually timed for each evaluated player, replaced when completing 40 min by the participant in the sequence, or by a staff, when the 30-min interval had not yet been finished. All assessment equipment was placed next to the court, close to the team's bench area.

GTP was adopted to quantify the offensive and defensive actions of the participants in each effort. In order to preserve game's validity and stimulate high competitiveness, no specific requirements that could influence the situation, context or positional variables were demanded. All official rules were applied, and the entire period of games was filmed by two GoPro HERO 3+ cameras (Woodman Labs Inc., USA) adjusted to a frequency of 60 Hz in full HD, totalling 4 hr of footage. The cameras were positioned at the highest point of the gymnasium bleachers, attached to metal structures, in order to frame the entire court.

Two researchers analysed and registered GTP through systematic video observation in a specific software (Kinovea 0.8.25). Considering the three measurement moments for each participant, the technical measures included the following set of analysis criteria: frequency of throws, defensive actions and recovery time (seconds) between each action (throw or defence). The researchers agreed that all actions in which the player moved towards the ball, independent on touching it, would be considered as defence. The density of actions (sum of throws and defences per minute) was also calculated at each moment. GTP indicators were selected according to the offensive and defensive principles that constitute goalball self-organization (Morato et al., 2017).

Reliability of GTP responses was assessed using the first 50 min of the footage (20% of the sample), analysed twice, at different times (15 days apart) by two observers, a goalball coach and an experienced researcher in the observational video analysis. The Kappa index was used for categorical variables (Fleiss et al., 2013) and was higher than 0.8 for the actions analysed for both intra-observer and inter-observer reliability. The ICC was adopted for numerical variables (Hopkins, 2000) and was higher than 0.9 for intra and inter-observer in recovery times.

Statistical analysis

The sample size was calculated by using predicted effect size of -1.32 provided by Milioni et al. (2016) for changes in the peak force associated with the Twitch Interpolation technique in knee extension IMVC measured before and after a futsal match. We used the G*power 3.1 software (Dusseldorf, Germany) that had revealed that eight participants would provide 95% power to detect differences at an α-level of 0.05. Therefore, for this study 10 players were recruited considering a possible sample loss of 20% throughout the experiment, which did not occur.

Statistical analyses were performed using the JASP software version 0.12.2 (Amsterdam, the Netherlands). A Bayesian statistical approach was used to provide probabilistic statements, as it offers a useful alternative with regard to the interpretation of the relative support of a null model against an alternative model (Wagenmakers, Love, et al., 2018). According to Wagenmakers, Marsman, et al. (2018), although both p values and Bayes factors generally reach similar conclusions, there are several advantages of Bayesian inference over classical inference. For instance, Bayes factors not only allow the quantification of evidence, but also the continuous monitoring as data accumulates without the need to identify the intent with which the data was collected (Wagenmakers, Marsman, et al., 2018). The authors also explain that from a Bayesian approach it is possible to quantify evidence that the data provide for the null hypotheses (H_0) vs. the alternative hypotheses (H_1), to quantify evidence in favour of H_0, in addition to not being strongly biased against H_0 (Wagenmakers, Marsman, et al., 2018).

Initially, the normality of data distribution was confirmed by the Shapiro Wilk test. The data were analysed by one-way analysis of variance (ANOVA) and Pearson's correlation. The Bayesian ANOVA was adopted to compare the differences between neuromuscular variables (F_{PEAK}, SIT, PT and VA), RPE, [La^-] and HR_{MEAN} in the moments before, after games 1, 2 and 3, and between $HR_{MAXGAME}$ and GTP variables (throws, defences, recovery and density) in games 1, 2 and 3. The Bayes factor (BF) was calculated for all variables employing the fixed effects of the r scale predefined by JASP, prior width of 0.5 for the prior distribution. Pearson's Bayesian correlations were used to verify possible associations between neuromuscular, physiological, perceptual and GTP variables. A prior beta pre-defined by JASP with width 1 was used, which assigns a prior probability equal to all the correlation values between -1 and 1. For the comparison of the registered heart rates, the 40 min recorded for each participant in each game were used.

The BF calculates the probability that H_0 or H_1 is true from the present data. If a significant Bayes factor favourable to H_1 (BF_{10}) was identified, a post-hoc (Westfall et al., 1997) was performed. Evidence for the alternative hypothesis (H_1) was set as $BF_{10} > 1$ and evidence for null hypothesis (H_0) was set as $BF_{10} < 1/3$. BF_{10} was reported to indicate the strength of the evidence for each analysis (within and between) and interpreted as *anecdotal* (BF_{10} = 1-3), *moderate* (BF_{10} = 3-10), *strong* (BF_{10} = 10-30), *very strong* (BF_{10} = 30-100) and *extreme* ($BF_{10} > 100$) when favouring the alternative hypothesis; or *anecdotal* (BF_{10} = 1-0.33), *moderate* (BF_{10} = 0.33-0.01), *strong* (BF_{10} = 0.01-0.03), *very strong* (BF_{10} = 0.03-0.01) and *extreme* ($BF_{10} < 0.01$) when favouring the null hypothesis (Wagenmakers, Love, et al., 2018). For each ANOVA, the *partial eta squared (η^2)* was calculated. For all comparisons, we also calculated the Cohen's d. Effect size limit values were $d > 0.2$ (small), > 0.5 (medium), and > 0.8 (large); $\eta^2 > .01$ (small), > .06 (medium), and > .15 (large; Cohen 1988).

Results

The means, standard deviation (SD) and BF_{10} related to the differences between the moments pre, games 1, 2 and 3 for the neuromuscular, physiological, perceptual and game technical performance variables are shown in Table 1.

[Table 1 near here]

Bayesian ANOVA reported evidence for H_1 for the neuromuscular variables F_{PEAK} (BF_{10} = 1.28, *anecdotal*, η^2 = .19) and VA (BF_{10} = 1.01, *anecdotal*, η^2 = .17). The significant decrease in the strength of IMVC is demonstrated by F_{PEAK} in the comparison between the moments pre vs game 2 (BF_{10} = 4.5, *moderate*, *d* = 0.94) and pre vs game 3 (BF_{10} = 2.6, *anecdotal*, *d* = 0.81), and for central factors through the significant decrease in VA in the comparison between pre vs game 2 (BF_{10} = 3.2, *moderate*, *d* = 0.86) and pre vs game 3 (BF_{10} = 1.5, *anecdotal*, *d* = 0.68). The post-hoc test also pointed to differences with medium and large effect sizes that occurred in RPE between pre vs game 1 (BF_{10} = 710.80, *extreme*, *d* = 2.79), pre vs game 2 (BF_{10} = 599.25, *extreme*, *d* = 2.74) and pre vs game 3 (BF_{10} = 5003.66, *extreme*, *d* = 3.37); [La^-] between pre vs game 1 (BF_{10} = 4.9, *moderate*, *d* = 1.33), pre vs game 2 (BF_{10} = 4.8, *moderate*, *d* = 1.33), pre vs game 3 (BF_{10} = 1.2, *anecdotal*, *d* = 0.88) and game 1 vs game 3 (BF_{10} = 0.73, *anecdotal for H_0*, *d* = 0.62); HR_{MEAN} between pre vs game 1 (BF_{10} = 56,591.73, *extreme*, *d* = 4.87), pre vs game 2 (BF_{10} = 629,929.79, *extreme*, *d* = 5.47) and pre vs game 3 (BF_{10} = 555,197.35, *extreme*, *d* = 5.42); frequency of throws between game 1 vs game 2 (BF_{10} = 0.68, *anecdotal for H_0*, *d* = 0.56); and frequency of defences between game 1 vs game 2 (BF_{10} = 0.65, *anecdotal for H_0*, *d* = 0.53).

The HR_{MAX} obtained in the incremental test was 190 ± 18 bpm. In all games, HR_{MEAN} remained in the range between 130 and 140 bpm, equivalent to an average intensity in games of 71 ± 2% of HR_{MAX} and 79 ± 3% of $HR_{MAXGAME}$. It is observed that in the three games the highest percentage of time identified is in the range < 130 bpm (Figure 2). Regarding the percentages established in different zones of intensity in relation to the HR_{MAX} of each participant, the following average values were obtained:

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

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

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

[Figure 2 near here]

Evidence for H_1 was also identified in the comparisons between the time spent at each intensity (BF_{10} = 1.061e +8, *extreme,* η^2 = .67) (Figure 3). The post-hoc test showed *extreme* evidence in the comparison between the relative time spent in the intensity between 65 and 85% of HR_{MAX} and the intensities < 65% (BF_{10} = 2458.8, *d* = 2.03) as well as > 85% (BF_{10} = 1.419e +8, *d* = 3.80), and *anecdotal* evidence between < 65% and > 85% (BF_{10} = 2.5, *d* = 0.85).

[Figure 3 near here]

The Bayesian correlation reported that RPE was positively correlated with HR_{MEAN}, r = 0.77 (BF_{10} = 285512.66, *extreme*), and negatively with GTP variables, as is the case of the frequency of throws, r = -0.58 (BF_{10} = 48.66, *very strong*), and density of actions, r = -0.53 (BF_{10} = 17, *strong*). $HR_{MAXGAME}$ presented a negative correlation with recovery time, r = -0.63 (BF_{10} = 66.99, *very strong*), and positive with density of actions, r = 0.55 (BF_{10} = 13.12, *strong*). A complete list of correlations is shown in Table 2.

[Table 2 near here]

Discussion

The aims of the study were to examine the neuromuscular responses of three consecutive simulated goalball games, the activity profile by monitoring GTP, heart rate and lactate, and the correlation between neuromuscular, physiological, perceptual and GTP parameters. To the best of our knowledge, this is the first study that evaluated neuromuscular parameters in a sample of goalball players and the main results were: (i) IMVC strength of knee extensor muscles and VA decreased significantly after the second and third games, indicating the presence of central fatigue; (ii) HR response remained predominantly in a range equivalent to moderate activity intensity in all games; and (iii) the RPE is associated with reduced frequency of throws and density of actions. Collectively, these data partly confirm the study's hypotheses that stimulus provoked by three subsequent goalball games cause central fatigue and that some dependent variables would significantly correlate with performance parameters. Consequently, it is possible that from the second game on, players experiencing central fatigue present a worsening of performance with consequent lower participation in the determinant actions of the game in addition to the greater need for recovery between goalball games in a competition day.

One of our main findings was the occurrence of central fatigue on the second and third games. The magnitude of fatigue change observed after the second game, with a large effect size for F_{PEAK} ($d = 0.94$) and VA ($d = 0.86$), is in line with what was demonstrated by Le Mansec et al. (2017) due to the substantial number of matches during a simulated table tennis competition, as IMVC strength reduced by 11% and VA by 13%. Moreover, these findings are also similar to the stimulus caused by a competitive 90-min soccer game, which revealed a 14% reduction in IMVC and 7% in VA (Brownstein et al., 2017), as well as a simulated 150-min tennis match, in which IMVC decreased by 13% and the VA by 11% (Girard et al., 2008). Hence, this strongly suggests that goalball coaches should ensure that strength and specific endurance training routines are included in the training plans in order to reduce the decrease of muscle function mediated by central fatigue by improving players' physical fitness.

The average recovery time between the determinant goalball technical actions greater than 30 s (Table 1) may explain the low [La^-] after games. Blood lactate concentration is one of the metabolic factors that can affect muscle contraction and fatigue as it increases with exercise intensity (Wan et al., 2017). However, despite the large effect sizes related to its significant increase after each game compared to basal values, [La^-] in all matches was lower than 4 mM (Table 1) as previously demonstrated (Alves et al., 2018; Theophilos et al., 2005). It may be explained by the fast execution time of throws and defences (less than 2 s) as well as the dependence of the density of actions on the alactic metabolism due to its importance for a higher frequency of actions per unit of time during games (Alves et al., 2018). In addition, the observed recovery periods may explain the predominance of heart rate that indicates moderate intensity (Figure 3).

Both HR_{MEAN} and the activity profile identified from the HR_{MAX} percentages were different from those previously recorded (Ikeda et al., 2019; Theophilos et al., 2005). Regarding the activity profile, the lowest percentage of time in very vigorous activity may be associated with the method used to estimate HR_{MAX}. In relative terms, we adopted the highest HR obtained at the end of an incremental test specific to goalball as a reference, whereas Theophilos et al.

(2005) considered the peak heart rate recorded during the games as HR_{MAX}. In fact, the $HR_{MAXGAME}$ was ~8% lower than the HR_{MAX} obtained in the incremental test in our study, suggesting that these authors could have underestimated the actual players HR_{MAX} and, consequently, identified very vigorous intensity in 40% of the time (Theophilos et al., 2005), whereas we identified a predominance of intensity between 65 and 85% of HR_{MAX} with large effect sizes in comparison with intensities < 65% (d = 2.03) and > 85% (d = 3.80). Moreover, the difference in HR_{MEAN} may be related to playing time, which in the present study was 40 min, closer to the proper context of goalball, while in the study by Ikeda et al. (2019), who observed a HR_{MEAN} of 155 ± 5 bpm, it was exactly 24 min (2 x 12 min), probably stimulating shorter intervals between actions and a consequent increase in cardiovascular demand. Hence, the more extended duration of the games in our investigation may be associated with a decrease in intensity to maintain performance, a crucial aspect for the proportion of central fatigue experienced (Martin et al., 2010).

In this study, the reduction in VA presented a significant difference with large and medium effect sizes after the second and third games, respectfully, allowing extrapolation of results to future research. Neuromuscular fatigue of central origin caused by intermittent sports of prolonged duration, such as tennis (Girard et al., 2008; Rota et al., 2014) and soccer (Brownstein et al., 2017), has shown to impair determinant technical actions as well as to require a long recovery period. When investigating the effect of a simulated tennis match lasting four sets of 40 min, Rota et al. (2014) identified considerable reductions in speed and accuracy of service, and decreases in accuracy and consistency of strokes. Furthermore, Brownstein et al. (2017) show evidence that soccer match-related fatigue may allow more than 48 hr to recover. It is important to highlight that soccer matches are likely more demanding than goalball, as players can cover more than 10,000 m and perform a frequency of very high intensity runs over 170 in a game (Bradley et al., 2010). Goalball is a sport with no territorial invasion in which elite players present a frequency of recovery actions higher than the sum of attack and defensive actions (Alves et al., 2018). On the other hand, tournaments often require teams to play the up to three games per day, requiring players to stay in the competition environment for up to 8 hours, even on consecutive days (IBSA, 2021). Therefore, it is possible to infer that after three goalball games in one day, players are not sufficiently recovered for a second day of competition, which may result in an impaired performance. However, this possibility needs to be further investigated.

Muscle strength represents an essential factor for successful goalball shooting (Morato et al., 2017). However, despite the occurrence of neuromuscular fatigue, significant correlations were not observed between neuromuscular variables and other parameters analysed. The non-significant correlations with perceptual, physiological and performance variables can be explained by the fact that although the incidence of neuromuscular fatigue is likely to cause a worsening in the quality of game technical actions, as observed in other sports (Rota et al., 2014), the number of actions may not have been affected, thus mitigating the physiological stress by decreasing shooting speed, for example. Consequently, we recommend future studies evaluate shooting speed and/or the success in the execution of defences in goalball games together with neuromuscular assessments, due to the possible deterioration in the quality of technical actions even if this does not affect their quantity.

Significant inverse correlations were observed between perceptual and physiological variables with GTP variables, demonstrating that exertion related to three subsequent simulated goalball games is associated with impaired technical performance. The increase in $HR_{MAXGAME}$ is proportional to the decrease in recovery time between actions, while the density of actions decreases as RPE increases, indicating that players experiencing fatigue tend to participate less in the game. This is illustrated by the non-significant decrease with medium effect sizes in the 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 system, that is, the three players on the court take turns performing the throws to preserve themselves for the subsequent games. In addition, coaches may instruct their players to focus the target of their attacks on just one opponent, thus being able to exacerbate fatigue in this player who, consequently, could be more susceptible to conceding goals. Finally, during a tournament of several matches for a limited time, the team can be modified at each game by the coaches, an option made easier when the complete squad of players (in championships: six) has similar goalball skills, so as not to impair team performance.

Some limitations should be noted. Firstly, the verification of neuromuscular fatigue in the upper limbs was not performed due to the limitations in the application of the TI technique in this muscle group (Norberto et al., 2020). However, the handgrip dynamometry (Gunha et al., 2020) could have been adopted. Secondly, the study was conducted with simulated games, which could have influenced the intensity of the game for the reason that individual performance in team sports is affected by teammates and opponents (Carron & Chelladurai, 2016). Furthermore, the results are limited to men; the neuromuscular assessments could have increased muscle fatigue to some extent; and, although the correlations indicated some interesting relationships, they are insufficient to infer causation. Despite these limitations, the results are innovative for the field of goalball and may provide a valid basis for further research.

Conclusions

In conclusion, the dispute of three subsequent simulated goalball games resulted in the reduction of muscle strength mediated by central fatigue from the second match. In addition to requiring a considerably long recovery time, the incidence of central fatigue may be responsible for impairing performance in key technical actions. Therefore, the results may have important implications both for the improvement of the players' physical fitness and strategies during the competition to delay fatigue, as well as for the reduction of the maximum number of matches per day from three to two games.

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

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

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

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

Figure legends

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.

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.

Figure 3. Percentages of time spent in low activity (< 65% HR_{MAX}), moderate activity (65 - 85% HR_{MAX}) and very vigorous activity (> 85% HR_{MAX}) 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.

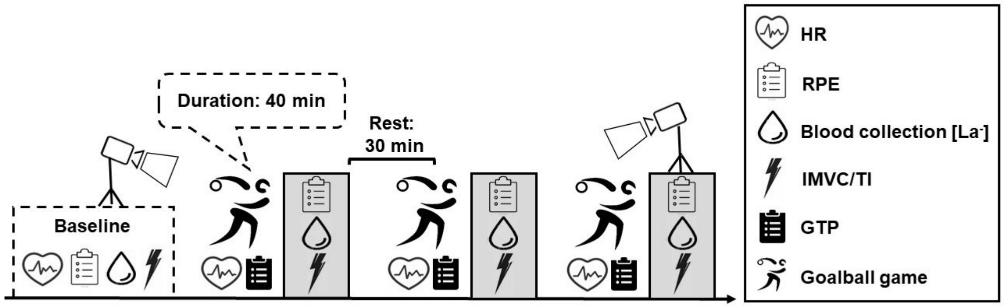
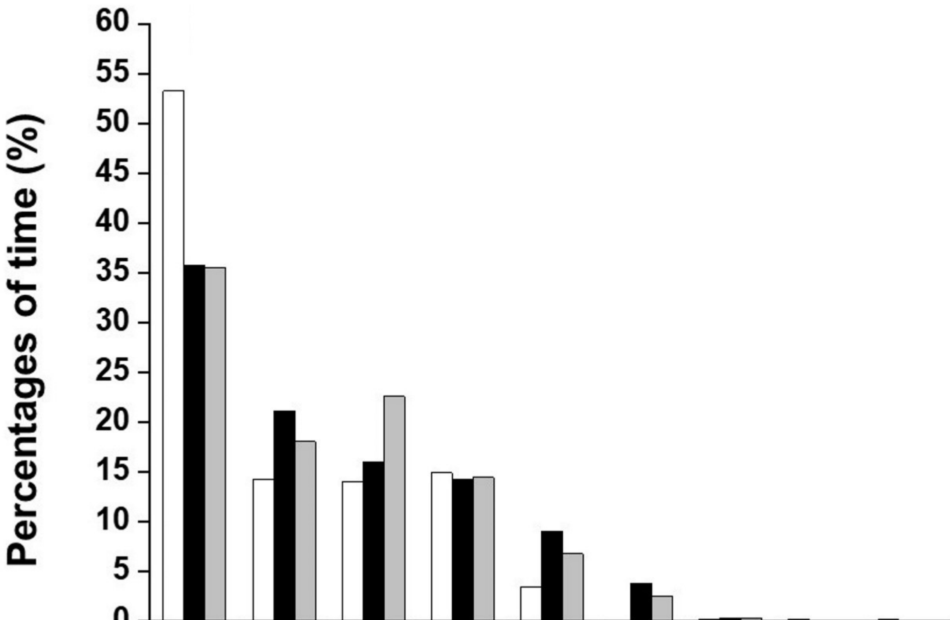


Figure 1. Organizational chart of the simulated goalball games evaluations. Order of collection of baseline and post-game procedures: 1) RPE; 2) blood collection [La-]; 3) IMVC/TI.

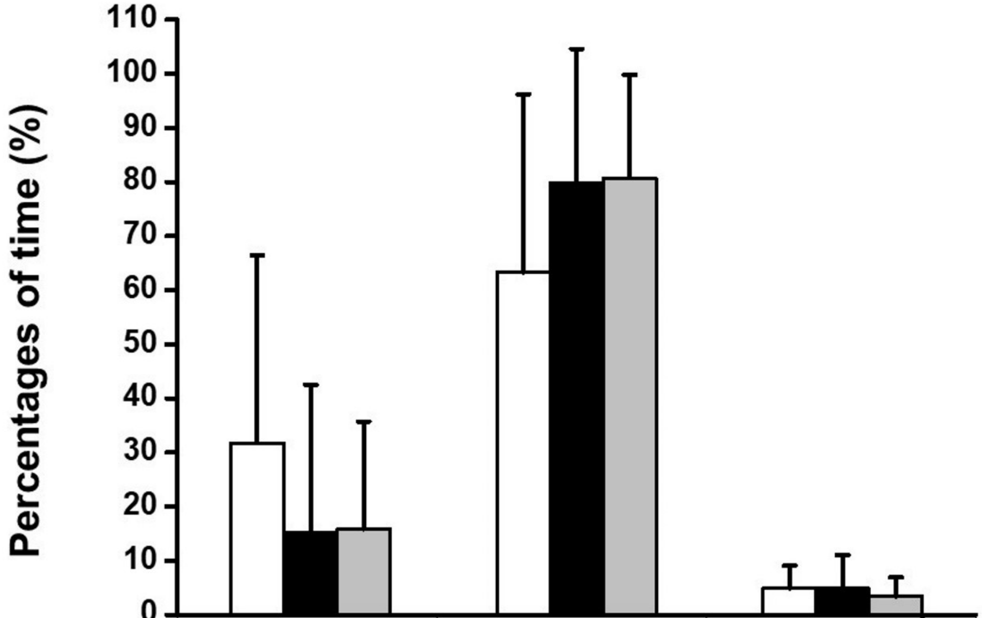
108x34mm (300 x 300 DPI)



	< 130	130-140	140-150	150-160	160-170	170-180	180-190	190-200	> 200
Game 1	53.3	14.2	14.0	14.9	3.4	0.0	0.1	0.2	0.1
Game 2	35.7	21.1	15.9	14.3	9.0	3.8	0.3	0.0	0.0
Game 3	35.5	18.1	22.5	14.4	6.8	2.6	0.3	0.0	0.0

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)