Effectiveness of Multi-activity, High-intensity Interval Training in School-aged Children

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Introduction
In recent years, research has discovered that the relative intensity and not the duration of exercise is of most importance in relation to all-cause mortality [1]. In a retrospective study van de Laar and colleagues [2] were able to determine that lifetime vigorous but not light-to-moderate physical activity favorably impacts cardiorespiratory risk. Studies conducted in youths discovered that only vigorous physical activity is associated with lower levels of waist circumference, body mass index, systolic blood pressure, and increased cardiorespiratory fitness [3]. Accordingly, it seems that, in addition to the volume of physical activity, the exercise intensity is a key variable that drives health benefits and should be increased. In this concern, high-intensity interval training (HIIT) has been proposed as an effective alternative to traditional moderate-intensity continuous exercise (MICE) inducing similar or even superior changes in cardiorespiratory fitness and health-related markers in adults [4]. Despite a substantially lower time commitment and reduced total exercise volume, HIIT stimulates physiological remodeling that is comparable to MICE [5].

Regardless of the positive effects, the evidence supporting the effectiveness of HIIT in children and adolescents is sparse. Nevertheless, two recent systematic reviews highlighted that HIIT may improve health-related markers in adolescents [6, 7].

Given that HIIT seems to be an effective exercise protocol for promoting health benefits in adults in less time and since this type of sporadic high-intensity exercise corresponds to the natural patterns of children’s habitual play [8], which may result in a higher
compliance, it would be of high interest to incorporate this kind of training into the school setting.

Emerging evidence now suggests that, apart from pressure measured in the brachial artery, other hemodynamic parameters such as central pressure, aortic pulse wave velocity (aPWV), and augmentation pressure (AP) are more strongly associated with pre-clinical organ damage [9] and are better related to future cardiovascular events [10]. Increased arterial stiffness is observed in young healthy subjects before any increase in peripheral BP [11].

Thus, the aim of the present study was to examine the effects of a regular school-based and child-specific HIIT intervention not only on AF and peripheral blood pressure (BP) but moreover on different parameters of arterial stiffness.

Materials and Methods

Subjects

The study sample (n = 46) of this parallel-arm cluster-randomized controlled trial was recruited from the pool of “project schools” taking part in the prevention project “Fitness für Kids” Verein für Frühprävention e.V.

One primary school was selected and two third grade classes were randomly allocated to either the intervention group (INT) or control group (CON). The randomization was carried out by the principal investigator using a computer-generated random number table. Prior to commencement of the study, participating children and their parents were informed about the purpose of the study and the testing procedures and written parental/guardian consent was obtained. The children were eligible to participate if they provided a written informed parental consent. Children with health conditions that did not allow unrestricted physical activity engagement were excluded. A cohort of 48 students was included in the study (mean age 10.7 ± 0.6 yr; 44% girls; BMI 19.7 ± 4.6 kg/m²; INT, n = 22; CON, n = 24). The study was reviewed and approved by the local Research Ethics Board and was conducted in accordance with international standards [12].

Measurements

Prior to the study, the subjects were familiarized with the study staff and all the experimental procedures and were subsequently tested on two different days on the school premises. The first day, anthropometric measures (body mass and height) were obtained to calculate the body mass index (BMI). Additionally, all participants completed the 6-minute run test from the KiGGS Study [13] to assess aerobic fitness. Furthermore, habitual physical activity was determined before and after the intervention period by means of the MoMo-AFB [14]. The MoMo-AFB is a commonly used physical activity questionnaire that has been validated using accelerometer data (ActiGraph GT1X) and activity logs [15].

On the second day, peripheral and central BP, AP, and aPWV were determined noninvasively using Mobil-O-Graph® (I.E.M., Stolberg, Germany), which is a clinically validated device for hemodynamic measurements [16, 17]. After subjects rested in a seated position in a climate-controlled room (22.7 ± 1.3 °C) for 10 min, a minimum of two readings were obtained from each subject and averaged for analysis. Custom-fit arm cuffs where used with the arm extended and placed on a customized arm support so that the heart and the pressure cuff were at the same level. The same test procedure was applied for the assessments at the end of the intervention period.

All measurements were performed by specially trained study staff members under standardized conditions. The same investigator performed the pre- and the post-test measurements. To avoid circadian variation in the parameters, the remeasurements after the observation period were performed at the same time of day. To rule out external influences, parents were instructed that their children should abstain from consuming caffeinated beverages and should refrain from intensive physical activity for 12 h prior to the test day.

Intervention

Throughout the 3-month intervention period, both the INT and CON took part in the regular PE classes 1 × 45 and 1 × 90 min a week. PE classes were conducted by the schools’ PE teachers following the regular curriculum. The main focus was on athletics and gymnastics. Various age-appropriate and sports-specific movement tasks and forms of play were practiced.

Only the children in the INT received instructed HIIT during the first 20 min of each PE. The PE classes and the HIIT intervention were obligatory for students and part of the school timetable. The HIIT was conducted by a qualified physical education teacher who was specifically trained in workshops.

The intervention was characterized by a vigorous interval regimen and consisted of different drills, circuit training, competitive games, relays, shuttle runs, suicide running drills, and choreographies. The goal was to provide a variety of different tasks and activities that were perceived as enjoyable during each session. Each session commenced with a 3-minute warm-up and ended with a 2-minute cool-down. The main protocol comprised 2 HIIT blocks lasting 6 min with a 3-minute recovery between the blocks. Within the HIIT blocks, exercise intervals lasting from 20 s to 2 min interspersed with 30–90 s of active or passive rest depending on the exercise activity (Fig. 1). The interval durations and the number of repetitions performed were adjusted according to the increased performance level throughout the intervention period. During the
The exercise intensity was documented using a heart rate (HR) monitor (Polar RS800CX; Polar Electro Oy, Kempele, Finland) once a week. In the INT, HR was monitored continuously throughout each HIIT session and during the subsequent PE class. For the CON, HR was obtained continuously throughout the PE class.

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics 23.0 (IBM Corp., Armonk, NY, USA). The normal distribution of the data was checked using the Kolmogorov-Smirnov test. Differences in subject characteristics between groups were determined using independent Samples t-test. Levene’s test was used to check the homogeneity of variance. To detect differences between means, a 2 × 2 repeated measures ANOVA was conducted. Values were adjusted for age, BMI, sex, and baseline values of outcome. A P-value < 0.05 was considered to indicate statistical significance.

Results

Descriptive data of the children’s baseline characteristics are shown in ▶ Table 1. With respect to German age- and sex-specific percentiles, 23.9 % (n = 11) of the children were overweight or obese [18]. According to German age-, height-, and sex-specific percentiles for systolic BP, 15.21 % of the children were defined as hypertensive [19]. In the IG, 9.09 % of the boys and 18.18 % of the girls were hypertensives. In the CG, 10 % of the boys and 14.28 % of the girls were measured as hypertensive.

Children in the INT and CON displayed no significant differences with respect to height, weight, and BMI (▶ Table 1). The groups did not differ at baseline with respect to systolic (P = 0.12) and diastolic (P = 0.07) peripheral BP or systolic (P = 0.09) and diastolic (P = 0.11) central BP. The same was evident for AP (P = 0.08) and aPWV (P = 0.09).

The records of the PE classes indicated that the session attendance rates were 96 % for the INT and 94 % for the CON. There were significant differences in the peak HR during the 20 minute HIIT session in the INT and the normal PE in the CON (207 ± 11 bpm vs. 163 ± 16 bpm; P = 0.008). The mean HR throughout the HIIT was significantly higher than during the normal PE classes (161 ± 16 bps vs. 133 ± 19 bpm; P = 0.023). (▶ Table 2)

The physical activity questionnaire revealed no significant differences in the weekly hours of habitual physical activity between the two groups (P = 0.91). No significant changes were observed throughout the intervention period either for the INT or the CON children, respectively (P = 1.00).

Throughout the intervention phase, there were no notifiable accidents or adverse events either in the INT or in the CON.

Analysis of pre- and post-test AF revealed a group by time interaction (P < 0.007). After the intervention period, AF was significantly (P < 0.007) improved in INT (5.58 z-score), whereas no significant (P = 0.321) differences occurred for the CON (−2.16 z-score) (▶ Table 2).

Pre- and post-test peripheral systolic BP data revealed a group by time interaction (P = 0.038). After the intervention period, peripheral systolic BP was significantly (P < 0.001) decreased in INT (−4.54 mmHg), whereas no significant (P = 0.538) differences occurred in the CON group (1.59 mmHg).

The central systolic BP also revealed a group by time interaction (P = 0.041). Throughout the intervention period there was a significant (P = 0.002) decrease in the INT (−5.19 mmHg). In the CON, however, no significant (P = 0.573) changes could be detected (1.037 mmHg). The analysis of pre- and post-test AP and aPWV displayed group by time interactions (P = 0.013; P = 0.041). The INT showed a decrease in AP (−1.13 mmHg, P = 0.028) and aPWV (−0.16 m/sec, P < 0.001), whereas CON displayed no significant (P = 0.142; P = 0.676) changes respectively (1.53 mmHg; 0.42 m/sec.) (▶ Table 2).

Discussion

The primary findings of this study were that the 3-month supervised HIIT was effective in improving the AF and reducing peripheral and central systolic BP, AP, and aPWV.

The HR measurements revealed significant differences in the peak HR between the INT and the CON. Additionally, the mean HR throughout the HIIT was significantly higher than the mean HR during the normal PE classes. Thereafter, the exercise intensity during the HIIT protocol was considerably higher than during the normal PE lessons.

The physical activity questionnaire revealed no significant differences in the weekly hours of habitual physical activity between the INT and CON and no significant changes were observed throughout the intervention period for either group.

The HIIT intervention resulted in a significant increase in the distance covered during the 6-minute run. Even though this test is only an indirect method for accessing aerobic capacity, a high correlation between the distance covered in the test and the VO2max has been suggested [20]. The effectiveness of HIIT on aerobic performance has been widely studied and confirmed in adults [4].

▶ Table 1 Subject’s characteristics at baseline.

<table>
<thead>
<tr>
<th>Items</th>
<th>Total (n=46)</th>
<th>INT (n=22)</th>
<th>CON (n=24)</th>
<th>P-Value for difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boys/Girls (n)</td>
<td>25/21</td>
<td>11/11</td>
<td>14/10</td>
<td>0.58</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>10.7 ± 0.6</td>
<td>10.8 ± 0.6</td>
<td>10.7 ± 0.7</td>
<td>0.91</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>148.8 ± 8.9</td>
<td>148.8 ± 8.9</td>
<td>148.5 ± 9.3</td>
<td>0.98</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>43.9 ± 13.9</td>
<td>43.9 ± 13.9</td>
<td>44.1 ± 11.8</td>
<td>0.89</td>
</tr>
<tr>
<td>Body mass index (kg · m−2)</td>
<td>19.6 ± 4.6</td>
<td>19.6 ± 4.6</td>
<td>19.7 ± 4.0</td>
<td>0.89</td>
</tr>
</tbody>
</table>

Values are means ± SD, unless stated otherwise.
wise, studies in children and adolescents have reported improvements in aerobic fitness ($\text{VO}_{2max}$) after HIIT interventions [6, 21, 22]. Although MICE has also been shown to improve $\text{VO}_{2max}$ in children, HIIT seems to be associated with greater benefits [22]. The fact that aerobic fitness relates to cardiovascular risk factors and mortality [23, 24] underscores the relevance of these results.

After the intervention period, the peripheral systolic BP of the children in the INT showed a significant reduction, whereas the children in the CON group displayed a slight increase in these parameters leading to significant between-group differences. These results are in line with previous studies [7, 25, 26] indicating significant effects of different HIIT protocols on the peripheral systolic BP in children and adolescents. A recent meta-analysis in overweight and obese adolescents states that the BP reduction after HIIT was even greater when compared to MICE [25]. Because BP levels are known to track from childhood into adulthood [26], interventions that can have a positive effect upon BP are vital to reduce the cardiovascular risk profile in later life.

Newer findings suggest that a higher central BP is more strongly related to precliminal organ damage and cardiovascular events than brachial pressure [27]. The present study revealed significant intervention effects for the central systolic BP favoring the INT. To the best of our knowledge, studies assessing the effects of HIIT on the central BP in children or adolescents are lacking. Only Beck et al. [28] assessed the central BP in adolescents after 8 weeks of resistance or endurance training, observing significant reductions for both interventions.

In the present study the AP was significantly lowered throughout the exercise intervention in the children of the INT. Furthermore, significant differences in between-group changes could be detected favoring the INT. The fact that higher AP values are an indication of higher left ventricular energy consumption and correlate with total mortality in adults [29] underscores the relevance of the results.

Only the children who took part in the HIIT intervention showed significant reductions in aPWV. The aPWV is a direct marker of arterial stiffness, which in turn is recognized as an independent predictor of cardiovascular events [29]. Even in children, lower levels of physical activity have been associated with increased arterial stiffness and endothelial dysfunction [30]. Regrettably, hardly any studies have assessed the effects of exercise interventions on the aPWV in children. In a previous study, we were able to detect similar effects of a daily school-based physical exercise intervention on aPWV [31].

Although the mechanisms responsible for the greater effectiveness of HIIT for improving hemodynamic parameters are not fully understood, the effects may be related to a higher distribution of vasoactive substances [28]. The higher exercise intensities leading to a higher oxygen demand in the working muscle may provoke greater blood flow through the vessel and therefore promote greater shear-stress-induced nitric oxide (NO) distribution [32]. Furthermore, exercises of higher intensity may lead to a higher reduction of sympathetic nervous activity [33, 34].

HIIT seems to be an effective strategy delivering relevant benefits to the cardiometabolic profile in children and youths. Knowing that children’s habitual physical activity patterns consist of short bouts of high-intensity exercises [8] suggests that HIIT is well suited in this age group. Moreover, enjoyment of exercise and thus compliance could be higher compared to exercise interventions applying MICE. Furthermore, literature confirms that children seem to tolerate HIIT better than continuous exercise, as they show a higher fatigue resistance and a fast recovery after exercises with high to maximum intensities [35, 36]. In a recent study, Birat and colleagues [30] observed that prepubertal children were metabolically comparable to well-trained adult endurance athletes and less fatigable during high-intensity exercise than untrained adults, making them the perfect HIIT athletes.

Therefore, given the promising findings regarding the effectiveness of HIIT, implementing this type of exercise program into the school environment should be considered. Furthermore, PE teachers should be encouraged to increase exercise intensity in PE classes to improve physical fitness and health status in children.

**Limitations**

Some limitations of our study should be considered. First, due to the cluster-randomized allocation, selection bias might have occurred. This lead to the heterogeneity between the two groups at baseline with respect to the outcomes assessed.

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**Table 2 Intervention effects for outcomes.**

<table>
<thead>
<tr>
<th>Outcome</th>
<th>INT</th>
<th>CON</th>
<th>Difference in Mean change (95 % CI)</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Follow-up</td>
<td>Baseline</td>
<td>Follow-up</td>
</tr>
<tr>
<td>pSBP (mmHg)</td>
<td>118.7 ± 7.7</td>
<td>114.2 ± 6.5 ** *  *  *</td>
<td>109.9 ± 15.3</td>
<td>110.6 ± 9.97</td>
</tr>
<tr>
<td>pDBP (mmHg)</td>
<td>71.9 ± 7.0</td>
<td>69.6 ± 4.5</td>
<td>68.1 ± 9.1</td>
<td>68.5 ± 5.9</td>
</tr>
<tr>
<td>cSBP (mmHg)</td>
<td>104.2 ± 9.1</td>
<td>100.4 ± 5.9 ** *  *  *</td>
<td>94.5 ± 11.9</td>
<td>95.6 ± 8.1</td>
</tr>
<tr>
<td>cDBP (mmHg)</td>
<td>74.2 ± 6.8</td>
<td>71.6 ± 4.3</td>
<td>69.9 ± 11.0</td>
<td>70.2 ± 5.7</td>
</tr>
<tr>
<td>AP (mmHg)</td>
<td>6.88 ± 3.3</td>
<td>5.8 ± 2.8 *</td>
<td>3.9 ± 5.3</td>
<td>4.8 ± 2.2</td>
</tr>
<tr>
<td>aPWV (m·s$^{-1}$)</td>
<td>4.8 ± 0.3</td>
<td>4.6 ± 0.2 ** *  *  *</td>
<td>4.4 ± 0.3</td>
<td>4.5 ± 0.3</td>
</tr>
<tr>
<td>AF (z-score)</td>
<td>88.1 ± 10.0</td>
<td>93.9 ± 11.5 ** *</td>
<td>97.9 ± 11.6</td>
<td>97.5 ± 10.4</td>
</tr>
</tbody>
</table>

Parameters before and after intervention period for intervention group (INT) and control group (CON). Values are mean ± SD. Values were adjusted for age, BMI, sex, and baseline values of outcome. * $p<0.05$; ** $p<0.01$; *** $p<0.001$ difference from baseline. CI, confidence interval; pSBP, peripheral systolic blood pressure; pDBP, peripheral diastolic blood pressure; cSBP, central systolic blood pressure; cDBP, central diastolic blood pressure; AP, augmentation pressure; aPWV, aortic pulse wave velocity; AF, aerobic fitness.
Second, sexual maturation status was not accounted for in this study. Furthermore, daily physical activity was only assessed using a questionnaire. Even though the applied questionnaire is validated and widely used in Germany, it is prone to recognition biases or social desirability needs of participants. It can be argued that an accelerometer based assessment would have been a more reliable and objective choice. Even though we assessed the exercise intensities regularly using HR readings, no concrete inference can be made about the percentage of maximum aerobic capacity at which the children were exercising during the HIIT protocol. However, that was not the intention of the study, whose main goal was to evaluate a program that is feasible to implement in the schools’ PE class.

Conclusion
In conclusion, school-based and child-specific HIIT induces meaningful changes in AF, peripheral and central systolic BP, AP, and aPWV in 11-year-old children. These results highlight the potential of embedding HIIT within the school setting, offering a time-efficient strategy for the strict school timetable. This may aid in the development of self-directed physical activity in later life and thus may reduce the burden of future cardiovascular disease.

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Conflict of Interest
The authors declare that they have no conflict of interest.

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