

Effects of specific high-intensity interval training on endurance performance on pommel horse and arm ergometer

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Published online: May 31, 2022

(Accepted for publication May 15, 2022)

DOI:10.7752/jpes.2022.05153

Abstract:

Problem Statement. While there is an agreement on specific endurance training for typical endurance sports such as running, swimming and cycling, there is a need for discussion for sports with short-term high-intensity exercise like artistic gymnastics. **Purpose.** The aim of this study was to investigate the effects of gymnastics-specific high intensity interval training on endurance performance on the pommel horse and the arm ergometer. **Materials and methods.** Endurance performance on the pommel horse was determined by the maximum number of circles, endurance performance on the arm ergometer by peak power and power at the ventilatory thresholds 1 and 2. In addition, the effect on oxygen uptake, peak blood lactate concentration and peak heart rate on the pommel horse and arm ergometer should be investigated. Eleven gymnasts (age: 15.27 ± 2.49 years; weight: 55.5 ± 12.8 kg; height: 163.5 ± 12.2 cm) from a local gymnastics club performed high intensity interval training 2 times per week for 4 weeks. The high intensity interval training consisted of ten 40 s intervals (2 x 5 upper body exercises with 90% of the maximum heart rate) and a rest period of 60 s between each interval. **Results.** The maximum number of circles (56.0 to 66.5), peak power (160.5 to 194.5 W), power at the ventilatory thresholds 1 (79.0 to 104.5 W) and power at the ventilatory thresholds 2 (132.5 to 156.0 W) increased significantly from pre- to post-test. Peak oxygen uptake shows a significant decrease on the arm ergometer (47.2 to 43.1 ml/min/kg), but no significant change on the pommel horse (42.9 to 43.2 ml/min/kg). Peak blood lactate concentration and peak heart rate show no change from pre to post test on the pommel horse and arm ergometer. **Conclusions.** The results of the study show that gymnastics-specific high intensity interval training is a time-efficient training method for improving upper body and pommel horse-specific endurance performance. **Key Words:** artistic gymnastics, high-intensity interval training, endurance training, pommel horse, maximum number of circles

Introduction

Training of specific endurance performance is an essential aspect in the development sport-specific performance as athletes in most sports need a high level of fitness to meet the physical demands of competition and to be able to use their tactical and technical skills throughout the competition (Bangsbo, 2015; Sawczyn, Biskup, Zasada & Mishchenko, 2018). While there is an agreement on specific endurance training for typical endurance sports such as running, swimming and cycling, there is a need for discussion for sports with short-term high-intensity exercise. One reason for this is that the direct study of muscle energetics during short-term high-intensity exercise is complex (Armstrong & Sharp, 2013).

Due to its load characteristics, artistic gymnastics is one of these sports. In male artistic gymnastics the routine duration on the individual apparatus (with exception of vault) ranges between 40 and 70 seconds (Seemann-Sinn, Brehmer, Naundorf & Wolfarth, 2021). Peak heart rate in the range of 160-190 bpm (Mkaouer et al., 2018) illustrates the high-intensity character of the sport. In artistic gymnastics, the goal is to achieve a high level of specific endurance in order to maintain a high intensity throughout the whole routine and to ensure a high technical quality of the movements (Sawczyn et al., 2018). Thus, the gymnast can improve his specific endurance capacity by increasing the efficiency and effectiveness of his metabolism by training specific energy systems, enzymes, substrates, mediators or metabolic pathways. (Sands, 2017).

According to older studies, anaerobic-lactic metabolism is the key criterion of gymnastics-specific endurance performance (Goswami & Gupta, 1998; Jemni, Sands, Friemel, Cooke & Stone, 2006) and aerobic power is classified as insignificant (Jemni et al., 2006). Studies from other sports with short-term high-intensity exercise like judo (Julio et al., 2017), indoor rock climbing (Bertuzzi, Franchini, Kokubun & Kiss, 2007) or rhythmic gymnastics (Guidetti, Baldari, Capranica, Persichini & Figura, 2000) show, however, that the aerobic contribution to energy supply is substantial during such exercise. Our own pilot study (Seemann-Sinn, Rüdlich, Naundorf & Wolfarth, 2021) as well as a recently published study (Kaufmann et al., 2022) on energetics in floor

exercise and pommel horse (PH) confirm the importance of the aerobic metabolism in the energy supply in artistic gymnastics. Therefore, more attention should be paid to aerobic power training in these sports. In artistic gymnastics, a change in thinking has also taken place in recent years and the training of aerobic power has gained importance (Marina & Rodríguez, 2014; Moeskops et al., 2019; Sawczyn et al., 2018).

Aerobic power training can be divided into three overlapping areas: low-intensity aerobic training, moderate-intensity training and high-intensity training, which produce different adaptations (Bangsbo, 2015). High intensity interval training (HIIT) is a training method consisting of short high-intensity exercise intervals ($\geq 90\%$ of the maximum oxygen uptake) interrupted by short rest periods, developed to train largely in the high-intensity zone (Buchheit & Laursen, 2013). Depending on the desired effect, the HIIT variables, intensity and duration of the exercise intervals as well as the duration of the rest periods, can be varied (Buchheit & Laursen, 2013). In the last few years, a large number of studies have been published which have shown positive effects of HIIT on aerobic power in children and adults. Positive effects are shown especially in maximum oxygen uptake (VO_{2max}), power at the ventilator thresholds (VT1 and VT2) and power at the lactate threshold (Engel, Ackermann, Chtourou & Sperlich, 2018; Esfarjani & Laursen, 2007; Helgerud et al., 2007; Laursen, Blanchard & Jenkins, 2002). In artistic gymnastics, HIIT as a training method for aerobic power has become a greater focus of attention (Salagas, Donti, Katsikas & Bogdanis, 2020).

An important reason for the increased focus on HIIT is the high intensity of the training method, which corresponds to the load characteristics of the discipline and enables training adaptations in the fast muscle fibers (Hoshino, Kitaoka & Hatta, 2016). Another reason for this is that the use of HIIT also allows for significant time saving compared to high-volume low-intensity aerobic training (Burgomaster et al., 2008). In artistic gymnastics, this aspect is important because there is little time for additional endurance training due to the high volume of gymnastics-specific training (about 30 hours a week) (Arkaev & Suchilin, 2009). HIIT also offers the possibility of performing endurance training with gymnastics-specific exercises, which enables a more specific endurance training. Nevertheless, there is no study which has investigated the effects of HIIT with gymnastics-specific exercises on aerobic power. Salagas et al. (2020) studied the heart rate characteristics of gymnastics-specific HIIT and concluded that gymnastics-specific HIIT is a useful endurance training method due to its heart rate characteristics. To our knowledge, there is no study which has shown that HIIT improves gymnastics-specific performance. In running, cycling, rowing, softball and hockey, this evidence of improvement in sport-specific performance has been demonstrated (Girard, Feng & Chapman, 2018). This illustrates that the evidence for HIIT with gymnastics-specific exercises as a useful training method for gymnastics-specific performance and aerobic power is limited.

The aim of the study was therefore to investigate the effects of gymnastics-specific HIIT on endurance performance on PH and the arm ergometer (AE). PH is one of the six apparatuses of male artistic gymnastics, which mainly demands the endurance performance of the arms and the upper body. Throughout the PH routine, the arms and upper body have to carry the body weight from one part of the apparatus to the other, while continuously performing different exercises and combinations (Jemni, Friemel, Lechevalier & Origas, 2000). Thus, for the PH, the endurance performance of the upper body is of primary importance. In addition to the effects on endurance performance, the influence of gymnastics-specific HIIT on cardiovascular and metabolic parameters on PH and AE was investigated.

Material & methods

Participants

Eleven male gymnasts (age: 15.27 ± 2.49 years; weight: 55.5 ± 12.8 kg; height: 163.5 ± 12.2 cm) from a local gymnastics club participated in the study. The criteria of the participants were: 1) healthy male gymnasts, 2) aged between 12 and 19 years, 3) membership in the regional or national squad, and 4) start of professional gymnastics training at the age of 6 years. The weekly training time of the participants was 24.5 ± 1.4 hours. In advance of the study, the parents and participants were informed about the experimental procedure and signed an informed consent. All procedures were conducted in accordance with the Declaration of Helsinki to ensure adherence to all standards for adequate protection and the well-being of participants.

Procedure

The study consisted of a pre- and post-test and a HIIT intervention. The pre- and post-test was performed three days before and three days after the training intervention. In the pre- and post-test, a ramp test (AET) on an arm ergometer (ergoselect 400, ergoline GmbH, Bitz, Germany) and a maximal circle test (CT_{max}) on the PH (Spieth Gymnastics, Alt-bach, Germany) were performed. In order to determine the maximum performance of the whole upper body, the AET was performed in a standing position. Depending on the gymnasts' body weight, two different protocols were performed. For gymnasts over 50 kg body weight, the AET started at 30 W for 2 minutes and then increased by 0.5 W/s. For gymnasts under 50 kg body weight, the AET started at 25 W and then increased by 0.25 W/s. The cranking frequency was set at 70 to 80 revolutions per minute for everyone. The test was stopped when the predefined cranking frequency could no longer be maintained after two requests.

The CT_{max} is a classical endurance test in gymnastics which determines the maximum number of circles. Depending on the gymnasts' abilities, the CT_{max} was performed on the PH (gymnasts ≥ 45 circles on the

PH) or the mushroom (diameter: 100 cm, height 48 cm) (Spieth Gymnastics, Altbach, Germany) (gymnasts <45 circles on the PH). This classification was made on the basis of the coaches' experience and the gymnasts' performance in the weeks before the study in order to achieve a load duration of at least 45 s in CT_{max} for each gymnast. Gymnasts who performed the pre-test on mushroom did the post-test also on mushroom.

Data collection

During and 3 minutes after AET, respiratory parameters (oxygen uptake (VO_2), carbon dioxide output and ventilation (VE)) and heart rate (HR) were measured breath by breath using a mobile spiroergometric system (K5, Cosmed Srl, Rome, Italia) and a paired pulse belt (HRM, Garmin Ltd, Schaffhausen, Switzerland). Prior to the tests, the spiroergometric system was heated and calibrated according to the manufacturer's instructions using room air, reference gas (5.0 % CO_2 and 16.0 % O_2) and a defined three-liter air volume. Peak HR (HR_{peak}) was defined as the highest value within the last 10 seconds of AET. Peak VO_2 (VO_{2peak}) was calculated as the mean value of the last 10 seconds of AET. From the measured respiratory parameters of the AET, the ventilatory thresholds 1 (VT1) and 2 (VT2) were additionally determined.

The determination of VT1 and VT2 was calculated using the progression of VE over time, whereby VT1 was defined as the first disproportionate increase in VE and VT2 as the second disproportionate increase in VE (Scharhag-Rosenberger, 2010). In order to determine the blood lactate concentration (BLA) at AET and CT_{max} , 20 μ l of capillary blood was taken from the earlobe 1 minute before the tests and at 1, 3, 5 and 7 minutes after the test and analyzed with a lactate analyzer (SuperGL analyzer, Dr. Müller Gerätebau GmbH, Freital, Germany). The VO_{2peak} at CT_{max} was determined by backward extrapolation, whereby the VO_2 data of the first 60 seconds of the post-exercise phase were extrapolated monoexponentially using the formula $y = ae^{-bx}$ (Leger, Seliger & Brassard, 1980). Before the use of backward extrapolation, the breath-by-breath VO_2 data were checked for quality and obvious outliers were manually eliminated. After this the data was smoothed over a three-breath moving average.

Training intervention

The training intervention took place during the preparation phase of the season. Over a period of 4 weeks, HIIT was performed in addition to normal gymnastics training. There were two HIIT sessions per week. Between the HIIT sessions, there was a time interval of at least 3 days. The HIIT consisted of 10 exercise repetitions with an exercise duration of 40 s and 60 s passive recovery between the exercises. The exercise intensity was set at 90 % of the maximum heart rate (HR_{max}). The HR_{max} of the gymnasts was determined by a treadmill ramp test one week before the pretest.

The ramp test started with a 2-minute warm-up. Every 30 seconds the speed was increased by 0.2 m/s. After the warm-up, the incline of the treadmill was increased by 0.6° every 30 seconds at a constant running speed until the gymnasts were subjectively exhausted. During the ramp test, the gymnast's heart rate was continuously measured using a heart rate sensor (H7, Polar Electro Oy, Kempele, Finland). The control of the exercise intensity during the HIIT was done via heart rate sensor (H7, (Polar Electro Oy, Kempele, Finland) and the "Polar Team" application on an tablet (iPad 6, Apple, Cupertino, USA), which displays the heart rate data in real time. For the HIIT, five exercises were selected which were completed two times in each session. (Tab. 1). The exercises were selected according to the following criteria: a) high equivalence to the load profile of the PH and b) achievement of the corresponding exercise intensity (Kwiatkowski, 2020). The achievement of the exercise intensity was tested in pilot studies prior to the study.

Table 1. Exercise description of the HIIT exercises

Exercise description
1. Circles on the PH or on the mushroom (diameter: 100 cm)
2. Battle Rope with alternate beating of the arms
3. Front support running with arms in the push-up position forward with the legs on slider
4. Alternating arm movement similar to cross-country skiing with a fixed bungee rope
5. Rear support running with arms and legs

Statistical analysis

The statistical analysis of the data was done using SPSS Statistics 23 (IBM®). Descriptive statistics (median and [interquartile range]) were calculated. Due to the small sample size, comparisons of the central tendency of the parameters between pre- and post were made using the Wilcoxon test. Significance was accepted at $p < 0.05$. The effect size r was calculated (Fritz, Morris & Richler, 2012) to measure the magnitude of the experimental effects, which were classified as trivial (0 - 0.09), small (0.10 - 0.29), medium (0.30 - 0.49), and large (0.50 and greater) (Cohen, 1992).

Results

During the study, 3 gymnasts dropped out due to injury or illness, so only eight gymnasts could be analyzed. The results are presented as median [interquartile range].

Peak power on the arm ergometer and maximum number of circles

After the four weeks of HIIT, there was a significant increase in peak power (P_{peak}) ($Z = -2.521$; $p = 0.012$; $r = 0.89$) from 160.5 [84.3] W to 194.5 [96.3] W in AET (as shown in Figure 1). P_{peak} increased by 21.2 % after the HIIT. In CT_{max} , the maximum number of circles increased significantly from 56.0 [15.0] to 66.5 [25.0]. ($Z = -2.521$; $p = 0.012$; $r = 0.89$). This corresponds to an increase of 18.8 % of the maximum number of circles after the HIIT.

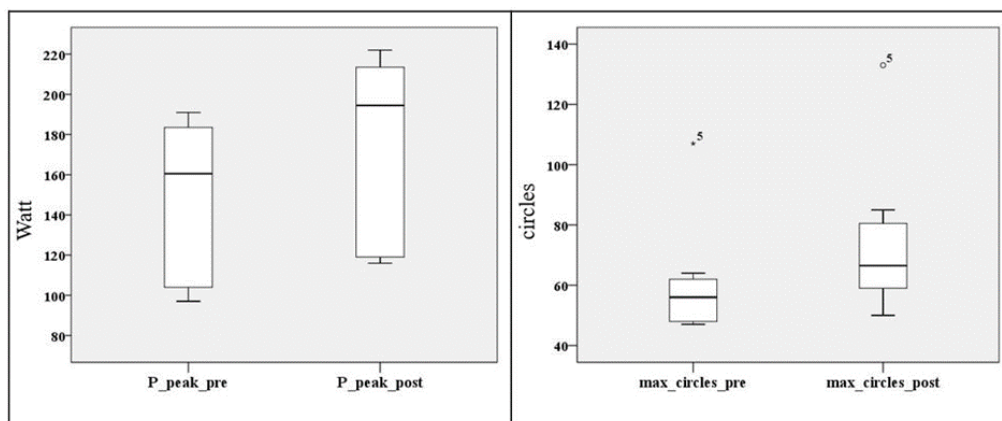


Fig 1. Changes in peak power (P_{peak}) and the maximum number of circles (max_circles) after 4 weeks of HIIT
Power at the ventilatory thresholds ($VT1$ and $VT2$)

Power at $VT1$ (P_{VT1}) significantly increased from 79.0 [49.3] W to 104.5 [48.8] W ($Z = 2.197$; $p = 0.028$; $r = 0.78$) in AET after 4 weeks of HIIT (as shown in Figure 2). This corresponds to an increase in power output of 32.3 %. The power at $VT2$ (P_{VT2}) also showed a significant increase after HIIT ($Z = -2.521$; $p = 0.012$; $r = 0.89$) from 132.5 [56.5] W to 156.0 [64.3] W. This corresponds to a power increase of 17.7 %.

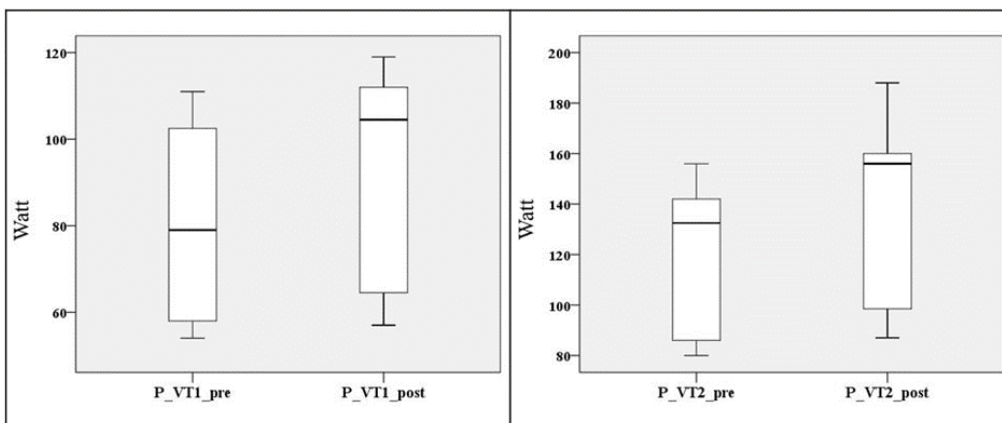


Fig 2. Change in performance at $VT1$ (left) and $VT2$ (right) in AET after 4 weeks of HIIT

Characteristic of the physiological parameters

Tab. 2 shows the changes in the peak values of the physiological parameters ($VO_{2\text{peak}}$, BLA_{peak} , HR_{peak} and VE_{peak}) in the AET and CT_{max} as well as the change in VO_2 , HR and VE at $VT1$ and $VT2$. The $VO_{2\text{peak}}$ in AET ($Z = -2.524$, $p = 0.012$; $r = 0.89$) shows a significant decrease in the post-test. The BLA_{peak} ($Z = -1.820$; $p = 0.068$; $r = 0.64$), HR_{peak} ($Z = 0.509$; $p = 0.611$; $r = 0.18$) and VE_{peak} ($Z = -0.140$; $p = 0.889$; $r = 0.05$) of AET showed no significant differences between pre- and post-test. In CT_{max} , $VO_{2\text{peak}}$ ($Z = 0.524$; $p = 0.600$; $r = 0.19$) and BLA_{peak} ($Z = 0.314$; $p = 0.753$; $r = 0.11$) show no significant difference between pre- and post-test.

At $VT1$, there are no significant differences in VO_2 ($Z = 1.680$; $p = 0.093$; $r = 0.59$), HR ($Z = 0.141$; $r = 0.888$; $r = 0.05$) and VE ($Z = -0.280$; $p = 0.779$; $r = 0.10$) between pre- and post-test. At $VT2$, VO_2 ($Z = -2.521$; $p = 0.012$; $r = 0.89$) decreased significantly in the post-test and was 15% lower than in the pre-test. HR ($Z = 0.000$; $p = 1.000$; $r = 0.00$) shows no significant difference between pre- and post-test, nevertheless in the post-test the HR is 3% lower at $VT2$ than in the pre-test. The VE at $VT2$ ($Z = -0.560$; $p = 0.575$; $r = 0.20$) also shows no significant difference between pre-test and post-test. However, the VE values at $VT2$ are 9% lower in the post-test than in the pre-test.

Table 2. VO_2 , BLA, HR and VE at AET and CT_{max} in the pre- and post-test after 4 weeks of HIIT (* = significant differences between pre- and post-test; ¹ = N 6).

	AET		CT_{max}	
	Pre	Post	Pre	Post
$\text{VO}_{2\text{peak}}$ [ml/min/kg]	47.2 [7.6]	43.1 [4.9]*	42.9 [9.4] ¹	43.2 [6.5] ¹
BLA_{peak} [mmol/l]	10.2 [3.6]	10.7 [4.9]	9.0 [1.0]	9.2 [2.5]
HR_{peak} [bpm]	192 [10]	194 [7]		
VE_{peak} [l/min]	105,9 [44.7]	108,7 [43.0]		
$\text{VO}_{2\text{VT1}}$ [ml/min/kg]	26.9 [6.1]	26.2 [6.9]		
$\text{VO}_{2\text{VT2}}$ [ml/min/kg]	40.7 [9.3]	34.8 [8.3]*		
HR_{VT1} [bpm]	151 [25]	151 [12]		
HR_{VT2} [bpm]	183 [15]	178 [15]		
VE_{VT1} [l/min]	44,1 [12.4]	42,3 [15.2]		
VE_{VT2} [l/min]	81,4 [17.5]	74,3 [33.7]		

Discussion

The aim of the present study was to investigate the effect of 4 weeks HIIT with gymnastics-specific upper body exercises on endurance performance on PH and AE. In addition, the effect on the cardiovascular and metabolic parameters VO_2 , HR, VE and BLA would be analyzed. The results of the study show that 4 weeks of HIIT with gymnastics-specific exercises, 2 times per week, significantly improves endurance performance at PH and AE. After the HIIT, the maximum number of circles in CT_{max} increased by 18.8 %. To our knowledge, this is the first study which investigates the effect of gymnastics-specific HIIT on gymnastics-specific endurance performance. The results of the study support the conclusion of Salagas et al. (2020) that HIIT with gymnastics-specific exercises is a suitable training method for gymnastics-specific endurance performance.

In the AET, there is a 21.2 % improvement in P_{peak} and a 32.3 % and 17.7 % increase in P_{VT1} and P_{VT2} . The results are thus in line with other studies which also showed an improvement in endurance performance in the AET through HIIT (Franchini et al., 2016; Schoenmakers, Reed, Van Der Woude & Hettinga, 2016; Turner et al., 2018). In the study by Franchini et al. (2016), three groups of judo athletes performed different HIIT variations twice a week for four weeks. The upper-body HIIT group also showed a significant increase in P_{peak} of 12.3%, as well as an increase in P_{VT2} of 15.0 %, which was, however, not significant. Further studies investigating the influence of HIIT on submaximal parameters (VT1 and VT2) in an AET were not found. For the upper body, Laursen et al. (2002) demonstrated an improvement in P_{VT1} and P_{VT2} in a cycling step test using HIIT. This shows that HIIT with gymnastics-specific upper body exercises can lead to similar adaptations in endurance performance to HIIT on the arm ergometer or cycle ergometer (Franchini et al., 2016; Laursen et al., 2002).

Interestingly, while previous improvements in endurance performance have been associated with an increase in $\text{VO}_{2\text{peak}}$, no such improvement was found in our study. The results of the study show that $\text{VO}_{2\text{peak}}$ after gymnastics-specific HIIT shows a significant decrease in the AET and no significant changes in the CT_{max} . These results are in line with those of Franchini et al. (2016) and Turner et al. (2018) whose study also showed no change in $\text{VO}_{2\text{peak}}$ after HIIT, but a significant improvement in endurance performance in the AET. The reason for the improved endurance performance observed in this study can be seen in the reduction of VE and HR at VT2 with a simultaneous increase in power output. This indicates an improvement in lactate buffering through improved acid-base buffering. This positive effect of HIIT on lactate buffer capacity is also described in the study by Edge, Bishop und Goodman (2006). Other explanations for the improved endurance performance could be an increased oxidation capacity of pyruvate, an increased muscle glycogen content or an increased maximum activity of citrate synthase (Burgomaster, Heigenhauser & Gibala, 2006).

The lack of improvement in $\text{VO}_{2\text{peak}}$ after HIIT in this study contradicts the results of Schoenmakers et al. (2016) who demonstrated an increase in $\text{VO}_{2\text{peak}}$ after HIIT. An increase in $\text{VO}_{2\text{peak}}$ after HIIT has also been shown in studies on the cycle ergometer or treadmill (Edge et al., 2006; Helgerud et al., 2007). One reason for the lack of increase in $\text{VO}_{2\text{peak}}$ can be seen in the difference in VO_2 uptake kinetics between upper and lower body exercise. The relatively slow response of the "fast component" of VO_2 and the relatively late onset of the slow VO_2 component in upper-body exercise compared to lower-body exercise suggests that the interval duration of upper-body HIIT which results in an improvement in oxygen uptake must be at least 2 minutes

(Schoenmakers et al., 2016). The interval duration of 40 s used in the present study thus explains the absence of $\text{VO}_{2\text{peak}}$ improvement in the AET. This also applies to the results of Franchini et al. (2016) and Turner et al. (2018) with interval durations of 20 s and 15 s. The improvement in $\text{VO}_{2\text{peak}}$ reported by Schoenmakers et al. (2016) is due to the use of a HIIT interval duration of 4 min. This shows that adequate planning of the HIIT variables must be taken into account in order to achieve the desired effects. However, this does not explain the significant decrease in $\text{VO}_{2\text{peak}}$ in the AET of the present study. The decrease is probably due to an incorrect measurement. For the K5 spirometry system used, it has been shown that older galvanic O_2 sensors can show significant variations at high loads with high ventilation in the breath-by-breath mode (Rüdrich, Wüstenfeld, Rossbach, Froberg & Wolfarth, 2019). This would also explain why there is no significant difference in VO_2 at VT1 between pre- and post-test.

The BLA_{peak} and HR_{peak} do not show any significant change after the HIIT in the AET, despite a significantly increased performance. The studies by Franchini et al. (2016) and Turner et al. (2018) also showed no change in HR_{peak} in an AET after HIIT. A study investigating the BLA_{peak} in an AET after HIIT was not able to be found. The sport-specific CT_{max} also shows no significant change in BLA_{peak} after the HIIT. The unchanged BLA_{peak} is in line with the results of Kamandulis et al. (2018). In the study reported by Kamandulis et al. (2018), an unchanged BLA_{peak} was also demonstrated after 4 weeks of HIIT in a simulated boxing match over 3 rounds. Despite an increase in sport-specific performance, it can be assumed that HIIT increased the lactate elimination rate. This assumption has been suggested by Rösler et al. (1985) but without direct scientific proof. However, an increased lactate elimination rate would be a further explanation for the improved endurance performance in the AET and CT_{max} demonstrated in the present study. The unchanged $\text{VO}_{2\text{peak}}$ and BLA_{peak} in the CT_{max} despite a significantly increased performance could also indicate an economization of the circle technique. The training of repetitive movements without great force and with a moderate metabolism can lead to an additional optimization of the movements in the process by reducing the energy requirement through the reduction of superfluous accompanying movements (Böning, Maassen & Steinach, 2017). As the normal gymnastics training was also carried out alongside the HIIT, the movement technique of the circles could have improved and thus the movement could have been economized. However, this aspect cannot be clarified further as the study did not use a control group that only performed the normal gymnastics training. However, the AET also shows a clear increase in performance which is not due to economization but to the physiological changes mentioned above. For this reason, the proven performance improvement in CT_{max} is largely due to the physiological change rather than to an improved economization.

In summary, it can be said that the factors underlying the improved endurance performance through HIIT could not be clearly clarified in the study and require further detailed investigations. However, many factors indicate an improvement in lactate buffering and elimination as the reason for the improved upper body and PH-specific endurance performance. Furthermore, it should be noted that the HIIT in this study was carried out in addition to the normal gymnastics training. Therefore, it could be that a part of the performance increase is due to the normal gymnastics training. In future studies, a control group should be used to eliminate this effect.

Conclusions

For the sports practice, it can be noted that four weeks of HIIT with gymnastics-specific exercises improves the endurance performance of young gymnasts on the PH and the arm ergometer. Improvements can be seen especially in the maximum number of circles, which is an important parameter of the pommel horse-specific endurance performance diagnostics, the P_{peak} , the P_{VT1} and P_{VT2} . Therefore, HIIT with gymnastics-specific exercises is a useful training method for improving upper body and pommel horse-specific endurance performance. A higher specific endurance performance is an important parameter for gymnast-specific performance as it helps to reduce the muscular fatigue that occurs during a gymnastics routine. Gymnasts who are not properly conditioned struggle to perform the exercises to their full potential, often leading to technical errors in skills and falls in competition. This leads to lower scores and therefore to lower gymnastics-specific performance. With a total time expenditure of approximately 20 min per week, the time required for this training method is low, so the coaches have sufficient time for element-specific gymnastics training. If the goal of a HIIT is to improve upper body $\text{VO}_{2\text{peak}}$, it has been shown that an interval duration of 40 s does not produce an improvement. In this case, an interval duration of at least 2 minutes seems to be necessary. Since this study showed an increase in specific endurance performance without an increase in $\text{VO}_{2\text{peak}}$, the improvement in performance at the ventilatory thresholds seems to be an important goal for gymnastics-specific endurance training.

Conflicts of interests

The authors declare no conflicts of interests with respect to the research, authorship and publication of this article.

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