Two-year training program-induced cardiorespiratory developments in adolescent female handball players:
The importance of playing position

B. BÉRES¹**, I. GYÖRE², G. PÁLINKÁS¹, T. SZABÓ³, I. DRENJANČEVIĆ⁴,⁵ and A. KOLLER¹,⁶,⁷,⁸

¹ Research Center of Sport Physiology, Hungarian University of Sports Science, Budapest, Hungary
² Department of Sports Medicine and Health Science, Hungarian University of Sports Science, Budapest, Hungary
³ Sports Science and Diagnostic Research Centre, Hungarian Handball Federation, Budapest, Hungary
⁴ Department of Physiology and Immunology, Faculty of Medicine Osijek, Josip Juraj Strossmayer University of Osijek, Osijek, Croatia
⁵ Scientific Centre for Excellence for Personalized Health Care, Josip Juraj Strossmayer University of Osijek, Osijek, Croatia
⁶ Department of Morphology and Physiology, Faculty of Health Sciences, Semmelweis University, Budapest, Hungary
⁷ Department of Translational Medicine, HUN-REN-SE, Cerebrovascular and Neurocognitive Disorders Research Group, Faculty of Medicine, Semmelweis University, Budapest, Hungary
⁸ Department of Physiology, New York Medical College, Valhalla, NY, USA

ABSTRACT

As there are few data available, we aimed to assess the development of the cardiorespiratory system of young female athletes following a two-year training program (2y-TP) and explore the game position-specific changes. Methods: Before and after the 2y-TP body compositions of young elite female handball players (age: 14.2 ± 0.5 years, n = 33) were investigated by dual-energy x-ray absorptiometry (DEXA). The morphological changes of the heart were assessed by echocardiography, and cardiorespiratory values were investigated by spiroergometry. Results: Compared to initial values, after the 2y-TP, significant increases were found in body mass (by 8.8%), skeletal muscle mass (by 7.7%), and body fat (by 11.3%), power (by 7.8%), VO₂ (by 10.6%), VCO₂ (by 8.3%), oxygen pulse (by 13.8%), ventilation (by 13.4%), tidal volume (by 13.7%), left ventricular mass (by 24.8%), stroke volume (by 21.2%), and stroke volume normalized to the body surface (by 16.4%). Heart rate decreased (by 2.9%), whereas respiratory frequency, load time, relative power, and relative VO₂ did not change. During the test, the goalkeepers run for a shorter time than the wing players at the initial time point and after the 2y-TP. Also, the maximum heart rate did not change in goalkeepers, whereas it decreased in wing players after the 2y-TP. Thus, the goalkeepers had a higher initial VO₂ peak value than wing players, and differences, which were maintained after the 2y-TP, as well. In contrast, in goalkeepers, the relative VO₂ at the VO₂peak was initially lower than in wing players, which remained lower after the 2y-TP, as well. Conclusions: In adolescent female handball players, the 2y-TP significantly improved skeletal muscle mass, which corresponded to significant improvements of cardiorespiratory function, which were more accentuated in wing players, compared to goalkeepers, likely due to the different loads during trainings and matches.

KEYWORDS

oxygen consumption, body compositions, echocardiography, spiroergometry, heart rate, cardiac parameters
INTRODUCTION

The primary purpose of physical training in sports is to increase the performance of skeletal muscles. This, however, necessitates the improvement of the cardiorespiratory system delivering oxygen and nutrients to support the increased needs of skeletal muscles. Indeed, findings of previous studies [1, 2] suggest that aerobic training improves aerobic capacity in the game performance of adult elite players, but it does only in a moderate manner. In contrast, Mohamed et al. [3] have shown that aerobic capacity improves substantially in adolescent male handball players. For example, the average relative maximum oxygen uptake (VO₂max) of players was 50 mL/min/kg, and the average workload of a handball match was around 80% of the VO₂max. During a handball match, players cover about 5 km, at an average speed of 5 km/h. Of this, high-intensity running is 2.5% of the total distance and the intensity changes ~700 times in a handball match [4]. Due to intensity fluctuations and many activity changes, players need to have a fast recovery time, which requires a well-functioning cardiorespiratory system. It can be achieved with a high level of aerobic exercise training. Helgerud et al. [5] showed that a 7% increase in maximum oxygen uptake could also affect the tactical and technical performances of players.

It is also known that maximal oxygen uptake is affected by chronological age, maturity status, gender differences, body mass, and lean body mass [6, 7]. Based on the above, to properly interpret the development of aerobic abilities in adolescence, gender and maturity need to be considered, which is associated with lean body mass [8].

On the other hand, the morphological and physiological characteristics of handball players are related to the game positions [9, 10]. Indeed, in adult players, there were significant differences found between wing players and players of other positions regarding anthropometric and body composition parameters [11]. The best performance in motor skills and VO₂max (estimated by a 20 m shuttle run test) was observed for the backs and wing players, whereas the goalkeepers underperformed compared to other players [12]. The differences are likely due to the differences in physical load to which the players are exposed during training and matches. However, there are only a few follow-up studies regarding the development of female adolescent handball players and even fewer, if any, data exist regarding their physical and cardiovascular fitness characteristics in a position-specific manner.

We hypothesized that a two-year training program (2y-TP), will elicit substantial adaptations in the cardiorespiratory system in female handball players, which will show position-specific characteristics, as well. Specifically, we hypothesized that adaptations of the cardiorespiratory system will be more accentuated in wing players compared that of goalkeepers. Thus, we aimed to follow the anticipated changes in VO₂ max, ventilation, tidal volume, blood pressure and maximal heart rate.

MATERIAL AND METHODS

Participants

There were 60 adolescent female handball players selected to participate in the two-year training study. The players were selected by the Hungarian Handball Association. From the initially selected 60 people, 27 dropped out due to illness or injury, thus in the final study 33 players were included and who participated in the measurements in 2017 and 2019.

The Research Ethics Committee of the Hungarian Sports University (TE-KEB/27/2020) approved the research. Players were informed in advance of the nature of the measurements, their course and risks, and their parents/guardians gave their consent in writing to do the measurements.

At the time of the initial diagnostic performance measurements players had been playing handball for an average of 9.1 ± 1.6 years and their training load was on average between 8.0 ± 1.7 h and 9.9 ± 3.2 h per week after two years of training program (2y-TP), including official handball matches on weekends. All trainings were similar in intensity. The goalkeepers worked with a specific goalkeeper coach and participated in individual training.

In the present study, young female players (age: 14.2 ± 0.5 years old, menarche: 12.6 ± 1.1 year of age, n = 33) were included. They were tested in resting conditions, and spirometric measurements, dual-energy X-ray absorptiometry (DEXA) and echocardiography were obtained during the competition period. Because we aimed to demonstrate position-specific differences, a control group was not necessary to include.

Study design and procedures

Body composition was investigated by the Lunar Prodigy Primo V16 type DEXA instrument [13]. Skeletal muscle mass (kg) was calculated according to Kim et al. [14]. We investigated the skeletal muscle mass and body.

Morphological changes of the heart were assessed by a Philips IE33 type echocardiography device, in M-mode, parasternal longitudinal view [15]. Left ventricular mass (g), stroke volume (mL) and stroke volume for body surface area (mL/m²) were calculated according to Devereux et al. [16]. The echocardiographic examinations were performed by a qualified cardiologist assistant.

The cardiorespiratory data were collected during the spiroergometry test on a treadmill (Woodway Gmbh, Weil am Rhein, Germany, Mazaheri, Tavana and Halabchi, 2019). The intensity of the exercise was increased linearly every minute until maximal oxygen uptake criteria were achieved (increase in VO₂ ≤ 2.1 mL/kg/min with an increase in workload, HRmax >95%). Subjective signs and symptoms were observed, too [17]. A vita maxima protocol was used.

The load started at a speed of 6 km/h, and intensity was increased every minute by increasing the speed and the inclination. The maximum speed for girls was 10 km/h; from this point, we only increased the inclination. Jaeger CPX
The following spiroergometry variables were measured at VO2peak: load time (sec), maximum heart rate (bpm), maximum ventilation (l/min), breath frequency (1/min), tidal volume (l), maximal CO2 emissions (VCO2max) (mL/min), maximal oxygen uptake (VO2max) (mL/min), relative maximal oxygen uptake (rel. VO2max) (mL/min/kg), and maximal oxygen pulse (mL).

In addition, maximum power (watt) and maximum power normalized to body weight (relative, watt/kg) were extracted from the gas analyzer software using the following two formulas: in the first load step: power (watt) = (speed (km/h)*body weight (kg) *((2.05 + 0.29°TAN (slope)*100) −0.6*body weight (kg) −151)/10.5; and in the second load step: power (watt) = (speed (km/h)*body weight (kg)*2.11 + 0.25°TAN (slope)*100) −2.2*body weight (kg) −151)/10.5 [18].

Statistical analysis

The primary aim of our retrospective study was to write a hypothesis-generating paper, which – if promising – can be followed up with a greater scale of investigation. Thus, we have performed statistical analysis (see Tables) only if enough participants could be grouped. Values are expressed as mean ± SD. A paired-sample t-test was applied to statistically compare the results of the groups. The initial and the after two-year data of the same athlete were compared thus each athlete served as their own control. The level of significance was set at α = 0.05. Data were analyzed by using the SPSS software (Version 19.0; IBM, New York, NY, USA). As far as playing positions are regarded, we did not use a control group because we were interested in the different development of the tested person in (or of) different playing positions, having the hypothesis in mind that they develop differently due to the different physical loads during training and matches.

RESULTS

Team changes

In female adolescent athletes, the systolic blood pressure increased, whereas diastolic blood pressure decreased, consequently the pulse pressure increased after the two-year training program (2y-TP) (Table 1).

Changes in anthropometric and body composition parameters after the 2y-TP are shown in Table 2. Body mass (by 8.8%), skeletal muscle mass (by 7.7%), and body fat (by 11.3%) significantly increased. There were no changes in body height, and the percentage of skeletal muscle mass and body fat normalized to body weight.

After the 2y-TP, there were significant increases in the left ventricular mass (by 24.8%), stroke volume (by 21.2%), and stroke volume normalized to body surface (by 16.4%) as shown in Table 3.

Spiroergometry test was used to assess the exercise capacity of players. After the 2y-TP, there were significant

Table 1. Changes in resting systolic, diastolic, and pulse blood pressure after the two-year training program (2y-TP). Data are mean ± SD (n = 33)

<table>
<thead>
<tr>
<th>Values</th>
<th>Initial</th>
<th>2y-TP</th>
<th>Difference (%)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBP (mmHg)</td>
<td>110.2 ± 8.1</td>
<td>117.0 ± 10.8</td>
<td>6.5 ± 10.8</td>
<td>0.01</td>
</tr>
<tr>
<td>DBP (mmHg)</td>
<td>67.6 ± 8.0</td>
<td>64.6 ± 6.6</td>
<td>−3.6 ± 11.3</td>
<td>0.01</td>
</tr>
<tr>
<td>PP (mmHg)</td>
<td>42.6 ± 5.7</td>
<td>52.4 ± 9.4</td>
<td>24.4 ± 23.3</td>
<td>0.05</td>
</tr>
</tbody>
</table>

2y-TP: two-year training program, SBP: systolic blood pressure, DBP: diastolic blood pressure, PP: pulse pressure.

Table 2. Changes in anthropometric and body composition parameters after the two-year training program (2y-TP). Data are mean ± SD (n = 33)

<table>
<thead>
<tr>
<th>Values</th>
<th>Initial</th>
<th>2y-TP</th>
<th>Difference (%)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body height (cm)</td>
<td>171.2 ± 5.5</td>
<td>173.1 ± 5.5</td>
<td>1.1 ± 0.6</td>
<td>0.01</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>63.3 ± 7.8</td>
<td>68.7 ± 8.3</td>
<td>8.8 ± 6.7</td>
<td>0.01</td>
</tr>
<tr>
<td>Skeletal muscle mass (kg)</td>
<td>22.9 ± 2.4</td>
<td>24.6 ± 2.9</td>
<td>7.7 ± 5.2</td>
<td>0.01</td>
</tr>
<tr>
<td>Skeletal muscle mass (%)</td>
<td>36.7 ± 1.8</td>
<td>36.4 ± 2.1</td>
<td>−0.9 ± 3.9</td>
<td>0.20</td>
</tr>
<tr>
<td>Body fat (kg)</td>
<td>17.1 ± 4.2</td>
<td>18.8 ± 4.7</td>
<td>11.3 ± 16.2</td>
<td>0.01</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>26.6 ± 3.7</td>
<td>27.0 ± 4.1</td>
<td>1.9 ± 9.9</td>
<td>0.34</td>
</tr>
</tbody>
</table>
(P < 0.05) increases in power (by 7.8%), oxygen pulse (by 13.8%), VO2 (by 10.6%), VCO2 (by 8.3%), ventilation (by 13.4%) and tidal volume (by 13.7%). Maximum heart rate significantly (P < 0.001) decreased (by 2.7%), whereas load time, relative power, relative VO2 and breath frequency did not change. The investigated spiroergometry parameters at VO2peak are shown in Table 4.

Although we found significant changes in some of the morphological and physiological parameters after the 2y-TP, the mean values may not reveal the specific load-dependent adaptations. This is due to the fact, that players in various team positions are exposed to different loads during training and matches.

### Position-specific changes (results of 10 players)

We chose these two categories because we judged that the greatest differences in the development of cardiorespiratory indicators could be detected between them. Thus next we analyzed the individual spiroergometric data of goalkeepers (indicated with red color) and wing players (indicated with blue color) known to be exposed to different workloads during training and matches (Figs 1–3), to reveal the trends in changes.

Figure 1 shows that – in general – during the test, the goalkeepers ran for a shorter time than the wing players at the initial time point and after the 2y-TP. Also, the maximum

### Table 4. Changes in spiroergometric parameters at VO2peak after the two-year training program (2y-TP). Data are mean ± SD (n = 33)

<table>
<thead>
<tr>
<th>Values for VO2peak</th>
<th>Initial</th>
<th>2y-TP</th>
<th>Difference (%)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load time (sec)</td>
<td>482 ± 53</td>
<td>474 ± 50</td>
<td>−1.1 ± 11.8</td>
<td>0.33</td>
</tr>
<tr>
<td>Power (watt)</td>
<td>258.6 ± 32.7</td>
<td>277.4 ± 33.8</td>
<td>7.8 ± 10.3</td>
<td>0.01</td>
</tr>
<tr>
<td>Relative power (watt)</td>
<td>4.15 ± 0.41</td>
<td>4.10 ± 0.39</td>
<td>−0.7 ± 10.7</td>
<td>0.47</td>
</tr>
<tr>
<td>Heart rate (beat/min)</td>
<td>193 ± 9</td>
<td>188 ± 8</td>
<td>−2.7 ± 3.0</td>
<td>0.01</td>
</tr>
<tr>
<td>Oxygen pulse</td>
<td>15.2 ± 1.7</td>
<td>17.2 ± 1.8</td>
<td>13.8 ± 11.7</td>
<td>0.01</td>
</tr>
<tr>
<td>VO2peak (mL/min)</td>
<td>2,928 ± 350</td>
<td>3,218 ± 329</td>
<td>10.6 ± 10.8</td>
<td>0.01</td>
</tr>
<tr>
<td>VO2peak rel. (mL/min/kg)</td>
<td>47.1 ± 4.7</td>
<td>47.7 ± 4.5</td>
<td>1.8 ± 9.5</td>
<td>0.43</td>
</tr>
<tr>
<td>VCO2 (mL/min)</td>
<td>3,178 ± 347</td>
<td>3,422 ± 350</td>
<td>8.3 ± 10.5</td>
<td>0.01</td>
</tr>
<tr>
<td>Ventilation (l/min)</td>
<td>87.2 ± 11.5</td>
<td>98.0 ± 10.1</td>
<td>13.4 ± 13.0</td>
<td>0.01</td>
</tr>
<tr>
<td>Tidal volume (l)</td>
<td>1.77 ± 0.25</td>
<td>2.01 ± 0.28</td>
<td>13.7 ± 10.3</td>
<td>0.01</td>
</tr>
<tr>
<td>Breath frequency (l/min)</td>
<td>49.7 ± 7.2</td>
<td>49.5 ± 7.1</td>
<td>−0.1 ± 10.7</td>
<td>0.75</td>
</tr>
</tbody>
</table>

VO2peak: peak oxygen uptake; VO2peak rel.: relative peak oxygen uptake; VCO2: CO2 expiration.

Fig. 1. Changes in individual spiroergometry data (load time at VO2peak, heart rate at VO2peak) of goalkeepers and wing players (known to be exposed to different workloads) after the two-year training program (2y-TP). Figure 1 shows the initial (1) values of three goalkeepers (red) and seven wing (blue) players after the two years of training (2) regarding load time at VO2peak (left panel) and heart rate at VO2peak (right panel)
Fig. 2. Changes in individual spiroergometry data (VO$_2$ at VO$_2$peak, relative VO$_2$ at VO$_2$peak) of goalkeepers and wing players (known to be exposed to different workloads) after the two-year training program (2y-TP). Figure 2 shows the initial (1) values of three goalkeepers (red) and seven wing (blue) players after the two-year training program (2) VO$_2$peak at VO$_2$peak (left panel) and relative VO$_2$peak at VO$_2$peak (right panel)

Fig. 3. Changes in individual spiroergometry data (Ventilation at VO$_2$peak, Breath frequency at VO$_2$peak, Tidal volume at VO$_2$peak) of goalkeepers and wing players (known to be exposed to different workloads) after the two-year training program (2y-TP). Figure 3 shows the initial (1) values of three goalkeepers (red) and seven wing (blue) players after the two-year training program (2) regarding ventilation (left panel), breath frequency (middle panel) and tidal volume (right panel) at VO$_2$peak.
heart rate did not change in goalkeepers, whereas it decreased in wing players after two years. Thus, the goalkeepers had a higher initial VO2 value at VO2peak (1) than wing players, and the differences maintained after the 2y-TP (2) as well. In contrast, in goalkeepers, the relative VO2 at VO2peak were initially (1) lower than in wing players, which remained lower after the 2y-TP (2), as well.

We have found that the ventilation of goalkeepers tended to increase whereas in most of the wing players, it did not change after the two-year training program. In general, breath frequency increased in goalkeepers, whereas reduced or did not change in wing players. The tidal volume slightly increased in players of both positions.

**DISCUSSION**

The salient novel finding of the present study is that a two-year training program (and weekend matches) elicited substantial cardiorespiratory (morphological and physiological) adaptations in young adolescent female athletes (handball players) and the pilot data show that these adaptations were specific to playing position. There are few if any follow-up studies regarding the development of the cardiorespiratory system in young adolescent female handball players in response to the two-year training program (2y-TP). Thus, the present study provides important data for previous and future comparative studies for cardiovascular adaptation of adolescent female and male athletes. In addition, we aimed to reveal playing position-specific adaptations, because players in different positions are exposed to different physical loads during the training and matches.

**Adaptation of anthropometric and body composition data of all players: natural development vs. physical training**

One of the novel findings of the study is that compared to the initial values, after the 2y-TP, the absolute values of anthropometric and body composition substantially increased but there were no differences in the percentage of skeletal muscle mass and of body fat.

In the present study sample, 14-year-old players were taller than non-athletes of the same age in other studies [19] and grew only slowly between the ages of 14 and 17, whereas their weight continued to increase, while body composition did not change. The higher absolute power, i.e. physical performance of all players (Table 4) likely resulted from the higher body weight, including absolute higher muscle mass (Table 2). Previously, Manchado et al. [20] showed that body size, fat-free mass and percentage of body fat seem to be important factors in the performance of handball players; the taller players with a higher fat-free mass are more successful in the games [20]. For example, in women handball higher muscle mass is an advantage in contact situations [20]. In the present study, we observed an 8% increase in skeletal muscle mass, whereas no significant difference was found in relative fat and skeletal muscles, i.e. body composition. This is presumably because the players gained more skeletal muscles due to the two-year training, while they also gained fat tissues, likely due to puberty.

**Cardiorespiratory adaptation system of all players: natural development vs. physical training**

Regarding the cardiac parameters of all players, 1) there were increases ($P < 0.05$) in left ventricular mass (by 24.8%), stroke volume (by 21.2%), PP (by 24.4%) and stroke volume normalized to the body surface (by 16.4%), 2), similarly the VO2 related cardiorespiratory absolute values also improved, while the relative values, the breath frequency did not change, and heart rate decreased. The VO2 values were similar to previous findings [20, 21, 22].

The observed higher VO2 is associated with higher ventilation, which in general was determined by age, gender, height, and other morphological factors, as it has been shown by Rowland [23]. Namely, in adolescence, the increase in absolute oxygen uptake is related to changes in body weight, skeletal muscle mass, and capacity of the lungs and heart [23]. Indeed, we have also found that left ventricular morphology and function increased in young female handball players. Although Oliveira et al. [24] suggested that increases in heart size is due to increases in body weight at this age. The increased oxygen uptake in the present study was due to the increased skeletal muscle mass (Table 2), and higher ventilation caused by increased tidal volume (Table 4).

The observed lower maximal heart rate, higher oxygen pulse, higher relative power, and relative oxygen uptake after 2y-TP suggests adaptation of the cardiovascular system due to peripheral vascular resistance [25] and cardiac morphological changes, as shown in Table 3 (left ventricular mass, stroke volume, stroke volume for body surface).

**Training-induced adaptation of VO2**

The present study confirmed that oxygen pulse in adolescence is suitable for monitoring the development of cardiopulmonary system in athletes, as it shows morphological and functional development of the heart [26, 27]. VO2 is strongly correlated with body mass, and this is conventionally calculated by simply dividing peak VO2 (mL/min) by body mass (kg) and expressing it as the simple ratio of mL/kg/min (refs). When peak VO2 is expressed in this manner a different change is found in boys, where peak VO2 remains remarkably constant from 6 to 18 years at ~ 48 mL/kg/min, whereas this value in girls shows a decline from ~45 to 35 mL/kg/min [6]. It is interesting to note that the changes in maximum VO2 during the adolescent period observed were similar to those reported by others [19], such as it progressively increases in boys and decreases in girls [19]. These findings can be important in the interpretation of the result obtained with adolescent girls in the present study because we have found that although body weight increased relative VO2 did not (Tables 2 and 4).

The present study showed that as the result of a 2y-TP, the cardiorespiratory function of adolescent female handball
Position-specific adaptations cardiorespiratory parameters

Pilot data obtained with goalkeepers and wing players suggest that in addition to age, the 2y-TP itself also elicited adaptive cardiac development (Figs 1–3). There was a trend in wing players to perform greater aerobic capacity indicating a better adaptation (Figs 1–3). The obtained data show that goalkeepers run for a shorter time on the test (shorter load time, Fig. 1, left panel) than wing players and exert less aerobic capacity (relative VO2, Fig. 2, right panel). Maximum heart rate did not change in goalkeepers, whereas it decreased in wing players.

All goalkeepers had a higher initial value for VO2peak than wing players; differences were maintained after the end of the 2y-TP as well. In contrast, relative VO2 for VO2peak were initially lower in goalkeepers than in wing players, which remained lower after the 2y-TP, as well, due to the difference in body weight. Ventilation of goalkeepers increased, whereas in wing players – except for one – it reduced. In general, frequency of respiration increased in goalkeepers, whereas it reduced or did not change in wing players. Thus, the ventilation of goalkeepers increased by increasing the respiratory frequency. Based on these findings, we suggest that the cardiopulmonary adaptations of the players are influenced by their playing position, already at this young age. This should be considered in the evaluation of the development of players, and also when the training load is designed.

In the studied population goalkeepers trained with a specific goalkeeper coach and participated in individual training. At the beginning, their training load was on the average of 7.5 h per week and by the end of the two-year training program, it was 10.7 h per week. Also, they played matches at each weekend. For the wing players, the initial training load was an average of 7.6 ± 0.2 h per week and it was 9.4 ± 2.6 h per week after 2y-TP and matches on each weekend. Previously, Massuca et al. [28] found that goalkeepers are the slowest players and wing players are the fastest, which is required for their game performance, as most counterattacks are performed by them during the match. An average wing players run 3.8 km, while the goalkeepers run 1.7 km during a match [29].

LIMITATION OF THE PRESENT STUDY

The primary purpose of this study was to generate hypotheses for later investigation, thus we accepted some of the limitations of the study given by the circumstances, such as the limited number of players in various playing positions. Thus, we showed only trends in the changes of various parameters. Also, we do not have exact data regarding their training load as they trained at different teams and played different matches. Nevertheless, the data in this study could be added to the literature, as less female data exists especially during adolescence and the data can help the identification and development of athletes and a training program specific to player position.

CONCLUSIONS

The data of the present study demonstrate that in adolescent female athletes (handball players) a two-year training program substantially increased the capacity of the cardiopulmonary system, aiming to serve the greater metabolic needs of skeletal and cardiac muscles during physical activities (trainings and matches). Compared to goalkeepers, these adaptations were more accentuated in wing players that are exposed to greater physical load confirming the importance of playing position-specific physical training to elicit playing position-specific adaptations in the cardiopulmonary system, providing a base for better game performance. Nevertheless, further studies are necessary to elucidate the underlying mechanisms for the observed cardiovascular adaptations [30] and the differences in adaptations due to playing positions.

Conflict of interest: Akos Koller is a member of the Editorial Board of the journal. Therefore, he did not take part in the review process in any capacity and the submission was handled by a different member of the editorial board.

ACKNOWLEDGEMENTS


REFERENCES


