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Titel | Title

Effects of heart rate controlled aerobic running load on the concentration ability of 10-11-year- old children
- A randomised controlled intervention study

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Abstract

Zielsetzung:

Diese Masterarbeit untersucht die Auswirkungen einer pulsfrequenzgesteuerten aeroben Laufbelastung auf die Konzentrationsfähigkeit von Kindern im Alter von 10–11 Jahren.

Design:

Es handelte sich um eine randomisierte kontrollierte Interventionsstudie mit zwei voneinander getrennten Gruppen und zwei Messzeitpunkten.

Methode:

Insgesamt nahmen 30 Schülerinnen und Schüler im Alter von 10 bis 11 Jahren teil, die schulisch zufällig einer von zwei Versuchsgruppen zugeteilt wurden. Nach dem Ausschluss von zwei unvollständigen Protokollen in einer Gruppe gingen die Daten von N = 28 Teilnehmenden in die Auswertung ein. Beide Gruppen durchliefen dasselbe Testverfahren. Eine Gruppe absolvierte zunächst eine Laufeinheit und anschließend eine Englischstunde, während bei der zweiten Gruppe die Reihenfolge umgekehrt war. Die aerobe Laufbelastung dauerte 20 Minuten. Vor und nach der Laufeinheit bzw. der Englischstunde führten alle Teilnehmenden den d2-Aufmerksamkeitstest durch. Als zentrales Auswertungsverfahren wurde eine Mixed-Design-ANOVA mit einem Innersubjektfaktor (Zeit) und einem Zwischensubjektfaktor (Gruppe) verwendet.

Ergebnisse:

Die Konzentrationsleistung verbesserte sich in beiden Gruppen von vor zu nach der aeroben Laufbelastung. Es zeigte sich ein signifikanter Haupteffekt des Messzeitpunkts auf die Konzentrationsleistung, was auf eine generelle Verbesserung der Konzentrationsfähigkeit über die Testzeitpunkte hinweg hinweist. Obwohl keine signifikante Interaktion zwischen Gruppe und Zeit festgestellt wurde, zeigten paarweise Vergleiche eine deutliche Verbesserung der Konzentrationsleistung nach der aeroben Bewegungseinheit im Vergleich zu davor. In beiden Versuchsabfolgen nahmen sowohl die Konzentrationswerte als auch die Verarbeitungsgeschwindigkeit signifikant nach der Sporteinheit zu, während sich die Fehleranzahl leicht verringerte, allerdings nicht konsistent zwischen den Gruppen.

Abstract

Objectives: This master's thesis examines the effects of pulse-controlled aerobic running load on the concentration ability of 10–11-year-old children. The aim of this study was to test whether exercise improves concentration performance.

Design: This was a randomized controlled intervention study with two separated groups and two distinct measurement occasions.

Method: 30 students aged 10 to 11 years were randomized to one of two test groups in school. After excluding two incomplete protocols in one group, N=28 were analysed. Both groups underwent the same testing procedure. One group had a running session first and then an English lesson. The other group had the same test procedure but in reverse test order. The aerobic running load lasted for 20 min. Before and after the running session/ english lesson, all participants completed the d2-test of attention. A mixed-design ANOVA with one within-subject factor (time) and one between-subject factor (group) was used as the main analysis method.

Results: Concentration performance increased from before to after the aerobic running load for both groups. The results showed a significant main effect of measurement time on concentration performance indicating that children's concentration improved across test sessions. Although no significant interaction between group and time was found, pairwise comparisons revealed a clear improvement after the aerobic exercise unit compared to before. In both experimental sequences, concentration scores and processing speed increased significantly following the sport session, while the number of errors decreased slightly but not consistently across groups.

Conclusions: Overall, the findings indicate that an acute bout of aerobic running load can lead to measurable improvements in concentration performance and processing speed in children, supporting the positive short-term cognitive effects of aerobic exercise identified in previous research. School administrators and teachers are encouraged to incorporate more aerobic running into their school curriculum to enhance students ‘concentration performance.

Outline

1. Introduction

Children's ability to concentrate plays an important part in the educational context. Concentration is essential not only for comprehending and following the learning content presented in class but also for solving problems efficiently and engaging meaningfully with academic tasks. In addition, sustained attention is a fundamental prerequisite for the development of higher cognitive functions such as memory, reasoning, and self-regulation, which are all crucial for long-term academic success. Especially during primary school years, concentration ability forms the basis for effective learning behaviour and the acquisition of essential skills (Gallen et al., 2023; Degol et al., 2023)

For teachers, students' capacity to maintain attention is an equally significant factor, as effective lesson planning depends on the duration and quality of children's focus when acquiring new knowledge. The degree of concentration within a class directly influences how much new content can be successfully conveyed and retained. When students are attentive, teaching time can be used more efficiently, classroom disruptions are reduced, and learning outcomes improve. Conversely, limited concentration often results in reduced learning efficiency, increased classroom management challenges, and lower academic performance.

In everyday school practice, attention difficulties and restless behaviour frequently occur, particularly at the beginning of lessons or after longer periods of sedentary activity. Many children struggle to transition from breaks or previous lessons into focused learning phases. Such challenges can impede a smooth and effective start to teaching and learning processes and place additional demands on teachers. Therefore, identifying practical and evidence-based strategies to enhance children's concentration during the school day is of great importance for educational practice (Burns, E. C., Martin, A. J., & Collie, R. J.,2021).

One potential approach to addressing this issue is physical activity. Numerous studies have investigated the influence of physical activity on children's attention and concentration; however, the findings remain inconsistent. While some studies have reported positive short-term effects of exercise on cognitive performance and attentional processes, others have found minimal or no significant effects. These mixed results may be explained by differences in study design, exercise intensity and duration, age groups, and the cognitive measures used. Nevertheless, the growing body of research suggests that physical activity has the potential to positively influence cognitive functioning, particularly when appropriately structured.

Running represents one of the most common and accessible forms of movement in physical education classes, serving both as a warm-up activity and as a central lesson component. It requires little equipment, can be easily adapted to different fitness levels, and can be implemented within limited time frames. Due to its simplicity, low resource requirements, and widespread implementation, running provides a practical opportunity to examine how structured physical activity influences cognitive performance in school-aged children. Moreover, aerobic running is particularly suitable for investigating cognitive effects, as it can be precisely controlled in terms of intensity and duration.

Accordingly, the present study aims to investigate the effects of pulse-controlled, aerobic running on the concentration ability of children aged 10 to 11 years. By using heart rate monitoring, the running intensity can be standardized across participants, ensuring that all children exercise within an aerobic range. This allows for a more accurate examination of the relationship between aerobic physical load and concentration performance.

Building on the existing body of research, the central research question of this master's thesis is whether an acute bout of heart rate-controlled aerobic running leads to measurable improvements in concentration ability in primary school children. More specifically, the study examines whether children show higher concentration performance and processing speed following an aerobic running session compared to measurements taken before physical activity or after a regular academic lesson. Based on previous findings suggesting positive short-term cognitive effects of aerobic exercise, it is hypothesized that pulse-controlled aerobic exercise leads to an improved ability to concentrate in children aged 10 to 11 years.

2. State of research and theoretical foundations

Concentration and attention are closely related yet distinct mental processes essential for learning, work, and daily life. To clarify these two terms, Moran (2012) defines attention as the ability to consciously direct cognitive resources toward a specific stimulus, filtering out irrelevant information, while concentration is the sustained effort to keep attention focused on one task without distraction. Therefore, the ability to concentrate plays an important role in the school context and warrants further investigation.

Several studies have examined the influence of aerobic exercise on the attention, concentration and cognitive performance of children and adolescents. In general, it is important to separate between acute (short-term) and chronic (long-term) effects of aerobic movement.

Chronic aerobic exercise, such as jogging, cycling, or swimming, improves blood circulation and oxygen flow to the brain. This helps brain development, supports new nerve connections, and strengthens brain function. These physiological changes can improve children's attention, concentration, and general cognitive abilities (Hillman, Castelli, & Buck, 2005; Hillman, Kamijo, & Scudder, 2011; Bailey et al., 2013). Other studies have shown that regular physical activity also improves executive functions, such as information processing, inhibition, working memory, and mental flexibility (Best, 2010).

Several meta-analyses support these findings. De Greeff et al. (2018) found small to moderate improvements in executive functions, attention, and school performance in children who regularly participated in aerobic activities. Similarly, Sibley and Etnier (2003) reported an overall positive relationship between physical activity and cognitive performance in children. In the *FITKids* randomized controlled trial, children who took part in a daily physical activity program showed better executive control and brain activity related to attention compared to a control group (Hillman et al., 2014; Drollette et al., 2018). Neuroimaging studies also found that children with higher aerobic fitness had better white-matter integrity and more efficient brain function (Chaddock-Heyman et al., 2014).

Acute physical exercise — a single bout of activity — can also improve attention and concentration. Budde et al. (2008) found that one session of coordinative aerobic exercise improved attention in adolescents. Pesce et al. (2009) compared two types of aerobic exercise of the same intensity: individual circuit training and group games. Both improved general arousal and memory, but the group games, which required more thinking and coordination, led to greater improvements in immediate recall. This suggests that exercise which also challenges the mind can have stronger cognitive effects.

A recent study by Altermann and Gröpel (2023) further supports these results. In their randomized controlled trial, 80 adolescents aged 15–18 took part in 25-minute sessions of endurance, strength, or coordination exercise, or no exercise at all. All three exercise groups showed significant improvements in attention and processing speed compared to the control group. However, there were no major differences between the types of exercise. The authors concluded that even a single, short period of physical activity can improve students' ability to focus, regardless of whether the activity involves running, strength training, or coordination tasks. They suggested that schools should include short activity breaks to help students concentrate and learn more effectively.

These results agree with other meta-analyses showing that 10–30 minutes of moderate to vigorous aerobic exercise can improve reaction time, accuracy, and attention in the short term (Ludyga et al., 2016; Xiong et al., 2020). In children with ADHD, even 20 minutes of moderate aerobic exercise has been shown to improve attention and academic performance for up to an hour afterward (Pontifex et al., 2013).

However, not every study finds a positive effect. For example, Stroth et al. (2009) found that 20 minutes of cycling at moderate intensity did not improve adolescents' performance in a go/no-go attention task. Tomporowski and McCullick (2014) also noted that differences in exercise intensity, timing, and the sensitivity of the attention tests may explain these mixed results.

Practical research also supports adding movement to school lessons. The Austrian project *Learning in Motion – The Vienna Model* showed that physical activity during lessons led to significant improvements in concentration and attention among primary school children (Stefan, 2012). Systematic reviews have also found that programs combining physical activity with thinking tasks—such as games or coordination exercises—produce the strongest short-term effects on attention and executive functions (Donnelly et al., 2016; Álvarez-Bueno et al., 2017).

In summary, both long-term and short-term aerobic activity can help improve children's attention and concentration. The degree of improvement depends on factors such as exercise intensity, duration, and the level of cognitive engagement. The findings of Altermann and Gröpel (2023) show that even short, well-planned exercise sessions—like a 25-minute run—can lead to better concentration in adolescents.

2.1 Executive functions and concentration in childhood

Concentration ability in children is closely linked to the broader construct of executive functions, which include inhibitory control, working memory, and cognitive flexibility (Best, 2010). These higher-order cognitive processes are essential for goal-directed behaviour and academic learning, as they enable children to regulate attention, suppress irrelevant stimuli, and maintain task goals over time. According to Diamond (2013), executive functions form the cognitive foundation for successful learning, problem-solving, and self-regulation in school settings.

During late childhood, executive functions undergo significant developmental changes. Neurodevelopmental research indicates that prefrontal brain regions associated with attentional control and executive processing continue to mature throughout primary school years (Best & Miller, 2010). Best (2010) emphasizes that this developmental period represents a sensitive phase in which environmental factors, such as physical activity, may exert particularly strong influences on executive functioning. Consequently, interventions targeting concentration through movement may be especially effective in children aged 10 to 11 years.

Empirical studies demonstrate that aerobic fitness is positively associated with executive function performance in children. Higher-fit children consistently outperform their lower-fit peers on tasks requiring sustained attention, inhibitory control, and cognitive flexibility (Hillman et al., 2005; Chaddock et al., 2011). These findings suggest that concentration improvements following aerobic exercise may be mediated by enhanced executive control rather than by simple increases in arousal alone.

2.2 Physical mechanisms linking aerobic exercise and attention

Several studies have been proposed to explain how aerobic exercise influences attention and concentration. From a physiological perspective, acute aerobic exercise increases cerebral blood flow, oxygenation, and glucose availability, thereby temporarily enhancing neural efficiency (Bailey et al., 2013; Hillman et al., 2011). These changes are particularly relevant for brain regions involved in attentional control and executive processing.

Neurochemical mechanisms may also contribute to exercise-induced cognitive benefits. Acute physical activity has been shown to increase the availability of neurotransmitters such as dopamine and norepinephrine, which play a crucial role in attention regulation and alertness (Pontifex et al., 2013). Best (2010) argues that these transient neurochemical changes may facilitate executive control processes, resulting in improved concentration performance immediately following exercise.

In addition to physiological mechanisms, psychological factors such as increased arousal, improved mood, and reduced stress may further support attentional functioning. Moderate aerobic exercise is assumed to induce an optimal level of arousal, which enhances cognitive performance according to the inverted-U hypothesis (Tomporowski & McCullick, 2014). Excessive exercise intensity, in contrast, may lead to fatigue and reduced cognitive efficiency.

2.3 Intensity, duration, and timing of exercise effects

The magnitude of cognitive benefits resulting from aerobic exercise appears to depend strongly on exercise characteristics, particularly intensity and duration. Best (2010) highlights that moderate-intensity aerobic exercise produces the most consistent positive effects on executive functions, whereas very light exercise yields less reliable outcomes. Meta-analytic findings support this assumption, indicating that exercise sessions lasting between 10 and 30 minutes at moderate intensity are most effective for improving attention and processing speed (Ludyga et al., 2016; Xiong et al., 2020).

Timing also plays a critical role. Acute cognitive benefits are typically observed immediately after exercise or within a short post-exercise window of up to 60 minutes (Pontifex et al., 2013). This temporal pattern is particularly relevant for school-based applications, as physical activity sessions can be strategically scheduled before cognitively demanding lessons to enhance learning readiness.

Heart rate-controlled exercise offers a methodologically sound approach to standardizing exercise intensity across individuals. In children, the aerobic exercise intensity is defined as a submaximal level of effort that remains below the anaerobic threshold. This intensity range corresponds to approximately 60–75% of maximal heart rate. Given that maximal heart rate in children is typically around 190–200 beats per minute, a heart rate range of approximately 120–140 bpm can therefore be classified as aerobic exercise intensity (Breithecker et al., 2021).

By ensuring that participants remain within an aerobic intensity range, interindividual variability related to fitness level can be reduced, thereby increasing internal validity (Best, 2010). This methodological consideration provides further justification for the design of the present study.

2.4 Methodological implications for school-based intervention studies

Research on exercise–cognition relationships in children faces several methodological challenges. Best (2010) emphasizes that inconsistent findings across studies are often attributable to variations in study design, cognitive outcome measures, and exercise protocols. Attention and concentration are multidimensional constructs that require sensitive and reliable assessment tools.

The d2 test of attention, which is used in the present study, assesses both processing speed and concentration performance under time pressure and has been widely applied in educational and psychological research. Measures combining speed and accuracy are considered especially suitable for detecting short-term exercise effects on executive control (Hillman et al., 2014).

School-based intervention studies benefit from ecologically valid designs that reflect real-world teaching conditions. Acute exercise interventions integrated into the school day offer a practical and feasible approach to investigating cognitive effects while maintaining high external validity. The current state of research suggests that well-controlled aerobic exercise interventions can provide meaningful insights into how physical activity may support attentional functioning in educational contexts (Donnelly et al., 2016; Álvarez-Bueno et al., 2017).

In summary, theoretical and empirical evidence indicates that concentration ability in children is closely linked to executive functions and that both chronic and acute aerobic exercise can positively influence these cognitive processes. Best's (2010) review provides a central framework for understanding the mechanisms, moderators, and methodological requirements of exercise-related cognitive effects in childhood. Based on the existing research, it becomes clear that aerobic exercise can have both immediate and lasting effects on children's attention and concentration. Building on these findings, the present study aims to examine how an acute bout of aerobic running load influences concentration ability of 10 -11-year-old children under controlled conditions.

3. Method

This section describes the methodological approach of the study. It presents the characteristics of the participants, the instruments used to measure physical and cognitive variables, the study procedure, and the statistical analyses.

3.1 Participants

Participants were students from the Gymnasium Sachsenbrunn. The sample consisted of 30 children (male and female), who were randomly assigned to two equal groups: a blue group (n=15) and a red group (n=13).The students in the blue group had an average age of 10.53 years (*SD* = 0.516), while those in the red group had an average age of *M* = 10.62 (*SD* = 0.506). In the red group, there were nine female students (60.0%) and six male students (40.0%), whereas in the blue group there were six female students (46.2%) and seven male students (53.8%).

Two people from the red group were excluded because their test sheets were incomplete and the results could not be evaluated.

3.2 Measures

To assess the effects of physical activity on concentration, physiological and psychological measures were applied:

3.2.1 Heart rate

Heart rate was measured using individual heart rate monitors (Model: Polar H9 HR) worn by all participants during the physical education lesson. The purpose of heart rate monitoring was to ensure a standardized aerobic load and to enable an individual running speed for each child. The children operated the heart rate monitors independently and were responsible for monitoring and maintaining their heart rate within the prescribed range. During the aerobic running task, participants were instructed to maintain a medium heart rate between 120 and 140 beats per minute (BPM) for approximately 20 minutes. The heart rate monitors ensured that children did not run too fast or too slowly, thereby remaining within the aerobic range of energy supply and keeping the physical load consistent across participants.

3.2.2 Concentration

The ability to concentrate was assessed using the standardized d2 Test of Attention. The d2 Test of Attention is a standardized psychological assessment designed to measure selective and sustained attention as well as concentration ability under time pressure. It is widely used in educational and clinical contexts because it captures both the speed and accuracy of information processing (Brickenkamp et al., 2010).

In the d2 test, participants must quickly find and mark certain target symbols. These targets are the letter “d” with exactly two small dashes. The letters appear in rows mixed with similar distractors—either “p” or “d” with a different number of dashes. The test is timed: each row must be processed within 20 seconds, and there are 14 rows in total.

On the following page, an example of the d2 test is shown. It illustrates the arrangement of letters and dashes, highlighting the complexity of the task. The combination of time pressure and visual similarity between targets and distractors makes the d2 test a sensitive measure of attentional control and concentration performance.

Figure 1:Illustration of the d2 Test

Three performance indicators were derived from the raw data of the d2 test, each reflecting different aspects of attention and concentration:

- Concentration performance (CP):

CP represents the number of correctly marked target symbols minus errors (incorrectly marked distractors). It serves as an indicator of the ability to work accurately and efficiently throughout the test. A high CP score reflects strong concentration capacity (Brickenkamp et al., 2010).

- Processing speed (PS):

PS refers to the total number of processed items, regardless of correctness. This measure captures psychomotor processing speed and the ability to respond quickly under time constraints. Improvements in PS are often interpreted as signs of increased activation and cognitive alertness (Altermann & Gröpel, 2023).

- Error percentage (F%):

F% indicates the proportion of errors relative to total processing. It serves as a measure of accuracy and error control. A low F% score suggests good self-regulation and stable attention, whereas a high score may indicate impulsive or careless performance (Brickenkamp et al., 2010).

3.3 Procedure

The d2 test was administered three times on the same day for each group. The sequence of lessons differed between the two groups (see figure below). Each testing session took place immediately after either an English lesson or a physical education lesson.

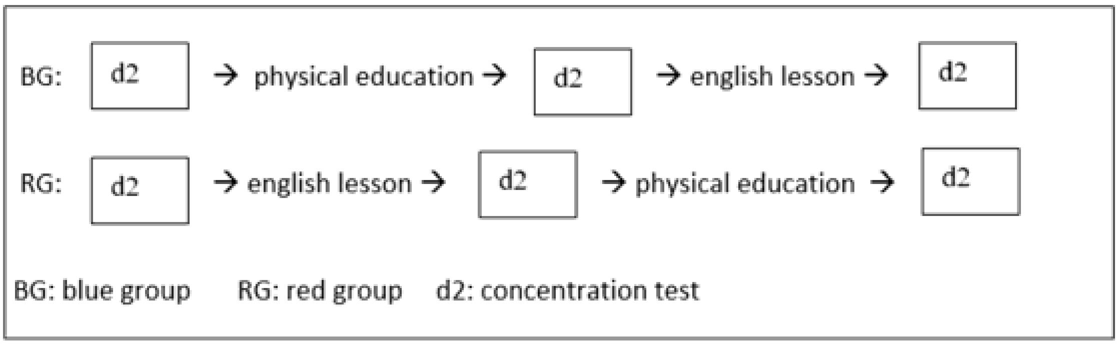

Figure 2:Visualisation of the test procedure

The physical education lesson included a short warm-up phase, followed by an explanation of how to use the heart rate monitors. Subsequently, participants completed an aerobic running task at a medium intensity (120–140 BPM) for approximately 20 minutes.

After each lesson (English or physical education), participants immediately completed the d2 test under standardized conditions.

3.4 Data analysis

To examine whether heart rate-controlled aerobic training improves concentration in children aged 10 to 11, the data were analysed using a mixed ANOVA. Three mixed ANOVAs were conducted—one each for concentration performance, processing speed, and error rate. Prior to analysis, assumptions were tested. The dependent variable, measured using a standardized test procedure (d2), can be considered interval scaled. The independent, nominal-scaled between-subject factor was represented by the two groups being compared. The independent within-subject factor was represented by the three measurement time points of the d2 test. Any unmet assumptions are reported separately for each of the three mixed ANOVAs.

4. Results

4.1 Concentration performance (CP)

Regarding the mixed ANOVA for concentration performance (CP), the assumption of normal distribution was met for all values in all groups—except for the third measurement time point in the blue group—as determined by the Shapiro-Wilk test ($p > .05$). Since the violation of normality affected only one group at one time point and there is evidence of high robustness of one-way ANOVA against violations of the normality assumption (Glass, Peckham, and Sanders, 1972), the analysis was continued despite the minor violation. Visual inspection of boxplots for the three time points revealed no outliers, thus this assumption was considered me (see Figure1 in Annex). Sphericity was tested using Mauchly's test, which indicated a violation (p = .003), so a Greenhouse-Geisser correction was applied. Homogeneity of error variances between groups was tested using Levene's test and was considered met ($p > .05$). Finally, equality of covariance matrices was tested using Box's test and was also considered met ($p = .320$).

The mixed ANOVA showed no significant interaction between the sequence of instructional units and concentration performance, Greenhouse-Geisser $F(1.466, 38.117) = 3.118$, $p = .070$, partial $\eta^2 = .107$. Concentration performance did not differ significantly between the two groups at any time point ($p > .05$). However, there was a statistically significant effect of measurement time on concentration performance, Greenhouse-Geisser $F(1.466, 38.117) = 31.784$, $p < .001$, partial $\eta^2 = .550$. The main effect of group was not significant, $F(1,26) = 0.499$, $p = .486$, indicating no significant difference between groups.

Bonferroni-corrected pairwise comparisons showed that in the group where students received the sports session first, concentration performance after the sports session ($M = 189.20$, $SD = 10.26$) was significantly higher than before the sports session ($M = 149.53$, $SD = 8.14$), $p = .002$. In the group that received the English session first, Bonferroni-corrected pairwise comparisons showed that concentration performance was significantly higher both after the English session ($M = 172.69$, $SD = 11.17$) compared to before ($M = 127.15$, $SD = 9.45$), and after the sports session ($M = 193.46$, $SD = 11.28$) compared to after the English session ($M = 172.69$, $SD = 11.17$), $p < .001$ and $p = .022$ respectively.

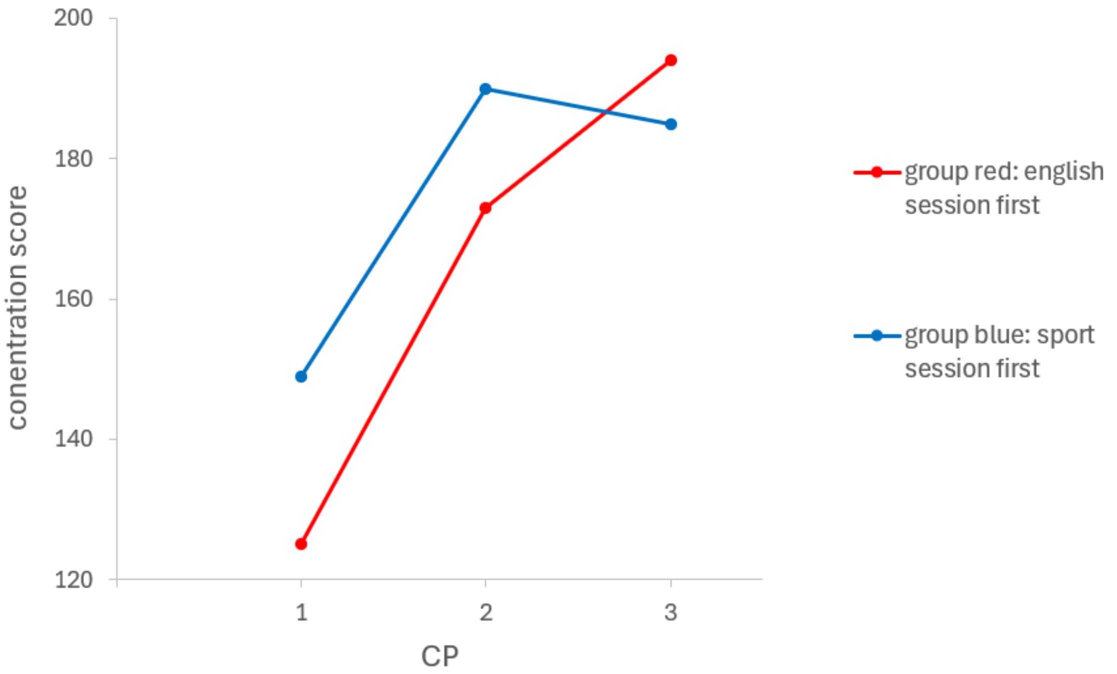

Figure 3:Marginal means of concentration performance

4.2 Processing speed (PS)

Next, a mixed ANOVA was conducted in relation to processing speed (PS), with a prior examination of assumptions. The normal distribution of the residuals of the dependent variable was met for all groups at each measurement time point of PS, as confirmed by the Shapiro-Wilk test ($p > .05$). Inspection of the boxplots for the three PS time points revealed no outliers, so this assumption was considered fulfilled. Furthermore, sphericity was tested using Mauchly's test, which indicated a violation of sphericity ($p = .023$), and therefore a Greenhouse-Geisser correction of degrees of freedom was applied. To examine the homogeneity of error variances between groups, Levene's test was used, which indicated that this assumption was met ($p > .05$). Finally, the assumption of equality of covariance matrices was tested using Box's test, which was also fulfilled ($p = .832$).

The mixed ANOVA showed a significant interaction between the sequence of instructional units and PS, Greenhouse-Geisser $F(1.586, 41.237) = 6.256$, $p = .007$, partial $\eta^2 = .194$. Additionally, there was a statistically significant effect of measurement time on PS values, Greenhouse-Geisser $F(1.545, 21.628) = 52.195$, $p < .001$, partial $\eta^2 = .789$. The main effect of PS was also significant, Greenhouse-Geisser $F(1.586, 41.237) = 77.005$, $p < .007$, partial $\eta^2 = .743$. The main effect of group was not significant, $F(1, 26) = 0.082$, $p = .777$, partial $\eta^2 = .003$, indicating no significant differences between the two groups.

Bonferroni-corrected pairwise comparisons in the group that received the sports session first showed that PS after the sports session ($M = 476.80$, $SD = 20.99$) was significantly higher than before the sports session ($M = 368.47$, $SD = 15.16$), $p < .001$. However, PS was significantly lower after the English session ($M = 451.33$, $SD = 23.00$) compared to after the sports session ($M = 476.80$, $SD = 20.99$), $p = .047$. In the group that received the English session first, Bonferroni-corrected pairwise comparisons showed that PS after the English session ($M = 451.92$, $SD = 23.40$) was significantly higher than before the English session ($M = 382.85$, $SD = 20.05$), $p < .001$, and also significantly higher after the sports session ($M = 486.15$, $SD = 24.08$) compared to after the English session ($M = 451.92$, $SD = 23.40$), $p = .018$.

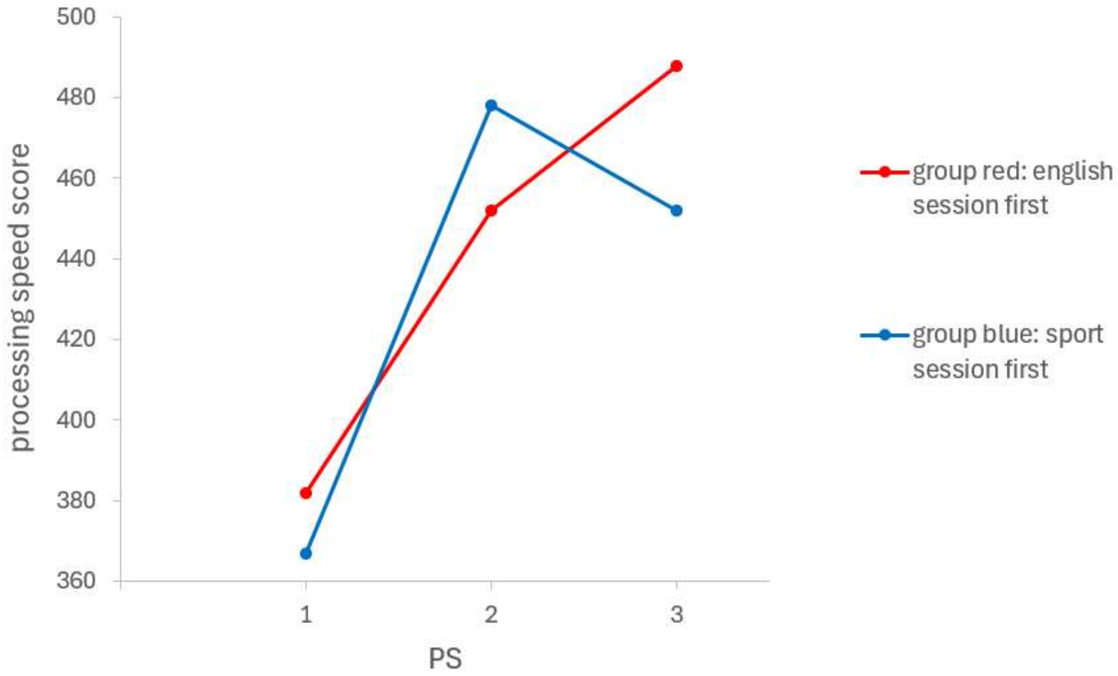

Figure 4: Marginal means of processing speed

4.3 Error rate (F%)

Finally, a mixed ANOVA was conducted with error rate as the dependent variable. The assumption of normal distribution for the error rate was met at all measurement time points and in all groups—except for the first measurement time point in the blue group—as determined by the Shapiro-Wilk test ($p > .05$). Given the evidence for the high robustness of one-way ANOVA against violations of the normality assumption (Glass, Peckham, and Sanders, 1972), the analysis was continued despite the minor violation. During visual inspection of the boxplots for outlier analysis, a total of four outliers were identified. However, since these were mild outliers, they were retained in the dataset and included in the analysis.

Sphericity was examined using Mauchly's test, which indicated a violation of the assumption ($p = .011$), and therefore a Greenhouse-Geisser correction of degrees of freedom was applied. The homogeneity of error variances between groups was tested using Levene's test, which showed that this assumption was not met for the error rate at the first measurement time point ($p = .003$). Due to this violation, the ANOVA results cannot be interpreted, and only the post-hoc comparisons are considered. Box's test for equality of covariance matrices indicated that this assumption was met ($p = .234$).

Bonferroni-corrected pairwise comparisons in the group that received the sports session first showed that the error rate did not differ significantly across the different measurement time points—before or after the sports session and after the English session. In contrast, Bonferroni-corrected pairwise comparisons in the group that received the English session first showed that the mean error rate after the English session (*M* = 4.23, *SD* = 0.69) was significantly lower than before the English session (*M* = 8.12, *SD* = 1.27), *p* = .002. However, the mean error rate after the sports session (*M* = 3.49, *SD* = 0.52) did not differ significantly from that after the English session (*M* = 4.23, *SD* = 0.69), *p* = .665.

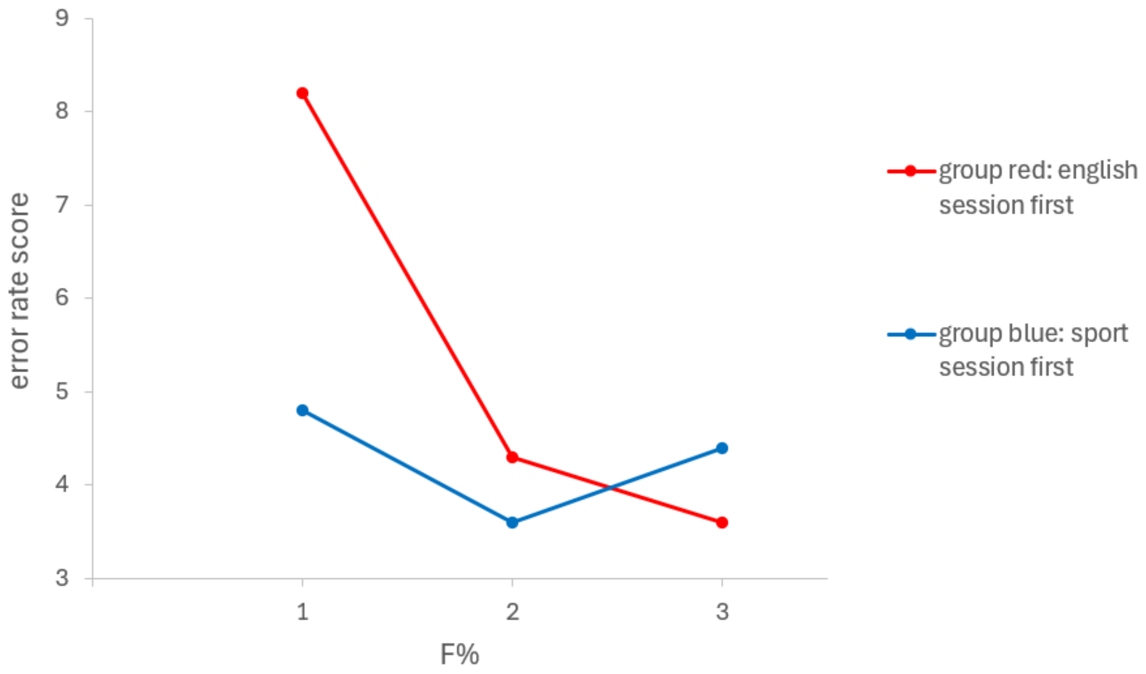

Figure 5: Marginal means of error rate

The results showed a significant main effect of measurement time on concentration performance (p = .007, η^2 = .347), indicating that children's concentration improved across test sessions. Although no significant interaction between group and time was found (p = .070), pairwise comparisons revealed a clear improvement after the aerobic exercise unit compared to before. In both experimental sequences, concentration scores and processing speed (PS) increased significantly following the sport session (p < .001), while the number of errors decreased slightly but not consistently across groups.

Overall, the findings indicate that a short, pulse-controlled aerobic activity can lead to measurable improvements in concentration performance and processing speed in children, supporting the positive short-term cognitive effects of aerobic exercise identified in previous research.

5. Discussion

The aim of the present master's thesis was to investigate the effects of an acute, heart rate-controlled aerobic running load on the concentration ability of 10–11-year-old children. Using a randomized controlled intervention design and the standardized d2 test, the study examined changes in concentration performance, processing speed, and error rate across different instructional sequences. Overall, the findings indicate that a short bout of aerobic running can lead to measurable improvements in children's attentional performance, particularly regarding concentration capacity and processing speed.

5.1 Interpretation of the main findings

The primary hypothesis of this study stated that pulse-controlled aerobic exercise would lead to an improved ability to concentrate in children aged 10 to 11 years. This hypothesis was partially supported by the results. While no significant interaction between group and measurement time was found for concentration performance, a significant main effect of time emerged, indicating that concentration scores increased across measurement occasions. Importantly, post-hoc analyses revealed that concentration performance improved significantly following the aerobic running session in both experimental sequences. These findings suggest that the aerobic exercise unit contributed substantially to the observed improvements in concentration.

Similarly, processing speed (PS) showed a significant interaction between group and time, as well as strong main effects of measurement time. In both instructional sequences, processing speed increased significantly after the sports session compared to the preceding measurement. Although a slight decrease in processing speed was observed after the subsequent English lesson in one group, overall performance remained higher than baseline. This pattern indicates that aerobic exercise may have a particularly robust short-term effect on processing speed, which is consistent with previous research showing faster information processing following physical activity.

The results for error rate were less consistent. While a reduction in errors was observed after the English lesson in one group, no clear or systematic effect of the aerobic running session on error rate could be identified. Due to violations of statistical assumptions, the ANOVA results for error rate could not be interpreted conclusively. Therefore, findings related to accuracy should be treated with caution. It is possible that the d2 error rate is less sensitive to short-term exercise effects than measures of speed and concentration capacity, as suggested by previous studies.

5.2 Comparison with previous research

The findings of the present study are largely consistent with previous research demonstrating positive acute effects of aerobic exercise on attentional and cognitive performance in children and adolescents. Meta-analyses by Ludyga et al. (2016) and Xiong et al. (2020) report that short bouts of moderate to vigorous aerobic exercise lasting between 10- and 30-minutes lead to improvements in attention, reaction time, and processing speed. The observed increases in concentration performance and processing speed following a 20-minute heart rate-controlled running session align well with these conclusions.

The present results also correspond closely with the randomized controlled study by Altermann and Gröpel (2023), who found significant improvements in attention and processing speed after acute endurance, strength, and coordination exercise in adolescents. Although the current study focused exclusively on aerobic running and included a younger age group, the similarity of findings suggests that acute exercise-related cognitive benefits are already observable in late primary school. This supports the assumption that the positive relationship between physical activity and attention is not restricted to adolescence but extends to earlier developmental stages.

In addition, the findings are in line with earlier studies indicating that aerobic exercise without additional cognitive demands is sufficient to elicit short-term improvements in processing speed and concentration (Hillman et al., 2011; Pontifex et al., 2013). While some research suggests that cognitively engaging or coordinative activities may produce stronger effects (Budde et al., 2008; Pesce et al., 2009), the present study demonstrates that a simple, well-controlled aerobic running task can also yield measurable cognitive benefits.

The lack of a significant group × time interaction for concentration performance may be attributable to practice effects resulting from repeated administration of the d2 test. Similar learning or familiarization effects have been reported in other exercise–cognition studies using repeated testing designs. Nevertheless, the substantially larger improvements observed after the aerobic running session compared to baseline measurements indicate that physical activity contributed meaningfully to the observed changes beyond mere test repetition.

Overall, the present findings reinforce existing evidence that acute aerobic exercise performed at moderate intensity can enhance children's attentional functioning in the short term. By confirming these effects in a school-based setting using heart rate-controlled running, the study adds methodological support to previous research and strengthens the practical relevance of aerobic exercise as a means to promote concentration in educational contexts.

5.3 Physiological and psychological mechanisms

Several physiological and psychological mechanisms may explain the observed effects. Acute aerobic exercise increases heart rate and cerebral blood flow, leading to enhanced oxygen and glucose supply to the brain. This temporary upregulation of neural resources may facilitate attentional processes and information processing speed. Additionally, exercise-induced increases in neurotransmitters such as dopamine and norepinephrine are associated with improved alertness and executive functioning.

From a psychological perspective, aerobic exercise may elevate general arousal and mood, reduce stress, and increase motivation, all of which can positively influence concentration. The heart rate-controlled design of the present study ensured that all children exercised within an aerobic intensity range, which is considered optimal for cognitive benefits. Excessively high intensities, in contrast, may lead to fatigue and impair cognitive performance, which could explain inconsistent findings in some previous studies.

5.4 Educational implications

The results of this study have important implications for educational practice. The finding that a single, relatively short aerobic running session can enhance concentration and processing speed suggests that physical activity may serve as an effective tool to improve learning readiness in school. Integrating structured aerobic activities or running units into the school day—particularly before cognitively demanding lessons—could help students focus better and process information more efficiently.

Given that running is easy to implement, requires minimal equipment, and can be adapted to different fitness levels through heart rate monitoring, it represents a practical and inclusive intervention for schools. These findings support calls for increased physical activity during the school day and align with pedagogical concepts such as “movement-integrated learning” and active breaks.

5.5 Limitations

Despite its strengths, the present study has limitations that should be considered when interpreting the results. The study focused only on short-term effects; therefore, no conclusions can be drawn regarding long-term cognitive benefits of repeated aerobic exercise. In addition, the intervention consisted solely of aerobic running activity, and no other forms of physical activity were included for comparison. As a result, it is not possible to determine whether the observed effects are specific to aerobic exercise or whether similar cognitive effects might also occur following other types of movement.

Additionally, although heart rate monitoring ensured standardized intensity, individual differences in fitness level, motivation, and familiarity with running may still have influenced the results. Finally, the study was conducted in a single school, which may limit the generalizability of the findings.

5.6 Directions for future research

Future studies should include larger and more diverse samples to increase generalizability and statistical power. Longitudinal designs could examine whether repeated acute exercise sessions lead to sustained improvements in attention and academic performance. Moreover, comparing different types of aerobic exercise and varying intensity levels may help identify optimal conditions for cognitive benefits. The inclusion of additional cognitive measures and neurophysiological indicators could further clarify the underlying mechanisms.

6. Conclusion

The present study provides evidence that a short, heart rate-controlled aerobic running session can significantly enhance concentration performance and processing speed in children aged 10 to 11 years. These findings contribute to the growing body of literature emphasizing the cognitive benefits of physical activity in educational settings and underline the practical feasibility of implementing structured exercise interventions during the school day. The results demonstrated that concentration scores and processing speed improved following the aerobic exercise unit, regardless of the instructional sequence. Although no significant interaction between group and time was observed for concentration performance, the main effect of measurement time and post-hoc comparisons indicate that aerobic exercise exerts a positive short-term influence on attentional functioning. These improvements are consistent with theoretical models suggesting that increased cerebral blood flow, enhanced neurotransmitter activity, and elevated arousal levels following exercise can temporarily optimize cognitive performance.

From an educational perspective, these findings have important implications. Schools often face challenges related to students' fluctuating attention levels, particularly after sedentary periods or during cognitively demanding lessons. Integrating short aerobic sessions—such as a 20-minute run—into the daily schedule represents a low-cost, inclusive, and evidence-based strategy to improve learning readiness. Given that running requires minimal equipment and can be easily adapted to different fitness levels, it offers a practical solution for diverse school environments. Such interventions not only support physical health but also foster cognitive development, thereby contributing to holistic education.

Despite these promising results, several limitations must be acknowledged. The relatively small sample size and single-school setting restrict the generalizability of the findings. Furthermore, the study focused exclusively on acute effects; therefore, no conclusions can be drawn regarding the sustainability of these cognitive benefits over time. Future research should address these limitations by employing larger, more diverse samples and longitudinal designs to examine whether repeated exercise sessions lead to lasting improvements in attention and academic performance.

Additionally, exploring different types of physical activity and varying intensity levels could help identify optimal conditions for cognitive enhancement.

In conclusion, this study reinforces the notion that physical activity is not merely a tool for promoting physical health but also a valuable resource for cognitive and educational development. By strategically incorporating aerobic exercise into the school day, educators can create learning environments that support both body and mind. These findings advocate for a paradigm shift in educational practice—one that recognizes movement as an integral component of effective teaching and learning.

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List of figures

Annex

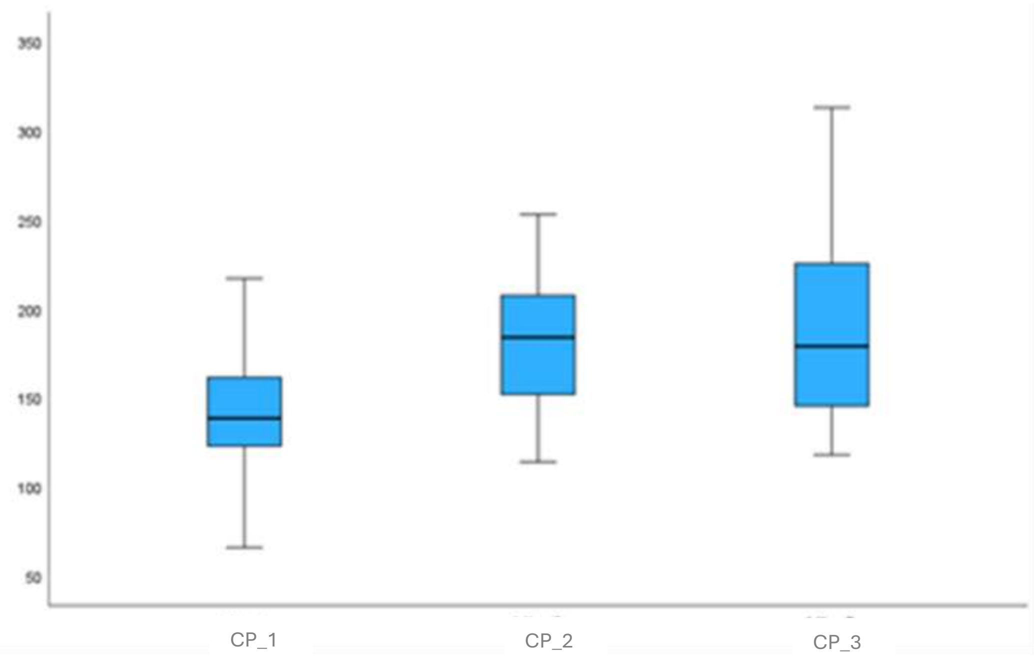

Figure 6: Box plots of concentration performance

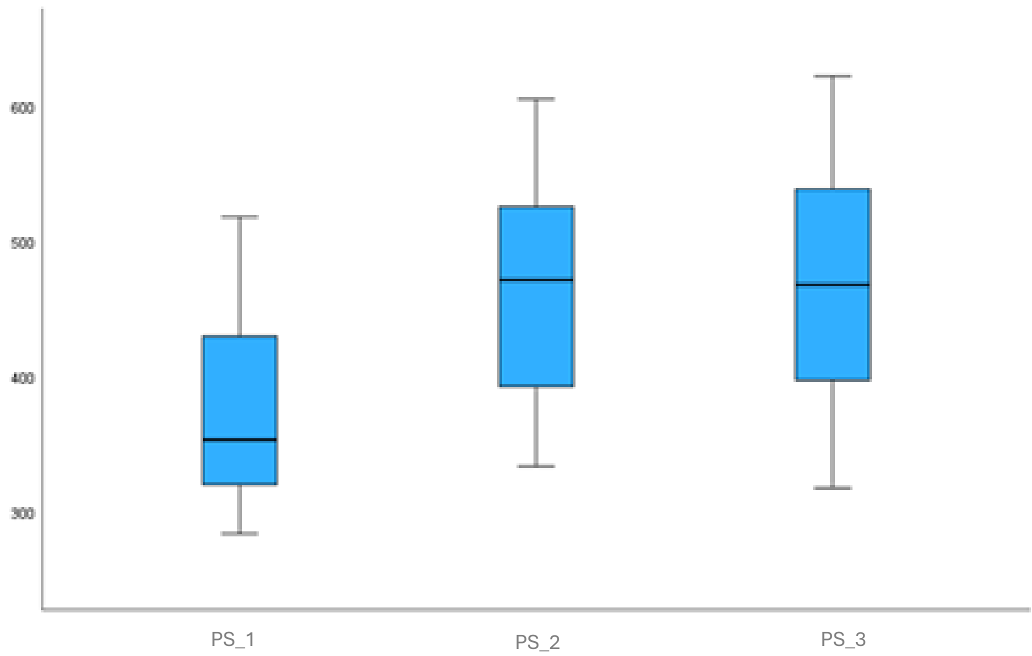

Figure 7: Box plots of processing speed

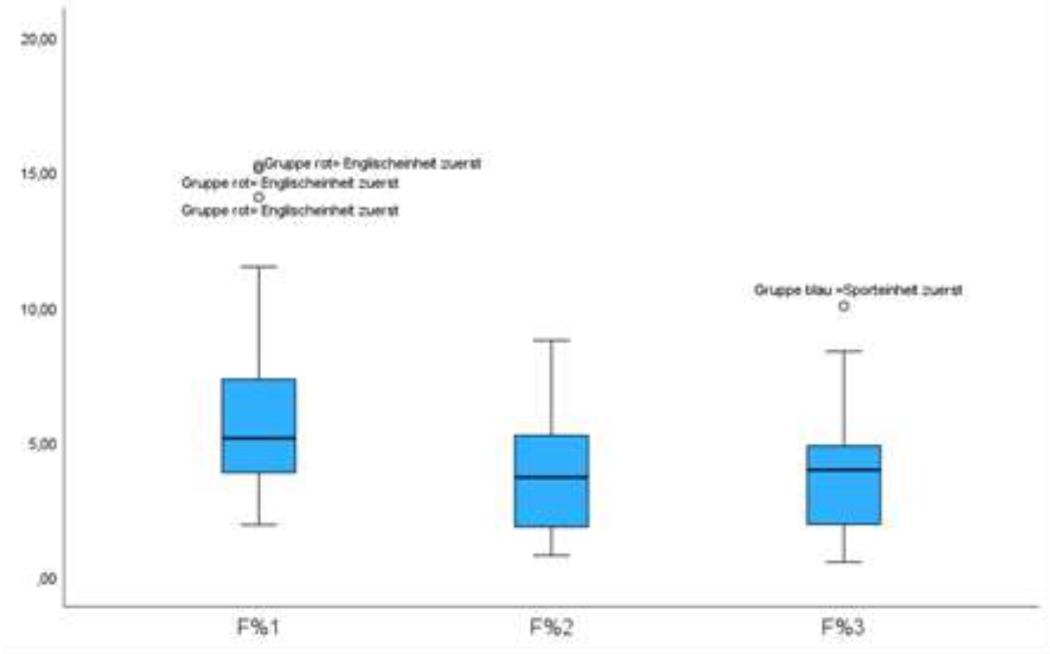

Figure 8:Box plots of error rate %

Declaration of authorship

I hereby declare that I have written the present master's thesis entitled

" Effects of heart rate controlled aerobic running load on the concentration ability of 10–11-year-old children"

independently and without any unauthorized assistance.

AI-based tools were used exclusively to improve the linguistic clarity and readability of the text. All content-related decisions, including the research design, data collection, analysis, interpretation, and conclusions, were developed independently by the author.

All sources and materials used, whether quoted directly or paraphrased, have been clearly identified and properly cited. This thesis has not been submitted, either in whole or in part, to any other examination authority for the purpose of obtaining an academic degree.

I confirm that I have complied with the principles of good scientific practice and that the present work does not violate any applicable regulations concerning academic integrity.