

Physiological responses and activity demands remain consistent irrespective of team size in recreational handball

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ABSTRACT: The aim of this study was to examine the impact of team size on acute physiological, perceptual, and activity demands of recreational handball to provide a better understanding for the potential prescription of recreational handball to achieve health benefits. Active, male college students (N=22) completed 3-, 4-, and 5-a-side handball game formats across three separate sessions following a repeated-measures, crossover design. Heart rate (HR), blood lactate concentration (BLa), rating of perceived exertion (RPE), distance covered, and frequency of accelerations/decelerations were monitored during games. Each game format elicited vigorous intensities with a mean HR in the range 82–85%HR_{max} and post-game BLa in the range 3.9–4.4 mmol·L⁻¹. No significant differences ($P>0.05$) in absolute ($\eta^2=0.40$), relative mean HR ($\eta^2=0.43$), BLa ($\eta^2=0.16$), total distance ($\eta^2=0.32$), total accelerations ($\eta^2=0.23$), or total decelerations ($\eta^2=0.23$) were observed between game formats. A significant effect was observed for RPE ($\eta^2=0.51$), where 3-a-side games elicited a higher RPE than 5-a-side games ($P=0.03$, *large*). Modifying player number has a negligible effect on the physiological and activity demands encountered during recreational handball games. Recreational handball consisting of 3–5 players imposes similar intermittent workloads, resulting in vigorous physiological responses concomitant with those recommended for overall health improvements as part of regular training.

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INTRODUCTION

Traditionally, weekly doses of moderate-intensity activity for 150 min [55–70% of maximum heart rate (HR_{max})] or 75 min of vigorous-intensity activity (70–90%HR_{max}) have been recommended by the American College of Sports Medicine (ACSM) as the minimum amount of aerobic exercise required for good health in the general population [1, 2]. However, high-intensity intermittent training (HIIT, >90%HR_{max}; ≤4 min/set) has been proposed as a time-efficient strategy for healthy adults to improve or maintain health [3]. Furthermore, recent meta-analyses have suggested that HIIT is more effective than low- to moderate-intensity exercise in eliciting favourable changes in physiological variables indicative of health status, such as maximal oxygen uptake (VO_{2max}), as well as biomarkers associated with vascular function, oxidative stress, and insulin sensitivity [4, 5]. However, a review by Krstrup et al. [6] highlighted the relatively high rating of perceived exertion (RPE~8) in HIIT, which might have ramifications related to exercise adherence. On the other hand, recreational team sports are perceived as less strenuous than HIIT (RPE=4) [6]. Consequently, it is possible that team sport

may provide individuals the opportunity to obtain the physiological benefits of HIIT without experiencing the high perceptual demand of traditional HIIT, thus serving to increase health and exercise adherence in the general population.

Previously, comparable heart rate (HR) responses have been observed between 4-a-side handball games and typical short-duration, intermittent running [7]. Due to the positive health effects of HIIT, researchers have started examining the effects of the intermittent running pattern common to team sports characterized by high-intensity bouts of exercise on improving the health of participants in recreational settings. A recent study demonstrated the potential health-related benefits of 6-a-side recreational handball, while quantifying the acute physiological [(HR response, blood lactate concentration (BLa)], rating of perceived exertion (RPE) and activity demands (distance covered across speed zones, jumps, throws, accelerations) in untrained men [8]. In addition to HR responses and distance covered across speed zones, Hornstrup et al. [9, 10] reported 3 months of 3- and 4-a-side handball participation (~2 times per

week for 4 x 12-min periods) improved cardiovascular and musculoskeletal fitness in untrained men and women. However, the results from these studies should be expanded as BLA and accelerometer data during recreational handball games are limited to only one study [8]. Quantification of BLA will provide important insight into glycolytic metabolic recruitment [11], while acceleration/deceleration data may provide further insight into metabolically demanding activities that increase both energy expenditure and muscle fatigue compared to movement at constant velocities [12].

Given the positive relationship between exercise intensity, exercise volume, and cardiorespiratory fitness [5], quantification of the physiological and activity demands of handball in a recreationally-active population is necessary to ascertain the potential health-promoting effects of playing recreational handball. As recreational handball is commonly played using varied team sizes ranging from 3 vs. 3 to 6 vs. 6 outfield players [8–10], assessing the physiological, perceptual, and activity demands of handball across varying team sizes is essential to identify how different game formats impact the acute exercise intensities, volumes, and movement patterns experienced, which mediate the potential health-promoting aspects of recreational handball. To date, no evidence is available regarding the physiological or activity demands elicited during handball games using different team sizes in recreational players. As a result we sought to determine the impact of team size on acute physiological, perceptual, and activity demands of recreational handball to improve the prescription of such exercise in the general population to achieve health-related benefits.

MATERIALS AND METHODS

Subjects

Twenty-two male college students were recruited for this study (age: 20.8 ± 1.1 years; stature: 179.4 ± 5.2 cm; body mass: 77.2 ± 11.7 kg; body fat: $14.9 \pm 5.3\%$; maximal running speed in 30–15 Intermittent Fitness Test [30–15IFT]: 16.9 ± 1.9 km·h⁻¹; HR_{peak}: 201.6 ± 7.7 b·min⁻¹). Subjects were recreationally active, performing 3–5 h·week⁻¹ of exercise for at least 6 months prior to participation, but did not have club-based experience in handball (handball experience ranged from 2 to 3 years as part of participation in physical education classes or recreational leagues). No subject reported a medical contraindication to exercise. The experimental design was explained to all subjects and written informed consent was obtained prior to commencing data collection. All procedures received approval from an institutional ethics committee.

Experimental design

A repeated-measures, crossover study design was applied in this study. During the second and third weeks, six sessions (three sessions per week) were administered at the same time of day (10:00–11:00 h) with 48 h of rest between sessions. To minimize confounding factors, subjects were instructed to refrain from physical exercise for the duration of this study. Subjects were divided into two groups with 10 players per group and the same two goalkeepers participating in

all games. The first group completed 5-, 4-, and 3-a-side handball games across the first week, while the second group completed the same handball game formats the following week in reverse order. One subject from each team was randomly excluded or included across game formats when team size was modified. Consequently, the 12 subjects (6 per group) who participated as outfield players in all game formats were included in the final dataset. Two goalkeepers were not included in the final data set due to their restricted movement requirements [16]. All testing sessions were performed on the same indoor handball court under similar environmental conditions (temperature: $14.5 \pm 1.0^\circ\text{C}$, humidity: $48.6 \pm 9.5\%$).

Subjects completed a 10-min standardized warm-up [moderate-intensity jogging (4 min), static and dynamic stretching (4 min), and accelerative running bouts (2 min)] before each handball game. Handball games consisted of 2 x 20-min halves, with a 5-min half-time break. Subjects were allowed to consume water during the half-time break. Data collected during the warm-up and half-time break were excluded from the analysis to ensure that the results were only indicative of game activities. All games were played on a full-size handball court (40 m x 20 m) with consistent goal sizes (2 m high x 3 m wide) [17, 18]. The rules of the games were consistent with standard handball competition [19], with the following exceptions as used previously in handball research examining modified games [20]: 1) no enforcement of 2-min exclusions; 2) no substitutions, and 3) throw-ins after goals were immediately made by goalkeepers from their 6-m area. All games were officiated by one of the investigators who had extensive knowledge of the rules and regulations of handball competition.

Data were collected across a 3-week period. During the first week, each subject had their body composition estimated using a bioelectrical impedance analyser (InBody 770, Biospace Co. Ltd, Seoul, Korea) following standard measurement procedures [13]. Height was measured using a portable stadiometer (Seca 220, Seca Corporation, Hamburg, Germany) with a graduation of 0.1 cm. HR_{max} was determined as the highest HR response attained during the 30–15 IFT. The 30–15 IFT consisted of repeated 30-s runs interspersed with 15-s recoveries at a walking speed [14]. The initial speed of the test started at 8 km·h⁻¹ followed by an incremental increase of 0.5 km·h⁻¹ every 45 s indicated by audio signals. The test was completed when each subject could no longer maintain the imposed running speed on three consecutive occasions or upon volitional exhaustion [15].

Heart rate monitoring

HR was continuously recorded at 1-s intervals using a Polar Team Pro System (Polar Electro, Kempele, Finland). The HR receiver was attached to an elastic strap and placed on the anterior surface of the chest at the level of the xiphoid process on each subject. Mean and peak HR responses were expressed as absolute (beats·min⁻¹) and relative values (%HR_{max}). The proportion (%) of game time spent in the following HR-mediated intensity zones was also calculated: <70%HR_{max}, 71–80%HR_{max}, 81–90%HR_{max}, and 91–100%HR_{max}.

Blood lactate concentration

Blood was taken from an earlobe in each subject immediately following each game [21] and measured with a handheld analyser (Lactate Scout, EKF, Senclab, Magdeburg, Germany) [22].

Rating of perceived exertion

Subjects reported RPE immediately after each game using Borg's Category-Ratio scale with 1 indicating a minimum response and 10 indicating a maximum response. Borg's Category-Ratio scale has been established as a reliable and valid indicator of exercise intensity [23].

Activity demands

The activity profiles of subjects were measured using 10-Hz global positioning systems (GPS) integrated with a 200-Hz accelerometer (Polar Team Pro, Kempele, Finland), which has been established as valid and reliable for monitoring movement characteristics [24]. Indoor GPS have been previously administered in basketball and handball [11, 20]. The GPS tracking system uses the Global Navigation

Satellite System network, which incorporates a range of satellites (minimum 4) to estimate the position and calculate distance from the transmitter. GPS signal quality may change depending on location and environmental obstruction, providing a more accurate data recording with a higher number of connected satellites [25, 26]. The number of available satellite signals ranged between 10 and 13, similar to previous team sport research (average 13.9 satellites) [27]. The total distance covered at different intensities was determined using the following zones [28]: standing/walking (<6 km·h⁻¹), low-speed running (6.01–12 km·h⁻¹), moderate-speed running (12.01–18 km·h⁻¹), high-speed running (18.01–24 km·h⁻¹), and maximal-speed running (>24 km·h⁻¹). The quantity of accelerations and decelerations performed at different intensities was determined using the following zones [29]: low (0.5–0.99 m·s⁻²), medium (1–1.99 m·s⁻²), and high (>2 m·s⁻²).

Statistical analysis

The normality of all data was verified using the Shapiro-Wilk test. Mean ± standard deviation (SD) was determined for all measures.

TABLE 1. The physiological and activity demands experienced during handball games with different team sizes in recreational players (n=12).

Variable	Game format			ANOVA P η _p ²		Comparisons between game formats		
	3-a-side	4-a-side	5-a-side			3- vs 4-a-side ES (90% CI)	3- vs 5-a-side ES (90% CI)	4- vs 5-a-side ES (90% CI)
<i>Physiological demands</i>								
HR _{mean} (beats·min ⁻¹)	170 ± 7	164 ± 10	165 ± 13	0.08	0.40	0.68 (-0.03 to 1.35)‡	0.48 (-0.22 to 1.14)	-0.10 (-0.77 to 0.57)
HR _{peak} (beats·min ⁻¹)	193 ± 8	194 ± 14	189 ± 9	0.38	0.18	-0.04 (-0.71 to 0.63)	0.57 (-0.13 to 1.24)†	0.47 (-0.23 to 1.13)
HR _{mean} (%HR _{max})	84.8 ± 5.2	81.7 ± 6.4	82.3 ± 8.0	0.06	0.43	0.53 (-0.17 to 1.20)†	0.37 (-0.32 to 1.03)	-0.08 (-0.75 to 0.59)
HR _{peak} (%HR _{max})	95.3 ± 5.0	94.8 ± 3.9	93.9 ± 6.1	0.75	0.06	0.11 (-0.56 to 0.78)	0.25 (-0.43 to 0.92)	0.18 (-0.50 to 0.84)
BLa (mmol·L ⁻¹)	4.4 ± 1.3	4.4 ± 1.5	3.9 ± 1.6	0.42	0.16	0.00 (-0.67 to 0.67)	0.34 (-0.34 to 1.01)	0.32 (-0.36 to 0.99)
RPE (AU)	5.3 ± 0.9	5.4 ± 2.4	3.9 ± 1.2	0.03	0.51	-0.06 (-0.72 to 0.62)	1.32 (0.54 to 2.01)§	0.79 (0.07 to 1.46)‡
<i>Activity demands</i>								
Total distance (m)	3341 ± 607	3285 ± 698	3181 ± 678	0.15	0.32	0.08 (-0.59 to 0.75)	0.25 (-0.43 to 0.91)	0.15 (-0.53 to 0.82)
Total accelerations (count)	500 ± 37	493 ± 37	507 ± 42	0.28	0.23	0.20 (-0.48 to 0.87)	-0.18 (-0.84 to 0.50)	-0.37 (-1.03 to 0.32)
Total decelerations (count)	514 ± 54	506 ± 47	517 ± 45	0.26	0.23	0.16 (-0.52 to 0.83)	-0.07 (-0.74 to 0.60)	-0.25 (-0.92 to 0.43)

Note: ES = effect size; CI = confidence intervals; HR_{mean} = mean heart rate; HR_{peak} = peak heart rate; %HR_{max} = percentage of maximum heart rate; BLa = blood lactate concentration; RPE = rating of perceived exertion; AU = arbitrary units; bolded values = significant difference at P<0.05; † *small* effect size; ‡ *moderate* effect size; § *large* effect size.

TABLE 2. Effect sizes (ES) with 90% confidence intervals (CI) for pairwise comparisons between game formats for physiological and activity intensity variables during handball games in recreational players (n = 12).

Variable	Comparisons between game formats		
	3- vs. 4-a-side	3- vs. 5-a-side	4- vs. 5-a-side
<i>Heart rate</i>			
<70%HR _{max}	-0.65 (-1.31 to 0.06)‡	-0.60 (-1.26 to 0.11)‡	-0.11 (-0.78 to 0.57)
71–80%HR _{max}	-0.16 (-0.83 to 0.52)	0.02 (-0.65 to 0.69)	0.20 (-0.48 to 0.86)
81–90%HR _{max}	0.28 (-0.41 to 0.94)	0.56 (-0.14 to 1.23)†	0.27 (-0.41 to 0.94)
91–100%HR _{max}	0.30 (-0.39 to 0.96)	-0.02 (-0.69 to 0.65)	-0.27 (-0.93 to 0.42)
<i>Distance covered</i>			
0–6 km·h ⁻¹	-0.26 (-0.93 to 0.42)	-0.15 (-0.82 to 0.53)	0.12 (-0.56 to 0.79)
6.01–12 km·h ⁻¹	0.21 (-0.47 to 0.88)	0.29 (-0.40 to 0.95)	0.08 (-0.59 to 0.75)
12.01–18 km·h ⁻¹	0.08 (-0.59 to 0.75)	0.34 (-0.35 to 1.01)	0.23 (-0.45 to 0.89)
18.01–23.99 km·h ⁻¹	0.08 (-0.60 to 0.74)	0.12 (-0.56 to 0.79)	0.05 (-0.63 to 0.72)
>24 km·h ⁻¹	0.09 (-0.59 to 0.75)	-0.08 (-0.75 to 0.59)	-0.16 (-0.82 to 0.52)
<i>Accelerations</i>			
0.50–0.99 m·s ⁻²	-0.25 (-0.91 to 0.44)	-0.52 (-1.18 to 0.18)†	-0.25 (-0.91 to 0.44)
1–1.99 m·s ⁻²	0.10 (-0.57 to 0.77)	-0.23 (-0.89 to 0.46)	-0.34 (-1.00 to 0.35)
>2 m·s ⁻²	0.38 (-0.31 to 1.05)	0.51 (-0.19 to 1.17)†	0.15 (-0.53 to 0.81)
<i>Decelerations</i>			
0.50–0.99 m·s ⁻²	-0.31 (-0.97 to 0.38)	-0.52 (-1.19 to 0.18)†	-0.20 (-0.87 to 0.48)
1–1.99 m·s ⁻²	0.14 (-0.54 to 0.81)	0.00 (-0.68 to 0.67)	-0.14 (-0.81 to 0.54)
>2 m·s ⁻²	0.56 (-0.15 to 1.22)†	0.50 (-0.20 to 1.17)	-0.01 (-0.68 to 0.67)

Note: %HR_{max} = percentage of maximum heart rate; † *small* effect size; ‡ *moderate* effect size.

Separate one-way repeated measures analyses of variance (ANOVA) were used to assess differences between game formats in HR_{mean}, HR_{peak}, HR zones, RPE, BLA, total distance, total accelerations, and total decelerations. Two-way repeated measures ANOVAs were used to assess differences between game formats (within each intensity zone) and between intensity zones (within each game format) for distance, acceleration, and deceleration data. Given that HR data were recorded as the proportion of time spent in each HR zone, analysis of differences between game formats was not permissible using a two-way repeated measures ANOVA. Accordingly, separate one-way repeated measures ANOVAs were conducted to analyse differences between game formats and intensity zones for HR data. Bonferroni post hoc tests were conducted for all ANOVAs where appropriate. The effect size was determined using partial eta squared (η_p^2). Cohen's effect size with 90% confidence intervals (CI) was also calculated to describe the magnitude of differences in all pairwise comparisons and interpreted as: *trivial* (<0.2), *small* (0.2–0.59), *moderate* (0.6–1.19), *large* (1.2–1.99), or *very large* (>2.0) [30]. An effect was deemed *unclear* if the CI overlapped ± 0.2 [30]. All statistical analyses were performed using IBM SPSS software (v25.0, IBM Corporation; Armonk, NY, USA). Statistical significance was set at $P \leq 0.05$.

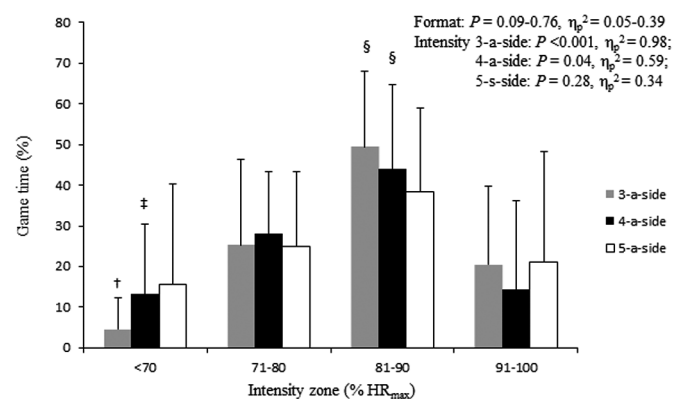


FIG. 1. Mean \pm standard deviation proportion of game time spent in different heart rate intensity zones during handball games with different team sizes in recreational players (n=12). Note: %HR_{max} = percentage of maximum heart rate; † significantly ($P \leq 0.05$) different to 71–80%HR_{max} and 81–90% HR_{max}; ‡ significantly ($P \leq 0.05$) different to 71–80%HR_{max}; § significantly ($P \leq 0.05$) different to 91–100% HR_{max}.

Demands in recreational handball small-sided games

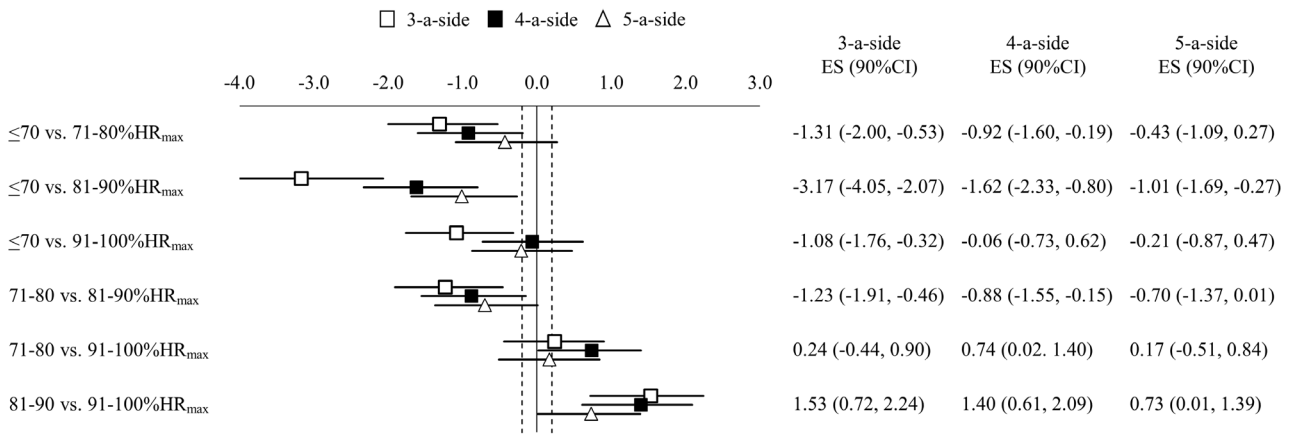


FIG. 2. Effect sizes (ES) with 90% confidence intervals (CI) for pairwise comparisons between heart rate intensity zones during handball games with different team sizes in recreational players (n=12).
 Note: %HR_{max} = percentage of maximum heart rate; *unclear* effect = CI overlapped ±0.2, *moderate* effect = 0.6–1.19, *large* effect = 1.2–1.99, and *very large* effect = >2.0.

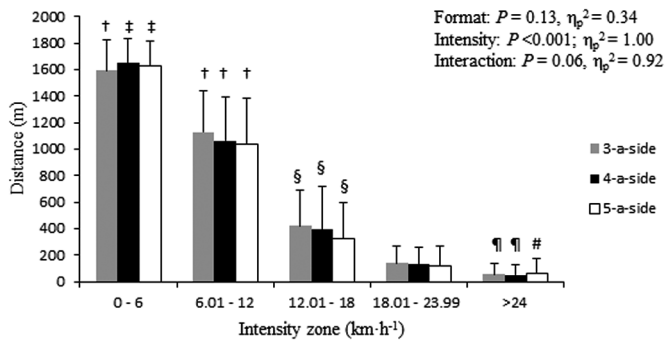


FIG. 3. Mean ± standard deviation distance covered working in different speed zones during handball games with different team sizes in recreational players (n=12). Note: † significantly ($P \leq 0.05$) different to zones above 12 km·h⁻¹; ‡ significantly ($P \leq 0.05$) different to all other zones; § significantly ($P \leq 0.05$) different to zones above 18 km·h⁻¹; ¶ significantly ($P \leq 0.05$) different to 12.01–18 km·h⁻¹ and 18.01–23.99 km·h⁻¹; # significantly ($P \leq 0.05$) different to 12.01–18 km·h⁻¹.

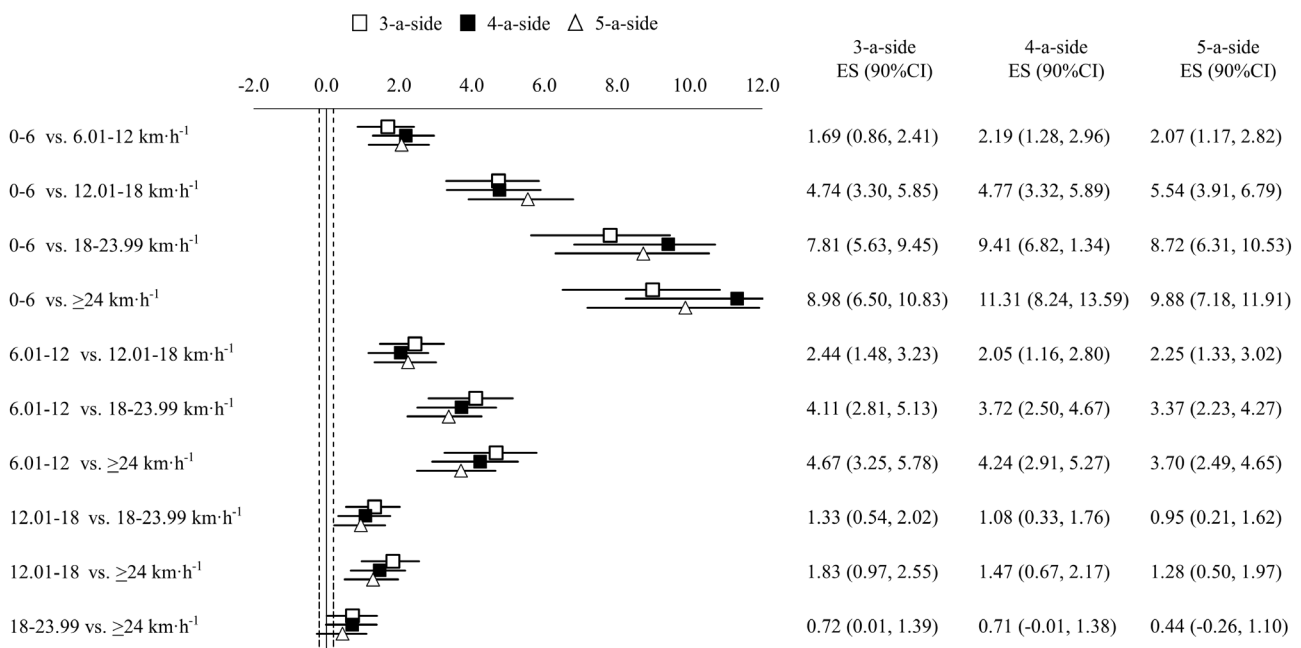


FIG. 4. Effect sizes (ES) with 90% confidence intervals (CI) for pairwise comparisons between distance intensity zones during handball games with different team sizes in recreational players (n=12).
 Note: *unclear* effect = CI overlapped ±0.2, *moderate* effect = 0.6–1.19, *large* effect = 1.2–1.99, and *very large* effect = >2.0.

RESULTS

No significant main effects of game format were observed for absolute HR, relative mean HR, BLa, total distance, total accelerations, or total decelerations (Table 1). A significant main effect of game format was observed for RPE in which 3-a-side games elicited a significantly higher RPE ($P=0.03$, *large*) than 5-a-side games.

The time spent in each HR intensity zone is presented in Figure 1. The corresponding ES statistics are shown in Table 2 and Figure 2. Separate one-way repeated measures ANOVAs indicated no significant effect of game format for time spent within HR intensity zones, but there were significant effects of intensity zone within 3-a-side and 4-a-side game formats. Specifically, more time was spent working at 71–80%HR_{max} (3-a-side, $P=0.003$, *large*; 4-a-side, $P=0.04$,

moderate) and 81–90%HR_{max} (3-a-side, $P<0.001$, *very large*; 4-a-side, $P=0.07$, *large*) than <70%HR_{max}. Further, more time was spent working at 81–90%HR_{max} than 91–100%HR_{max} during 3- and 4-a-side games (3-a-side, $P=0.02$, *large*; 4-a-side, $P=0.05$, *large*).

Distance covered in each intensity zone during each game format is presented in Figure 1. The corresponding ES statistics are shown in Table 2 and Figure 4. A non-significant interaction ($P=0.06$, $\eta^2=0.92$) and non-significant main effect for format ($P=0.13$, $\eta^2=0.34$) was detected. However, there was a significant main effect for intensity zone ($P<0.001$; $\eta^2=1.00$). Specifically, significant ($P<0.001$ – 0.03 , *moderate* to *very large*) reductions in distance covered were observed as the speed zone increased [(0–6 km·h⁻¹ vs. 6.01–12 km·h⁻¹, $P=0.03$, *very large*; 0–6 km·h⁻¹ vs. 12.01–18 km·h⁻¹,

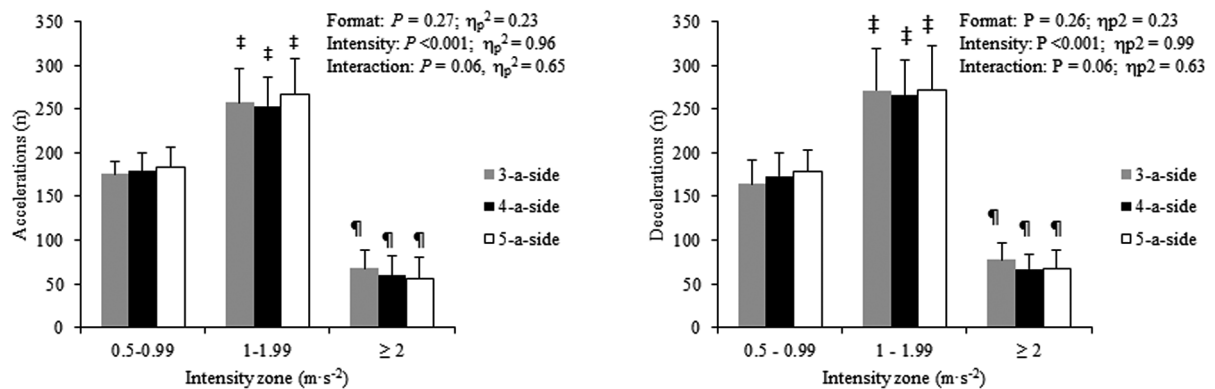


FIG. 5. Mean \pm standard deviation accelerations (A) and decelerations (B) performed in different intensity zones during handball games with different team sizes in recreational players ($n=12$).

Note: ‡ significantly ($P \leq 0.05$) different to 0.5–0.99 m·s⁻² and > 2 m·s⁻²; ¶ significantly ($P \leq 0.05$) different to 0.5–0.99 m·s⁻².

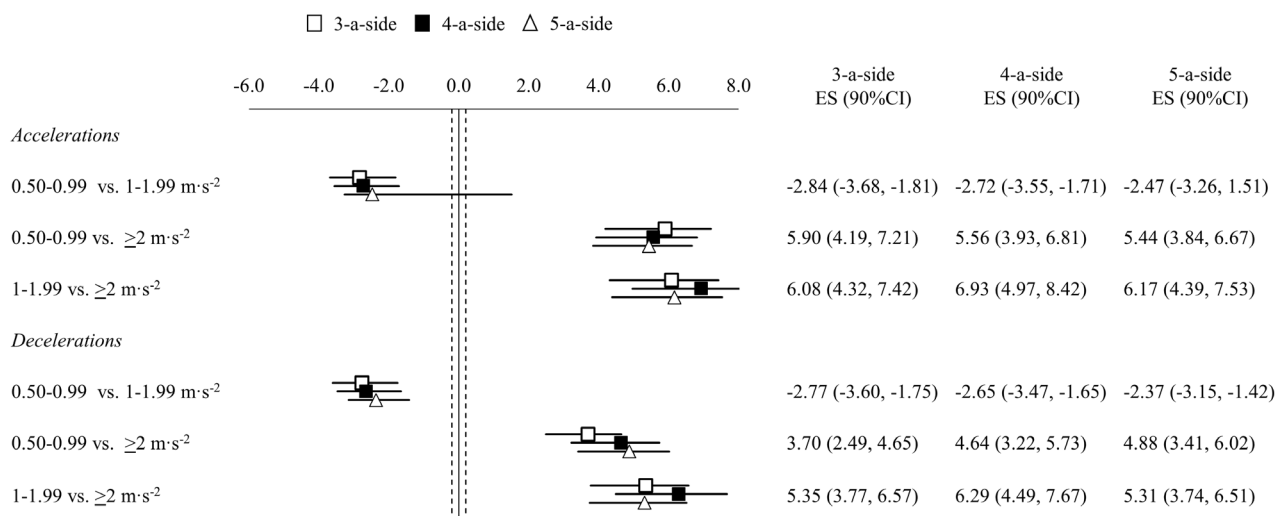


FIG. 6. Effect sizes (ES) with 90% confidence intervals (CI) for pairwise comparisons between acceleration and deceleration intensity zones during handball games with different team sizes in recreational players ($n=12$).

Note: unclear effect = CI overlapped ± 0.2 , very large effect = > 2.0 .

$P < 0.001$, *very large*; $0\text{--}6 \text{ km}\cdot\text{h}^{-1}$ vs. $18.01\text{--}23.99 \text{ km}\cdot\text{h}^{-1}$, $P < 0.001$, *very large*; $0\text{--}6 \text{ km}\cdot\text{h}^{-1}$ vs. $>24 \text{ km}\cdot\text{h}^{-1}$, $P < 0.001$, *very large*), ($6.01\text{--}12 \text{ km}\cdot\text{h}^{-1}$ vs. $12.01\text{--}18$, $P < 0.001$, *very large*; $6.01\text{--}12 \text{ km}\cdot\text{h}^{-1}$ vs. $18.01\text{--}23.99 \text{ km}\cdot\text{h}^{-1}$, $P < 0.001$, *very large*; $6.01\text{--}12 \text{ km}\cdot\text{h}^{-1}$ vs. $>24 \text{ km}\cdot\text{h}^{-1}$, $P < 0.001$, *very large*), ($12.01\text{--}18 \text{ km}\cdot\text{h}^{-1}$ vs. $18.01\text{--}23.99 \text{ km}\cdot\text{h}^{-1}$, $P = 0.002$, *moderate*; $12.01\text{--}18 \text{ km}\cdot\text{h}^{-1}$ vs. $>24 \text{ km}\cdot\text{h}^{-1}$, $P = 0.002$, *large*), ($18.01\text{--}23.99 \text{ km}\cdot\text{h}^{-1}$ vs. $>24 \text{ km}\cdot\text{h}^{-1}$, $P = 0.01$, *moderate*)).

Frequency of accelerations and decelerations performed in each intensity zone during each game format is presented in Figure 5. The corresponding ES statistics are shown in Table 2 and Figure 6. A non-significant interaction (accelerations: $P = 0.06$, $\eta^2 = 0.65$; decelerations: $P = 0.06$; $\eta^2 = 0.63$) and a non-significant main effect for format (accelerations: $P = 0.27$, $\eta^2 = 0.23$; decelerations: $P = 0.26$; $\eta^2 = 0.23$) were evident. However, there was a significant main effect for intensity zone in regard to accelerations ($P < 0.001$; $\eta^2 = 0.96$) and decelerations ($P < 0.001$; $\eta^2 = 0.99$). Post hoc analyses revealed that significantly more ($P < 0.001$, *very large*) low- and medium-intensity accelerations and decelerations were performed compared to high-intensity accelerations and decelerations. Furthermore, subjects completed significantly more ($P = 0.001$, *very large*) medium-intensity accelerations and decelerations than low-intensity accelerations and decelerations across game formats.

DISCUSSION

Modifying player number had a negligible effect on the physiological and activity demands encountered during recreational handball games. Our findings demonstrate that handball games consisting of 3–5 players per team elicit extensive intermittent activity demands targeting aerobic ($82\text{--}85\%HR_{\max}$) and rapid glycolytic energy pathways (BLa of $3.9\text{--}5.4 \text{ mmol}\cdot\text{L}^{-1}$), which potentially can lead to marked health-related benefits in outfield players.

Mean HR was in the range $82\text{--}85\%HR_{\max}$ across handball game formats with the majority of game time (59–70%) spent working at $>80\%HR_{\max}$. Our results are in agreement with data collected on outfield players during 6-a-side recreational handball games in untrained men (mean HR of $82 \pm 6\%HR_{\max}$, with 71% of game time working $>80\%HR_{\max}$) [8]. Further, the mean HR we reported corresponds to the upper threshold intensity of vigorous intensity exercise, as defined by the ACSM ($60\text{--}85\%HR_{\max}$) [1, 2]. These findings might be of specific interest for training prescription because aerobic-anaerobic activities promoting higher exercise intensities elicit a greater magnitude of health benefits (i.e. $VO_{2\max}$, as well as biomarkers associated with vascular function, oxidative stress, and insulin sensitivity) compared to activities performed at lower intensities in recreationally active individuals [4, 5, 31]. Results from our study and that of Povoas et al. [8] suggest that irrespective of the number of players participating in games (3–6 players per team), recreational handball imposes an intense exercise stimulus that has potential to improve the physical health of outfield players.

When comparing HR data between game formats a non-significant relative mean HR was evident during 3-a-side ($84.8 \pm 5.2\%HR_{\max}$), 4- ($81.7 \pm 6.4\%HR_{\max}$, *small*), and 5-a-side games ($82.3 \pm 8.0\%HR_{\max}$, *unclear*). In addition, *moderate* decreases in the proportion of game time spent working $<70\%HR_{\max}$ were apparent in 3-a-side ($5 \pm 8\%$) compared to 4- ($13 \pm 17\%$) and 5-a-side games ($15 \pm 25\%$). Similar to our findings, young (<13 years of age) female and male handball outfield players experienced comparable mean HR responses during 15-min 4-, 5-, and 6-a-side games on a medium-size court (30 m x 20 m), as well as 15-min 5- and 6-a-side games on a full-size court (40 m x 20 m) [32]. In contrast, Bělka et al. [33] reported an inverse trend between HR responses and team size during sub-elite handball games, noting a significantly higher mean HR in 3-a-side ($87.9 \pm 4.8\%HR_{\max}$) than 4-a-side ($84.6 \pm 6.3\%HR_{\max}$) and 5-a-side game formats ($80.4 \pm 7.4\%HR_{\max}$) during 4-min handball games in outfield players. More opportunity for HR recovery in larger teams due to less player engagement likely contributed to these findings [33], and may also explain the *moderately* greater playing time spent working at $<70\%HR_{\max}$ in larger teams we observed. However, we reported a lower HR response ($84.8\%HR_{\max}$ and $81.7\%HR_{\max}$) with smaller team sizes (3- and 4-a-side) across 40-min handball games than the responses recorded by Bělka et al. [33] across 4-min games. While discrepancy across studies may relate to various factors including coach encouragement during games and the competitive level of the subjects (sub-elite vs. recreational), the factor likely explaining the differences across studies was the shorter game durations. In this regard, greater anaerobic and aerobic conditioning and shorter game durations [34, 35] in the sub-elite players examined by Belka et al. [33] likely promoted higher HR responses than we observed. In addition, longer playing durations may have encouraged players to modulate their effort according to a subconscious strategy eliciting behavioural changes to limit physical exertion (pacing) and avoid unsustainable elevations in physiological responses [36].

In addition to high cardiovascular strain, BLa data reflected an important glycolytic energy contribution, with mean responses ranging from 3.9 to $4.4 \text{ mmol}\cdot\text{L}^{-1}$ during the handball games. In turn, non-significant, *unclear* differences in BLa were evident between game formats. Although no research has explored BLa with varying team sizes in handball players, our results concur with those observed during 6-a-side recreational handball in untrained outfield players ($3.6 \text{ mmol}\cdot\text{L}^{-1}$) [8]. BLa observed across game formats indicates that recreational handball games consisting of 3–5 outfield players per team similarly stress the rapid glycolytic metabolic pathway. The frequent bursts of high-intensity accelerations, decelerations, and running likely promoted spikes in lactate concentration, but concomitant periods at lower intensities likely allowed oxidation of lactate in body tissues, keeping mean responses somewhat close to concentrations typical of the lactate threshold.

Despite the lack of physiological differences between game formats, subjects reported 3-a-side ($5.3 \pm 0.9 \text{ AU}$, *large*) and 4-a-side

(5.4 ± 2.4 AU, *moderate*) game formats to be more demanding than 5-a-side games (3.9 ± 1.2 AU) measured with RPE. This finding, although non-significant, concurs with research examining sub-elite players using a 6–20 RPE scale (3-a-side: 17.7 ± 1.5 AU; 4-a-side: 14.6 ± 1.5 AU; 5-a-side: 12.3 ± 1.2 AU) [33]. However, in opposition to our findings, these previous data were accompanied by greater HR and total activity demands during games with smaller team sizes [33]. Our results revealed *small* increases in frequency of high-intensity accelerations in 3-a-side compared to 5-a-side, which might partly underpin the higher perceived effort, considering that comparable physiological and total activity demands were encountered across game formats. In this context, Gaudino et al. [37] and Tang et al. [38] observed that the intermittent demands encountered are significant contributors to RPE in soccer players. In addition, individual effort likely decreases with increasing team size due to the well-established psychological phenomenon of social loafing, in which a person exerts less effort to achieve a goal as the number of individuals working towards the goal increases [39].

While modifying team sizes affected the perceptual responses of outfield players during handball games in our study, the activity demands encountered were less impacted. More precisely, differences in distance data between game formats were non-significant and *unclear*. Our results concur with previous investigations reporting comparable activity demands between game formats in young, outfield handball players [32]. In contrast to our findings, Bělka et al. [33] reported that significantly greater total and high-intensity distances (working at 12.2 – 18.7 $\text{km}\cdot\text{h}^{-1}$) were covered during 3-a-side compared to 4- (9% and 16%) and 5-a-side games (9% and 36%) in sub-elite, outfield handball players. It has been suggested that a smaller area per player accompanying larger team sizes promotes less space to travel, particularly at higher intensities (>13 $\text{km}\cdot\text{h}^{-1}$), in team sports [40]. However, comparisons between studies showed that greater relative distances were covered in sub-elite players during various game formats (119 – 130 $\text{m}\cdot\text{min}^{-1}$) [33] compared to less-trained, young handball players (66 – 86 $\text{m}\cdot\text{min}^{-1}$) [32] and the recreational players recruited in the present study (80 – 84 $\text{m}\cdot\text{min}^{-1}$). These variations in findings may be underpinned by the competitive sub-elite players examined by Bělka et al. [33] being able to better maintain consistent work rates due to possessing a more extensive training history and participating in shorter games than used in other studies (4 min vs. 15–40 min).

Given that the distance covered during handball games was predominantly at low (0 – 12 $\text{km}\cdot\text{h}^{-1}$ = 81–83%) and moderate (12 – 18 $\text{km}\cdot\text{h}^{-1}$ = 10–12%) intensities, specific actions such as accelerations, decelerations, dribbles, duels, upper-body contacts, and collisions likely exert an important influence on the overall physical load encountered during recreational handball games. In this regard, a high frequency of accelerations and decelerations, particularly at medium intensities, was observed across game formats in our study (Figure 6). Comparisons between game formats showed that the overall acceleration and deceleration demands were similar with

different team sizes; however, further analyses according to intensity zones revealed *small* differences, whereby 5-a-side games required players to perform more accelerating and decelerating at low intensities than 3-a-side, while 3-a-side games promoted more high-intensity accelerations and decelerations than 5-a-side games. Given that the court size was identical across game formats in our study, a greater area per player during games with smaller team sizes may predispose to frequent transitions up and down the court [40], creating more high-intensity accelerations and open shot opportunities. In contrast, defensive structures adopted in games with larger team sizes likely impose more low-intensity accelerations and decelerations due to restricted space promoting more contacts with other players, as well as heightened sideways movements. Nevertheless, the comparable overall intermittent physical demands encountered across handball game formats may be important for musculoskeletal fitness given the dynamic strain placed on bones and lower-limb musculature [41]. Therefore, each game format might be an effective form of training for developing musculoskeletal fitness.

Although this study provides useful insight regarding the potential prescription of recreational handball for health benefits, some limitations should be acknowledged. First, BLa and RPE were measured only at the end of exercise, making it difficult to quantify fatigue responses across halves and post-competition recovery from the current data. Second, shuffling movements, sideways running, and physical contacts were not quantified and are likely frequently performed during handball games. Moreover, findings from this study cannot be transferred to elite handball players or individuals unaccustomed to handball due to the sample-specific response; therefore the demands of different handball game formats in other populations warrant further investigation. Future research should incorporate the use of additional technologies such as time-motion analysis to provide these data, given that these activities have been suggested to exacerbate player demands [18, 42].

CONCLUSIONS

Modifying player number has a negligible effect on the physiological and activity demands encountered during recreational handball games. Recreational handball consisting of 3–5 players per team imposes similar intermittent workloads, resulting in vigorous physiological responses. In contrast, the perceptual response showed that 3- and 4-a-side game formats were more demanding compared to 5-a-side games.

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