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Original paper

Cardiorespiratory responses during running and sport-specific exercises in handball players

M. Buchheit [a,*], P.M. Lepretre [b], A.L. Behaegel [c], G.P. Millet [d], G. Cuvelier [c], S. Ahmaidi [a]

[a] *Laboratoire de Recherche, EA 3300 (APS et conduites motrices: Adaptations Réadaptations), Faculté des Sciences du Sport d'Amiens, Université de Picardie Jules Verne, Allée P. Grousset, 80025 Amiens Cedex 1, France*
[b] *Laboratoire de Biomécanique et Physiologie, Institut National du Sport et de l'Education Physique, France*
[c] *Laboratoire d'étude du mouvement et de la performance, Section kinésithérapie, Haute Ecole Provinciale du Hainaut Occidental, Belgium*
[d] *Aspire, Academy for Sports Excellence, Qatar*

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Abstract

To determine whether a 4-a-side handball (HB) game is an appropriate aerobic stimulus to reach and potentially enhance maximal oxygen uptake ($\dot{V}O_2$max), and whether heart rate (HR) is a valid index of $\dot{V}O_2$ during a handball game. Nine skilled players (21.0 ± 2.9 yr) underwent a graded maximal aerobic test (GT) where $\dot{V}O_2$max and HR $-$ $\dot{V}O_2$ relationship were determined. $\dot{V}O_2$, HR and blood lactate ($[La]_b$) were recorded during a 2×225 s (interspersed with 30 s rest) 4-a-side handball game and were compared to those measured during an 480-s running intermittent exercise (IE). Mean $\dot{V}O_2$ tended to be higher in handball compared to IE (93.9 ± 8.5 vs. 87.6 ± 7.4% O_2max, $p = 0.06$), whereas HR was similar (92.3 ± 4.9 vs. 93.9 ± 3.9% of the peak of HR, $p = 0.10$). $[La]_b$ was lower for handball than for IE (8.9 ± 3.5 vs. 11.6 ± 2.1 mmol l^{-1}, $p = 0.04$). Time spent over 90% of $\dot{V}O_2$max was higher for handball than for IE (336.1 ± 139.6 s vs. 216.1 ± 124.7 s; $p = 0.03$). The HR $-$ $\dot{V}O_2$ relationship during GT was high ($r^2 = 0.96$, $p < 0.001$) but estimated $\dot{V}O_2$ from HR was lower to that measured ($p = 0.03$) in handball, whereas there was no difference in IE. 4-a-side handball game can be used as a specific alternative to IE for enhancing aerobic fitness in handball players. Nevertheless, the accuracy of HR measures for estimating $\dot{V}O_2$ during handball is poor.

Keywords: Handball; Intermittent exercise; Maximal oxygen uptake; Heart rate; Specific aerobic training

Introduction

Although technical skills, anthropometric characteristics and muscle strength and power are the most important factors for successful participation in elite levels of handball (HB) leagues,[1,2] the importance of aerobic capacity should not be underestimated. Indeed, during a match play, players run about 4–6 km[3] at a mean intensity close to 80–90% of maximal heart rate.[4] Significant associations between maximal oxygen uptake ($\dot{V}O_2$max) and playing level have also been shown.[1,2]

To enhance aerobic fitness, it has been suggested that training at or near $\dot{V}O_2$max may be effective[5–7] or even necessary in well-trained runners.[6] Although there is currently little evidence that high intensity intermittent exercise (IE) may be more effective in improving aerobic component than lower exercise intensities, recent results have shown that running IE may induce greater improvement of maximal aerobic capacity and endurance performance than moderate continuous exercise (85% of maximal heart rate, HR).[8] Nevertheless, since running is not usually the favourite activity of HB players, and because maintaining technical skills is determinant, HB-specific training has emerged as an alternative means for improving players' aerobic capacity while maximising training time with the ball.[3] However, it is not known whether HB-specific training fulfils the criterion of effective intermittent training to improve $\dot{V}O_2$max, namely an exercise intensity higher than 90% of $\dot{V}O_2$peak for a duration of at least three minutes.[6,7] Moreover, in contrast to IE, it is not easy to precisely control the intensity of small HB game. Individualizing IE intensity is generally performed by using

* Corresponding author.
E-mail address: martin.buchheit@u-picardie.fr (M. Buchheit).

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a reference speed ($v\dot{V}O_2$max)[5,7,9,10] but recent findings support that an intermittently determined reference speed (i.e. the speed reached at the end of the 30–15 Intermittent Fitness Test, V_{IFT}) is a relevant alternative in team sports.[11] Despite that HR is the only physiological parameter recordable during field session, it is not known whether HR accurately reflects $\dot{V}O_2$ demands during HB games and the validity of prescribing HB intensities with HR is unknown.

The first purpose of the present study was thus to determine whether 4-a-side HB-specific aerobic exercise is an appropriate alternative to IE to stimulate the aerobic system at high intensity. The second aim was to assess whether HR is a valid index of $\dot{V}O_2$ level during HB and whether it could be used for assessing and adjusting small game HB intensity.

Methods

Nine skilled national level handball players (mean (95% CI) 21.0 (18.1; 21.9) yr, 181.0 (178.0; 184.0) cm and 78.4 (72.6; 84.2) kg, 20.4 (18.2; 22.5) kg total muscle mass, training 5.1 (4.4; 5.8) h wk^{-1}) took part in the study. Muscle mass was estimated with a multi-frequency impedance-meter (Aminostat Bio Zm, Aminogram, La Ciotat, France). Before the study, each participant signed an informed consent form in accordance with the Declaration of Helsinki.

Players performed five tests at the same time of day (±1 h): explosive power of lower limbs tests, a graded maximal test,[12] the 30–15 Intermittent Fitness Test (30–15$_{IFT}$),[11] HB games and IE. Each test was separated by at least 48 h and was performed in similar environmental condition. All tests were preceded by a standardized 15-min warm-up[9] and specific handball conditioning. At the end of all the tests, participants, who were familiar with that procedure, indicated their rating of perceived exertion (RPE) by pointing to the number that corresponded with their perception of effort, based on the 0–10 Borg scale.[13]

Lower limb explosive power was assessed as previously described[11] by (1) a vertical countermovement jump height (CMJ; cm) measured by an Optojump (Ergojump, Globus Italia, Codogne, Italy), and (2) a 10-m standing-start run (10 m; s) recorded with photoelectric cells (Wireless Timing-Radio Controlled, Brower Timing System, Colorado, USA).

Players performed a graded test (GT) on an indoor track (initial speed of 10 km h^{-1} increased by 0.5 km h^{-1} per 1-min stage).[12] Respiratory gas exchanges and HR were measured using an automated breath-by-breath system (K4b^2, Cosmed, Rome, Italy). Before each test, the O_2 and CO_2 analysis systems were calibrated as recommended by the manufacturer. Data were filtered and averaged on 5-s basis. Maximal oxygen uptake ($\dot{V}O_2$max) was arbitrary defined as the highest $\dot{V}O_2$ values attained in two consecutive 20-s periods (obtained from four averaged 5-s data). A HR peak attained next to maximal predicted value, a [La]$_b$ higher than 8 mmol l^{-1} and respiratory exchange ratio (RER) > 1.1 were additionally required to confirm the maximal nature of the test. The velocity associated with $\dot{V}O_2$max ($v\dot{V}O_2$max) was the lowest running speed which elicited a $\dot{V}O_2$ value equal to $\dot{V}O_2$max.[14] [La]$_b$ were measured three min after the end of the exercise (see below for details).

Players also performed the 30–15 Intermittent Fitness Test (30–15$_{IFT}$), an intermittent and shuttle incremental field test shown to be accurate for individualizing intermittent and shuttle running exercise.[11] The 30–15$_{IFT}$ consists of 30-s shuttle runs interspersed with 15-s passive recovery periods. The velocity attained during the last completed stage was determined as the player's V_{IFT}. Only HR was recorded during 30–15$_{IFT}$.

Small group HB play was organised as 4-a-side, excluding goalkeepers. Two consecutive 225 s playing periods were carried out, separated by 30 s of passive rest to reach similar total exercise duration than IE (8 min). Coaches encouraged the players to achieve an intensity as high as possible during small games.[15,16] Moreover, usual HB rules were simplified to avoid game interruption and increase exercise load: dribbling and defence contacts were not allowed, infringements of minor technical rules (i.e. 'walking', 'double dribble') were not sanctioned, throw-on after a goal was immediately made by the goalkeepers from their 6-m area, and the investigator was always available to immediately replace the ball when it was thrown out from the playing area. Finally, all four players had to be in the opponent half court for the goal to be validated. Respiratory gas exchanges, HR and [La]$_b$ were measured as for GT. Peak oxygen uptake (HB $\dot{V}O_2$peak) was defined as the highest $\dot{V}O_2$ attained in one 20-s period. The time spent above 90% of $\dot{V}O_2$max (t90% $\dot{V}O_2$max) and HR peak (t90% HRpeak) was calculated using the 5-s averaged data. Three distinct small HB games were necessary to record cardiorespiratory responses of the nine athletes.

The on-field displacements of the players were recorded by a video camera (HDV HVR-Z1E, Sony, Japan). Players' motions and total distance covered were analysed by two experienced operators. Using a HB court picture (scale 1/160, Adobe Photoshop 6.0, as presented in Fig. A in Supplement file), player's distance covered was estimated via automatic mouse tracking (MousotronPro, Blacksunsoftware, Turnhout, Belgium). Results from both operators were averaged. The difference in the values determined by the two assessors was <30 m (<3%).

Players finally performed an 8-min shuttle IE consisting in 15 s effort interspersed with 15 s of passive recovery. Such intermittent protocol with passive recovery has been shown to enable athletes to reach $\dot{V}O_2$max.[9,17] Exercise intensity (controlled by the intermittent running distance), was set at 95% of the V_{IFT}, which corresponds to ≈120% of $v\dot{V}O_2$max but additionally take into account players' ability to change direction and to recover between exercise bouts.[11] During the 15-s exercise period, athletes were required to run back and forth over a 40 m area so that they covered the distance determined according to their V_{IFT}. Respiratory gas exchanges, HR and [La]$_b$ were measured as for GT. IE $\dot{V}O_2$peak, IE

t90% $\dot{V}O_2$max and IE t90% HRpeak was defined as for HB game.

Three minutes after the end of each exercise set, a fingertip blood sample (5 μl) was collected and $[La]_b$ was determined (Lactate Pro, Arkray Inc, Japan).[18]

The energy contribution to each exercise bout, as well as the total aerobic/anaerobic energy contribution and the net energy expenditure during exercise were calculated from measured oxygen and/or oxygen equivalents of PCr and lactate.[18]

Post-exercise HR recovery was assessed during the 10-min recovery period immediately following each exercise (S810, Polar Electro, Kempele, Finland), while players remained seated. The post-exercise HR recovery time constant (HRRτ) was then produced by modelling the resultant 10-min of beat-to-beat HR data using an iterative technique (Sigmaplot 10, SPSS Science; Chicago, IL, USA).[18]

Statistical analysis

Statistical analyses were carried out using Minitab 14.1 Software (Minitab Inc., Paris, France) and data is presented as means and 95% confidence intervals. As data were normally distributed and displayed similar variance, paired T-tests (8 degrees of freedom) were used to compare $\dot{V}O_2$, HR, RPE data and distance covered between HB and IE. Pearson's correlation coefficients were also determined to assess relationships between variables. A one-way (game) ANOVA with Tukey's post-hoc test was applied to check eventual differences in overall activity (i.e. number of ball possession, distance covered, etc.) between the three small HB games. Significance was set at $p < 0.05$.

Results

Mean height for CMJ was 46.9 (42.4; 51.4) cm. Sprint 10-m times were 1.90 (1.89; 1.90) s. Mean values for $\dot{V}O_2$max, HR peak, $v\dot{V}O_2$max, $[La]_b$ and RPE during GT were 57.3 (52.6; 62.0) ml min^{-1} kg^{-1}, 190 (182; 199) bpm, 15.7 (14.9; 16.5) km h^{-1}, 9.3 (8.0; 10.6) mmol l^{-1} and 6.6 (5.8; 7.4) respectively. Mean V_{IFT} was 19.7 (19.1; 20.3) km h^{-1}. Peak HR during the 30–15$_{IFT}$ was 194 (187; 201) bpm, which was not significantly different to GT peak HR ($p = 0.133$, $t = -1.67$). As expected, 95% of V_{IFT} corresponded to 119.4 [118.6; 120.2]% of $v\dot{V}O_2$max.

During HB games, mean individual ball possessions, shoots, goals, interceptions, technical faults and total distance covered (see Fig. A in Supplemental file) were similar for the three small HB game sessions ($p > 0.05$ for all elements).

Cardiorespiratory responses, aerobic and anaerobic contributions and total covered distance observed for HB and IE exercises are presented in Table 1. Absolute $\dot{V}O_2$peak and mean $\dot{V}O_2$ were similar in HB and IE (see illustration of $\dot{V}O_2$ responses of a representative player in Supplemental file, Fig.

Table 1
Data measured during specific handball exercise and high intensity intermittent exercise

	$\dot{V}O_2$peak (ml min^{-1} kg^{-1})	Mean $\dot{V}O_2$ (ml min^{-1} kg^{-1})	HR peak (bpm)	Mean HR (bpm)	$[La]_b$ (mmol l^{-1})	Aerobic energy (%)	Anaerobic energy (%)	RPE	Distance covered (m)
HB	60.2 (57.6; 62.8)	53.3 (51.1; 55.5)	187 (180; 194)	175 (170; 181)	8.9 (6.6; 11.2)	92.4 (90.9; 93.9)	7.6 (6.1; 9.1)	6.3 (6.0; 6.6)	1233 (1159; 1309)
IE	56.4 (51.2; 61.6)	50.1 (45.4; 54.8)	189 (184; 194)	179 (173; 184)	11.6 (10.2; 13.0)*	90.4 (89.7; 91.1)*	9.6 (8.9; 10.3)*	6.6 (6.3; 6.9)	1183 (1148; 1217)
HB – IE difference	3.8 (−1.4; 8.9)	3.2 (−1.4; 7.8)	−2 (−8; 4)	−3 (−9; 2)	−2.6 (−6.2; 1.0)	2.1 (0.3; 3.9)	−2.1 (−3.9; 0.2)	−0.3 (−2.9; 1.5)	52 (−113; 11)

Mean (95% CI) peak oxygen consumption ($\dot{V}O_2$peak), mean $\dot{V}O_2$, peak heart rate (HRpeak), mean HR, blood lactate ($[La]_b$), percentage of aerobic and anaerobic contribution, rate of perceived exertion (RPE), total distance covered during small side-HB games (HB) and high intensity intermittent runs (IE).
* Significant difference between the two exercises ($p < 0.05$).

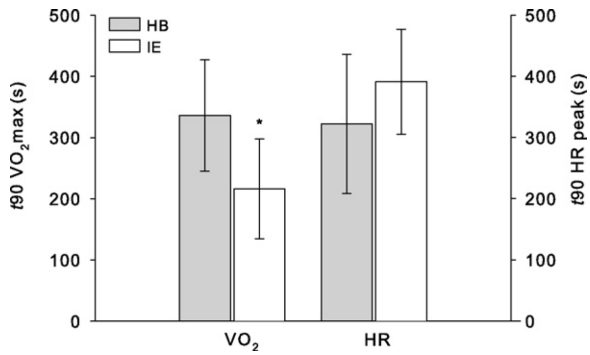

Figure 1. Mean (95% CI) time spent above 90% of maximal oxygen uptake ($t90\dot{V}O_2$max) and above 90% of maximal heart rate (t90HR peak). *Significant difference between small HB game and IE exercise.

B). Expressed as a percentage of $\dot{V}O_2$max, HB $\dot{V}O_2$peak was significantly higher than IE $\dot{V}O_2$peak (106.0 [100.3; 111.7]% vs. 98.7 [93.5; 103.9]%, $p=0.05$ and $t=-1.86$). Mean $\dot{V}O_2$ tended to be higher in HB than in IE (93.9 [88.2; 99.6]% vs. 87.6 [82.7; 92.5]%, $p=0.06$ and $t=-1.79$). However, $\dot{V}O_2$peak during HB was significantly higher than $\dot{V}O_2$max ($p=0.01$ and $t=2.52$), whereas there was no difference between IE $\dot{V}O_2$peak and $\dot{V}O_2$max ($p=0.31$ and $t=-0.51$). HR peak was similar for GT, HB and IE. Mean HR and RPE were similar for the HB and IE ($p=0.11$, $t=1.34$ and $p=0.29$, $t=0.72$ for HR and RPE). Expressed in relative value, mean HRs were equivalent in both exercise too (92.3 [89.0; 95.6]% vs. 93.9 [91.3; 96.5]% HR peak in HB and IE respectively; $p=0.10$ $t=1.38$). $[La]_b$ and percentage of anaerobic participation were significantly higher in IE compared to HB ($p=0.03$ $t=2.12$ and $p=0.02$ $t=2.64$). Total net exercise cost was not different in both exercises (144 [95.3; 192.7] kcal vs. 137 [89.7; 184.3] kcal for HB vs. IE respectively; $p=0.17$ and $t=-1.01$). Fig. 1 shows that $t90\dot{V}O_2$max was significantly higher for HB than for IE (336.1 [243.0; 429.2] s vs. 216.1 [133.0; 299.2] s; $p=0.03$ and $t=-2.19$), whereas t90HRpeak was not significantly different (322.2 [205.9; 438.5] s vs. 391.1 [303.4; 478.8] s for HB and IE, respectively; $p=0.15$ and $t=1.11$). In other words, players spent 70.0 [50.6; 89.4]% vs. 45.0 [27.7; 62.3]% of total exercise time above 90% of $\dot{V}O_2$max ($p=0.03$ and $t=-2.20$) and 67.1 [42.8; 91.4]% vs. 81.5 [63.2; 99.8]% above 90% of HR peak ($p=0.15$ and $t=1.10$) for HB and IE, respectively. Finally, HRRτ was significantly shorter for HB than for IE (51.0 [48.7; 53.3] s ($r=0.98$ [0.97; 0.99]) vs. 59.4 [56.7; 62.1] s ($r=0.98$ [0.97; 0.99]), $p=0.04$ and $t=-1.92$).

Fig. 2 presents the relation between $\dot{V}O_2$max measured during GT and its percentage sustained during HB exercise. %$\dot{V}O_2$max and $t90\dot{V}O_2$max were negatively related to $\dot{V}O_2$max during HB ($r^2=0.77$, $p<0.05$, and $r^2=0.76$, $p<0.001$), but not during IE ($r^2=0.07$, $p=0.49$ and $r^2=0.03$, $p=0.61$). $t90\dot{V}O_2$max was negatively related to V_{IFT} ($r^2=0.43$, $p=0.05$); whereas the relationship was not significant for $v\dot{V}O_2$max ($r^2=0.28$, $p=0.14$). A significant negative relationship was found between CMJ and total

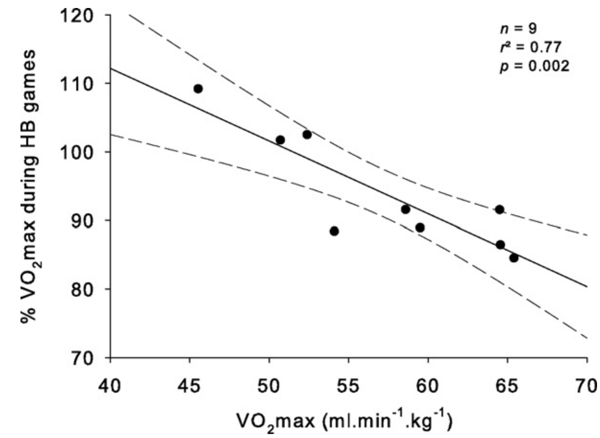

Figure 2. Relationship between cardiorespiratory fitness (maximal oxygen uptake, $\dot{V}O_2$) and mean %$\dot{V}O_2$max during small HB games. Shaded lines represent 95% confidence intervals.

distance covered during HB ($r^2=0.61$, $p=0.01$). No other physiological quality (i.e. 10 m sprint time, V_{IFT}, $v\dot{V}O_2$max or $\dot{V}O_2$max) was related to total covered distance. There was no relationship between playing efficiency (i.e. shoots, goals, etc.) and total covered distance or any physiological quality.

The HR − $\dot{V}O_2$ relationship was very good for GT ($r^2=0.96$ [0.95; 0.97], $p<0.001$ for every player), whereas it was significant but moderate for HB and IE exercise, respectively ($r^2=0.63$ [0.62; 0.64] and 0.58 [0.56; 0.60], $p<0.001$). Mean results for the slope and y-intercept were 0.51 (0.46; 0.56) and −40.48 (−47.77; −33.19), 0.47 (0.34; 0.60) and −28.82 (−51.43; −6.21), and 0.47 (0.26; 0.68) and −31.86 (−65.99; 2.27) for GT, HB and IE, respectively. Fig. 3 illustrates that $\dot{V}O_2$ estimated from HR was lower than measured $\dot{V}O_2$ for HB ($p=0.03$ and $t=-2.11$), whereas there was not significant difference for IE ($p=0.29$ and $t=0.76$). The Bland and Altman plot of measured versus estimated $\dot{V}O_2$ for HB and IE are shown in Fig. 4. Although almost all differences remained into the confidence interval, it reveals individual differences as large as 8.7 and 11.6 ml min^{-1} kg^{-1} for HB and

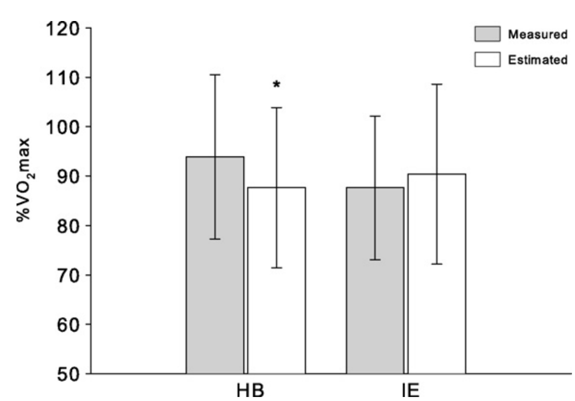

Figure 3. Mean (95% CI) measured and estimated oxygen consumption (from the HR/$\dot{V}O_2$ relationship during the graded aerobic test) observed during HB games and IE exercise, expressed as a percentage of maximal oxygen consumption ($\dot{V}O_2$max). *Significant difference between measured and estimated values.

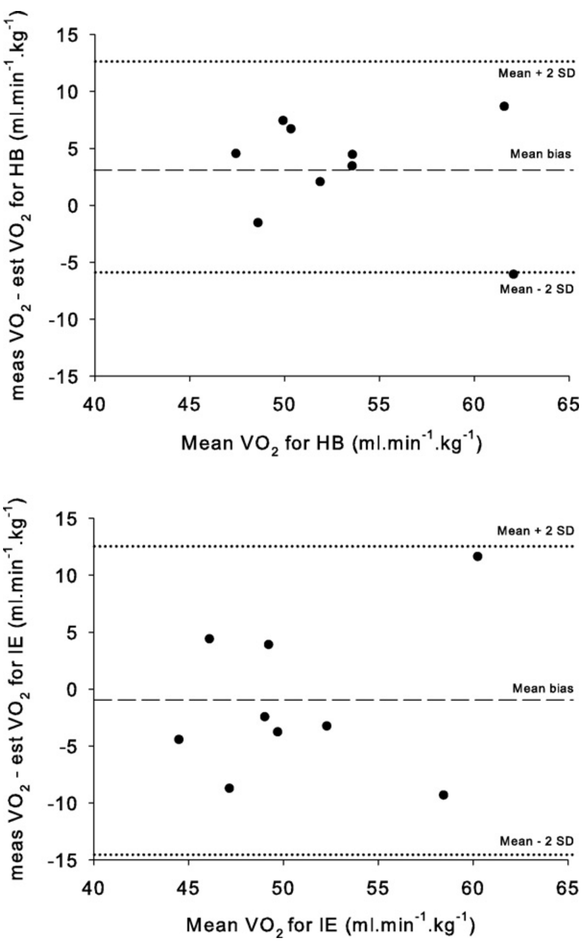

Figure 4. Bland and Altman plot of difference between measured (meas $\dot{V}O_2$) and estimated $\dot{V}O_2$ (est $\dot{V}O_2$) during HB games (upper plot) and IE exercise (lower plot) ($r^2 = 0.52$, $p = 0.03$ for HB and $r^2 = 0.19$, $p = 0.23$ for IE).

IE, respectively. Estimated and measured $\dot{V}O_2$ were moderately correlated for HB ($r^2 = 0.52$, $p = 0.03$) but not for IE ($r^2 = 0.19$, $p = 0.23$).

Discussion

This study determined whether a 4-a-side handball-specific aerobic exercise can solicit the aerobic system at high intensity, and whether using HR alone can assess the cardiorespiratory level during HB exercise. Specially designed handball-specific games were effective enough for reaching high percentage of $\dot{V}O_2$max. However, estimating $\dot{V}O_2$ and exercise intensity from HRs during small HB games was not highly accurate.

In our study, a level of 94% $\dot{V}O_2$max was achieved during HB exercise, which is higher than that observed in soccer or basketball. Playing 5-a-side led elite soccer players to reach 85% of $\dot{V}O_2$max[15] and recreational young players 75%.[19] In basketball, an activity closer to handball, mean $\dot{V}O_2$ ranged between 69 and 79% of its maximal value (from 4 games vs. 4 games to 2 games vs. 2 games).[20] The higher muscular mass engaged in HB due to upper limbs activity, when compared to soccer, and the higher running distances, when compared to basket ball, could explain partly these results. Other explanations may be related to playing rules, small games duration, field size, the number of players in a team and participants fitness levels and motivation as detailed recently.[16] Another interesting finding is that HB $\dot{V}O_2$peak was significantly higher than $\dot{V}O_2$max determined during the GT (about 3 ml min^{-1} kg^{-1}). This suggests that $\dot{V}O_2$max values derived from usual running maximal graded test is not relevant for an accurate estimate of maximal cardiorespiratory fitness in handball players. The specific handball patterns (i.e. accelerations, decelerations, jumps, changeovers as well as upper arm involvement when passing or shooting) are widely different to running. As suggested in tennis,[21] during small HB games muscles were recruited at higher rate than during the GT, which may have increased $\dot{V}O_2$peak. The higher values reached in the HB game may also be the result of greater motivation when players played with the ball.

Concerning the time for which high intensity (>90% $\dot{V}O_2$max) was sustained, we are not aware of any data of comparison in small game play. During high IE, $t90\dot{V}O_2$max has been reported to vary with exercise protocol from 48 s[9] to 14 min 31 s[22] for 15 s −15 s intermittent runs; the higher $t90\dot{V}O_2$max being obtained for exercises with work and recovery intensities of 100 and 70% of $v\dot{V}O_2$max, respectively.[22] In the present study, $t90\dot{V}O_2$max for HB games was significantly higher than for IE (Fig. 1) and corresponded to 70% of total exercise time. During 4-a-side-HB games, even if work intensity is variable (e.g. accelerations, sprints, shoots, replacement at low pace), there is no complete resting period and thus exercise can be compared to an intermittent exercise with active recovery and reduced amplitude. This prevents the $\dot{V}O_2$ to decrease between motion sequences and results in accelerated $\dot{V}O_2$ kinetics at the onset of each work interval, inducing overall a higher $\dot{V}O_2$. This type of 'active recovery' at light-to-moderate intensities, known to facilitate lactate disposal,[23] might also explain the lower blood lactate levels observed for HB games.

Presents results suggest that HB game represents a time-efficient stimulus and that it could be a good alternative to IE for improving aerobic fitness. These findings are in accordance with a recent longitudinal study in soccer, which showed that small-sided games were as effective as IE in enhancing aerobic fitness in junior players.[24] We also believe that during the season HB game might be preferred to IE, especially when coaches' priorities are to maintain a high level of aerobic solicitation while avoiding excessive neuromuscular constraint. Indeed, present results show that compared to IE, playing HB game is associated with lower $[La]_b$, and on the basis of shorter HR recovery time constant, it can be also hypothesized that HB is associated with lesser system stress metabolite accumulation (i.e. noradrenaline).[25]

The fact that players with the highest $\dot{V}O_2$max had the lowest mean $\dot{V}O_2$ and $t90\dot{V}O_2$max during small HB group play indicates that the playing situation designed for this experiment may have a ceiling effect for developing aerobic endurance in these individuals[15] (Fig. 2). In order to increase the cardiorespiratory demand of small HB game in the fittest players, we would invite coaches to add specific rules (i.e. additional jumps or accelerations after each ball possession). Finally, the significant negative relationship between total covered distance and CMJ (see Fig. B in Supplemental file) suggests that players with the lowest explosive power may compensate this weakness by moving to a larger extent, preserving a wider area of motion, which might give them the opportunity to avoid direct duels with their opponents.

Comparisons of estimated versus measured $\dot{V}O_2$ mean values during HB and IE exercise suggest that HRs may not precisely estimate the true individual aerobic involvement, especially in HB (Figs. 3 and 4). As previously emphasized,[26] $\dot{V}O_2$ estimation in the field from a graded continuous test HR $-$ $\dot{V}O_2$ relationships may only be valid at group level. Previous studies that have shown that HR during non-stationary exercise[27,28] or soccer games[19,29] have a lower predictive ability of the actual aerobic involvement when compared to continuous exercise; especially for high intensity exercise.[28] The reason for such a difference between HB and GT may be attributable to the nature of exercise bouts. Emotional stress (direct contact to opponents players), perceptive concentration (controlling the ball), heat, or other occasional, specific match movements such as backward- or sideward-running, sprinting, jumping or isometric muscular actions may partly explain the different HR $-$ $\dot{V}O_2$ relation observed during small HB games. Further studies should evaluate whether additional tools (i.e. accelerometers, GPS)[30] could improve or correct HR-derived predictions during HB games.

Practical implications

- 4-a-side small HB games can be used as a recreational alternative to IE to optimise the development of cardiorespiratory fitness in handball players.
- Since cardiorespiratory responses during small HB games are inversely related to fitness level, coaches are invited to add specific rules to increase the activity of the fittest players.
- Compared to IE, playing small HB games is associated with a lower anaerobic participation and lesser system stress metabolite accumulation, which encourages its use during competition phases.
- The accuracy of estimating $\dot{V}O_2$ during HB via HR measurement is not highly accurate.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jsams.2007.11.007.

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