EUJAPA

Article

The effects of fatigability on shooting skill performance in goalball penalty shots

Jônatas Augusto Cursiol [1,*], Tarine Botta de Arruda [1,2], Isabella dos Santos Alves [1,3], Luiz Henrique Palucci Vieira [4], Fabio Augusto Barbieri [4] and Ricardo Augusto Barbieri [1]

Received: 22nd December 2021; Accepted: 26th June 2022; Published: 2nd December 2022

Abstract: This study evaluated the influence of acute fatigue on shooting skill performance in goalball penalty shots. Eleven sub-elite male players were evaluated in an official court using a two-dimensional procedure (60 Hz) to compute the mean radial error, bivariate variable error and accuracy, and three-dimensional kinematics (240 Hz) to measure ball velocity. Rating of perceived exertion, blood lactate concentration and knee extension isometric maximal voluntary contractions were assessed at rest and immediately after the completion of an incremental test specific to goalball. Although significant differences were observed for rating of perceived exertion (pre: M = .36 AU, SD = .67; post: M = 9.27 AU, SD = .79), blood lactate concentration (M = 1.33 mM, SD = .51; M = 9.04 mM, SD = 2.25) and peak force (M = 597.85 N, SD = 132.35; M = 513.37 N, SD =107.00) at the end of the incremental test, no differences were identified in the pre and post moments for mean radial error (M = .10 m, SD = 1.01; M =.37 m, SD = 2.19), bivariate variable error (M = 3.56 m, SD = .70; M = 3.25 m, SD = .70), accuracy (M = 3.68 m, SD = .74; M = 3.78 m, SD = 1.13) and ball velocity (M = 18.53 $m \cdot s^{-1}$, SD = 1.53; M =18.46 $m \cdot s^{-1}$, SD = 1.65). We concluded that even though significant levels of fatigability can be attributed to the incremental test specific to goalball, shooting skill performance in goalball penalty shots does not appear to be affected. However, further investigations are needed so that goalball coaches can develop strategies that contribute to improve performance in this technical action. Such improvements are decisive for the outcome of a match.

Keywords: athletes; visual impairment; perceptual parameter; physiological response; neuromuscular response; performance analysis; accuracy; three-dimensional kinematics

Introduction

Goalball is a Paralympic sport developed specifically for people with a visual impairment characterized by short-duration, high-intensity intermittent attack and defence actions (Alves et al., 2018). Under the current rules, a team may play up to three times on the same day on consecutive days, which consequently requires them to remain in the competition environment for several hours (IBSA, 2021). Moreover, previous researchers demonstrated intense cardiovascular demands on players, with heart rates exceeding 70% of their maximum heart rate for more than half of playing time (Ikeda et al., 2019; Theophilos et al., 2005). In addition, physiological demands are also likely to be adversely affected by external factors, such as the substantial cognitive effort made by athletes with visual impairments to adequately maintain performance during sports practice (Eddy & Mellalieu, 2003; Powis, 2018). Hence, these characteristics may demonstrate strenuous demands of the game and that it is likely to induce significant levels of fatigability in goalball athletes.

According to Enoka and Duchateau (2016), the level of fatigue experienced by an individual may limit his cognitive and physical function due to interactions between perceived fatigability and performance fatigability. Consequently, the performance in technical actions that determine the result of a game can be impaired, as is the case of the ball throwing in goalball. However, the researchers have presented divergent results regarding the effect of fatigue on throwing performance in team sports. By adopting the simulated Handball match, Fábrica et al. (2008) identified a decrease in throwing velocity in the second half, while Zapardiel Cortés et al. (2018) did not detect differences when analysing real games. Furthermore, even though Nuño et al. (2016) observed significant reductions in both the accuracy and velocity of the shots after a specific exercise circuit with a gradual decrease in the interval between laps, Andrade et al. (2016) did not identify changes after performing simulated game activities. Nevertheless, in addition to the pattern of movement of the throw being different from the technique typically used in handball, the effect of fatigue on this determinant action is still unknown in goalball.

Similar to handball (Meletakos et al., 2011), penalty goals in goalball provide a significant influence in the result of a game. According to Furtado and colleagues (2021), 25% of goals in goalball matches are the result of penalty shots. Furthermore, in addition to the effectiveness of penalty shots being greater than that of effective play shooting (50% vs. 3%) (Magalhães et al., 2013), winning teams generally convert more penalties on goals compared to losers (53% vs. 31%) (Furtado et al., 2021). Therefore, considering that the fatigue induced by the game is likely to undermine the performance in key technical actions, as is the case of the goalball throw, we hypothesize that sub-elite athletes experiencing significant levels of fatigue will present impaired performance on penalty shots. To the best of our knowledge, no study in goalball has investigated the relationship between fatigue and specific motor skills. Hence, the aim of this study was to investigate the influence of acute fatigue induced by an incremental exercise with specific goalball motor skills on accuracy and ball velocity in a penalty shooting protocol.

Materials and Methods

Participants

Participants were recruited from Brazilian teams from a state competition in 2019. Participants trained at least 3 times/week for at least 150 min, and their experience in the sport was on average 6 y (SD = 4y). One player had been part of the youth national team, with experience in the Goalball Youth World Championship. According to the international classification levels (IBSA, 2021), seven players were classified as B1 (visual acuity less than LogMAR 2.6), two players as B2 (visual acuity ranging from LogMAR 1.5 to 2.6 [inclusive] 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] or visual field restricted to a diameter less than 40 degrees). Although B2 and B3 players are more effective in attacking from the effective game, there is evidence to suggest that there is no difference between blind and low vision players in the penalty shot performance (Molik et al., 2015). The participants were informed about the study conditions and provided written informed consent. All procedures were performed in accordance with the Declaration of Helsinki, and the School of Physical Education and Sport of Ribeirão Preto Ethics Committee approved the protocol (nº 03121318.3.0000.5659).

Experimental design

All players were previously familiarized with the evaluation procedures that took place in the morning on an official goalball court. The evaluation order was random, with one player at a time, lasting approximately 25 min per participant. First, baseline assessments were performed to determine the pre study values in the following order; 1. rating of perceived exertion (RPE), 2. blood lactate concentration ([La^-]) and 3. neuromuscular parameters through knee extension isometric maximal voluntary contractions (IMVC) (approximately 3:30 min). Subsequently, players underwent a brief warm-up of about 5 min, consisting of the simulation of specific defensive and attack gestures, and then performed the pre study penalty shooting protocol for the assessment of accuracy parameters and ball velocity (V_{BALL}) (approximately 2:30 min). Following these tests, the athletes underwent the application of the incremental test specific to goalball (M = 8:52 min, SD = 1:45), and immediately after its completion, the post penalty shooting protocol (approximately 2:30 min) was performed and followed by the evaluations to determine the post values (approximately 3:30 min). Only one baseline [La^-] collection was performed, as well as only one collection immediately after the final penalty shooting protocol. In addition, all penalty shots were fully recorded for later two-dimensional and three-dimensional kinematic analyses.

Fatigability assessment procedures

RPE determination was carried out by the Borg CR-10 scale (Borg, 1982), verbally, adapted by Foster et al. (2001). This is a valid and reliable method which presented an Intraclass Correlation Coefficient (ICC) > .80 as well as strong correlations with selected objective methods in different types of physical exercise and sports, regardless of gender, age group and skill level (Haddad et al., 2017). Blood samples from the earlobe (25 µL) were collected in capillary tubes previously calibrated and hyperbarized, immediately deposited in 1.5mL Eppendorf tubes containing 50 µl of Sodium Fluoride (NaF-1%) and frozen for further [La^-] analysis in an electrochemical lactate analyser YSI 2300 STAT (Yellow Springs, OH, USA).

Force data acquisition was performed through knee extension IMVC, which is a valid and reliable measure classically adopted to describe fatigability. Place and colleagues (2007) observed high levels of absolute reliability with an ICC of .90 and a coefficient of variation (CV) of 3.5% for quadriceps IMVC torque with a typical error lower than 5%, and confirmed the validity of the test. Neuromuscular assessments based on IMVC performed in the lower limbs have been demonstrated to have adequate applicability in a sample of goalball players, thus allowing the identification of neuromuscular fatigue (Cursiol et al., 2022). The strong correlation ($r = .75$) identified by Goulart-Siqueira and colleagues (2019) between V_{BALL} and countermovement jump in simulated goalball penalty shots indicate lower limb strength is essential for faster throws. In addition, previous studies show evidence that not only the respiratory function of goalball athletes moderately correlates with their lower limb muscle strength ($r= .53$; Balcı et al., 2021), but the strength of the lower limbs is essential for the V_{BALL}. This is because, during shot execution, players usually cover 2 - 4 m with a displacement speed that increases by 70% until the ball is released (Monezi et al., 2018).

The test was conducted according to Milioni and colleagues (2016) through three 5-s knee extension IMVC with a 1 min interval between them performed against a 200 kg load cell (CSR-1T, MK Controle®, São Paulo, Brazil), and the data acquisition was done in a Labview 2015 environment (National Instruments®) with an acquisition frequency of 1000 Hz. Players were positioned on an ergometer designed specifically for this analysis, in which they remained with the trunk attached to the chair, with the hips and knees flexed at 80°

and 90°, respectively, and firmly attached to the seat by two belts crossed at chest height and waist height. The participant's preferred leg was attached to the equipment approximately 3 cm above the lateral malleolus by a Velcro tape attached to a metal wire attached to the load cell. The IMVC with the highest strength value during the trials was used to determine the peak force (F_{PEAK}) and mean force (F_{MEAN}).

Penalty throwing protocol

This task consisted of simulating eight penalty throws, without the presence of a defender, all with distinct origins and targets through the sector division method proposed by Morato and colleagues (2017). Two throws were performed in the parallel direction and six in the long diagonal direction (Figure 1). Studies that verified the accuracy and V_{BALL} of soccer players' kicks (Barbieri et al., 2010; Vieira et al., 2018) and handball players' throws (Nuño et al., 2016) methodologically adopt pre-defined targets. The choice of eight penalties in pre-defined sessions corresponds to the fact that they represent shooting patterns most commonly performed in real matches (Furtado et al., 2021), which consequently reflect in the training routine.

Randomly, at each new attempt, players were informed during the preparation of the attack movement (after the whistle) the origin and target at which the throw should be performed. In that manner, several options of origins and targets proposed took into account all six sectors of 1.5 m from the court, explored different possibilities of the ball's trajectory and eliminated the aspect of predictability and learning effect. Prior to the beginning of the protocol, each participant was provided with the following instruction: "Throw the ball at maximum velocity at the target to be informed." Players threw the ball utilizing the technique that best suited them, always starting at the crossbar, in the origin sector previously informed, following the official rules regarding the goalball penalty shot. The throwing techniques and ball type typically used in goalball are detailed by Nascimento and Camargo (2012) and could be identified in this study through video analysis.

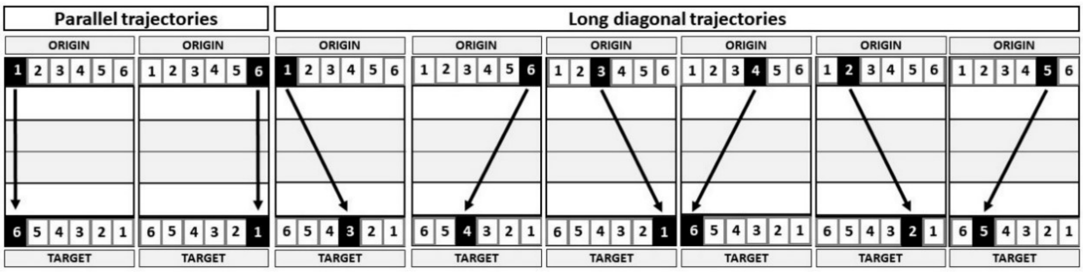

Figure 1. Trajectories proposed in the penalty shooting protocol.

Incremental test specific to goalball

The incremental test specific to goalball was based on the evaluation proposed by Gulick and Malone (2011) and included the use of the ball during the protocol. This game-specific testing protocol was adopted to induce players to exhaustion and, consequently, to the highest level of fatigue at a physiological and neuromuscular level. The test consists of a sequence of four specific actions of the goalball game: defense simulation, transition to attack, frontal throwing technique performance with progression and re-establishment of the expectation position on the demarcated line. The execution of this sequence took place during a predetermined period of time with 30 s rest intervals between each stage. The increase in intensity occurred with an increase in the density of actions along the stages through additions of a sequence of four actions and decreases in the duration of time to perform it. The stages were performed until the participant opted to terminate test protocol or was unable to return to the first action of the sequence before the emission of the audible signal performed by a metronome in a free application (Exercise Timer, Neuron Digital) for two consecutive trials (Gulick & Malone, 2011).

Kinematic procedures

The experimental protocol was monitored by three digital video cameras positioned at specific points on the court to place the analysis region in the centre of the image frame, where the distortions produce less effect (Barbieri et al., 2010; Vieira et al., 2018) as shown in Figure 2.A. To determine the accuracy of the shots, a camera (camera 1) (GoPro HERO 3+ Black Edition, Woodman Laboratories Inc., USA) at 60 Hz (1280 x 720-pixel resolution; NTSC standard) was positioned frontally and 18 m away from the goal line to identify the image frame in which the ball crosses the goal plane (Figure 2.A). This plane was calibrated for two-dimensional (2D) analysis based on 14 points (Figure 2.B) with a known position on the x and y axes by dividing the width of the court into six sectors of 1.5 m wide (Morato et al., 2017). The centroid of the ball was digitized manually using the DVIDEOW Software (Figueroa et al., 2003) through the procedures of calibration, frame marking and 2-D reconstruction. By means of specific Matlab routines (The MathWorks Inc, Natick, MA, USA), the distance from the ball to the centre of the target (D_{TARGET}; Barbieri et al., 2015) was calculated, and from this value, the dependent variables of mean radial error (MRE), bivariate variable error (BVE), and accuracy (ACUR; Vieira et al., 2016) were calculated according to the Equations described by Vieira and colleagues (2018).

For three-dimensional (3-D) kinematic analysis, two cameras (cameras 2 and 3) (GoPro® Hero 7 Black Edition, GoPro GmbH, München–Germany) tripod-mounted and operating at 240 Hz (1280x960 pixel; 1/480s shutter speed; Wide field-of-view mode; NTSC standard) and synchronized via Wi-Fi (GoPro smart remote control) were distributed around the region where shots occurred in order to cover overall events of interest (Figure 2.A). They were placed with a distance of 3 m from the side line, forming an angle of 90° between them and 45° with the ball. For the spatial calibration, a graduated topographic stick with eleven marks with known distances (90, 204, 400, 602, 802, 1002, 1201, 1321,1614, 1815 and 2016 mm) was positioned vertically, levelled and recorded in eight previously demarcated positions where the throws would later be performed (9 x 6 m) (Figure 2.C). Subsequently, the image sequences were transferred to the computer for the procedures (Barbieri et al., 2010; Vieira et al., 2018) to synchronize the cameras through an event in common (e.g., bouncing the ball on the ground in the centre of the calibration area), defining a calibration frame (XX x YY x ZZ m), marking the frames, and 3D-DLT (Direct Linear Transformation) reconstruction (Abdel-Aziz & Karara, 1971) in the DVIDEOW Software. In this way, data matrices were obtained containing the 3-D spatial coordinates of each attempt.

The mean 3-D V_{BALL} was measured from the displacement of the centroid of the ball and ten frames were considered from its first contact with the ground (Figure 2.D) based on previous studies (Barbieri et al., 2010; Milioni et al., 2016; Vieira et al., 2018). The treatment of the data was carried out by a routine written in a Matlab environment (The MathWorks Inc, Natick, MA, USA), which made it possible to calculate the velocity of the ball by dividing the distance covered by the course time. In addition, the accuracy test to determine the measurement error proposed by Ehara et al. (1997) was adopted. The calculated accuracy was M = 5.0 cm, SD = 3.7; precision M = 4.1 cm, SD = 4.5; and bias M = 2.6 cm, SD = 3.9.

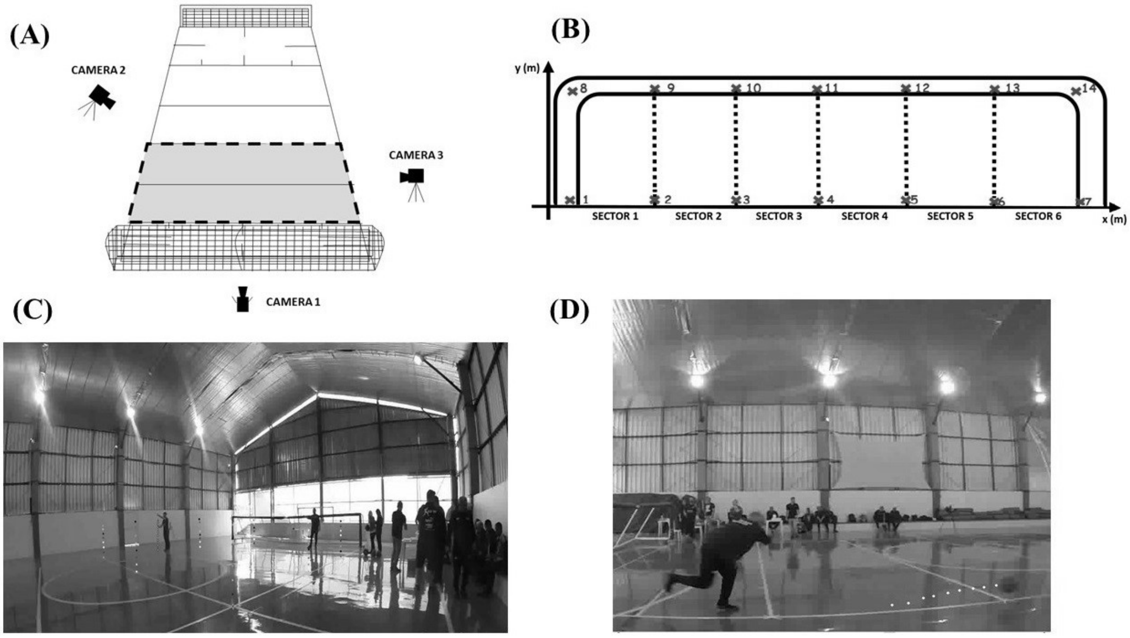

Figure 2. (A) Framing area of each video camera for accuracy and ball velocity measurements; (B) Frame of camera 1, points used for 2-D calibration and identification of the target sectors; (C) Image from camera 3 showing the displacement of ten frames from the centroid of the ball to measure velocity; and (D) Image from camera 2 of the positioning of the topographic stick to perform the 3-D calibration.

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 knee extension IMVC measured before and after a futsal penalty shooting protocol. We used the G*power 3.1 software (Dusseldorf, Germany) resulting in the need for eight players to provide 95% power to detect differences at an α-level of .05. Therefore, for this study 11 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). The normality distribution of the variables was confirmed through the Q-Q plots and Shapiro-Wilk test ($p > .05$). A Bayesian paired samples t-test was used to assess the difference between the pre and post moments for the variables RPE, $[La^-]$, F_{PEAK} and F_{MEAN}, indicators of perceptual and performance fatigability induced by the incremental test specific to goalball, in addition to comparisons between MRE, BVE, ACUR and overall V_{BALL}, as well as D_{TARGET} and V_{BALL} for attempts from the same origin and target sector. Data are presented as mean (M) and standard deviation (SD).

According to Wagenmakers, Marsman, and colleagues (2018), although both p values and Bayes factors generally reach similar conclusions, there are several advantages of Bayesian inference over classical frequentist 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).

The Bayes factor favourable to H_1 (BF_{10}) was calculated for all variables using the pre-defined value by JASP as "non-informative" prior hypothesis (Cauchy, .707). Estimates of median standardized effect size (ES) and 95% credible interval (CI) were calculated (Ly et al., 2016). The ES was interpreted as described by Cohen as *trivial* < .2, *small* .2-.6, *moderate* .6-1.2, *large* 1.2-2.0 and *very large* > 2.0 (Cohen, 1988). Evidence for H_1 was set as BF_{10} > 3 and evidence for 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-.33), moderate (BF_{10} = .33-.01), strong (BF_{10} = .01-.03), very strong (BF_{10} = .03-.01) and extreme (BF_{10} < .01) when favouring the null hypothesis (Wagenmakers, Love, et al., 2018).

Intra- and interrater reliability were calculated for throwing technique and ball type responses from 44 randomly selected attempts (50% of the sample). For intrarater reliability, the first author, who is a goalball coach with more than 3 years of experience, completed a test–retest protocol separated by 15-day time-interval (O'Donoghue, 2010). The interrater reliability was assessed using the same data set notated by the first and second authors. The kappa index was used to determine the reliability of all the variables (Fleiss et al., 2013). The intra- and interrater kappa index of throw technique and ball type were .96 and .98, respectively.

Results

Eleven sub-elite male players (M = 40 yrs, SD = 12; M = 85.1 kg, SD = 16.8; M = 173.5 cm, SD =7.1; M = 28.5 kg/m², SD = 5.3), with no history of muscle disorders were recruited. In addition, the techniques used for shooting were the frontal (pre: 67 - 77%; post: 68 - 78%) and spin (pre: 20 - 23%; post: 19 - 22%) throws. The ball type was predominantly flat (pre: 85 - 98%; post: 87 - 100%) and bounced (pre: 2 - 2%; post: 0 - 0%).

In Table 1, the results for the variables that indicate fatigability and shooting performance are presented. From the Bayesian paired t-test the players exhibited significant levels of fatigability due to the substantial increases observed in RPE (BF_{10} = 18,180.00, *extreme*) and [La⁻] (BF_{10} = 9,480.00, *extreme*) as well as a significant decrease in F_{PEAK} (BF_{10} = 3.66, *moderate*). In contrast, for the shooting performance parameters, no differences were detected between pre and post moments, and only trivial or small effect sizes were identified.

Table 1. Mean and standard deviation (standardized ES with a 95% confidence interval) for fatigability (n = 11) and overall shooting performance variables (n = 87).

Variables	Pre		Post		ES		95% CI	BF_{10}	Interpretation
	M	SD	M	SD					
RPE (AU)	.36	.67	9.27	.79	-2.90	Very Large	-4.52; -1.46	18,180	Extreme
[La⁻] (mM)	1.33	.51	9.04	2.25	-2.67	Very Large	-4.18; -1.32	9,480	Extreme
F_{PEAK} (N)	597.85	132.35	513.37	107.00	0.70	Moderate	.007; 1.41	3.66	Moderate
F_{MEAN} (N)	508.92	130.58	427.87	91.04	0.59	Small	-0.01; 1.26	2.09	Anecdotal
MRE (m)	.10	1.01	.37	2.19	0.27	Small	-0.26; 0.85	.50	Anecdotal
BVE (m)	3.56	.70	3.25	0.70	0.25	Small	-0.29; 0.81	.46	Anecdotal
ACUR (m)	3.68	.74	3.78	1.13	-0.07	Trivial	-0.60; 0.46	.31	Moderate
V_{BALL} ($m \cdot s^{-1}$)	18.53	1.58	18.46	1.65	0.08	Trivial	-0.16; .031	.17	Moderate

RPE = rating of perceived exertion; [La⁻] = blood lactate concentration; F_{PEAK} = peak force obtained in knee extension isometric maximal voluntary contractions; F_{MEAN} = mean force obtained in knee extension isometric maximal voluntary contractions; MRE = mean radial error; BVE = bivariate variable error; ACUR = accuracy; V_{BALL} = ball velocity in the throw; ES = effect size; CI = credible intervals; BF_{10} = Bayes factor favourable to H_1; AU = arbitrary units; mM = millimolar; N = newtons; m = meters; $m \cdot s^{-1}$ = meters per second.

In Table 2, there are the results for shooting performance from attempts of same origin and target sector in the pre and post moments. Only the long diagonal throw with origin in Sector 2 directed to the target Sector 2 significantly increased the distance from the target (BF_{10} = 4.76, *moderate*), with moderate effect size. No significant differences were observed in V_{BALL}, and only trivial or small effect sizes were identified.

Table 2. Mean and standard deviation (standardized ES with a 95% confidence interval) for shooting performance variables according to attempts of same origin and target (n = 87).

Attempt	Pre		Post		ES		95% CI	BF_{10}	Interpretation
	M	SD	M	SD					
D_{TARGET}									
O1-T6 (m)	2.27	2.45	0.92	2.72	.52	Small	-0.08; 1.20	1.38	Anecdotal
O6-T1 (m)	0.35	2.19	1.39	3.65	.40	Small	-0.17; 1.04	0.82	Anecdotal for H_0
O1-T3 (m)	0.87	1.31	0.67	3.75	-.04	Trivial	-0.54; 0.51	0.31	Moderate for H_0
O6-T4 (m)	1.37	3.51	0.56	2.64	-.33	Small	-0.95; 0.23	0.62	Anecdotal for H_0
O3-T1 (m)	0.33	1.96	1.19	2.73	.29	Small	-0.26; 0.90	0.54	Anecdotal for H_0
O4-T6 (m)	1.14	2.45	1.57	3.93	-.08	Trivial	-0.67; 0.49	0.32	Moderate for H_0
O2-T2 (m)	0.64	2.38	1.89	2.55	.80	Moderate	0.10; 1.57	4.76	Moderate
O5-T5 (m)	0.20	1.21	0.27	3.66	.11	Trivial	-0.44; 0.069	0.33	Anecdotal for H_0
V_{BALL}									
O1-T6 ($m \cdot s^{-1}$)	18.80	1.67	18.63	2.16	.04	Trivial	-0.59; 0.68	0.36	Anecdotal for H_0
O6-T1 ($m \cdot s^{-1}$)	18.33	1.28	18.64	1.44	-.52	Small	-1.29; 0.14	1.18	Anecdotal
O1-T3 ($m \cdot s^{-1}$)	18.61	1.58	18.46	1.75	.14	Trivial	-0.49; 0.81	0.39	Anecdotal for H_0
O6-T4 ($m \cdot s^{-1}$)	18.48	1.00	18.48	1.40	.06	Trivial	-0.54; 0.67	0.34	Anecdotal for H_0
O3-T1 ($m \cdot s^{-1}$)	18.30	1.52	18.49	1.68	-.25	Small	-0.91; 0.36	0.48	Anecdotal for H_0
O4-T6 ($m \cdot s^{-1}$)	18.46	1.50	18.51	1.38	.45	Small	-0.17; 1.14	0.94	Anecdotal for H_0
O2-T2 ($m \cdot s^{-1}$)	18.46	1.82	18.77	1.81	-.33	Small	-0.98; 0.26	0.61	Anecdotal for H_0
O5-T5 ($m \cdot s^{-1}$)	18.71	1.47	18.00	1.42	.43	Small	-0.18; 1.11	0.87	Anecdotal for H_0

O = throw origin; T = throw target; number after the letter = sector number; ES = effect size; CI = credible intervals; BF_{10} = Bayes factor favourable to H_1; m = meters; $m.s^{-1}$ = meters per second.

Discussion

The aim of the present study was to investigate the effect of fatigue induced by an incremental test specific to goalball on accuracy measurements (MRE, BVE, ACUR) and ball velocity in simulated penalty shots performed by sub-elite male players. To the best of our knowledge, this is the first study that evaluated the effects of fatigue on goalball technical skills. The main findings demonstrate that even though the incremental test specific to goalball induced significant levels of perceived and performance fatigability in the players by increasing RPE and [La^-] as well as decreasing F_{PEAK}, shooting skill performance in goalball penalty shots remained unchanged. Hence, the study hypothesis was not confirmed.

These results are in line with the findings of studies that investigated the effect of fatigue on throwing performance in other sports. Andrade and colleagues (2016) demonstrated that although simulated handball games cause a significant reduction in the strength of the glenohumeral musculature, a performance fatigability indicator (Enoka & Duchateau, 2016), V_{BALL} in penalty shots was not impaired. Moreover, Zapardiel Cortés and colleagues (2018) demonstrated that V_{BALL} remained unchanged in shots performed in the second half of official handball games. In the context of water polo, Royal and colleagues (2006) adopted an incremental exercise with specific motor skills to induce fatigue and identified that despite significant increases in RPE and heart rate, which are perceived fatigability indicators (Enoka & Duchateau, 2016), shooting accuracy and V_{BALL} were unaltered. On the other hand, other studies that evaluated the influence of fatigue on the performance of handball shooting skills demonstrated a decrease in accuracy and V_{BALL}, which may be related to the player's position (Fábrica et al., 2008) and reduction in the rest interval between fatigue-inducing exercises (Nuño et al., 2016).

A common feature among our study and other investigations that did not identify impairments in the performance of shooting skills, is the fact that the specificity of the task was taken into account in the fatigue induction process, either through the type of movement performed in the incremental exercise or through the game itself. Previous studies point to the fact that the implementation of this strategy allows skilled athletes in strenuous situations to perform an unconscious self-regulation of effort that minimizes the decline in cognitive effort. Such self-regulation occurs through maintaining the focus of attention and control of arousal (Nuño et al., 2016; Royal et al., 2006). In addition, the biomechanical analysis of the movement performed by skilled players during key technical actions indicates that such athletes are able to make fine adjustments when exercising at high intensities to maintain performance, as observed in the futsal kick (Barbieri et al., 2010; Milioni et al., 2016) and handball throw (Andrade et al., 2016).

From the calculations which represent measures of error during the throw, we identified that MRE, BVE, and ACUR did not appear to be impaired by acute fatigability. It is interesting to note that such results were obtained using 1.5 m targets, as earlier, researchers showed that goalball players can increase shooting efficiency when wide bandwidth targets (1.98 m) are adopted (Shimony et al., 2020). However, as demonstrated by Furtado and colleagues (2021), penalty shooting efficacy tend to decrease in the second half of goalball real games, probably due to a considerably greater emotional pressure experienced by the penalty taker. Moreover, from the D_{TARGET}'s analysis there were no attempts that appeared to be affected, except for those with origin in Sector 2 directed to target Sector 2, with a *moderate* decrease in efficacy. In fact, long diagonal throw trajectories not only represent the most significant probability of scoring a goal in penalty shots, with 87% of efficacy for the trajectory 2 – 2 (Furtado et al., 2021), but also in effective game shooting (Fujita et al., 2021; Morato et al., 2018). In addition, the trajectories that target sectors 2 and 5 increase the rates of the ball hitting the goal when compared to targets 1 and 6, which are closer to the goal posts and present lower effectiveness and higher rates of balls going out of the side line (Furtado et al., 2021).

The mean V_{BALL} achieved in our study was lower than those identified by identified by Bowerman and colleagues (2011) in the frontal (M = 20.68 $m \cdot s^{-1}$, SD = 5.34) and spin techniques (M = 25.52 $m \cdot s^{-1}$, SD = 6.42 $m \cdot s^{-1}$), but higher than that reported by Goulart-Siqueira and colleagues (2019) with the frontal throw (M = 14.21 $m \cdot s^{-1}$, SD = 1.89), who adopted a sports radar, an instrument that is likely to underestimate speed measurements (Robinson & Robinson, 2016). Furthermore, the higher incidence of the frontal technique in our study are in line with the findings of Furtado and colleagues (2021), who identified 59% of penalty shots in real games with this characteristic. According to Molik and colleagues (2015), even though spin throws are faster, this technique shows less success in relation to the conversion into goals, which may explain the predominance of frontal throws in our study, even if spin throws occur more frequently in the effective game (Monezi et al., 2018). In addition, despite being less recurring in the effective game, flat balls are usually faster than bounced balls (Link & Weber, 2018; Morato et al., 2018). In this manner, attempts in which the technique used was frontal and the type of ball was flat may indicate more significant control of accuracy in the context of goalball penalty shots.

The main limitations of the present study, and consequently points for future investigations, refer to the option for the execution of the penalty shots without the presence of a defender, the command given to players during the execution of penalty throws, the adoption of an incremental exercise to induce fatigue,e and the absence of a test to assess variations in strength of the upper limbs together with the lower limbs. Previously, researchers have demonstrated that the presence of a defender reduces shot efficacy in 62% (Canossa et al., 2016) since adjustments in movements during the execution of the throw need to be performed (Vila & Ferragut, 2019). In the context of the goalball penalty shot, body communication plays an essential role (Gomes-da-Silva et al., 2015), as the attacking athlete avoids emitting any excessive sounds to minimize the chance that the defender will discover the position of origin of the throw. Thus, we recommend that future studies include some player or defensive mechanism to increase the ecological validity of the assessment. Furthermore, athletes in competitions are likely to slow down their penalty shots to increase the chance of hitting a specific target, so a more adequate guideline to adopt in the penalty throwing protocol could have been "Perform your best penalty shot, as if you were in a competition." The measurement of shooting skills performance in the midst of goalball matches can be approached for a more precise understanding of the fatigue related to the game and its influence on this technical aspect. Finally, heart rate monitoring could be an effective tool for confirming that athletes have actually reached the highest level of exhaustion possible in the incremental test.

In conclusion, by employing 2-D and 3-D kinematic procedures to measure the performance of shooting skills in goalball penalty shots, we identified that perceived fatigability and performance fatigability were induced by an incremental exercise composed by movements specific to goalball and caused significant increases in RPE and [La$^-$]. In addition, there was a decrease in peak force in the knee extensor muscles, but did not change the accuracy measurements and ball velocity. Therefore, success in penalty shots does not seem to depend on the level of fatigue experienced by a goalball player.

Perspectives

From the results of this study, we identified that symptoms of perceived and performance fatigability do not seem to be associated with worse performance on goalball penalty shots. However, this situation still needs further investigation so that goalball coaches can develop strategies that contribute to improving performance on this technical action that is a decisive factor in the outcome of a goalball match (Furtado et al., 2021).

Considering that, despite its lower velocity, the frontal throw seems to show higher success in relation to the conversion into goals, it seems reasonable that goalball players train and improve this technique to achieve more significant control of accuracy in the context of goalball penalty shots.

Author affiliations:

[1] School of Physical Education and Sport of Ribeirão Preto, University of São Paulo (USP), Ribeirão Preto, SP, Brazil; joe_a_c@hotmail.com. tarine.arruda@alumni.usp.br. santosalvesisabella@gmail.com. rab@usp.br.

[2] Medical School of Ribeirão Preto (FMRP), University of São Paulo, Ribeirão Preto, São Paulo, Brazil; tarine.arruda@alumni.usp.br.

[3] Faculty of Physical Education, State University of Campinas (UNICAMP), Campinas, SP, Brazil; santosalvesisabella@gmail.com.

[4] Human Movement Research Laboratory (MOVI-LAB), School of Sciences, Graduate Program in Movement Sciences, Department of Physical Education, São Paulo State University (UNESP), Bauru, SP, Brazil; luiz.palucci@unesp.br. fabio.barbieri@unesp.br.

* Correspondence: joe_a_c@hotmail.com; Tel.: +55-16-3315-0529

Author Contributions: Conceptualization, J.A.C. and R.A.B; Methodology, I.S.A., J.A.C., L.P.V. and R.A.B; Formal Analysis, J.A.C., T.B.A, L.P.V. and R.A.B; Writing-Original Draft Preparation, J.A.C. and R.A.B; Writing-Review & Editing, J.A.C., F.A.B. and R.A.B.

Funding: This research received no external funding.

Availability of data and materials: The data that support the findings of this study are available from the corresponding author, J.A.C. upon reasonable request.

Acknowledgments: The authors would like to thank the members of the Biomechanics and Motor Control Laboratory (LABIOCOM) for the loan of the equipment used for the kinematic procedures, the Group of Studies in Physiological Science and Exercise (GECIFEX) for help in carrying out the experiment, and the Association of the Visually Impaired of Ribeirão Preto and Region (ADEVIRP), for providing their goalball court for the experiments

Conflicts of Interest: The authors declare no conflict of interest.

References

Abdel-Aziz, Y. I., & Karara, H. M. (1971). Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrammetry. *Proceedings of the ASP/UI Symposium on Close-Range Photogrammetry*, 1–18.

Alves, I. S., Kalva-Filho, C. A., Aquino, R., Travitzki, L., Tosim, A., Papoti, M., & Morato, M. P. (2018). Relationships between aerobic and anaerobic parameters with game technical performance in elite goalball athletes. *Frontiers in Physiology, 9*(NOV), 1–10. https://doi.org/10.3389/fphys.2018.01636

Andrade, M. S., Carvalho, K. F., Benedito-Silva, A. A., Da Silva, A. C., & De Lira, C. A. B. (2016). Effect of fatigue caused by a simulated handball game on ball throwing velocity, shoulder muscle strength and balance ratio: A prospective study. *BMC Sports Science, Medicine and Rehabilitation, 8*(1), 1–7. https://doi.org/10.1186/s13102-016-0038-9

Balcı, A., Akınoğlu, B., Kocahan, T., & Hasanoğlu, A. (2021). The relationships between isometric muscle strength and respiratory functions of the Turkish National Paralympic Goalball Team. *Journal of Exercise Rehabilitation, 17*(1), 45–51.

Barbieri, F.A., Gobbi, L. T. B., Santiago, P. R. P., & Cunha, S. A. (2010). Performance comparisons of the kicking of stationary and rolling balls in a futsal context. *Sports Biomechanics, 9*(1), 1–15. https://doi.org/10.1080/14763141003690211

Barbieri, F.A., Gobbi, L. T. B., Santiago, P. R. P., & Cunha, S. A. (2015). Dominant–non-dominant asymmetry of kicking a stationary and rolling ball in a futsal context. *Journal of Sports Sciences, 33*(13), 1411–1419. https://doi.org/10.1080/02640414.2014.990490

Borg, G. A. V. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise 14*(5), 377–381.

Bowerman, S., Davis, R., Ford, S., & Nichols, D. (2011). Phases of movement of goalball throw related to ball velocity. *Insight: Research & Practice in Visual Impairment & Blindness, 4*(4), 153–159.

Canossa, S., Abraldes, J. A., Soares, S. M., Fernandes, R. J., & Garganta, J. M. (2016). Vertical jump and shot speed, efficacy and accuracy in water polo. *International Journal of Performance Analysis in Sport, 16*(1), 64–79. https://doi.org/10.1080/24748668.2016.11868871

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Lawrence Erlbaum.

Cursiol, J. A., Arruda, T. B., Nakamura, F. Y., & Barbieri, R. A. (2022). Three simulated goalball games in the same day cause central fatigue and can impair game technical performance. *Adapted Physical Activity Quarterly, 39*(3), 356-373. https://doi.org/10.1123/apaq.2021-0171

Eddy, K. A. T., & Mellalieu, S. D. (2003). Mental imagery in athletes with visual impairments. *Adapted Physical Activity Quarterly, 20*(4), 347–368. https://doi.org/10.1123/apaq.20.4.347

Ehara, Y., Fujimoto, H., Miyazaki, S., Mochimaru, M., Tanaka, S., & Yamamoto, S. (1997). Comparison of the performance of 3D camera systems II. *Gait and Posture, 5*(3), 251–255. https://doi.org/10.1016/S0966-6362(96)01093-4

Enoka, R. M., & Duchateau, J. (2016). Translating fatigue to human performance. *Medicine & Science in Sports & Exercise, 48*(11), 2228–2238. https://doi.org/10.1249/MSS.0000000000000929

Fábrica, C. G., Gómez, M., & Fariña, A. R. (2008). Angle and speed in female handball penalty throwing: Effects of fatigue and player position. *International Journal of Performance Analysis in Sport, 8*(1), 56–67. https://doi.org/10.1080/24748668.2008.11868422

Figueroa, P. J., Leite, N. J., & Barros, R. M. L. (2003). A flexible software for tracking of markers used in human motion analysis. *Computer Methods and Programs in Biomedicine, 72*(2), 155–165. https://doi.org/10.1016/S0169-2607(02)00122-0
Fleiss, J. L., Levin, B., & Paik, M. C. (2013). *Statistical methods for rates and proportions*. John Wiley & Sons.
Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., & Dodge, C. (2001). A new approach to monitoring exercise training. *The Journal of Strength & Conditioning Research, 15*(1), 109–115. https://doi.org/10.1519/00124278-200102000-00019
Fujita, R., Furtado, O. L. P., & Morato, M.P. (2021). Ball trajectories and probability of scoring a goal in elite male goalball throws. *European Journal of Adapted Physical Activity, 14*(1), 1–11. https://doi.org/10.5507/euj.2021.001
Furtado, O. L. P., Häyrinen, M., Alves, I.S., Travitzki, L., & Morato, M. P. (2021). Factors associated with penalty outcome on male elite goalball. *Adapted Physical Activity Quarterly, 38*, 506–518. https://doi.org/10.1123/apaq.2020-0117
Gomes-da-Silva, P. N., Almeida, J. E. A., & Antério, D. (2015). The bodily communication in the game Goalball. *Movimento (ESEFID/UFRGS), 21*(1), 25. https://doi.org/10.22456/1982-8918.43323
Goulart-Siqueira, G., Benítez-Flores, S., Ferreira, A., Zagatto, A., Foster, C., & Boullosa, D. (2019). Relationships between different field test performance measures in elite goalball players. *Sports, 7*(6), 1–7. https://doi.org/10.3390/sports7010006
Gulick, D. T., & Malone, L. A. (2011). Field test for measuring aerobic capacity in paralympic goalball athletes. *International Journal of Athletic Therapy and Training, 16*(5), 22–25. https://doi.org/10.1123/ijatt.16.5.22
Haddad, M., Stylianides, G., Djaoui, L., Dellal, A., & Chamari, K. (2017). Session-RPE method for training load monitoring: Validity, ecological usefulness, and influencing factors. *Frontiers in Neuroscience, 11,* 612. https://doi.org/10.3389/fnins.2017.00612
IBSA. (2021). *IBSA - Goalball*. International Blind Sports Federation. https://goalball.sport/
Ikeda, T., Iguchi, Y., Ishihara, Y., Shimasaki, Y., Ikeda, H., & Yoshimura, M. (2019). Activity Profiles of international goalball players using wearable devices. *Juntendo Medical Journal, 65*(3), 279–285. https://doi.org/10.14789/jmj.2019.65.jmj19-oa06
Link, D., & Weber, C. (2018). Finding the gap: An empirical study of the most effective shots in elite goalball. *PLoS ONE, 13*(4), 1–11. https://doi.org/10.1371/journal.pone.0196679
Ly, A., Verhagen, J., & Wagenmakers, E. J. (2016). Harold Jeffreys's default Bayes factor hypothesis tests: Explanation, extension, and application in psychology. *Journal of Mathematical Psychology, 72*, 19–32. https://doi.org/10.1016/j.jmp.2015.06.004
Magalhães, T., Furtado, O. L. P., Morato, M. P., Gamero, D. H., & Misuta, M. S. (2013). Quantificação das ações ofensivas do goalball nos jogos paralímpicos de Londres 2012. [Quantification of offensive goalball actions at the London 2012 Paralympic Games]. *Proceedings of the 4th Congresso Internacional de Jogos Desportivos,* 4(1), 1-6. https://docplayer.com.br/5106943-Exemplo-quantificacao-das-acoes-ofensivas-do-goalball-nos-jogos-paralimpicos-de-londres.html
Meletakos, P., Vagenas, G., & Bayios, I. (2011). A multivariate assessment of offensive performance indicators in Men's Handball: Trends and differences in the World Championships. *International Journal of Performance Analysis in Sport, 11*(2), 284–294. https://doi.org/10.1080/24748668.2011.11868548
Milioni, F., Vieira, L. H. P., Barbieri, R. A., Zagatto, A. M., Nordsborg, N. B., Barbieri, F. A., dos-Santos, J. W., Santiago, P. R. P., & Papoti, M. (2016). Futsal match-related fatigue affects running performance and neuromuscular parameters but not finishing kick speed or accuracy. *Frontiers in Physiology, 7*(NOV), 1–10. https://doi.org/10.3389/fphys.2016.00518
Molik, B., Morgulec-Adamowicz, N., Kosmol, A., Perkowski, K., Bednarczuk, G., Skowronski, W., Gomez, M. A., Koc, K., Rutkowska, I., & Szyman, R. J. (2015). Game performance evaluation in male goalball players. *Journal of Human Kinetics, 48*(1), 43–51. https://doi.org/10.1515/hukin-2015-0090

Monezi, L. A., Magalhães, T. P., Morato, M. P., Mercadante, L. A., Furtado, O. L. P., & Misuta, M. S. (2018). Time-motion analysis of goalball players in attacks: differences of the player positions and the throwing techniques. *Sports Biomechanics, 18*(5), 470–481. https://doi.org/10.1080/14763141.2018.1433871

Morato, M. P., Furtado, O. L. P., Gamero, D. H., Magalhães, T. P., & Almeida, J. J. G. (2017). Development and evaluation of an observational system for goalball match analysis. *Revista Brasileira de Ciencias Do Esporte, 39*(4), 398–407. https://doi.org/10.1016/j.rbce.2016.08.002

Morato, M. P., Menezes, R. P., Fonseca, S., & Furtado, O. L. P. (2018). Faster balls increase the probability of scoring a goal in female and male elite goalball. *Revista Brasileira de Ciencias Do Esporte, 40*(4), 427–434. https://doi.org/10.1016/j.rbce.2018.03.027

Nascimento, D. F., & Camargo, W. (2012). Decodificando o Goalball para professores - técnicos de Educação Física Adaptada: Fundamentos Técnicos. *Caderno de Formação RBCE, 3*(1), 57–74.

Nuño, A., Chirosa, I. J., Van Den Tillaar, R., Guisado, R., Martín, I., Martinez, I., & Chirosa, L. J. (2016). Effects of fatigue on throwing performance in experienced team handball players. *Journal of Human Kinetics, 54*(1), 103–113. https://doi.org/10.1515/hukin-2016-0039

O'Donoghue, P. O. (2010). *Research methods for sports*. Routledge.

Place, N., Maffiuletti, N. A., Martin, A., & Lepers, R. (2007). Assessment of the reliability of central and peripheral fatigue after sustained maximal voluntary contraction of the quadriceps muscle. *Muscle and Nerve, 35*(4), 486–495. https://doi.org/10.1002/mus.20714

Powis, B. (2018). Visual impairment, sport and somatic work: The auditory experiences of blind and partially sighted cricket players. *Senses and Society, 13*(2), 147–162. https://doi.org/10.1080/17458927.2018.1468689

Robinson, G., & Robinson, I. (2016). Radar speed gun true velocity measurements of sports-balls in flight: Application to tennis. *Physica Scripta, 91*(2), 1–19. https://doi.org/10.1088/0031-8949/91/2/023008

Royal, K. A., Farrow, D., Mujika, I., Halson, S. L., Pyne, D., & Abernethy, B. (2006). The effects of fatigue on decision making and shooting skill performance in water polo players. *Journal of Sports Sciences, 24*(8), 807–815. https://doi.org/10.1080/02640410500188928

Shimony, N. D., Lidor, R., & Ziv, G. (2020). The effectiveness of bandwidth knowledge of results on a throwing task in goalball players with visual impairments. *European Journal of Adapted Physical Activity, 13*(2), 1–16. https://doi.org/10.5507/EUJ.2020.009

Theophilos, P., Antonios, C., Helen, D., Antonios, A., & Savvas, T. P. (2005). Heart rate responses and blood lactate concentration of goal ball players during the game. *Proceedings of the 10th Annual Congress of the European College of Sport Science* 10(1), 1-2. http://smas.org/2-kongres/papers/14521.pdf

Vieira, L.H.P., Cunha, S. A., Moraes, R., Barbieri, F. A., Aquino, R., Oliveira, L. de P., Navarro, M., Bedo, B. L. S., & Santiago, P. R. P. (2018). Kicking performance in young U9 to U20 soccer players: Assessment of velocity and accuracy simultaneously. *Research Quarterly for Exercise and Sport, 89*(2), 210–220. https://doi.org/10.1080/02701367.2018.1439569

Vieira, L. H. P., Serenza, F. D. S., De Andrade, V. L., Oliveira, L. D. P., Mariano, F. P., Santana, J. E., & Santiago, P. R. P. (2016). Kicking performance and muscular strength parameters with dominant and nondominant lower limbs in Brazilian elite professional futsal players. *Journal of Applied Biomechanics, 32*(6), 578–585. https://doi.org/10.1123/jab.2016-0125

Vila, H., & Ferragut, C. (2019). Throwing speed in team handball: a systematic review. *International Journal of Performance Analysis in Sport, 19*(5), 724–736. https://doi.org/10.1080/24748668.2019.1649344

Wagenmakers, E. J., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Selker, R., Gronau, Q. F., Dropmann, D., Boutin, B., Meerhoff, F., Knight, P., Raj, A., van Kesteren, E. J., van Doorn, J., Šmíra, M., Epskamp, S., Etz, A., Matzke, D., … Morey, R.

D. (2018). Bayesian inference for psychology. Part II: Example applications with JASP. *Psychonomic Bulletin and Review, 25*(1), 58–76. https://doi.org/10.3758/s13423-017-1323-7

Wagenmakers, E. J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Love, J., Selker, R., Gronau, Q. F., Šmíra, M., Epskamp, S., Matzke, D., Rouder, J. N., & Morey, R. D. (2018). Bayesian inference for psychology. Part I: Theoretical advantages and practical ramifications. *Psychonomic Bulletin and Review, 25*(1), 35–57. https://doi.org/10.3758/s13423-017-1343-3

Zapardiel Cortés, J. C., Ferragut Fiol, C., Manchado, C., Abraldes Valeiras, J. A., & Vila Suárez, H. (2018). Difference of the speed of handball throwing during the competition in relation to efficiency: Analysis between the first and the second half. *Journal of Human Sport and Exercise, 12*(3), 872–881. https://doi.org/10.14198/jhse.2017.12.proc3.11