

Repeated jump tests for children and adolescents at various stages of basketball games, and their relationships to aerobic capacity

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Published online: June 30, 2022

(Accepted for publication June 15, 2022)

DOI:10.7752/jpes.2022.06193

Abstract

The aim of the study was to compare repeated jump tests (RJT's) performance indices of adolescent and prepubertal basketball players during different stages of basketball games, and to examine their relationships to aerobic capacity. The study included 34 male basketball players – 18 children (age 12.1±0.4 yrs) and 16 adolescents (age 17.2±0.4 yrs.) – who were asked to perform RJT after a warm-up, at halftime, at the end of a game, as well as an aerobic power test. A significant decrease in Ideal jump height (IJH) between half-time and full-time was seen among the adolescents ($p<0.01$), yet not among the children. Moreover, while the Total jump height (TJH) was significantly increased ($p<0.05$) among the children at the end of the game compared to at the warm-up, this significantly decreased among the adolescents ($p<0.01$). Significant correlations were found between the IJH at halftime and full-time and the aerobic fitness, and between the TJH at halftime and the aerobic fitness among the children's group. No significant correlations were found between aerobic fitness and any RJT performance indices in the adolescents' group. The findings demonstrate that prepubertal children are superior in maintaining repeated jumping performance during basketball games compared to adolescents. The findings also suggest that the aerobic system is a significant energy contributor among children, but not among adolescent players, during repeated jump activity. Coaches of young basketball players may consider these differences, allowing more breaks for recovery during training sessions for adolescents' groups when an intense activity such as repeated jumps is involved.

Keywords: sprints, high intensity, warm-up, performance decrement

Introduction

Basketball is characterized by numerous explosive short activities, such as sprints, jumps, and changing direction. Previous studies have monitored basketball players' activity patterns and physiological responses during games (Ben Abdelkrim, El Fazaa & El Ati, 2009; Scanlan, Dascombe & Reaburn, 2011). McInnes et al. (1995), for example, found that the frequency of all activities during a game is 997 ± 183 , with changes to the movement category occurring every two seconds. Klusemann et al. (2013) reported an average of 809 ± 80 activities during a game by young basketball players (under 18 years). Recently, Ferioli et al. (2020) reported an average of 642 ± 168 movements per game for players in the Italian First Division Basketball League. In a study that followed the physiological responses of top-level Spanish players, a heart rate (HR) of 198 b/m (96.8% of maximal HR) with an average HR of 158 b/m (78% of MHR) was found during seven league basketball league games (Torres-Ronda, et al., 2016). These findings indicate that basketball is an intense intermittent-type sport that entails frequent changes in players' movements.

In basketball, the vertical jump is an important type of activity that is performed as a single or repeated action during different stages of a basketball game. The jumps are performed in both defensive and offensive activities – such as rebounds, making shots, or blocking shots to the basket (Paes et al., 2022). A study that analyzed the activities of young elite basketball players (under 19 years) reported an average of 44 ± 7 vertical jumps per player during a game (Ben Abdelkrim, El Fazaa & El Ati, 2009). Earlier, McInnes et al. (1995) reported an average of 46 ± 12 jumps during a game for professional adult players. When comparing activity at four different levels among adult basketball players, an average of 27 ± 11 , 25 ± 9 , 25 ± 11 , and 22 ± 14 jumps were found for the first, second, third, and fourth basketball divisions, respectively (Ferioli et al., 2020).

Over the years, the repeated activity test (RAT) has become a popular method for measuring anaerobic fitness in team sport players. While this test has been mostly applied to running and cycling (Fitzsimons, Dawson & Ward, 1993; Gharbi et al., 2015; Sanders et al., 2017), few studies have measured the anaerobic capabilities of players of team sports using the repeated jump test (RJT) (Meckel et al., 2015; Segev & Meckel, 2020). In these studies, the players performed 6 X 6 maximal vertical jumps with 30-second periods between sets. Segev and Meckel (2020) examined RJT performance indices at various stages of basketball games: after warm-up, at halftime, and at the end of the game. Their findings revealed that RJT performance indices were

significantly higher at halftime compared to post warm-up (i.e., prior to the beginning of the game). Similar findings were found for performance indices of repeated sprint test (RST) at different stages of basketball game, suggesting the need for a more effective preparation process prior to the beginning of the game (Meckel, Gottlieb & Eliakim, 2009).

The relationship between aerobic capacity ($\text{VO}_2 \text{ max}$) and RAT performance indices was also examined. While significant relationships were found between $\text{VO}_2 \text{ max}$ and RST performance indices at halftime and at the end of the game (Meckel, Gottlieb & Eliakim, 2009), no significant relationships were found between $\text{VO}_2 \text{ max}$ and RJT performance indices at any stage of the game (Segev & Meckel, 2020). This suggests that working muscles have different physiological needs when performing repeated jumps and when performing repeated sprints. The lack of significant correlations between aerobic capacity and RJT performance indices may suggest that repeated jump activities do not profoundly rely on the aerobic system as an energy supplier.

Relationships between aerobic fitness and RJT performance indices have previously been examined among late-adolescent male basketball players (17-18 years) (Meckel, Gottlieb & Eliakim, 2009), but not among children. These relationships are particularly interesting, since recovery during repeated activity (i.e., running and cycling) is significantly higher among children than among adolescents and adults (Ratel et al., 2002; Ratel, Williams, Oliver & Armstrong, 2006). The aim of the present study, therefore, was to compare RJT performance indices and physiological responses at different stages of the basketball game, between children and adolescents. In addition, to examine the involvement of the aerobic energy system in the repeated jumping activity of children and adolescents throughout the game, we looked at the relationships between aerobic capacity and the performance indices of RJTs during different stages of the game in both groups. We hypothesized that the decrease in RJT performance indices throughout the game will be lower among children than among adolescents, with the younger group demonstrating a stronger relationship between aerobic capacity and RJT performance indices compared to the adolescents, at different stages of the game.

Materials and Methods

Participants

The study included 34 male basketball players, with 18 players from the children's category and 16 from the adolescents' category. The children's group (age = 12.1 ± 0.4 years; height = 1.58 ± 0.1 cm; weight = 43.3 ± 9.6 kg; body fat = 13.0 ± 3.2 %) trained four days a week and competed every two weeks. The aerobic score for the children's group, was 703 ± 180 m, measured by the distance attained in the 20-meter shuttle run test. The adolescents' group (age = 17.2 ± 0.4 years; height = 1.77 ± 0.07 m; weight = 66.7 ± 5.9 kg; body fat = 12.2 ± 1.9 %) trained four days a week and competed every weekend. The aerobic score for the adolescents' group was 1104 ± 384 m, also indicated by the 20-meter shuttle run test.

A standard calibrated scale and stadiometer were used to measure height and body mass. Skinfold measurements were taken from triceps, biceps, sub-scapular, and supra-iliac regions, to calculate percent body fat using standard equations. Pubertal status was assessed by the Tanner Stages for pubic hair, with all players in the adolescents' group being at stages 4-5, and all players in the children's group being at stages 1-2 (i.e., pre-pubertal). The testing procedures were explained to the players, and written informed consent was obtained from the players and their parents. The institutional ethical committee approved the study.

Design and Testing Procedures

The study was conducted a few weeks before the end of the basketball season for both groups, when players are usually in peak physical shape. Training sessions for both groups at this time of the season included mainly tactical and technical drills, with no aerobic or resistance workouts. The participants from both groups performed four tests: one aerobic power test and three RJTs. Each test was performed on a separate day, with 3-4 days of low-intensity workouts between the tests. All tests were conducted during the late afternoon, at the teams' home basketball arena, and with comfortable weather conditions.

Aerobic power test. The 20m shuttle run was used for this test, consisting of shuttle runs at increasing speeds between two markers placed 20m apart (St Clair Gibson, Broomhead, Lambert & Hawley, 1998). The starting speed of 8.5 km/hour was maintained for the first minute, after which the speed was increased every minute by 0.5 km/hour. A portable compact disc dictated the test pace by emitting tones at appropriate time intervals; the participant was required to be at one end of the 20m course when the signal was sounded. The test continued until the participant could no longer keep up with the required pace and withdrew from the test. The total distance achieved by each player during the test was considered his test score. We used this test because its back and forward run imitates players' movement patterns during a typical basketball game.

Repeated jump tests. Three RJTs were performed on three different days and at three different stages of the game, as follows: after a warm-up, after a halftime game, and after a full game. The RJT in each testing session consisted of six sets of six consecutive maximal vertical jumps, with a 30-second rest between sets. This protocol has been previously described and validated for professional volleyball players (Segev & Meckel, 2020) and adolescent basketball players (Meckel, Gottlieb & Eliakim, 2009), using the free countermovement jump (FCMJ) technique. In this study, each participant first stood in an erect position, then moved into a semi-squat position, and finally used a vigorous double-arm swing to achieve a maximal jump. All jumps were performed

using the Optojump system (Microgait, OGA002, Italy), which recorded the flight time and height of all jumps. The participants were instructed to exert maximal effort during each jump and to avoid pacing themselves.

One RJT was performed after a standard warm-up procedure that included five minutes of jogging, five minutes of stretching, and about 10-15 minutes of specific running and jumping drills, with and without a ball. This procedure is usually performed by players before every official basketball game. Another RJT was performed at halftime, with each player completing a continuous 15 minutes of "live time" (i.e., actual playing time) before quickly going to a nearby room to perform the RJT. Finally, for the test conducted after the game, each player completed a continuous 15 minutes of "live time" during the first half, following by a 10-minute break, and then followed by another continuous 15 minutes "live time" during the second half of the game, i.e., a total of 30 minutes live playing time before performing this RJT. For each participant, each RJT began about 60 seconds after the end of each stage (i.e., the end of the warm-up, the end of the halftime, and the end of the full game time). Finally, the 15-minute play for each half of the game simulates average "real playing time" for the young basketball players.

Regular basketball rules were used during the 15 or 30-minute playing time, with the game being stopped for foul violations and penalty shots. However, the coaches did not call any time-outs during the games. Although the games were not official matches, the players were instructed and encouraged to play at full intensity. In order to enable 12 prepubertal basketball players and 10 adolescent basketball players to perform the RJTs at the end of the first and second halves of the game, 18 and 16 players were needed to play during the game, respectively. The additional players, however, did not play for a full 15 or 30 minutes. As they only replaced the players who left the game to perform the RJTs, they did not participate in the study and did not perform the RJTs. Thus, at the end of the 15 or 30 minutes, two players were taken out of the game to perform the RJT test, while two additional players joined the game as temporary replacements. The two players who then performed the RJT were asked to jump the six sets alternately: with one player performing one set while the other was given a 30 second rest. The two players then switched roles, continuing this process until both had completed six jumping sets. They then returned to the game, allowing two additional players to perform the RJT.

Measurements

The following three performance indices were calculated for each player in each RJT: (a) ideal jump height (IJH), calculated as the highest jump in each set multiplied by six; (b) total jump height (TJH), calculated as the sum of all jump heights in all sets; and (c) performance decrement (PD), used as an indication of fatigue and calculated as $[(TJH / IJH) \times 100] - 100$. These calculations were adopted from commonly used calculations for assessing anaerobic capabilities in repeated maximal running and cycling tests (Fitzsimons, Dawson & Ward, 1993). In addition, HR was measured using a Polar HR monitor (Polar Accurex Plus, Polar Electro, NY), immediately prior to and following each RJT. In addition, rate of perceived exertion (RPE) was determined using the modified Borg scale (Borg, 1982) on a scale of 1 to 10, immediately prior to and following each RJT.

Statistical Analyses

The Shapiro-Wilk method was used in order to ensure normal distribution of the results. ANOVA for repeated measures with post hoc Bonferroni correction was used to determine differences in IJH, TJH, PD, HR, and RPE following the RJT at the three different points in time, within and between groups. Pearson correlations were calculated between the aerobic capacity scores and the performance indices in the three RJTs (game stages) of the two groups. Data are presented as mean $\pm$ SD. Significance level was set at $p < 0.05$. Data analysis was performed using SPSS version 25.

Results

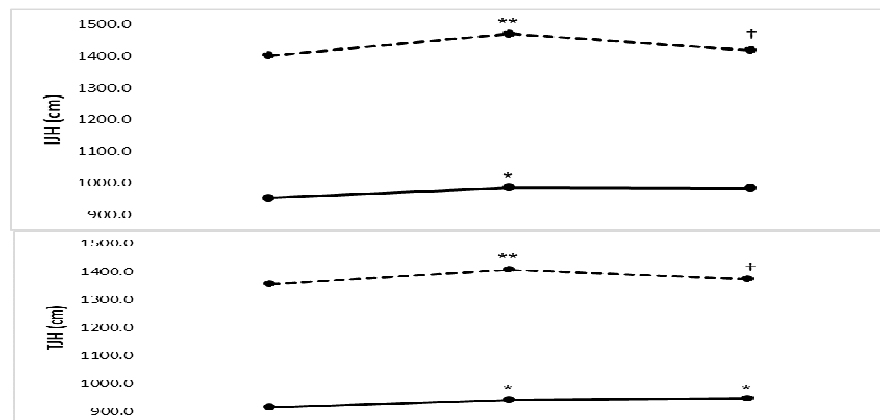


Figure 1. Performance indices for both groups at the three game stages.

* $p < 0.05$ compared to warm-up, ** $p < 0.01$ compared to warm-up, † $p < 0.01$ compared to halftime

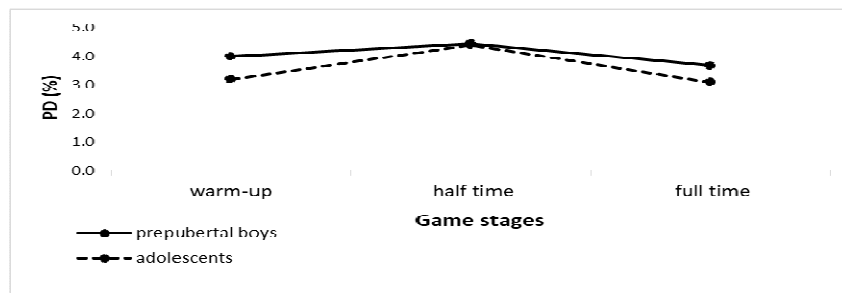


Figure 1 presents the IJH, TJH, and PD performance indices for the participants from both groups, following the 6X6 RJT at the three different time points. The findings indicate that the IJH significantly increased in both groups at halftime compared to after warm-up (children = $p < 0.05$, adolescents = $p < 0.01$). A significant interaction for the IJH was found between group and game stage ($F_{(1,20)} = 8.825$, $p < 0.01$, $\eta^2 = 0.306$). A significant decrease was found in the IJH between halftime and full-time for the adolescents' group ($p < 0.01$), but not for the children's group. The TJH significantly increased for both groups at halftime compared to after warm-up (children = $p < 0.05$, adolescents = $p < 0.01$). The interaction between group and game stage was also significant for TJH ($F_{(1,20)} = 6.729$, $p < 0.05$, $\eta^2 = 0.252$). TJH significantly increased in the children's group at the end of the game compared to the warm-up ($p < 0.05$), while TJH in the adolescent group significantly decreased ($p < 0.01$). Finally, there were no significant differences in the PD indices between groups at the three game stages. Table 1 presents the participants' HR and RPE before and after RJT, at the three different game stages. In the children's group, HR was significantly lower prior to the RJT at warm-up ($p < 0.01$) than at the two later stages (i.e., halftime and after a full-time game). In addition, significant differences were found after a full-time game between pre and post RJT ($p < 0.01$). In the adolescents' group, a significantly lower HR was found after warm-up compared to the two later stages ($p < 0.01$ for both). Furthermore, a significant difference was found after a full game for HR post RJT compared to HR before RJT ($p < 0.05$). A significant interaction for HR was found between group and game stage ($F_{(1,19)} = 40.285$, $p < 0.01$, $\eta^2 = 0.680$). The children's HR at the end of the game decreased after the RJT compared to before, yet the adolescents' HR increased. There were significant RPE differences in both groups at halftime compared to after warm-up, and after a full-time game compared to after warm-up and halftime ($p < 0.05$). In the children's group, after warm-up there was a significant increase of RPE after the RJT compared to before ($p < 0.01$). In the adolescents' group, there were significant RPE differences in all RJTs and in all stages compared to the previous stage of the game ($p < 0.01$). A significant interaction for RPE was found between the groups in all the game stages ($F_{(1,19)} = 40.285$, $p < 0.01$, $\eta^2 = 0.680$). The adolescents' RPE responses significantly increased after RJT compared to before at all three game stages, while the children's RPE remained unchanged.

Table 1. Heart rate and RPE responses at different game stages in children and adolescent basketball players (mean $\pm$ SD).

Stage	Adolescents	Children
Warm-up		
HR (beat/min)		
After warm-up	136 $\pm$ 25	160 $\pm$ 15
After RJT	168 $\pm$ 15*	165 $\pm$ 13
RPE (1–10)		
After warm-up	2.5 $\pm$ 0.7	3.2 $\pm$ 0.6
After RJT	*4.8 $\pm$ 1.3	4.5 $\pm$ 0.8*
Halftime		
HR (beat/min)		
At halftime	168 $\pm$ 19*	192 $\pm$ 10*
After RJT	174 $\pm$ 12	185 $\pm$ 11
RPE (1 – 10)		
At halftime	*3.7 $\pm$ 1.1	5.6 $\pm$ 1.4*
After RJT	†6.0 $\pm$ 1.3	5.8 $\pm$ 1.2
Full game		
HR (beat/min)		
After full game	167 $\pm$ 9*	195 $\pm$ 8*
After RJT	¥175 $\pm$ 12	179 $\pm$ 9**
RPE (1–10)		
After a full game	†*5.1 $\pm$ 1.6	7.1 $\pm$ 0.7***
After RJT	**7.4 $\pm$ 1.2	7.6 $\pm$ 0.8

* $p < 0.01$ compared to warm-up,

** $p < 0.01$ compared to a full game

*** $p < 0.05$ compared to halftime

¥ $p < 0.05$ compared to a full game

† $p < 0.01$ compared to halftime

The relationships between RJT performance indices and aerobic fitness (measured by the 20m shuttle run test) in both groups at the different game stages are presented in Table 2. For the children's group, significant correlations were found between aerobic fitness and IJH at halftime and after the full-time game. In addition, a significant correlation ($p < 0.05$) was found between TJH at halftime and aerobic fitness for the children's group. No significant correlations were found between the adolescents' aerobic fitness and any RJT performance indices at any of the game stages.

Table 2. Relationships between Calculated Peak Vo_2 and Performance Indices at Different Game Stages in the Children's and the Adolescent Groups.

Stage	Warm-up	Halftime	Full game
Children			
Ideal jump height (cm)	0.473	0.644*	0.587*
Total jump height (cm)	0.376	0.648*	0.568
Performance decrement (%)	-0.285	-0.080	-0.373
Adolescents			
Ideal jump height (cm)	0.423	0.379	0.351
Total jump height (cm)	0.423	0.437	0.399
Performance Decrement (%)	-0.061	-0.362	-0.273

*Significant correlation at $p < 0.05$

Discussion

In accordance with our hypothesis, the study findings showed that although the adolescents' group achieved higher absolute jumping scores than the children, at all game stages, they were unable to maintain their jumping performance level throughout the game. In contrast, however, and despite lower absolute jumping scores, the children's group demonstrated better maintaining of their jumping ability as well as reduced fatigue at late game stages compared to the adolescents' group. The children's superior jumping maintaining ability was demonstrated through their IJH and TJH performance, and through their HR and RPE responses.

The children's superior jumping maintaining ability compared to that of the adolescents was demonstrated by the significant between-group interactions for IJH and TJH at halftime compared to the end of game stage (Figure 1). The significant reduction in IJH and TJH at the end of the game among the adolescents' group probably reflected an accumulative fatigue effect following full-game activity, as well as their inability to recover in the short rest time between the RJT sets. A similar fatigue effect was not seen among the children's group, as they were able to sustain their IJH and TJH performance at the end of the game compared to their halftime ability. These findings are in line with those of Ratel et al. (2006), whereby children (aged 11.7 ± 0.5 years) were better able to sustain their intensity levels than adults during a series of maximal short activity (1-2% decrease among children compared to 3-5% decrease among adults). The ability to sustain performance level among children could be related to their higher muscle oxidative activity, which allows faster re-synthesis of creatine phosphate (CP) stores after each maximal jumping set, compared to adolescents (Ratel et al., 2002). This greater reliance on aerobic metabolism in children might be due to higher muscle oxidative enzyme activity (Berg, Kim & Keul, 1986), greater relative volume density of mitochondria (Bell, MacDougall, Billeter & Howald, 1980), or faster adaptation of the oxygen transport system (Williams, Carter, Jones & Doust, 2001). These have all been supported by Taylor et al. (1997), who showed that the rate of CP re-synthesis after maximal exercise was twofold higher among children (aged 6-12) than among adults. In addition, although blood or muscle lactate levels were not monitored in the present study, it is possible that the children's lower glycolytic energy turnover led to reduced muscle acidosis and, in turn, to reduced levels of fatigue compared to the adolescents (Zanconato, Buchthal, Barstow & Cooper, 1993). Accordingly, the children's high HR at the end of the game decreased after the RJT, while the HR of the adolescents' group increased after the RJT at the end of the game. Similarly, RPE increased after RJT at halftime and at the end of the game among the adolescents' group but not among the children's (see Table 1). This demonstrates the difficulty of the adolescents' group in performing RJTs at halftime and at the end of the game, when recovery time between the game and the RJTs (~60 sec) and between the RJT sets (30 sec) was short. In contrast, the children showed no signs of fatigue while recovering during the short recovery times after the game and between the RJT sets (see Figure 1 and Table 1).

Interestingly, IJH and TJH in the present study were significantly higher at halftime compared to during the warm-up for both groups. This is consistent with previous studies that found improved repeated activity test indices at halftime compared to after pre-game warm-up among trained young basketball players (Meckel, Gottlieb & Eliakim, 2009) and soccer players (Meckel, Einy, Gottlieb & Eliakim, 2014). It was speculated that the warm-up procedure might have been too short and/or not intense enough to adequately prepare the players for the all-out RJT. It was also suggested that activity during the first half of the game provided a more efficient warm-up than the actual warm-up performed by the players before the game. Thus, coaches who choose to execute an intense and aggressive game opening for their team should carefully consider warm-up procedures and various physical preparations before games.

The present study also examined relationships between RJT performance indices and aerobic capacity (measured by the 20m shuttle run test) at different stages (before, at halftime, at the end of the game) of the game. Significant correlations were found between IJH at halftime and after a full game, as well as between TJH at halftime and aerobic fitness – yet only among the children's group. In contrast, no significant correlations were found between aerobic fitness and any of the RJT performance indices at any game stage among the adolescents' group (see Table 2). It has been suggested that a high level of aerobic fitness is a requirement for improved anaerobic performance during repeated high intensity activities, and that PC re-synthesis occurs primarily by oxidative processes (Ratel, Williams, Oliver & Armstrong, 2006). However, the current findings suggest that this is valid only for children and that the aerobic system does not serve as a profound energy supplier for repeated jumping activity in adolescent players. In line with this, Meckel et al. (2015) found no significant correlations between the aerobic fitness of professional adult volleyball players and any RJT performance indices (e.g., IJH, TJH, or PD), performed after regular warm-up. The fact that significant relationships between RJT and aerobic fitness were only found among children, not adolescents, might be related to the previously mentioned greater aerobic metabolism energy supply in children, due to higher muscle tissue oxidative enzyme activity (Berg, Kim & Keul, 1986) and greater relative mitochondrial volume density (Bell, MacDougall, Billeter & Howald, 1980). Although more research should be conducted on the role of the aerobic system during intense intermittent activity, and its effect on performance-level maintenance, the present findings suggest that coaches should consider implementing a greater number of aerobic workout sessions in their training program, as a means for improving aerobic capacity among adolescent and adult players.

Conclusions

The present study indicates that adolescent basketball players reach higher absolute jumping scores compared to prepubertal players at all stages of a basketball game. However, the findings also indicate that adolescent basketball players are unable to maintain a repeated jumping activity level throughout the entire game, and they experience fatigue and significant performance reduction towards the end of the game. In contrast, prepubertal players were able to consistently maintain their jumping activity levels at different stages of the game, without presenting a reduction in their activity levels. The results also suggest that the aerobic system is a significant energy contributor to children during intermittent activity such as repeated jumps. However, the aerobic system does not seem to serve as a significant energy source in repeated jumping activities among adolescent basketball players. These findings may be applicable to coaches who are training young basketball players and are interested in implementing intense sessions that involve repeated jumping exercises. It seems that while young children are capable of sustaining long jumping sessions with only short recovery time between sets, adolescent players will have to settle for less jumps, with more frequent and longer recovery time between sets.

Future studies could benefit from investigating differences in intense repeated activity performance indices (jumping or sprinting) between children and adolescents in additional team sports such as volleyball, handball, or football.

Acknowledgments

The authors would like to thank the participants for their efforts in completing the physical tasks needed for the study. The authors would also like to thank the coaching staff for their cooperation and support during the present study.

Conflict of interest

The authors state no conflict of interest.

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