Effects of whole-body high-intensity interval training and different running-based high-intensity interval training protocols on aerobic capacity and strength endurance in young physical education students

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Abstract:
High Intensity Interval Training (HIIT) sessions effectively improve aerobic fitness in children and adolescents in relatively short time. Circuit Training arrangements using highly intensive whole-body drills may reach similar results and may seem an appropriate training method for Physical Education settings. So far, only few studies compared the effects of running-based HIIT intervals lasting less than one minute and whole-body circuit training with a control group. This intervention study examined the effects of 12 units of running-based HIIT protocols (10x1 min vs. 15x30 sec.) and a Circuit training regimen implemented over 12 weeks within regular P.E. lessons. 108 students from two secondary schools in Baden Württemberg and Niedersachsen took part in the study. Pre and posttests were conducted to determine training effects with regard to VO_{2max} and strength endurance. The results showed significant improvements in aerobic fitness (+ 5-9%) and strength parameters for all training groups (HIIT 1: $t(28) = -1{,}886$, $p < 0.05$; HIIT 2: $t(27) = -2{,}631$, $p < 0.01$; CIRCUIT: $t(25) = -2.834$, $p < 0.01$). Ultrashort intervals and circuit training based on whole-body drills were perceived as significantly more motivating by the students than longer intervals lasting 60 seconds ($g = 0.21$, 95% CI 0.055-0.356, $p < 0.001$).
Key Words*:* **High Intensity Interval Training; Whole Body Drills; Circuit Training; Physical Education; Cardiorespiratory Fitness**

Introduction

Children and adolescents spend a lot of time sedentarily or inactively (Bauer et al., 2022; Fox et al., 2004). Worldwide, 81% of the children do not reach the WHO recommendations for moderately intensive activities and strength training according to their age group (Guthold et al., 2020). For example, in Germany motor and conditional abilities of young students are therefore underdeveloped (Albrecht, 2016; Hanssen-Doose et al., 2020) and an increasing number of them show low levels of cardiorespiratory fitness (Engel, Wagner, et al., 2018). Low levels of fitness are problematic since they positively correlate with morbidity and mortality from all causes, obesity and cardiovascular diseases (Atakan et al., 2022). They are also associated with a more detrimental health status later in life (Albrecht, 2016).

Schools and physical education (P.E.) settings could help increase students' aerobic fitness levels by implementing highly efficient and motivating endurance training methods. Since time-consuming training sessions are considered a barrier to regular engagement in endurance training (Ai et al., 2021) and adherence to classical high volume training methods therefore is usually low (Menz et al., 2019), High-intensity Interval Training (HIIT) sessions have the potential to increase students' motivation for participating in endurance training programs. HIIT consumes a fraction of training time that MICT (Moderate-intensity Continuous Training) sessions require (Su et al., 2019) and can be regarded as a suitable training method in the P.E. setting due to fast physiological adaptations and multiple positive side effects, for example improved executive functions (Kunz et al., 2019).

HIIT has repeatedly been proven to induce significant improvements in cardiorespiratory fitness in relatively short time (Eather et al., 2019; Engel, Wagner, et al., 2018). It is characterized by short and highly intensive training intervals with heart rates above 90% of an individual's peak heart rate. The intervals last between 10 seconds and 5 minutes and are interspersed by rest periods or low-intensity activity ranging from 15 seconds up to 3 minutes (Buchheit & Laursen, 2013; Engel, Wagner, et al., 2018; Wahl et al., 2010). The ideal ratio between training and recovery periods is defined as 1:1 or 2:1 (Engel, F., Sperlich, B., 2014). Ultrashort exercise intervals have recently successfully been used (Menz et al., 2019), even though research focusing on intervals lasting less than one minute is scarce.

Effects of HIIT sessions on various cardiorespiratory fitness parameters (peak oxygen uptake, maximal running performance, running performance at lactate threshold, anaerobic power output, increased stroke volume, heart rate recovery) have been numerously studied and confirmed in recent years (Atakan et al., 2022; Cao et al., 2019; Costigan et al., 2015a; Eather et al., 2019; Engel, Ackermann, et al., 2018; Kunz et al., 2019; Su et al., 2019). Previous studies showed that HIIT sessions can improve cardiorespiratory fitness and maximal oxygen consumption in endurance athletes (Mallol et al., 2019; T. L. Stöggl & Björklund, 2017; T. Stöggl & Sperlich, 2014), moderately or untrained adults (Burgomaster et al., 2008; Eather et al., 2019; Helgerud et al., 2007) and adolescents and children (Bauer et al., 2022; Cao et al., 2019; Engel, Ackermann, et al., 2018; Kunz et al., 2019). Several authors could show similar (Su et al., 2019) or even better cardiorespiratory improvements compared to MICT in settings with adults, adolescents and children (Cao et al., 2019; Costigan et al., 2015a; Engel, Ackermann, et al., 2018; Kunz et al., 2019).

In a meta-analysis, Cao et al. (2019) compared the effects of HIIT and MICT on cardiorespiratory fitness in adolescents and children. A total of 563 subjects from 17 studies were included in the analysis. The authors concluded that HIIT induces greater improvements of aerobic fitness among children and adolescents compared with MICT. Also, similar or even better effects with regard to cardiovascular risk factors, fat reduction, mitochondrial biogenesis and strength endurance capacity could be documented (Atakan et al., 2022; Gist et al., 2014; Kunz et al., 2019; Menz et al., 2019; Su et al., 2019). Such factors are generally associated with better metabolic health (Atakan et al., 2022).

However, classical exercise contents such as running, cycling or swimming may be perceived as unenjoyable, especially by young students. Short, intense and varying whole-body drills as a form of functional training are becoming increasingly popular and may be more motivating and challenging for children and adolescents (Bossmann et al., 2022). They can be implemented in P.E. lessons without much equipment and space and be applied indoors as well as outdoors.

Unlike traditional running-based HIIT sessions, training benefits of HIIT programs based on whole-body drills go beyond increasing aerobic capacity. Other physical abilities like strength endurance can be improved simultaneously (Bossmann et al., 2022; Menz et al., 2019). Several studies showed similar or slightly better cardiorespiratory adaptations of whole-body high intensity interval training compared to traditional HIIT sessions based on running and MICT in healthy men (Menz et al., 2019; Schaun et al., 2018), women (Buckley et al., 2015; McRae et al., 2012; Menz et al., 2019; Myers et al., 2015) and children (Bossmann et al., 2022).

However, the ideal composition of exercise content, exercise intensity and number of intervals for optimizing HIIT sessions still remains equivocal. Paquette et al. (Paquette et al., 2017), for example, documented similar adaptations of VO_{2max} when using submaximal (85% of maximal aerobic power) versus supramaximal (115% of maximal aerobic power) training intervals in moderately endurance trained men. Especially in the school setting, research on the optimal composition of HIIT sessions is still scarce. Most of the previous studies conducted with students lacked a control group, so that alternative reasons for performance improvements could not be ruled out. Also, only few studies conducted with children and adolescents directly compared different training contents (running versus whole-body drills) or included training intervals lasting less than one minute.

Training programs used in P.E. lessons should induce optimal physiological adaptations and be as inviting and motivating as possible. Therefore, this study aims at comparing the effects of three 7-week-long endurance training interventions (HIIT 1: 10 x 1 minute of running-based HIIT Training; HIIT 2: 15 x 30 seconds of running-based HIIT Training; CIRCUIT: 10 x 1 minute CIRCUIT Training using whole-body-drills), conducted in a regular P.E. setting, on endurance and strength endurance parameters.

Assuming that the main stimulus for increased aerobic capacity is training intensity (Engel, Ackermann, et al., 2018), we hypothesized that a circuit training session using whole-body-drills may induce similar or better effects on aerobic capacity and strength endurance parameters like a similarly designed running-based HIIT session. Also, we assumed that even ultrashort training intervals lasting 30 seconds may have similar training effects as intervals lasting 1 minute, even when total training time is considerably shorter.

Material & methods

A randomized controlled study with 118 female and male young students (mean age: 11,4 years) of two secondary schools in Germany (Baden-Württemberg and Niedersachsen) was carried out from September 11th, 2022 until December 9th, 2022. All participating students attended grade 5 or 6 of their school. Due to various reasons (absence and missed training sessions), data from 10 students had to be removed before statistical analysis could be conducted.

All participants were physically healthy. The study was implemented in regular Physical Education (P.E.) lessons and the students' P.E. teachers instructed the training sessions. All teachers had been fully informed on how to guide the training sessions prior to the study. The given study is in line with existing school curricula in Baden Württemberg and Niedersachsen, which prescribe fitness training and whole-body exercises to enhance students' conditional abilities in P.E. lessons.

We received permission to conduct this study from the relevant educational organizations. Children and their parents had been informed on the scope and content of the study at the start of the school year. The study protocol complied with the ethic code of the World Medical Association for experiments with human beings, the declaration of Helsinki (WMA, 2013).

The published study included a pretest containing Luc Léger's shuttle run test and four tests on strength endurance based on the German Motoric Test protocol (Deutsche Vereinigung für Sportwissenschaft, 2009). After the pretests, the four participating classes were randomly assigned into one of four groups. Three training groups conducted either running-based HIIT sessions or a Circuit training consisting of whole-body drills. One group functioned as a control group. Students in this group participated in regular P.E. lessons without specific strength or endurance training. A final posttest was assessed the training adaptations. The posttest was similar to the pretest and terminated the study.

All fitness tests were conducted by teams consisting of at least two P.E. teachers of the participating schools. All teachers had been instructed on how to guide through the fitness tests prior to the study and were handed out the test protocols in written form. The training sessions of the three experimental training groups were integrated at the beginning of the P.E. lessons and carried out in a standardized form. The warm-up program consisted of 3 minutes of various coordination exercises, slow running and 2 minutes of stretching exercises including legs, hips and upper body. The main part consisted of either a running course (which was exactly similar for the two running-based HIIT groups) or the Circuit training.

During the 7-week training program, each experimental group completed 12 training sessions in total (twice a week). After each lesson, the students' level of motivation and their level of perceived exhaustion was determined via training protocols and the modified BORG-CR-scale. After the training intervention, the students were asked to evaluate their general level of motivation for the training and could suggest improvements.
In order to compare the effects of each training program, a control group attending regular P.E. lessons that excluded HIIT training was used. This group underwent the same testing procedures (pre- and posttest) as the other three groups. Only data from students who had completed at least 10 training sessions and completed both fitness tests had been included in the statistical analyses.

Pre and Posttests

The following test procedures of the German Motoric Test (Deutsche Vereinigung für Sportwissenschaft, 2009) were applied:

- Number of Pushups carried out within 40 seconds
- Number of Situps performed within 40 seconds
- Distance covered with a Standing Long Jump
- Number of Lateral Side Jumps (two-footed) conducted within 15 seconds
- Running performance determined via Luc Léger's shuttle run test (Léger et al., 1988)

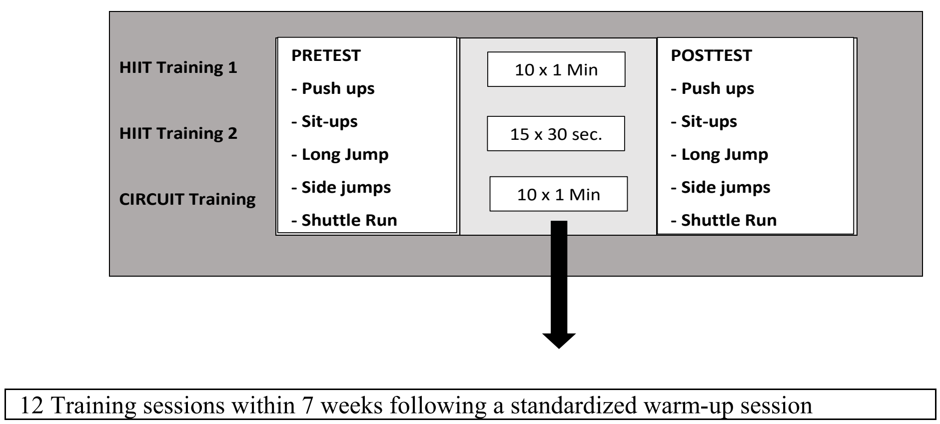

Figure 1. Study design

According to Bös and Tittlbach (Bös, 2016), the German Motoric Test has the following test quality criteria: Objectivity: mean value of correlation coefficient (r) for all 8 test items = .95; test-retest-reliability: r = .82; content-related validity (expert rating on a scale from 1 (very good) to 5 (poor): 2.1 for validity, 1.8 for feasibility. The shuttle run test is recommended by the Institute of Medicine (IOM) (Pate et al., 2012) as the most accurate and appropriate field-based measure of cardiorespiratory fitness in young people and shows a high degree of standardization. The test-retest reliability is stated with a medium coefficient of r = .86. The correlation with the maximal oxygen uptake capacity is r = .73 (Bös, 2016).

The students had to run back and forth between two flags marking a 20-meter running section. Acoustic signals indicated the pace students had to adhere. The running speed increased every minute by 0.5 kilometers per hour (km/h) and started at 8 km/h. The acceleration was signaled by shortened intervals between the acoustic

signals. When the students were running too fast, they had to wait at the flag for the next beep. The test was being terminated when the flags could not be reached three consecutive times in a row.
The maximal running speed (max. speed = MS) was converted into maximal aerobic speed (MAS) according to a formula introduced by Billat and Koralsztein (Billat & Koralsztein, 1996):
MAS = 2.4 x MS – 14.7

Training intervention

HIIT Training 1 (experimental group 1) consisted of 10 x 1 minute of running interspersed by breaks lasting 40 seconds. The total training duration was 16 minutes. HIIT Training 2 (experimental group 2) consisted of 15 x 30 seconds of running interspersed by breaks lasting 30 seconds. The total training duration was 15 minutes. The students were encouraged to maintain a high intensity of 90% of their HR max. The standardized request for the students was to run each interval 'almost as fast as you can'.
Both running-based training programs were conducted within a running course depicted in figure 2.

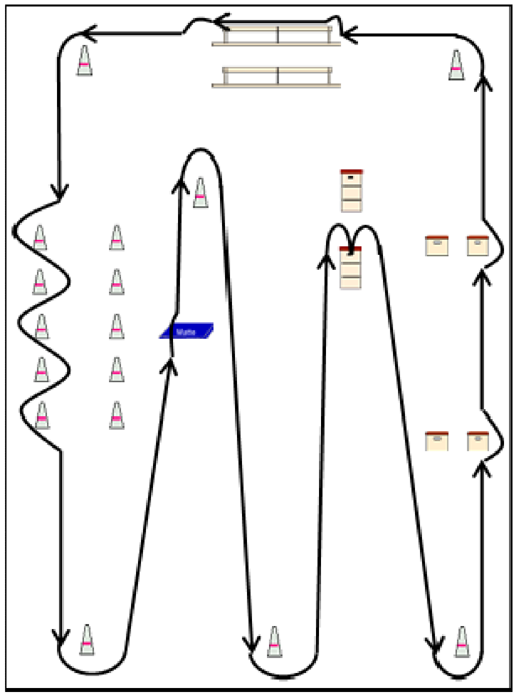

Figure 2. Running course

The Circuit Training was conducted at 10 different stations. At each station, the students performed a given whole-body drill for 60 seconds (see: Appendix A: Training program), interspersed by recovery break of 40 seconds. The standardized instruction was to exercise "almost as intensively or fast as you can". Training parameters were similar to the running-based HIIT group 1.

There were no changes in the design of the lessons in which the training sessions took place. After each lesson, students estimated their motivation and rating of perceived exhaustion (RPE) on a scale from 0-10 using the modified BORG-CR-scale (Williams, 2017).

Statistical Analyses

All data were depicted as mean values +/- standard deviation (Appendix B). The differences between pre- and posttests had been checked for normal distribution via Shapiro-Wilk-Test and the used data was checked for equality of error variance with the Levene-Test. Differences between pre- and posttests (MAS / Strength parameters) within and between the four groups were analyzed via t-tests. The level of significance was set at $p < .05$, the tests were conducted one-sidedly since improvements were to be expected.
The statistical analysis was conducted with SPSS, Version 25.

Results

Only data from students participating in at least 10 training sessions were included in the statistical analysis. Thus, data from 10 students had to be excluded from the original data set.

Shuttle run test

HIIT group 1 (10 x 1 Min) reached a performance increase in maximal aerobic speed (MAS) of 4.5%, HIIT group 2 (15 x 30 sec.) of 5.6% and the CIRCUIT group of 8.9%. The control group showed a performance decrease of 4.8%. The increase in aerobic performance through the training intervention was statistically significant for HIIT group 1 (10 x 1 Min.), HIIT group 2 (15 x 30 sec.) and for the CIRCUIT group:

- HIIT group 1 (10 x 1 Min), t(28) = -1,886, $p < 0.05$
- HIIT group 2 (15 x 30 sec.), t(27) = -2,631, $p < 0.01$
- CIRCUIT (10 x 1 Min), t (25) = -2.834, $p < 0.01$

Strength parameters

In **HIIT group 1** (10 x 1 Min), significant positive adaptations could be shown in regards to Lateral Side Jumps, Pushups and Situps. No significant improvements could be shown for the Standing Long Jump.

- Lateral Side Jumps: t(28) = -4.70, $p < 0.05$
- Pushups: t(28) = -1,81, $p < 0.05$
- Situps: t(28) = -0.95, $p < 0.05$

In **HIIT group 2** (15 x 30 sec.), significant improvements could be shown regarding Situps and Pushups. There were no significant improvements in Lateral Side Jumps the Standing Long Jump.

- Situps: t(27) = -2.87, $p < 0.05$
- Pushups: t(27) = -2.28, $p < 0.05$

In the **CIRCUIT group**, significant improvements could be shown in Lateral Side Jumps, Pushups and Situps. There were no significant improvements in the Standing Long Jump.

- Lateral Side Jumps: t(25) = -2.883, $p < 0.01$
- Pushups: t(25) = -3.101, $p < 0.01$
- Situps: t(25) = -1.774, $p< 0.05$

In the **CONTROL group**, significant improvements in Situps and Lateral Side Jumps could be documented.

- Lateral Side Jumps: t(24) = -4.631, $p < 0.01$
- Situps: t(24) = -2.683, $p < 0.01$

Figures, Tables and Schemes

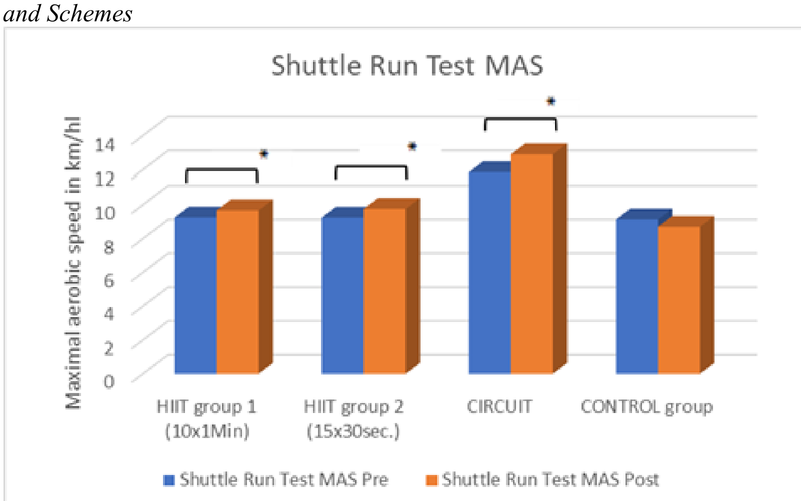

Figure 3. Changes in aerobic endurance capacity within groups. *significant difference between pre- and posttest ($p < 0.05$)

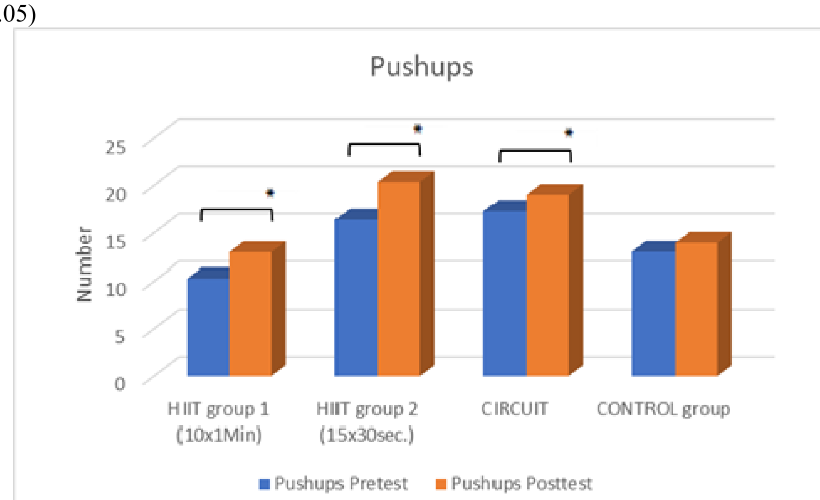

Figure 4. Changes in number of Pushups within groups. *significant difference between pre- and posttest ($p < 0.05$)

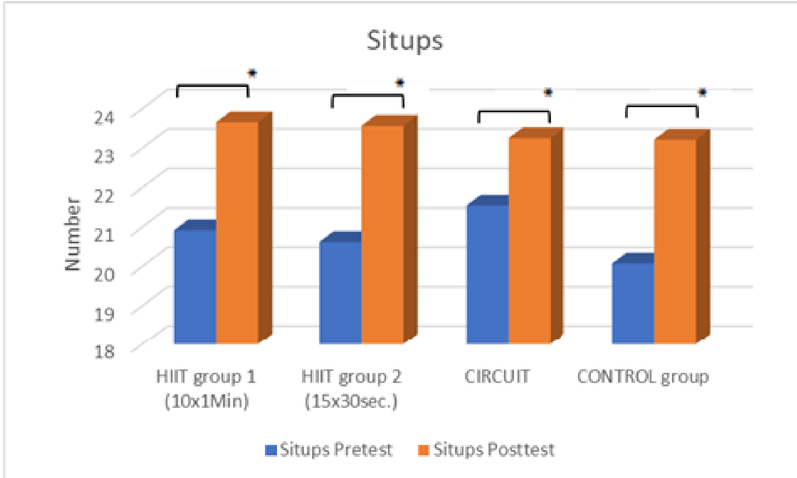

Figure 5. Changes in number of Situps within groups. *significant difference between pre- and posttest ($p < 0.05$)

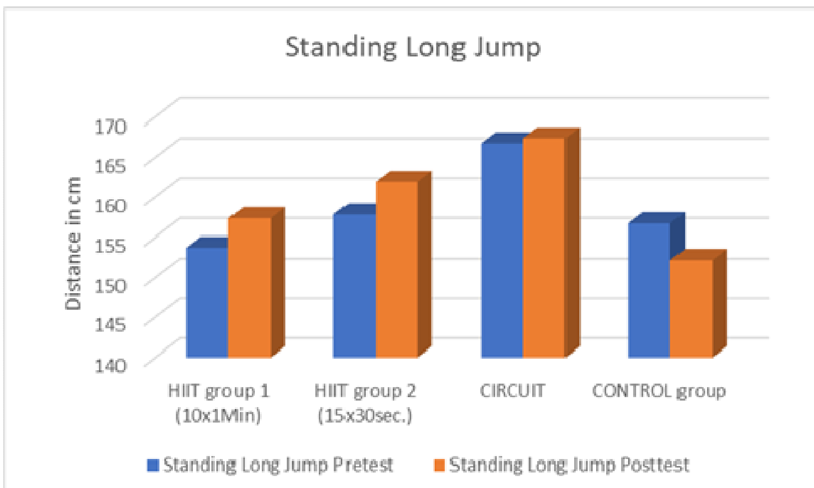

Figure 6. Changes in distance covered with Standing Long Jump within groups. *significant difference between pre- and posttest ($p < 0.05$)

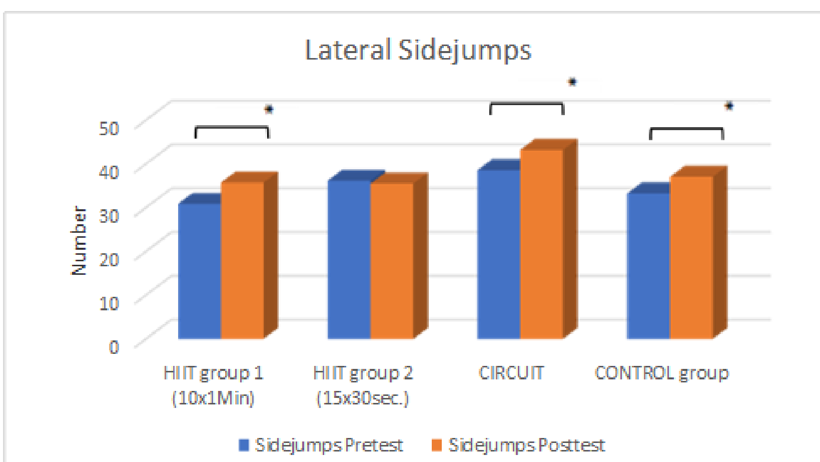

Figure 7. Changes in number of Lateral Side Jumps performed in 15 seconds. *significant difference between pre- and posttest ($p < 0.05$)

Table 1. Mean values and standard deviation of performance parameters evaluated via Pre- and Post-Tests for all three intervention groups and the control group								
	HIIT 1 (10x1 Min.) (n= 29)		**HIIT 2 (15x30 Sec.) (n=28)**		**CIRCUIT HIIT (n=26)**		**Control GROUP (n=25)**	
Sex	14 boys, 15 girls		14 boys, 14 girls		16 boys, 10 girls		12 Boys, 13 girls	
Mean age	11.9		11.3		12.2		11.7	
Parameter	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest
Endurance Capacity (MAS)	9.25 +/- 1.99	9.67* +/- 2.36	9.24 +/- 1.63	9.76* +/- 1.72	11.85 +/- 2.10	12.90* +/- 2.32	9.13 +/- 2.15	8.70 +/- 1.93
Lateral Side-jumps	30.85 +/- 6.50	35.72* +/- 5.67	35.83 +/- 5.83	35.50 +/- 6.33	38.54 +/- 5.73	43.19* +/- 8.17	33.25 +/- 5.53	37.04* +/- 5.96
Pushups	10.27 +/- 5.87	12.59* +/- 8.02	17.06 +/- 8.35	20.38* +/- 10.30	17.25 +/- 3.77	19.00* +/- 3.62	13.00 +/- 7.02	13.93 +/- 7.71
Situps	20.91 +/- 5.89	23.65* +/- 6.34	20.06 +/- 6.42	23.56* +/- 6.09	21.54 +/- 5.42	23.25* +/- 5.79	20.07 +/- 5.70	23.21* +/- 4.25
Standing Long Jump	153.74 +/- 20.31	157.35 +/- 28.66	158.83 +/- 24.36	161.94 +/- 35.32	166.79 +/- 21.00	167.42 +/- 21.91	156.71 +/- 18.95	152.21 +/- 17.19

*** Significant difference between pre- and posttest ($p < 0.05$)**

Discussion

Traditional running-based HIIT training interventions have often been shown to increase aerobic and anaerobic performance even more effectively than MICT (Cao et al., 2019). The documented improvements in aerobic performance for the implemented running-based training protocols (4.5% for HIIT group 1; 5.6% for HIIT group 2) confirm the initial assumption that ultrashort training intervals lasting shorter than one minute can have similar training effects with regard to aerobic capacity compared with longer intervals. The results are in line with comparable studies focusing on children and adolescents (Atakan et al., 2022; Bauer et al., 2022; Bossmann et al., 2022; Delextrat & Martinez, 2014; Engel, Ackermann, et al., 2018; Engel, F., Sperlich, B., 2014). Engel at al. (2018) conducted a meta-analysis involving 577 adolescent athletes training with running-based HIIT sessions and could show average improvements of VO_{2peak} of 7.2%. Alternative interventions based on MICT methods led to smaller improvements with significantly more extensive training time (Buckley et al., 2015; Gist et al., 2014; Gist et al., 2015).

In the presented study, the CIRCUIT training group reached the largest improvement in aerobic capacity (8.9%). The assumption, that circuit training with whole-body exercises can be equally effective as running-based training could be confirmed. Similar improvements of VO_{2max} of around 9-11% could be shown in previous studies implementing whole-body drills over a time period of 4-16 weeks (Bossmann et al., 2022; Jeneviv et al., 2022; Menz et al., 2019; Myers et al., 2015; Schaun et al., 2018). A meta-analysis on the effects of resistance training involving large muscle groups on aerobic capacity showed comparable effects (Leslie et al., 2012). Lower improvements of VO_{2max} through whole-body drills were documented in studies with army cadets (Gist et al., 2015), recreationally active females (Buckley et al., 2015; McRae et al., 2012) and sedentary young females (Myers et al., 2015).

Jeneviv et al. (2022) analyzed the effects of moderately intensive (50-70% of HR_{max}) whole-body training intervals including resistance and aerobic exercises. VO_{2max} of the investigated obese undergraduates improved by 10% over a training period of 6 weeks. In a similar study to ours, Costigan et al. (Costigan et al., 2015b) used ultrashort intervals of 30 seconds (ratio of exercise and breaks: 1:1) and similar exercises as the CIRCUIT group. Here, aerobic capacity improved by only 6%. In contrast to the presented study, no improvements in strength parameters could be shown. Contradictory findings showing no substantial training adaptations were published elsewhere by Schmidt et al. (2016). The authors examined the effects of a high intensity circuit training regimen in 106 active college students and could not document any changes in aerobic capacity.

The ideal composition of training parameters in HIIT sessions requires further research. Slight increases in the duration of training intervals of approximately 15% can lead to a substantial increase in glycolytic anaerobic system requirements and a substantial increase of lactate production (Florian & Hurych, 2022).

However, the presented results suggest that training intensity seems to be more relevant than interval duration, as Cao et al. (Cao et al., 2019) report. One possible explanation is presented by Wahl et al. (Wahl et al., 2010) who assume that the main stimulus for morphologic adaptation of the myocardium is a mechanical overload of the heart muscle caused by an increased resistance during heart strokes. This mechanical overload could only be reached by high intensities.

However, the precise physiological mechanisms explaining the superiority of this training method are still equivocal. Some authors assume that intracellular signaling sequences caused by the increased muscular stimulus would lead to an increase in the 5-AMP-activated protein kinase (AMPK) activity in muscle cells and an increase in peroxisome proliferator activated receptor-γcoactivator-1α (PGC-1α) mRNA and protein, an increase in the mRNA and protein expression of the mitochondrial oxygenation enzyme and eventually to an improvement in aerobic capacity (Atakan et al., 2022; Terada et al., 2005). It is also speculated that a higher training intensity would lead to larger responses on cellular and molecular levels, leading to a partial recovery from endothelial dysfunction (Hanssen et al., 2015; Ito, 2019).

Some authors address possible health risks through prolonged HIIT units and question the feasibility for obese or unathletic students (Atakan et al., 2022). Martland et al. (2020) conducted a meta-analyses to establish the benefits, safety and adherence of HIIT interventions across all populations. According to their review based on 33 systematic reviews on the topic, HIIT not only improves cardiorespiratory fitness and anthropometric measures, but also blood glucose, glycaemic control, arterial compliance, vascular function, and some inflammatory markers. Improvements in anxiety and depression were also seen compared to pre-training. No acute injuries were reported, and mean adherence rates surpassed 80% in most systematic reviews (Martland et al., 2020).

Whatever physiological reasons eventually cause the high efficiency of HIIT, the most important training parameter seems to be training intensity. Any form of physical exercise leading to (sub)maximal heart rates will eventually, when conducted regularly, lead to highly efficient adaptations of VO_{2max}. Since aerobic capacity is the strongest predictor of future health and all-cause mortality, this training form can be recommended for P.E lessons and young students. HIIT sessions can be realistically tolerated by people with a sedentary lifestyle, independent of prevalent obesity, fitness level or age (Ito, 2019).

Practical consequences for Physical Education settings in schools

The students participating in the presented study perceived their level of motivation differently according to the used training regimen. Students in HIIT group 2 (15x30 sec) and the CIRCUIT group rated their motivation during training sessions significantly higher than HIIT group 1 (10x1 Min.) (g = 0.21, 95% CI 0.055-0.356, $p < 0.001$). On a Likert scale ranging from 0-3, HIIT group 2 reached a value of 2.7, the CIRCUIT group of 2.6. HIIT group 1, which trained with the longest intervals, reached a value of 1.8.

Continuous low intensity physical activity may not sufficiently motivate young people (Segovia & Gutiérrez, 2022), so that HIIT sessions using shorter intervals or whole-body drills are recommended for the specific context of P.E. lessons. It seems obvious that training forms which can additionally enhance muscular performance and strength endurance capacity are advantageous, especially in a context where time and space is scarce. In the presented study, the running-based training interventions reached similar improvements regarding strength parameters as the CIRCUIT group. This seems somewhat surprising, because only in the CIRCUIT group were whole-body drills included. However, since this training intervention took place in a regular P.E. setting, we could not control for the entire content of the lessons. Improvements in strength parameters for the running-based groups can very well be explained with additional exercises performed during the rest of the lessons. This may, at least to some extent, be true for the increase in aerobic performance in any training group.
This study, however, could document that school-based training interventions and programs can have great health promotion potential to increase physical fitness levels in students. P.E. lessons can be considered the ideal context to enhance students' physical activity levels (Segovia & Gutiérrez, 2022). In no other context, can a larger percentage of children and teenagers be reached than in the school setting. Small-sided games, as suggested by Feigenbaum et al. (Faigenbaum et al., 2020) and whole-body drills seem to be a beneficial and a more motivating alternative than other forms of running-based training.

The presented study suggests that HIIT sessions including highly intensive whole-body drills lead to significant adaptations in endurance and strength capacity and show similar results to traditional running-based HIIT programs. Shorter training intervals seem to be more motivating for young students than longer intervals – and equally effective.

Limitations

Since this study was being conducted during regular P.E. lessons, it was not possible to randomly assign students according to their aerobic fitness levels. However, except for one training group (Circuit), initial fitness levels were almost identical between groups.

Secondly, this study, as most studies conducted in the P.E. setting, lacked objective measurement of training intensity. Therefore, it was impossible to ensure that each individual student reached heart rates of above 90% of HR_{max}. Students were encouraged to run or perform the drills 'almost as intensively as possible'. However, subjective observations during the lessons were in line with objective data on students' perceived level of exhaustion: Not all students seemed to have reached the necessary intensity level. Accordingly, even slightly lower training intensities can lead to significant adaptation of VO_{2max}, as documented elsewhere (Jeneviv et al., 2022). Still, reliable heart rate monitoring during tests and training sessions could ensure a more objective recording of training intensity and estimation of the level of exhaustion the participants reach.

Also, complex diagnostic procedures which may assess students' fitness and health related parameters more accurately cannot be conducted in the school setting due to ethical reasons. However, indirect performance measurements like Léger's Shuttle Run Test reliably indicate an increase in aerobic capacity. The test was specifically developed for children and teenagers and shows a high accuracy when predicting VO_2 max (Léger et al., 1988).

Conclusion

P.E. lessons face multiple organizational challenges and teachers have to take into account complex demands and educational goals. Improving physical fitness is just one relevant goal mentioned in German school curricula. However, if lessons are aiming at improving aerobic capacity and physical fitness in students, HIIT is an efficient and feasible method. It seems to be more suited than volume-oriented endurance training – in terms of motivational and physiological training effects.

Evidence from this study highlights the potential of implementing circuit training contents to additionally improve strength capacity in students. The contents of circuit sessions can be individually adapted according to students' fitness levels and interests. Interval lengths of 30 seconds only are enough to significantly improve VO_{2max} and strength endurance capacity. The present study shows that P.E. lessons may significantly contribute to students' health if ultrashort HIIT sessions or HIIT based on whole-body drills are being implemented.

Long-term effectiveness and possible risks of HIIT sessions should be evaluated in future studies with longer follow-up periods. Also, future studies should include heart rate measures during training to ensure that all participants reach the given training intensity of HIIT protocols.

Conflicts of interest

All authors consent final approval of the version to be published and agree to be accountable for all aspects of the work. They ensure that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Informed Consent Statement: Informed consent was obtained from parents of all students involved in the study. Written informed consent has been obtained from the participants' parents to publish this paper" if applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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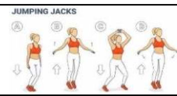
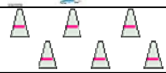
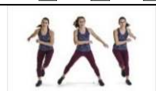
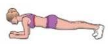
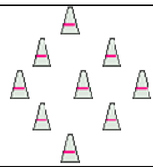
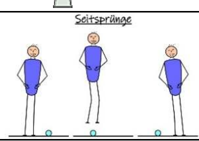
Appendix A: CIRCUIT Training program

	Rope Skipping
	Burpees / Push-ups
	Jumping Jacks
	Knee-lift high impact (knee-lift combined with short jumps)
	Zigzag sprints from one tag to the next and back
	Lateral side jumps: Jumps as powerful and wide as possible; arms in forward position during jump
	Elbow planks
	Short sprints: from the center tag to each of the outside tags and back to the center tag. Face always positioned to the front.
	Lateral side jumps between two marked zones (German Motoric Test protocol)
	Stair climbing on a crate (height: 80cm)

Appendix B

Table 2. Training Intervention Protocols.

Group	Method	Intervals	Duration of breaks	Intensity
1	HIIT 10x1 (RUNNING)	10 x 1 Min	60 seconds	approx. 90% of the running speed that could be uphold for 1 minute
2	HIIT 15x30 (RUNNING)	15 x 30 sec.	40 seconds	approx. 90% of the running speed that could be uphold for 30 sec.
3	CIRCUIT*	10 x 1 Min	40 seconds	90%
4	Control	-	-	-

Table 3. Content CIRCUIT TRAINING.

Station	Content
1	Rope Skipping
2	Burpees combined with push-ups
3	Jumping Jacks
4	Knee-lift (high-impact)
5	Zigzag sprints
6	Lateral side jumps
7	Elbow planks
8	Short Sprints (different directions)
9	Rope Skipping
10	Climbing stairs (high impact)
11	Lateral side jumps
12	Stair climbing