Article

The Team Handball Game-Based Performance Test Is Better than the Yo-Yo Intermittent Recovery Test to Measure Match-Related Activities in Female Adult Top-Elite Field Team Handball Players

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Abstract: In team handball, suitable tests determining the match-related physical performance are essential for the planning of optimal physical training regimens. Thus, the aims of the present study were (a) to determine the relationships between the physical and physiological test results from a team handball game-based performance test (GBPT), the Yo-Yo intermittent recovery test, level 1 (Yo-Yo IR1 test) and a separate linear 30-m single sprint performance test (SSPT) in female adult top-elite field team handball players, in order to establish the significance (validity) of tests for measuring relevant elements for team handball match-play; and (b) to compare and evaluate the results from the aforementioned tests for the same players in relation to the different playing positions. Twenty-three female adult top-elite field team handball players from the Danish Premier Female Team Handball League performed the GBPT, the Yo-Yo IR1 test and the 30-m SSPT test on separate days. As main findings, significant correlations between the GBPT and the Yo-Yo IR1 test in about 1/3 of the variables were found, indicating that the Yo-Yo IR1 test is reflecting most of the locomotive match activities in female adult top-elite team handball. However, the Yo-Yo IR1 test results were not correlated to the GBPT in any of the match-related activities in the team handball GBPT that included technical playing actions such as tackles, passes, jumping and shooting during specialized movements in offence and defence. Overall, the results revealed that the GBPT is better than the Yo-Yo IR1 test to evaluate female adult top-elite field team handball players' ability to perform physical match-related activities including both locomotive and technical playing actions executed as during competitive match-play. Similar to the Yo-Yo IR1 test, the 30-m SSPT was not correlated to any of the team handball GBPT activities, which included technical playing actions. These data suggest that the SSPT only to a certain extent can measure the individual sprint capacity of elite team handball players. In addition, unexpectedly no significant differences between the various playing positions were found neither for the GBPT, the SSPT nor the Yo-Yo IR1 test. However, several effects sizes indicated that the lack of positional differences primarily was due to the relatively small sample size in each playing position and the composition of the specific group of players. In conclusion, this study clearly indicated that team handball specific physical performance, as measured by the GBPT, and general physical performance, as measured by the Yo-Yo IR1 test and the 30-m SSPT, are different components. This must be taken in consideration when using physical test results for the planning of optimal physical training regimens in elite team handball.

Keywords: team handball specific physical performance; technical playing actions; oxygen uptake; blood lactate; general physical performance; positional differences

1. Introduction

Playing performance in team handball is determined by the players' technical, tactical, psychological/social and physical characteristics. All these factors are of high importance in team handball and also closely interlinked, making team handball an especially complex type of sport. For example, team handball requires a high level of physical fitness, if elite team handball players should be able to utilize their technical and tactical qualities during an entire match [1,2]. Both the individual playing performance, the team performance (especially tactics and social factors) and external influences (material and environmental conditions) have a significant impact on the on-court match performance [3–5].

Regarding the physical aspects of the sport, elite team handball is a fast and intense game performed by well-trained players, who must be able to perform many different movements such as running, side-cutting, jumping, shooting, changing direction and pace and technical playing actions (e.g., tackles and screenings) with a high degree of physical contact with opponents. During the sixty minutes of match-play (30 min each half), players work intensely for short, intermittent time intervals, while performing walking, running, sprinting, moving forwards and backwards and side-stepping, while at the same time being tackled, grappled and pushed [2].

The physical on-court performance of the players is crucial for the playing performance of the team. Any training schedule for a team handball player should be based on an analysis of the demands of the game to determine what qualities are important for a good performance. This must be compared with a capacity analysis of the individual players, so that their strengths and weaknesses can be identified [6]. This allows the trainer to assess which aspects the training should contain in particular. A capacity analysis is performed by physical testing of the players using suitable tests, which are, as much as possible, directly related to the activity pattern during real team handball match-play. Thus, scientists and coaches constantly seek for the best test methods in order to determine the player's physical performance level and develop an individual physical profile relevant to the game.

Based on previous scientific studies and knowledge about the practical world of sport, testing of the physical performance in team ball sports seems to have been performed mainly by use of general tests that are almost identical for the various team ball sports. This also applies specific to team handball [7–9]. The results of these general tests have, e.g., been used to determine individual physical performance profiles, to evaluate the effects of various kinds of training, to separate players into various performance groups and to determine if the players were ready to return to play after a period of injury. Furthermore, it has been used in the player selection process of top-level teams. Thus, it is absolutely essential to know if the results from general aerobic, anaerobic or strength tests are specifically related to the on-court performance in team handball match-play.

A previous study showed that a highly advanced game-based performance test (GBPT) for team handball was a valid and reliable test to analyse team handball performance (using both physical, physiological and biomechanical variables) under conditions similar to competition match-play [10]. The GBPT was developed according to previous time-motion analysis of elite team handball matches, which has shown that match activities every minute include numerous high-intensity events (accelerations, decelerations and change of directions) and also various team handball specific movements such as passes, throws, blocks, screenings, jumps, claspings, tackles and fast breaks [1,11–13].

In the GBPT, peak oxygen uptake (VO$_2$-peak), blood lactate concentration (BLC), heart rate (HR), sprinting time, time of offensive and defensive actions as well as running intensities time (in offence, defence, fast break and fast retreat), throwing velocity and jump height were measured [10]. The playing intensities during the GBPT were for the same players similar to the intensities during a team handball test game, and identical to the playing intensities found while analysing match performance in Danish elite team handball [1]. Furthermore, when comparing the physical and physiological variables, high correlations were found between the GBPT and the team handball test game. Rating of motivation, exertion and specificity of the GBPT showed that the players were highly

motivated to perform their personals best. Moreover, exertion during the test was very high and close to the exertion of a typical team handball game. Thus, the GBPT was proved to be very well-suited to measure team handball performance and closely reflects the physical performance during real team handball match-play.

In another study, Wagner et al. [14] found that specific anaerobic and aerobic performance factors are pivotal for high-level performance in team handball, and to gain knowledge of these aspects for individual players, it is essential to measure the on-court performance of the players under conditions similar to competition match-play. The GBPT was proved to be appropriate to measure this.

The well-known Yo-Yo tests were developed at the University of Copenhagen in Denmark in the mid-1990s for testing the physical, and more specifically, the locomotive performance of athletes while running back and forth on an indoor or outdoor court. These high recognized tests are applied world-wide and are used both in practical and research contexts. There has been special interest in the Yo-Yo intermittent recovery tests (the Yo-Yo IR tests), since they evaluate the athletes' ability to perform prolonged, intermittent and repeated intense exercise and with that, their potential to recover from intensive exercise. In many sports, for example team ball games like soccer and team handball, the exercise is namely intermittent, and the physical performance is related to the players' ability to repeatedly perform intense exercise throughout the entire game. The reproducibility and the validity of the Yo-Yo IR tests and the physiological response to the tests have been examined intensely [15–18] and especially when related to elite soccer [19–21].

The Yo-Yo IR test may be performed at two different levels with different speed profiles (level 1 and 2). Level 1 (Yo-Yo IR1) starts at lower speed and with the increases in speed being more moderate than for the level 2 test (Yo-Yo IR2). For a trained person, the Yo-Yo IR1 lasts 10–20 min and is mainly focusing on an individual's ability to repeatedly perform intermittent exercise with a high aerobic component towards the end of the test, whereas the Yo-Yo IR2 lasts 5–15 min and aims at evaluating a trained person's ability to perform a repeated intense exercise bout with a high anaerobic energy contribution [15,16]. Both tests evaluate the individual's ability to recover from intense exercise.

Thus, the major difference between the two tests is the degree of activating the anaerobic system. However, the Yo-Yo IR1 test fully stimulates both systems for less trained persons and is therefore normally used to test male non-elite athletes, beginners and female athletes. Level 2 are mostly used to test male elite or sub-elite athletes. In general, the increases in speed in the level 2 version of the test are happening so fast that female athletes with a lower maximum speed compared to male athletes in most cases will reach near their maximum speed level very rapidly and thus experiencing fatigue before achieving their actual potential for performing repeated intense exercise. Consequently, in the present study with female elite team handball players the Yo-Yo intermittent recovery test, level 1 was used. Converted to team handball, it is all about measuring the ability of the players to maintain a high playing pace throughout the entire game, where the players, e.g., repeatedly have to perform fast breaks and fast retreats.

Team handball is characterized by multiple, repeated periods of high-intensity exercise mixed with periods of less activity such as walking and jogging during the whole match of 60 min [11,22]. Thus, it is not surprising that Yo-Yo IR tests often are used as a measure of the physical performance in elite team handball considering the tests consists of repeated exercise bouts at progressively increasing velocities, interspersed with intervals of active recovery and performed until exhaustion. Testing elite soccer players, it was demonstrated that the aerobic loading approached maximal values, at the same time as it imposed a significant stress upon the anaerobic energy system [15].

However, it must be emphasized that the activity pattern of team handball differs much from that of soccer. The number of physical confrontations with opponents and the number of technical playing actions such as tackles, screenings, jumps and shots are considerable higher in team handball. The demands for especially upper body explosive muscular strength are much less in soccer. In fact, studies have shown that although

low-intensity activities (standing still, walking) in, for example, female elite team handball constituted about 75% of mean effective playing time, the players demonstrated a mean relative workload of around 80% of VO_2-max during the periods of effective match-play [11].

This indicates that the number of high-intensity, strength-related technical playing actions had a marked influence on the high HR values and hence on the relative workload without contributing substantially to the total distance covered during match-play. Playing actions such as tackles, offensive breakthroughs, claspings and screenings may result in elevated HR for more extended periods of time (due to elevated HR in the subsequent recovery phase). Thus, using only locomotion match data seems to underestimate the physical demands of elite team handball match-play [1,11]. Consequently, it seems reasonable to believe, that it is decisive in team handball to use a test that is not solely a measure of the locomotive capacity of the players.

Therefore, it is highly relevant and very interesting to examine and compare the results of the advanced and complex GBPT and the more practical Yo-Yo IR test for elite team handball players. The GBPT has been proved to be closely reflecting the physical performance during real team handball match-play [10], which may be due to the fact that it, in contrast to the Yo-Yo IR test, also contains technical playing actions such as tackles, specific movement patterns in offence and defence, multiple changing of directions and jumping and shooting with a ball.

Potential non-significant correlations between various test parameters will mean that the GBPT better reflects competitive match-play in team handball. Revealing significant correlations between most of the test results will mean that for practical purposes it is more appropriate to use the Yo-Yo IR test to examine team handball players ability to perform repeated intense exercise and to recover from this type of exercise. It is important to use physical tests which mimic the demands of competitive team handball match-play as much as possible to be able to use the individual test results among other things to plan optimal physical training for the players. The GBPT is a field test that replicates the physical demands of team handball by incorporating specific locomotive and technical elements of the game. Despite its practical utility, no previous studies have assessed the relationship of the GBPT to the Yo-Yo IR test, which is a test that has a significant popularity both in research and in world of sport practice.

The 30-m single sprint performance test (SSPT) is a general test, which is often used to test elite team handball players' ability to sprint without changes of direction and including a ball. The linear 30-m SSPT was chosen as sprint test in the present study, since it is the most applied sprint test when scientific studies have used general tests to examine the sprint ability of team handball players [23–26]. In addition, it is easy to standardize. Thirty meter is the longest linear distance that team handball players may sprint during match-play (wing players). However, most sprints are of shorter distance and usually performed with changes of direction [1,11]. Consequently, it is relevant to compare this version of a sprint test to the other two tests in the present study.

Moreover, it can also be applicable to investigate the potential differences in test results between the above-stated tests in relation to the different field playing positions (wings players, backcourt players and pivots) to establish the sensibility of the tests, the ability to capture small differences in physical performance between individual players in the various test categories. This study was designed to examine possible relationships between the GBPT including similar movements and intensities as in competition, a 30-m SSPT and the Yo-Yo IR1 test for elite team handball field players.

Thus, the aims of the present study were: (A) To determine the relationships between the physical and physiological test results from the GBPT, the separate linear 30-m SSPT and the Yo-Yo IR1 test (level 1) in female adult top-elite field team handball players in order to establish the significance (validity) of the Yo-Yo IR1 test for measuring relevant elements for team handball match-play. (B) To compare and evaluate the physical and physiological test results from the aforementioned tests, in relation to the different playing positions in female adult top-elite field team handball players. Gaining knowledge about these

aspects may provide insight into the value of more general tests such as the 30-m SSPT and especially the Yo-Yo IR test regarding specifically the latter's ability to measure the effects of relevant physical training and to use the results for planning of optimal physical training regimens in elite team handball.

It was hypothesized that significant relationships between the locomotive test results from the various tests would be found, i.e., when players are performing linear running without ball handling as in fast retreat, 30-m sprint and during the Yo-Yo IR1 test, but that no significant correlations between the GBPT and the Yo-Yo IR1 test and the 30-m SSPT, respectively, regarding technical match-related activities for female adult top-elite field team handball players would be demonstrated in the present study. In addition, that significant differences in test results between the various field playing positions would reveal that the GBPT is a more suitable test to measure differences in all kinds of relevant parameters of individual team handball players, thereby demonstrating a high capability to distinguish differences between individual top-elite field team handball players´ physical performance. Overall, it was hypothesized that the GBPT is better than the Yo-Yo IR1 test to measure both locomotive and technical match-related activities for female adult top-elite field team handball players.

2. Materials and Methods

2.1. Subjects

Twenty-three female subjects (age: 24.6 ± 3.3 years (group means ± SD); body height: 1.75 ± 0.76 m; body mass: 72.4 ± 9.1 kg) volunteered to participate in the present study. They were recruited from three teams of the Danish Premier Female Team Handball League and included ten backcourt players (BP), seven wing players (WP) and six pivots (PV) of whom seventeen were right-handed and six were left-handed players. Since the activity pattern of goalkeepers obviously differ greatly from those of field players, all the subjects were field players.

All participants were adult top-elite team handball players. During the two preceding seasons, 16 players were champions in the Danish Premier Female Team Handball League. In addition, 16 players were playing or have played in the Women´s European Handball Federation Champions League, and 12 players were world-class players and were playing or have played in the European and/or World Championships for their respective national teams, representing multiple nations. All subjects were physically healthy and reported no injuries, infections or cardiopulmonary risk factors during the time of the study. They were all fully informed of all experimental procedures and possible discomforts and risks associated with the study before giving their written informed consent to participate. The study was approved by the Ethics Committee of the University of Salzburg and the Ethics Committee of Copenhagen and Frederiksberg communities. The study was conducted in accordance with recognized ethical standards as described by Harriss et al. [27] and with the principles of the Declaration of Helsinki in sport and exercise research [28].

2.2. Study Design—Testing Procedures

The study was carried out during the beginning of the last part of the preparation phase (i.e., after the summer break) where the players were not involved in any important matches. All testing procedures were performed indoor under thermoneutral conditions in terms of temperature (18–22 °C) and humidity (50–70%). Each club were tested separately, but within the same training week to reduce the impact of seasonal variation on physical performance. Each player was verbally encouraged throughout all tests. The tests were performed on two different days.

On the first testing day, all players from the same club performed the Yo-Yo Intermittent Recovery test, level 1 (Yo-Yo IR1 test) at the start of a normal training session on their home indoor playing court. All of the players had previously performed the Yo-Yo IR1 test. However, before the start of the training session the test leader informed all participants about the test procedures including test objectives and execution of the test. This was

followed by a 30-min individual warm-up without ball handling, where last part was a few repeated runs of the actual test at the lowest speed levels. The Yo-Yo IR1 test was performed in heats with maximum eight players at a time.

On the second testing day, all players performed a linear 30-m sprint performance test and the GBPT on an indoor playing court at the University of Copenhagen in Denmark. Before starting the tests, all players were introduced and familiarized with the testing equipment and procedures of the GBPT by the test leader (theoretical familiarization). To enable optimal test efficiency, they were separated in groups of four players, where one player performed the test, two were used to pass balls during the test, and the fourth player was warming up for the following test.

The individual warm-up consisted of 25 min general and specific warm-up with similar exercises as in training and competition including ball handling. After the warm-up, each player performed two 30-m sprints (the 30-m sprint performance test). After finishing the 30-m sprint, the measuring equipment for the GBPT was attached to the player, and all systems were calibrated and started simultaneously. A period of approximately 20 min passed between the two tests, so the player was most likely fully recovered before starting the GBPT. Thereafter, the player performed a specific warm-up heat in the GBPT (practical familiarization) including the movements of the test conducted only at submaximal intensity before starting the actual GBPT with a total of eight heats.

2.3. The Yo-Yo Intermittent Recovery Test, Level 1 (Yo-Yo IR1 Test)

All the female adult top-elite field team handball players completed the Yo-Yo intermittent recovery test, which was performed as previously described [15]. The Yo-Yo IR tests consist of repeated 2×20-m shuttle runs back and forth between the starting, turning and finishing line at a progressively increased speed until exhaustion controlled by audio signals from a compact-disc player. Between each running bout, the players have a 10-s active recovery period, consisting of 2×5 m of low intensity exercise (decelerating and walking back to the starting line). The players need to stand completely still behind the starting/finishing line each time before starting a new running bout and not make a false start. When the players are not able to maintain the speed twice and have failed to reach the finishing line in time with the bleep or are not able to complete the last running bout at the required speed, the distance covered at that point is recorded. The total distance covered is considered as the test result in which the last running bout that the players is starting to perform has to be fully included. Thus, the last 2×20 m is included in the final test result.

The Yo-Yo IR1 test consists of four running bouts at 10–13 km^{-1} (0–160 m) and another seven runs at 13.5–14 km·h^{-1} (160–440 m), whereafter it continues with stepwise 0.5 km·h^{-1} speed increments after every eight running bouts (i.e., after 760, 1080, 1400, 1720 m, etc.) until exhaustion. The test was performed indoor on a team handball court, marked by cones, having a width of 2 m and a length of 20 m. Another cone placed 5 m behind the finishing line marked the running distance during the active recovery period. In the present study, the total duration of the test for the players was 9–17 min.

A heart rate belt with a wearable sensor (Polar Team Pro sensor, Polar Electro Oy, Kempele, Finland) was placed on each player approximately 15 min before testing. The sensor is equipped with Bluetooth technology that enables continuous data transfer with a range of up to 200 m. This enabled live monitoring of each player during the test on an iPad. The HR was monitored throughout the entire test. Post-hoc HR analyses were performed using Polar Team Pro analytics software on an iPad (Polar Electro Oy, Kempele, Finland).

2.4. The 30-m Single Sprint Performance Test (30-m SSPT)

In the single sprint performance test (SSPT), each player performed a maximal, linear 30-m sprint after a 25-min profound, individual warm-up on an indoor playing court as previously described. The players had to repeat the sprint test twice with at least 4 min of

recovery between tests. The fastest 15-m and 30-m sprint times were considered to be the test results and was used for analysis. Players were encouraged to complete the sprints as fast as they could. Consistent verbal support was given to the players during each sprint. In order to record the time to cover the sprint distance, three light beams/timing gates (Brower Timing System CM L5, Brower, UT, USA) was placed at 0 m, 15 m and 30 m of the testing distance. The test was performed from an individually chosen standing position with the players front foot one meter behind the first timing gate. Players were instructed to adopt a forward lean and start voluntarily. On their own initiation of each sprint, players passed the starting line and through the first timing gate which automatically started time recording. This arrangement allowed the calculation of times needed for two distances.

2.5. The Team Handball Game-Based Performance Test (Team Handball GBPT)

To assess the physical ability of the players to perform team handball specific on-court movements including locomotive activities with the ball, the female top-elite adult top-elite field team handball players completed the game-based performance test (GBPT), which was performed in accordance to a description by Wagner et al. [10,29].

Briefly, all players performed eight heats of team handball specific movements including defence, defence to offence, offence, offence to defence and active recovery (see Figure 1). Since the GBPT was developed according to previous time-motion analysis of elite team handball matches [1,11–13,30], the on-court movements varied in the eight heats reflecting that the activity pattern of team handball players is constantly changing throughout a match (see Table 1). However, standardization of the test was also taking into account.
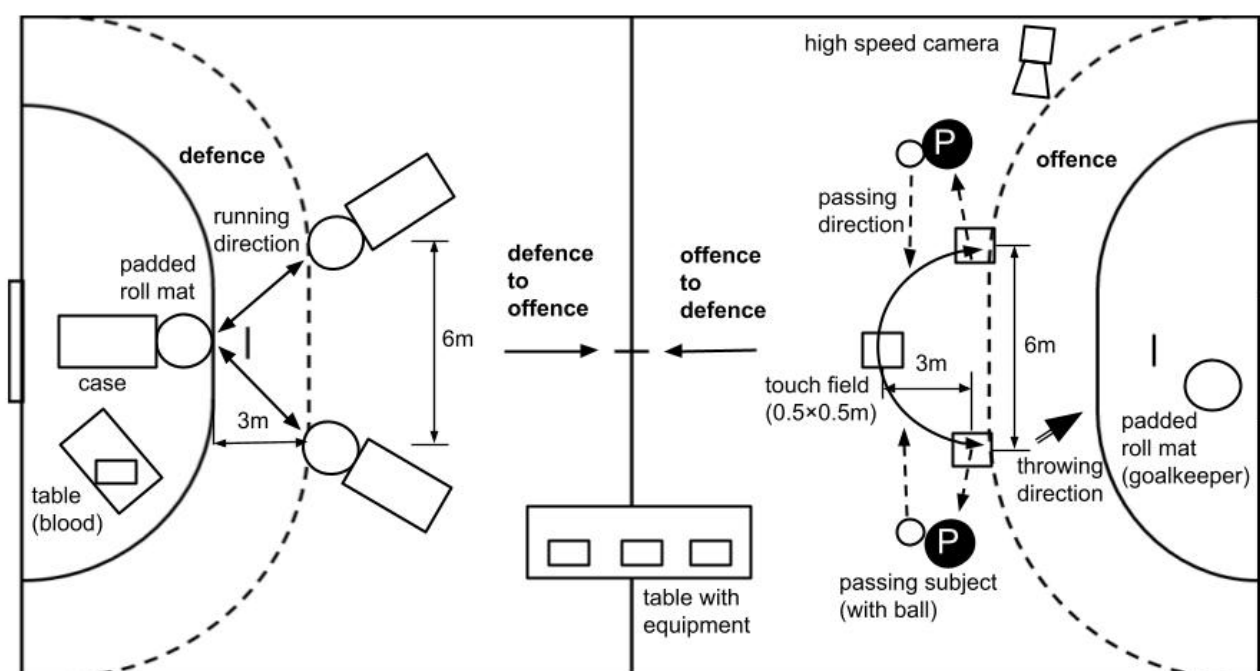

Figure 1. Schematic diagram of the team handball game-based performance test (GBPT) including measuring and testing equipment.

Table 1. Test sequences of the team handball game-based performance test (heat #1–8), including the number of change of directions (COD), tackles, passes, jump shots, sprints (fast break and fast retreat) and duration of breaks, defence to offence, offence to defence, blood lactate measurements and total duration in each heat and the sum of all heats.

	Heat #1	Heat #2	Heat #3	Heat #4	Heat #5	Heat #6	Heat #7	Heat #8	Heat #1–8
Defence #1	3 tackles	3 tackles + screening	3 tackles	3 tackles	3 tackles	3 tackles	3 tackles	3 tackles + screening	
Break (min:s)			00:15	00:15		00:15			00:45
Defence #2			3 tackles + screening	3 tackles		3 tackles + screening			
Defence to offence (min:s)	00:20	00:20	00:20 + fast break	00:20	00:20	00:20 + fast break	00:20	00:20	02:40
Offence #1	5 passes	4 passes + jump shot	5 passes	5 passes	5 passes	5 passes	5 passes	4 passes + jump shot	
Break (min:s)			00:15	00:15		00:15			00:45
Offence #2			4 passes + jump shot	4 passes + jump shot		4 passes + jump shot			
Offence to defence (min:s)	00:20	00:20	00:20	00:20 + fast retreat	00:20	00:20 + fast retreat	00:20	00:20	02:40
Lactate measure	00:40	00:40	00:40	00:40	00:40	00:40	00:40	00:40	05:20
COD	7	7	15	15	7	16	7	7	81
Tackles	3	3	6	6	3	6	3	3	33
Passes	5	4	9	9	5	9	5	4	50
Jump shots	0	1	2	1	0	2	0	1	7
Sprints	0	0	1	1	0	2	0	0	4
Time (min:s)	01:38	01:41	02:29	02:27	01:38	02:29	01:38	01:41	15:41

During defensive actions, players had to tackle padded roll mats on the 6-m and 9-m line with both hands, starting at the 6-m line and finishing at the 9-m line (two times left side, one-time right side for right-handed players, and vice versa for left-handed players). In offence, players had to catch and pass the ball during sprinting between the 9-m line and 12 m, whereas they have to touch the 0.5×0.5-m touching fields on the floor, starting at 12 m and finishing at the 9-m line (two times right side, one-time left side for right-handed players, and vice versa for left-handed players). In five out of eight heats, players had to finish the offensive actions with a jump shot, throwing as fast as possible to the lower left corner of the goal after maximal take-off from the left foot (for the right-handed players, and vice versa for left-handed players). In heat 3 and 6, the players had to sprint from defence to offence, finishing with a jump shot (fast break) and in heat 4 and 6 sprint from offence to defence (running back/fast retreat). Players were instructed to jump and throw as high and as fast as possible and to sprint and move as fast as possible in both defence and offence. They were constantly verbally supported by the test leaders and their teammates to ensure maximal effort throughout the test.

The number of activity changes, changes in directions, shots, passes and tackles were carefully selected based on match analyses in elite male and female team handball [1,11–13,30]. All distances during these actions were standardized by markers on the court or the positions of the padded roll mats (see Figure 1). Pauses (15 s between two defensive or offensive actions, 20 s between offence and defence and vice versa, and 40 s for blood lactate measurement between two heats) were controlled by the Multi-Timer-Ultimate software (Multi-Timer-Ultimate 3.1, Wallroth, Berlin, Germany). These specific actions were selected to simulate the specific physical performance during team handball competition match-play.

During the GBPT, oxygen uptake and HR were measured in each heat using a portable respiratory gas exchange measurement analysis system in breath-by-breath mode (K5, Cosmed, Rome, Italy) and a heart rate belt with a sensor module (Suunto T6d, Suunto, Vantaa, Finland). Since VO_2-max normally are calculated as the mean value of the oxygen uptake measured over at least a 30-s period, the peak oxygen uptake (VO_2-peak) was determined as the peak value of VO_2 instead. This was due to the fact that only short-term (less than 30 s) increases in oxygen uptake occurred during the GBPT. To prevent errors in determination of VO_2-peak, only peak values were used where two breath-by-breath values before and after the peak value were not less than 90%. Blood lactate concentration (BLC) was obtained from the hyperaemic earlobe by an experienced medical laboratory technologist using 20 μL capillary tubes utilizing a fully enzymatic amperometric measurement system (Biosen 5040, EKF Diagnostics, Leipzig, Germany). The maximal values (VO_2-peak, peak HR and BLC) in all heats during the GBPT were calculated and subsequently evaluated.

To determine offence and defence times, a hand stop watch (Hanhart Stratos 2, Hanhart GmbH, Gütenbach, Germany) was used to measure the time between the first and last contact on the padded roll mats (in defence) or touch fields (in offence) as well as for the fast breaks and running back (fast retreats) times. Using a hand stop watch instead of a local positioning measuring system as in previous studies [10,29,31,32] was necessary to be able to perform the test in a sport hall without a local positioning measuring system. However, the mean difference between using a hand stop watch and a local positioning measuring system (Inmotiotec, Abatec, Regau, Austria) has been determined in a previous study to be as small as 0.03 [28]. The mean values of all defence and offence times in all heats were calculated for subsequent analysis and evaluation. Throwing velocity and jump height during the jump throws in the GBPT were measured by calculation of 2D-position of the center of the ball and flight time from high-speed (200 frames per second) video files (JVC-GC-PX100BE, JVC, Yokohama, Japan) utilizing Tracker Video Analysing Software (Tracker 4.59, Douglas Brown, Aptos, CA, USA). The mean values of the best three attempts were used for subsequent analysis and evaluation.

2.6. Statistical Analyses

All statistical analyses were conducted using SPSS ver. 27 (IBM Corp., Armonk, NY, USA) with the level of significance set at $p < 0.05$ for all tests. Mean values $\pm$ standard deviations, range, F-statistics, 95% confidence intervals (95% CI) and statistical power of the variables were calculated for descriptive statistics. Normality of the data were verified by the Shapiro-Wilk test, and normality was found for all used variables. The differences in performance between backcourt players, wing players and pivots were determined utilizing one-way analysis of variance (ANOVA) with Bonferoni post-hoc tests. Effect size (η^2) calculations (eta squared; small ($\eta^2 \geq 0.01$), medium ($\eta^2 \geq 0.06$) and large ($\eta^2 \geq 0.14$) [33]) were used to estimate the magnitude of the results (differences between groups) and were reported as a measure of practical significance. To determine the relationship between the GBPT, Yo-Yo IR1 test and the SSPT, Pearson product-moment correlation coefficients were calculated. Linear regression between Yo-Yo IR1 running distance and VO_2-peak in the GBPT, between Yo-Yo IR1 HR and the HR in the GBPT, between the 30-m sprint time in the SSPT and GBPT defence time, as well as between Yo-Yo IR1 running distance and fast retreat time in the GBPT, were additional calculated.

3. Results

Descriptive data, group means, standard deviations ($\pm$SD), 95% confidence intervals (CI), F-statistics, range, effect sizes (η^2), *p*-values of the one-way ANOVA and statistical power ($1 - \beta$), for all variables are depicted in Tables 2 and 3. No significant differences between the different playing positions was found. However, there was a large effect size ($\eta^2 \geq 0.14$) in the body mass as well as in the VO_2-peak, HR, jump height and 20-m fast break time in the GBPT. A medium effect size ($\eta^2 \geq 0.06$) was found in age, and in total running distance and HR in the Yo-Yo IR1 test, 15-m and 30-m sprint time in the SSPT as well as in offence time, 10-m fast break time and fast retreat time in the GBPT.

In the Pearson Product-moment correlations (see Table 4), a significant within the test correlation was found between 15-m and 30-m sprint time in the SSPT (R = 0.944, *p* < 0.001) and in the GBPT between VO_2-peak and HR (R = 0.437, *p* = 0.042) and also the fast retreat time (*R* = −0.482, *p* = 0.020), between blood lactate concentration and throwing velocity in the jump shot (R = 0.445, *p* = 0.033), defence and offence time (R = 0.803, *p* < 0.001), 10-m and 20-m fast break time (R = 0.831, *p* < 0.001) and between fast retreat and 10-m fast break time (R = 0.626, *p* = 0.001) and also the 20-m fast break time (R = 0.668, *p* = 0.001). Between the different tests (see Table 4), a significant correlation was found between Yo-Yo IR1 running distance and 10-m fast break time (R = −0.513, *p* = 0.012) and fast retreat time in the GBPT (R = −0.603, *p* = 0.002) as well as with 15-m (R = −0.557, *p* = 0.006) and 30-m sprint time in the SSPT (R = −0.458, *p* = 0.028), respectively. In addition, significant correlations were also found between VO_2-peak in the GBPT and Yo-Yo IR1 running distance (R = 0.563, *p* = 0.005) and Yo-Yo IR1 HR (R = 0.515, *p* = 0.014), respectively, between HR in the GBPT and HR in the Yo-Yo IR1 test (*R* = 0.833, *p* < 0.001), between 10-m fast break time in the GBPT and 15-m (R = 0.426, *p* = 0.043) and 30-m sprint time in the SSPT (R = 0.438, *p* = 0.036), between 20-m fast break time in the GBPT and 15-m sprint time in the SSPT (R = 0.445, *p* = 0.038) and between fast retreat time in the GBPT and 15-m sprint time in the SSPT (R = 0.445, *p* = 0.034).

To further analysing the results in the between test correlations, linear regression plots were made between Yo-Yo IR1 running distance and VO_2-peak in the GBPT (A), between Yo-Yo IR1 HR and HR in the GBPT (B), between 30-m sprint time in the SSPT and GBPT defence time (C) as well as between Yo-Yo IR1 running distance and fast retreat time in the GBPT (D), which are shown in Figure 2.

Table 2. Anthropometric characteristics and results from the Yo-Yo intermittent recovery test, level 1 and the single 30-m sprint performance test for female adult top-elite field team handball players. Group means ± standard deviations (SD), 95% confidence intervals (CI), F-statistics, range (for alle players combined), effect sizes (η^2), *p*-values and statistical power (1 − β) for the main effect of measurements are specified.

Playing positions	All Players Combined (*n* = 23)	Backcourt Players (*n* = 10)	Wing Players (*n* = 7)	Pivots (*n* = 6)					
Variables	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	F	Range	η^2	*p*	(1 − β)
Anthropometric variables									
Body mass (kg)	72.4 ± 9.1 (68.4–76.3)	72.6 ± 10.3 (65.2–80.0)	66.6 ± 5.3 (61.7–71.6)	78.6 ± 6.2 (71.4–85.8)	3.38	55.1–85.2	0.25	0.05	0.66
Body height (cm)	175.3 ± 7.6 (172–179)	175.6 ± 9.1 (169–182)	173.1 ± 8.2 (166–181)	177.3 ± 3.1 (175–183)	0.48	157–187	0.05	0.62	0.28
Age (years)	24.6 ± 3.3 (23.2–26.1)	25.5 ± 4.1 (22.6–28.4)	23.8 ± 3.3 (20.7–26.9)	24.2 ± 1.5 (22.6–25.9)	0.58	17.9–29.3	0.06	0.60	0.28
Yo-Yo intermittent recovery test, level 1									
Running distance (m)	1329 ± 236 (1227–1431)	1268 ± 263 (1080–1456)	1371 ± 89 (1290–1453)	1380 ± 287 (1050–1710)	0.56	880–1760	0.06	0.58	0.27
Heart rate (beats·min^{-1})	193 ± 6 (185–190)	190 ± 7 (185–195)	196 ± 4 (188–201)	195 ± 6 (188–201)	1.14	177–204	0.11	0.34	0.55
30-m single sprint performance test									
15-m sprint time (s)	2.36 ± 0.11 (22.32–2.41)	2.35 ± 0.12 (2.27–2.44)	2.34 ± 0.07 (2.28–2.40)	2.41 ± 0.10 (2.29–2.53)	0.77	2.17–2.57	0.07	0.48	0.35
30-m sprint time (s)	4.36 ± 0.18 (4.28–4.44)	4.33 ± 0.21 (4.18–4.48)	4.33 ± 0.11 (4.23–4.43)	4.46 ± 0.17 (4.25–4.67)	1.07	3.98–4.68	0.10	0.36	0.42

Table 3. Results from the team handball game-based performance test for female adult top-elite field team handball players. Group means ± standard deviations (SD), 95% confidence intervals (CI), F-statistics, range (for all players combined), effect sizes (η^2), *p*-values and statistical power (1 − β) for the main effect of measurements are specified.

Playing Positions	All Players Combined (*n* = 23)	Backcourt Players (*n* = 10)	Wing Players (*n* = 7)	Pivots (*n* = 6)					
Variables	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	F	Range	η^2	*p*	(1 − β)
Team handball game-based performance test									
VO$_2$-peak (ml O$_2$·min^{-1}·kg^{-1})	62.9 ± 6.2 (60.2–65.6)	62.2 ± 4.6 (58.9–65.4)	60.7 ± 4.7 (56.3–65.0)	66.9 ± 8.1 (57.6–76.2)	1.90	55.0–79.7	0.16	0.18	0.51
Blood lactate concentration (mM)	9.6 ± 2.8 (8.4–10.8)	9.1 ± 3.0 (7.0–11.3)	9.5 ± 2.6 (7.1–12.0)	10.5 ± 2.8 (7.2–13.7)	0.40	3.6–14.2	0.04	0.68	0.26
Heart rate (beats·min^{-1})	188 ± 6 (185–190)	185 ± 6 (181–189)	190 ± 6 (185–195)	190 ± 4 (186–194)	2.48	177–201	0.21	0.11	0.49
Jump height (m)	0.32 ± 0.05 (0.30–0.35)	0.29 ± 0.04 (0.27–0.32)	0.35 ± 0.05 (0.30–0.39)	0.34 ± 0.06 (0.28–0.41)	3.28	0.22–0.42	0.25	0.06	0.66
Throwing velocity (m·s^{-1})	23.0 ± 1.7 (22.3–23.7)	23.3 ± 1.6 (22.2–24.4)	22.3 ± 1.8 (20.9–24.1)	23.1 ± 1.9 (20.9–25.4)	0.42	20.0–25.0	0.04	0.66	0.31
Defence time (s)	6.08 ± 0.24 ((5.98–6.19)	6.06 ± 0.26 (5.87–6.25)	6.11 ± 0.28 (5.86–6.37)	6.09 ± 0.16 (5.91–6.27)	0.10	5.61–6.53	0.01	0.90	0.11
Offence time (s)	6.13 ± 0.35 (5.98–6.28)	6.07 ± 0.29 (5.86–6.27)	6.30 ± 0.46 (5.87–6.73)	6.04 ± 0.25 (5.76–6.32)	1.22	5.63–7.08	0.11	0.32	0.41
10-m fast break time (s)	2.02 ± 0.11 (1.97–2.07)	2.00 ± 0.10 (1.92–2.07)	2.06 ± 0.14 (1.93–2.19)	2.00 ± 0.08 (1.91–2.09)	0.75	1.83–2.27	0.07	0.48	0.32
20-m fast break time (s)	4.14 ± 0.22 (4.05–4.24)	4.09 ± 0.17 (3.97–4.22)	4.28 ± 0.23 (4.06–4.49)	4.05 ± 0.20 (3.77–4.33)	2.30	3.78–4.62	0.20	0.13	0.56
Fast retreat time (s)	2.24 ± 0.18 (2.17–2.32)	2.28 ± 0.13 (2.19–2.37)	2.26 ± 0.23 (2.05–2.48)	2.16 ± 0.16 (1.97–2.34)	1.04	1.88–2.74	0.09	0.37	0.36

Table 4. Pearson product-moment correlation coefficients between the Team Handball Game-Based Performance Test (GBPT), Yo-Yo Intermittent Recovery Test, Level 1 (Yo-Yo IR1) and the 30-m Single Sprint Performance Test (SSPT). Significant correlations are indicated in bold.

	GBPT BLC (mM)	GBPT VO$_2$-peak (ml·kg^{-1}·min^{-1})	Yo-Yo IR1 running distance (m)	GBPT HR (beats·min^{-1})	Yo-Yo IR1 HR (beats·min^{-1})	GBPT jump height (m)	GBPT throwing velocity (m·s^{-1})	GBPT defence time (s)	GBPT offence time (s)	GBPT 10-m fast break time (s)	GBPT 20-m fast break time (s)	GBPT fast retreat time (s)	SSPT 15-m sprint time (s)	SSPT 30-m sprint time (s)
GBPT blood lactate concentration (mM)		0.092	0.019	0.132	−0.225	0.224	**0.445 ***	0.289	0.273	−0.258	−0.230	−0.266	0.014	0.143
GBPT VO$_2$-peak (ml·kg^{-1}·min^{-1})			**0.563 ****	**0.437 ***	**0.515 ***	0.303	0.269	−0.174	−0.234	−0.260	−0.254	**−0.482 ***	−0.127	−0.088
Yo-Yo IR1 running distance (m)				0.087	0.189	0.376	0.056	−0.330	−0.237	**−0.513 ***	−0.407	**−0.603 ****	**−0.557 ****	**−0.458 ***
GBPT HR (beats·min^{-1})					**0.833 *****	0.237	0.313	0.242	0.136	0.300	0.208	−0.174	−0.164	−0.064
Yo-Yo IR1 HR (beats·min^{-1})						0.225	0.135	−0.016	−0.013	0.240	0.254	−0.045	−0.179	−0.179
GBPT jump height (m)							0.062	−0.149	−0.038	−0.284	−0.110	−0.375	−0.121	−0.171
GBPT throwing velocity (m·s^{-1})								−0.062	−0.292	−0.054	−0.171	−0.276	−0.075	0.048
GBPT defence time (s)									**0.803 *****	0.224	0.091	0.085	0.163	0.272
GBPT offence time (s)										0.142	0.276	0.227	0.166	0.250
GBPT 10-m fast break time (s)											**0.831 *****	**0.626 ****	**0.426 ***	**0.438 ***
GBPT 20-m fast break time (s)												**0.668 ****	**0.445 ***	0.420
GBPT fast retreat time (s)													**0.445 ***	0.339
SSPT 15-m sprint time (s)														**0.944 *****
SSPT 30-m sprint time (s)														

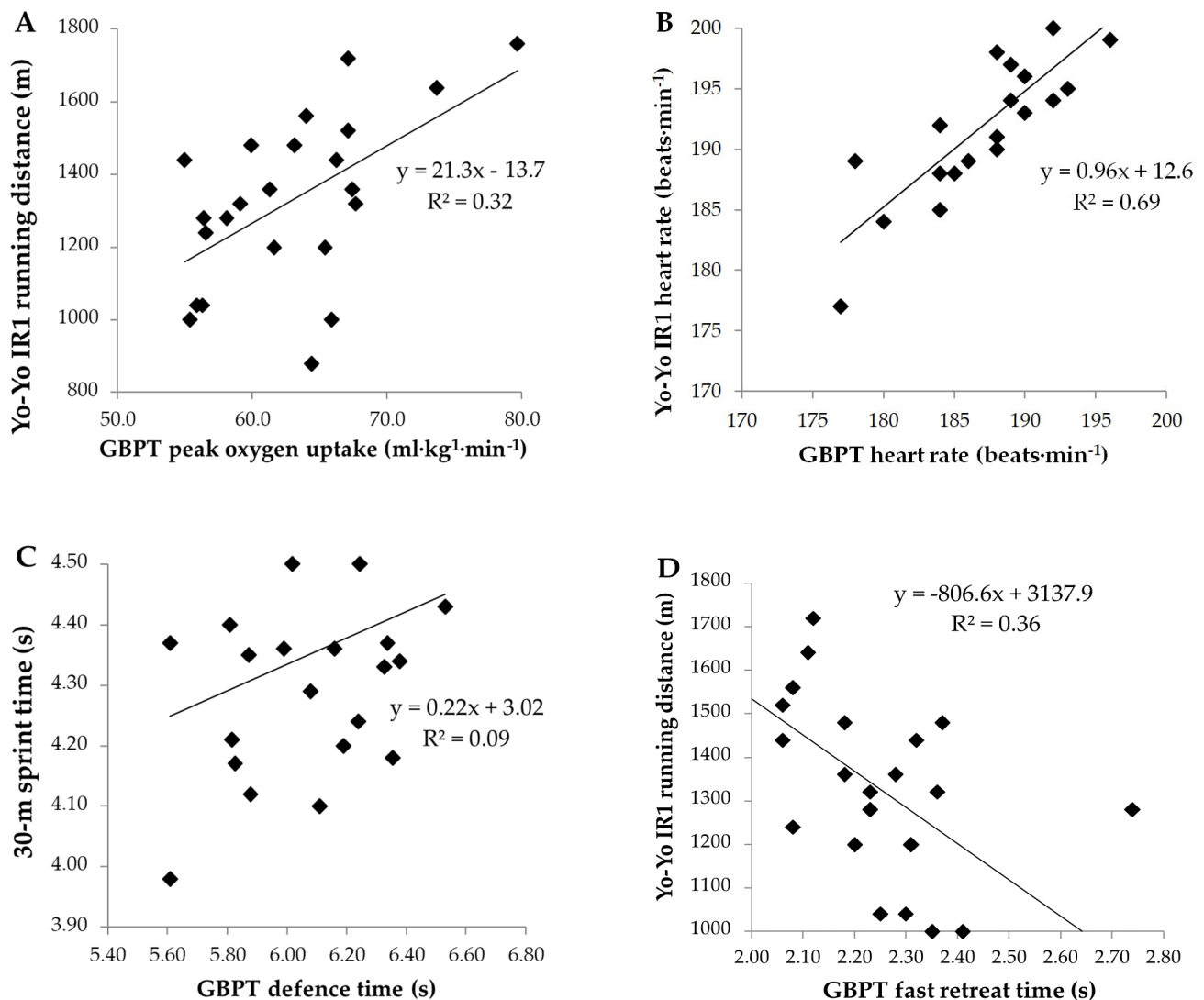Significant correlation: $p < 0.05$ *, $p < 0.01$ **, $p < 0.001$ ***.

Figure 2. Linear regression analysis plots between (**A**) the total running distance covered in the Yo-Yo intermittent recovery test, level 1 (Yo-Yo IR1) and peak oxygen uptake in the team handball game-based performance test (GBPT), between (**B**) the HR in the Yo-Yo IR1 and HR in the GBPT, between (**C**) sprint time in the 30-m single sprint performance test (SSPT) and defence time in the GBPT as well as between (**D**) the total running distance covered in the Yo-Yo IR1 and the fast retreat time in the GBPT.

4. Discussion

To the best of our knowledge, this is the first study to examine and compare physical test results of an advanced, validated team handball game-based performance test and the widely used Yo-Yo IR test [34] as well as the SSPT for elite team handball players. As main findings, the GBPT was shown to be better than the Yo-Yo IR1 test to evaluate female adult top-elite field team handball players´ ability to perform physical match-related activities including both locomotive and technical playing actions executed as during competitive match-play. In addition, no significant differences between the various playing positions were found either for the GBPT, the SSPT and the Yo-Yo IR1 test.

Yo-Yo intermittent recovery test (level 1)

To evaluate the validity of the Yo-Yo IR1 test in team handball, the optimal study procedure will be to compare the Yo-Yo IR1 test performance with physical match activities

(performance) during team handball competitive match-play [34]. Only one study has previously tried to do this [35]. However, the study participants were young male non-elite players (aged 14 years) examined during 50 min experimental matches with special rules. In addition, the total running distance covered during match-play was remarkable low, and no significant relationships were found between Yo-Yo IR1 test performance and high-intensity match activities. The latter findings are challenged by numerous studies showing much higher total match running distance covered and in particular by the conclusion that high-intensity activities are crucial for the performance of adult elite field team handball players during competitive match-play [1,11,14,22,36].

The GBPT has been validated for experienced male team handball players [10]. However, the present study wanted to examine the physical performance of female adult top-elite field team handball players. As a consequence, it was not possible to include real team handball matches in the investigation. The study took place during the beginning of the last part of the preparation phase, i.e., in the end of July after the summer break. At this time, there are no competitive matches for professional clubs. Additionally, the clubs were not interested to play friendly games against high-level opponents, and colleagues, from the Danish Premier Female Team Handball League at this particular time during their early preparations for the up-coming season. Furthermore, to change their training schedule and spend two training days on the present study was enough for them.

Thus, it was not possible to examine the direct validity of the Yo-Yo IR1 test in female adult top-elite field team handball players. Consequently, in the present study, we analysed the relationship between the more complex team handball GBPT and the more practical Yo-Yo IR1 test, as well as the SSPT, the most frequently used physical performance tests in team handball. In a previous study, the GBPT was found to be very well suited to measure team handball match-related activities, since it closely mirrors the physical performance during actual team handball match-play [10]. The percentage of the various exercise intensities was almost similar in the two cases, and similar to real team handball match-play the GBPT also contains technical playing actions such as jumping and shooting with a ball, specific movement patterns in offence and defence, multiple changing of directions and tackles. By comparing the test results of the Yo-Yo IR1 test to the results of the GBPT, the indirect validity of the Yo-Yo IR1 test was determined, which is important for the potential use of the test in elite team handball.

The mean body mass, body height and age in the present group of players were 72.5 kg, 175 cm and 25 years, respectively, which is comparable to that of other female adult top-elite field team handball players from the Danish Premier Female Team Handball League [13], National players from the First Spanish Team Handball League [37] and players in the Czech and the Serbian Female National Handball Team, respectively [38,39]. The mean total running distance covered in the Yo-Yo IR1 test was ~1330 m, which is somewhat lower (~7%) than previously reported in adult top-elite field team handball players from the Danish Premier Female Team Handball League (~1440 m, [11]) and the Brazilian Female National Handball Team (~1440 m, [40]), and also much less compared to female youth (mean age 17 years) top-elite international players (~1660 m, [41]).

One of the reasons for this difference could be due to the timing of the testing in the present study. The tests were carried out in the first days after the summer break—in the early phase of the preparation period—where the players were not used to team handball-like movements such as accelerations, decelerations and change of directions in the same manner as during the competitive season. If the tests had been performed during the competition season, the test results would most certainly have been better as previously shown in other studies with female adult top-elite team handball players [11,42]. One of the participating clubs performed the Yo-Yo IR1 test much later in the season—in the competition period just before the play-offs—and achieved significantly higher mean results. However, all the mentioned results for adult players are still lower than previous Yo-Yo IR1 test performances, for example measured in the Danish Female National Team, which won Olympic Gold in 2000 (~1510 m, mean body mass 68,5 kg, *n* = 16), finished

fourth in the World Championships in 2001 (~1675 m, mean body mass 65,5 kg, n = 12) and won the European Championship in 2002 (~1540 m, mean body mass 66 kg, n = 18) [42]. This may indicate that the mean results of the Yo-Yo IR1 test has not improved significantly for at least female adult top-elite field team handball players the last couple of decades. One reason could be that the mean body mass (and hence probably the muscle mass) has increased markedly for female adult elite field players since the millennium [13,37,43,44]. However, the mean body mass values of present-day female elite teams seem to have almost reached a maximum.

Today's female adult elite team handball players are even more professional and better physical trained than two decades ago. Nevertheless, the players are also larger with increased body mass, which may have a negative impact on the Yo-Yo IR1 test performance due to the many repeated decelerations, accelerations and 180 degrees change of directions during the test. In return, the increased body anthropometry will enhance the on-court performance in other important match activities as tackling, screening, blocking, throwing, jumping and breakthroughs. Studies have shown that body height, body mass and thus muscle mass and maximum muscle strength have important influence on especially the technical playing actions and hence on the match performance in modern female adult top-level team handball [2,7,13,37,45–47]. Likewise, muscle power is an essential factor in female team handball, which is required in actions such as sprinting, one-to-one situations and rapid change of directions. An example of such players is depicted in Figure 2A (in the bottom of the figure). Two players with high body mass (80.8 kg and 79.9 kg) performed badly in the Yo-Yo IR1 test (880 m and 1000 m). However, they both reached a high VO_2-peak (64.4 and 65.9 mL $O_2 \cdot min^{-1} \cdot kg^{-1}$) during the GBPT. Apparently, they can perform at a high level during competitive match-play, but are both too heavy to achieve a high total Yo-Yo IR 1 running distance. In return, they will be strong in the numerous, crucial physical confrontations with the opponents.

Team handball game-based performance test

The mean results of the present players in the GBPT and the 30-m SSPT were general higher compared to semi-professional players from the Austrian Female Handball League [32]. This applied to, for example, VO_2-peak (62.9 versus 54.2 mL $O_2 \cdot min^{-1} \cdot kg^{-1}$), offence time (6.13 versus 6.33 s), throwing velocity (23.0 versus 21.0 m·s^{-1}) and 30-m sprint time (4.36 versus 4.70 s). This illustrates the importance of characteristic physical competences such as throwing and team handball specific movements (agility) to become an elite team handball player in accordance with previous study data [32]. Several strong within test correlations were found in the GBPT, e.g., between the test times in fast break versus fast retreat and in offence versus defence, respectively. Thus, the team handball specific agility seems to be the same in fast break and fast retreat and in offence and defence.

Significant correlations were found between the total running distance covered in Yo-Yo IR1 test and 10-m fast break time and the fast retreat time in the GBPT, respectively. It is definitely not a surprise that the Yo-Yo IR1 total running distance corelates with the high intense locomotive measurements in the GBPT, considering the Yo-Yo IR1 test ends with repeated exercise bouts performed at very high intensity. In support of this notion, the Yo-Yo IR1 test performance was also significant correlated with 15-m and 30-m sprint time in the SSPT. Furthermore, the Yo-Yo IR1 test has been proved to measure the ability to repeatedly perform intermittent exercise with a high aerobic component towards the end of the test [15]. Thus, a relationship between Yo-Yo IR1 total running distance and VO_2-peak and HR in the GBPT, respectively, and also between Yo-Yo IR1 HR and VO_2-peak in the GBPT was expected.

In both tests, the aerobic component has been shown to approach maximal values. The player with the absolutely highest VO_2-peak (79.7 mL $O_2 \cdot min^{-1} \cdot kg^{-1}$) also covered the longest total running distance in the Yo-Yo IR1 test (1760 m) as seen in Figure 2A (furthest to the right). Interestingly, this world-class player was the only one who was able to perform the entire GBPT without a decrease in time in the offensive and defensive actions. A greater contribution from the aerobic metabolism apparently helped the player to avoid a decrease

in the repeated, anaerobic actions throughout the entire test [14]. Noteworthy, this may also happen for elite players during real competitive matches. The high level of VO$_2$-peak in GBPT may enable a faster recovery during both training and match-play, and players will be able to perform on a higher level for a longer time.

In the present study, the mean VO$_2$-peak was 62.9 mL O$_2 \cdot$min$^{-1} \cdot$kg^{-1}, which is markedly higher than the VO$_2$-max previously measured in adult female elite team handball players (48–54 mL O$_2 \cdot$min$^{-1} \cdot$kg^{-1}, ref. [11,48]). It has been suggested that increased VO$_2$-peak in a GBPT/during match-play compared to VO$_2$-max measured in a typical incremental treadmill running test may be due to higher rate of muscle recruitment and higher motivation [49]. By contrast during the treadmill test, the muscle activation continuously changes and even reduces during team handball-related movements because of the constantly changing playing actions. This might postpone the time of exhaustion and lead to higher oxygen uptake. The muscle recruitment/activation is different during the specific and the general physical test, respectively. A very strong correlation between the HR-values in the two tests were found, and further documented in the linear regression plot with a R^2-value of 0.69 (see Figure 2B). Since the HR-values were almost similar in the two tests for nearly all players, this means that the players were just as exhausted in the GBPT as in the Yo-Yo IR1 test. Thus, both tests were performed with highest possible effort.

30-m single sprint performance test

The linear 30-m SSPT is the most applied sprint test when scientific studies are testing the sprint ability of team handball players without including ball handling [23–25,32]. This occurs despite the fact that most sprints in team handball are of shorter distance and usually performed with changes of direction where the players may never reach their maximal sprint velocity [1,11,22,50]. Consequently, a 15-m split sprint time was also measured in the present study. However, it may happen that team handball players (especially wing players) sprint for 30 m during match-play, for example, a goal scorer lying/standing in the goal area close to the goal when the opponents are taking a fast throw-off. The within test correlation between 15-m and 30-m sprint time was found to be very strong. The performance in the 30-m SSPT was at the same level as the Danish Female National Team, which was tested regularly in the period 2000–2016, in which they belonged to the international top-elite [48].

In line with our hypothesis, several significant relationships between the sprint performance in the SSPT and in the Yo-Yo IR1 test performance and locomotive results in the GBPT, respectively, were demonstrated. The Yo-Yo IR1 running distance was strongly correlated with both the 15-m and 30-m sprint time in the SSPT. In addition, significant relationships were found between 10-m fast break time, 20-m fast break time and fast retreat time, respectively, in the GBPT and the 15-m sprint time as well as only in one occasion with the 30-m sprint time. This indicate that a 15-m sprint test are more relevant for team handball players than the 30-m sprint test, which is in agreement with results from previous studies regarding sprint distances covered during elite team handball match-play [1,11]. This support previous findings showing that sprint training exercises in team handball primarily should target reaction speed and acceleration (i.e., rate of force development, RFD) rather than focus on maximum running speed [1,5,11].

Additionally, the 30-m SSPT was not correlated to any of the GBPT activities, which included technical playing actions such as tackles, jumping and throwing with a ball (during defensive and offensive actions). These data suggest that on-court sprinting with and without a ball may not be the same, and that the SSPT only to a certain extent can measure the individual sprint capacity of elite team handball players who during match-play always are sprinting with or looking for the ball. The special movement pattern during training and matches is unique for team handball (specific team handball agility), and the high-intensity actions in team handball are performed very differently compared to the activity in a linear, 30-m sprint test.

Relationships between the various tests

As hypothesized, some significant relationships in test results between the GBPT and the Yo-Yo IR1 test regarding the locomotive distances, VO$_2$-peak and HR revealed that the Yo-Yo IR1 test are related to the GBPT and hereby also to the on-court performance in team handball match-play. However, it is notable that the Yo-Yo IR1 test results were not correlated to the GBPT in any of the match-related activities in the team handball GBPT that included technical playing actions such as tackles, passes, jumping and shooting during specialized movements in offence and defence. The exact same team handball GBPT, which was used in the present study, has been proved to be very well suited to measure team handball match-related activities [10]. Consequently, in this study, the indirect validity of Yo-Yo IR1 test was found to be only valid for locomotive activities, but not for team handball match-activities including technical playing actions, which otherwise is a very important part of elite team handball match performance [4,7,12,13,24,51–55]. The Yo-Yo IR1 test is solely a measure of some of locomotive activities used in team handball (e.g., not side-to-side change of directions and full-power, explosive accelerations). Moreover, using only locomotion match data seems to underestimate the physical demands of elite team handball match-play [1,11]. It seems reasonable to believe that it is decisive in team handball to use a test that contain all kinds of activities performed by the players during training and match-play.

The indirect validity of the Yo-Yo IR1 test was determined to be only partly valid for measuring relevant elements for team handball match-play. Using the Yo-Yo IR1 as a test to evaluate the physical capacities of elite team handball players will therefore not give a full picture of the level of physical performance of the players in question, instead, the test must be supplemented by others tests. This is an important finding in order to establish the potential use of the Yo-Yo IR1 test in elite team handball.

Conversely, the GBPT has previously been found to be very suitable to measure all types of team handball match-related activities, because it also includes technical playing actions such as jumping and shooting with a ball, specific movement patterns in offence and defence and multiple changing of directions and tackles [10]. Consequently, the results of the present study confirmed our hypothesis that the GBPT is better than the Yo-Yo IR1 test to measure all types of team handball actions, i.e., both locomotive and technical match-related activities for female adult top-elite field team handball players. In addition, all players were asked to rate their motivation and exertion, and specificity of the GBPT on the scale from 1–10, 10 being the highest value. The results revealed high values in both motivation (9.2 $\pm$ 1.0), exertion (8.8 $\pm$ 1.0) and specificity (9.2 $\pm$ 1.2) showing that the players were highly motivated to perform their best in a test they found highly relevant.

Moreover, this study clearly indicated that team handball specific performance, as measured by the GBPT, and general physical performance, as measured by the Yo-Yo IR 1 test and the SSPT in the present study, are different elements in line with previously study data [32]. Using general tests for examining the physical performance of team handball players provides information of general, separate physical qualities, which may differ substantially from the physical on-court performance during match-play. This must be taken into consideration when evaluating the effect of relevant physical training, and when the coaches are using the results of general tests for the planning of optimal physical training regimens in elite team handball, which aims to increase the on-court performance during match-play.

Positional differences in test results

Another study aim was to compare and evaluate the physical test results in relation to the different playing positions in the present players. Disproving our hypothesis, surprisingly no positional differences were demonstrated in all three physical tests. Potential positional differences in the team handball GBPT have not been examined before, but in regard to the Yo-Yo IR1 test and the 30-m SSPT, our study findings are in contrast to data from to previous studies in team handball [11,24]. However, there were several large effect sizes ($\eta^2 \geq 0.14$) especially in the GBPT (VO$_2$-peak, HR, jump height and 20-m fast break

time), and numerous medium effect sizes ($\eta^2 \geq 0.06$) were also seen primarily in the Yo-Yo IR1 test (total running distance covered, HR) and in the SSPT (15-m and 30-m sprint time). This indicates that the sample size in the three groups (six pivots, seven wing players and ten backcourt players) in many cases was too small [56]. In contrast to the statistical significance, effect sizes facilitate the interpretation of the importance of the results. Thus, had the sample sizes been larger, significant positional differences would probably have been demonstrated, especially in the GBPT.

Furthermore, three very small players (1.62–1.68 m) with excellent running capacities were noteworthy not wing players (which is normal), but backcourt players in present group of female adult top-elite field team handball players. Normally, in running tests such as the Yo-Yo IR1 test and the 30-m SSPT, wing players are performing better than the other playing positions [8,11,48]. Hence, this contributed to reduce the difference in test performance between the various playing positions. In total, however, the present study could not provide direct evidence that either the GBPT, the 30-m SSPT or the Yo-Yo IR1 test are capable of measuring differences between individual female top-elite field team handball players´ physical performance.

Study limitations

A study limitation was that the direct validity of the Yo-Yo IR1 test, and the team handball GBPT, was not examined. However, if you want to examine the best players, top elite adult team handball players, it is very difficult to conduct a study at the most ideal time. During the competitive season, it is possible to measure the activity pattern of the players during real competitive matches. However, at that time most clubs are not willing to chance their training and match preparation schedule in the middle of a very busy period with multiple important matches. If you study the players in the off-season, like in the present study, the willingness of the clubs and the chance to allow them to participate in a study is much better. Unfortunately, in this period there are no competitive matches. After talking to the clubs, we agreed to choose the latter option. Thus, it was only possible to examine the indirect validity of the used tests. However, future studies should examine the direct validity of the tests in question and also include male top-elite adult team handball players as study participants, so their specific physical on-court performance abilities also can be determined.

A limitation to a test such as the team handball GBPT will always be that the specific test movements can never be completely the same as performed by the players during real match-play (e.g., screenings, claspings and tackles of real opponents). This is primarily due to the complexity of the game and the need to standardize the test. Thus, the test results cannot be transferred directly to the physical demands of the game. However, the movements in the present team handball GBPT test reflects to a large extent the match activities during competitive team handball.

5. Conclusions

The aims of the present study were to determine the relationships between the physical and physiological test results from the team handball GBPT, the linear 30-m SSPT and the Yo-Yo IR1 test in female adult top-elite field team handball players. In addition, also to compare and evaluate the results from the aforementioned tests in relation to the different playing positions.

As a key finding, several significant correlations between the locomotive results in the GBPT and the sprint performance in the 30-m SSPT and in the Yo-Yo IR1 test performance, respectively, were demonstrated. This indicate that the Yo-Yo IR1 test is reflecting most of the locomotive match activities in female adult top-elite team handball. However, the Yo-Yo IR1 test results were not correlated to the GBPT in any of the match-related activities in the team handball GBPT that included technical playing actions such as tackles, passes, jumping and shooting during specialized movements in offence and defence. Today's female adult elite team handball players are larger with increased body mass than two decades ago, which may have a negative impact on the Yo-Yo IR1 test performance. On

the other hand, this increased body anthropometry will enhance the on-court performance in other important match activities as tackling, screening, blocking, throwing, jumping, one-to-one situations and rapid change of directions and hence on the total performance during match-play. Overall, these aforementioned data collectively suggest that the Yo-Yo IR1 test performance does not reflect and measure the overall specific physical on-court performance of female elite team handball players, but solely an individual player's ability to repeatedly perform intermittent running exercise and the ability to recover from such intense exercise, which does not include technical playing actions.

The results of the 30-m SSPT was also not correlated to any of the team handball GBPT activities, which included technical playing actions such as tackles, jumping and throwing with a ball (during defensive and offensive actions). These data suggest that on-court sprinting with and without a ball may not be the same, and that the 30-m SSPT only to a certain extent can measure the individual sprint capacity of elite team handball players who during match-play always are sprinting with or looking for the ball.

Unexpectedly, no significant differences between the various playing positions were found either for the team handball GBPT, the 30-m SSPT and the Yo-Yo IR1 test. However, several effects sizes indicated that the lack of positional differences was ambiguous, and that it primarily was due to the relatively small sample size in each playing position and the composition of the specific group of players. In total, the present study could still not provide direct evidence that either the GBPT, the Yo-Yo IR1 test or the 30-m SSPT are well suited to measure differences between individual female top-elite field team handball players´ physical performance.

The main study finding was that the results revealed that the team handball GBPT is better than the Yo-Yo IR1 test to measure and evaluate female adult top-elite field team handball players´ ability to perform physical match-related activities, including both locomotive and technical playing actions executed as during competitive match-play. Additionally, this study also clearly indicated that team handball specific physical performance, as measured by the GBPT, and general physical performance, as measured by the Yo-Yo IR1 test and the 30-m SSPT, are different components. This must be taken in consideration when using physical tests results for the planning of optimal physical training regimens in elite team handball.

6. Practical Applications

The present study confirmed that the team handball GBPT is a valid and reliable test to analyse team handball physical performance under conditions similar to competition match-play, also for female adult top-elite field team handball players. However, to conduct a team handball GBPT requires many resources, intense planning, high advanced equipment, a lot of space, high knowledge and experience about physiology and testing, including blood sampling and portable respiratory gas exchange measurement of VO_2. In addition, the test is very time consuming, since only one player can be tested at a time. Furthermore, several people to help during the test is also needed, for example to pass the ball during the offensive actions. As a consequence, this is not a test which is suitable for regular testing of players in small clubs or at a lower performance level. Maybe only in elite clubs or National Teams with many resources, where collaboration with federations/elite organisations and universities sometimes takes place, is it realistic to perform the GBPT in an appropriate manner and with a suitable frequency. Nevertheless, the results from the team handball GBPT may emphasize the importance of team handball specific physical performance.

Instead, general physical tests such as the Yo-Yo IR1 test and the 30-m SSPT may be used. Both tests can test a whole team squad within an hour. Additionally, the Yo-Yo IR1 test, in particular, does not require a lot of equipment or human resources. It can easily be performed, also in clubs at a lower level. The Yo-Yo IR1 test examines the intermittent endurance running capacity and is relevant due to its team sport-specific character. In addition, as shown in the present study, it is correlated to the locomotive categories in the

GBPT. However, it must be emphasized that these tests have to be supplemented with other general tests, for example different strength and jumping tests, to give an overall picture of the physical capacity of team handball players. The 30-m sprint test can advantageously be reduced to a 20-m sprint test and performed while measuring different split times, e.g., at 5 m, 10 m and 15 m. It may also be performed several times with short breaks in between as a repeated sprint test in order to measure the repeatedly sprint ability of the players [8,57], which is an activity the players often perform during a match. Furthermore, it can be conducted with changes of directions or with offence and defence movements as a specific test for agility in team handball.

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