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Distraction versus Intensity: The Importance of Exercise Classes for Cognitive Performance in School

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Significance of the Study

- In this study, it was only exercise that induced a decrease in brain cortical activity and its relation to cognitive performance in school. These findings could contribute to the understanding of the underlying neurophysiological effects of exercise and probably have practical implications for school.

Keywords

Electroencephalography · Exercise and art classes · Cognitive function

Abstract

Objective: The aim of this study was to compare the influence of a class of aerobic exercise and an art class on brain cortical activity and possible effects on cognitive performance. ***Subject and Methods:*** Electroencephalography was used to record the electrocortical activity of 16 schoolchildren (8–10 years old) before and after an aerobic exercise class and an art class. Performance in a standardized test of educational attainment (VERA-3) was assessed following both classes. ***Results:*** A significant decrease in cortical activity was detected in all 4 lobes after exercise but not after art classes ($p < 0.05$). No changes in cognitive performance were observed after exercise and art classes. ***Conclusion:*** In this study, cortical activity was reduced after an exercise class but no effect on cognitive performance was observed. Hence, the neurophysiological effect of exercise should be further evaluated regarding different kinds of cognitive performance: creativity, knowledge acquisition as well as the outlasting effects of exercise on academic achievement.

Introduction

Within a more and more sedentary society, sport and exercise play a prominent role in health improvement [1], whereas exercise science in the recent decades had promoted physical activity as a valuable tool to maintain physical health and more attention has been drawn to the mental health aspect of exercise, i.e. mood [2] and cognitive performance [3, 4]. The fact that schoolchildren are

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required to sit and learn implies the imperative for activity mainly to enable them to be receptive to the content of the next lessons.

There is an increasing body of literature that reported on positive effects of exercise on academic achievement and cognitive performance [5–7]. Just recently Booth et al. [8] have shown an increase in academic achievement in mathematics, English and science classes at ages 11, 13, and 16 following a regular physical activity of moderate-vigorous intensity.

One of the most prominent theories to explain these effects on a neurophysiological basis is the theory of a transient hypofrontality, by Dietrich [9]. This theory assumed a shift of cortical activity away from frontal and prefrontal brain regions, towards the motor cortices [9]. Some research assumes this shift to be caused by a limitation of cortical resources [10] and a shift towards regions of the brain that are necessary to maintain physical performance, especially as this effect is only visible during higher exercise intensity [11]. Other attempts also take into consideration that the idea of shifting of resources is accompanied by a relocation of attention (distraction) caused by the joy of exercise [11, 12]. Following these ideas, it seems reasonable to argue not only for more school sport in order to increase academic achievement, but also other non-major subjects such as art and/or music classes are an important antipole to the cognitively orientated major subjects (languages, mathematics, and science).

One important aspect to consider when exploring the effectiveness of interventions on mental performance is to avoid a laboratory setting [12]. Although this is not always possible, one should aim to interfere as little as possible with the participants' natural setting.

It was hypothesized to find a decrease in frontal cortex activity following the exercise class, going along with a better performance in the VERA-3 (Vergleichsarbeiten in der 3. Jahrgangsstufe, 3rd-grade comparative tests) assessment. In order to distinguish between the possible effects of intensity and/or distraction, a regular art class served as control condition. The objective of this study was to determine whether an exercise class in contrast to an art class could provoke a decrease in brain cortical activity and whether or not this has any acute impact on cognitive performance in a standardized school assessment.

Materials and Methods

Participants and Procedure

This study was approved by the German Sport Universities Ethics Committee. Sixteen healthy children, 8 boys and 8 girls at the age of 8–10 years, volunteered to participate in this study. All participants were 3rd-grade students of a local primary school with different fitness levels. All parents signed consent forms (according to the Declaration of Helsinki) and completed a medical questionnaire prior to the beginning of the experiment. They were informed that they could withdraw from the study at any stage. Participants performed in randomized order a 45-min endurance-orientated exercise, consisting of aerobic running and small games with sprints, and a 45-min art class, where pupils were asked to draw their favourite animal. Electroencephalography (EEG) activity was recorded for 3 min in a seated rest position with eyes closed prior to exercise (pre) and immediately after the exercise and art classes (post), and this was followed by a standardized assessment of educational attainment (VERA-3) as well as a more game-orientated assessment of cognitive performance (MemoryMatrix® by Lumosity [12]). After finalizing the cognitive assessment, which took approximately 15 min, another EEG was recorded (post15).

Electroencephalographic Recording

A 32-channel portable EEG system (Brain Products, Munich, Germany) was used for data acquisition. Twenty minutes prior to classes the students wore an EEG cap (ActiCap, Brain Products, Munich, Germany). The cap was adapted to individual head size and built of 32 Ag-AgCl electrodes and 1 reference electrode (mounted in the triangle of FP1, FP2, and FZ) in the 10-20 system [13]. EEG activity was recorded on positions FP1, FP2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, TP9, CP5, CP1, CP2, CP6, TP10, P7, P3, Pz, P4, P8, PO9, O1, Oz, O2, and PO10. The cap, fixed with a chin strip to prevent shifting during the exercise trials, was permeable to air in order to prevent an increase in heat during exercise. Distances between electrodes were approximately 5 cm to prevent possible cross-talk after exercise due to salt bridges between electrodes. Each electrode was filled with SuperVisc™ electrode gel (EasyCap GmbH, Herrsching, Germany) for signal transduction. If impedance of an electrode exceeded 10 kΩ, the electrode was excluded from further analysis. The analogue signal of the EEG was amplified and converted to digital signals using Brain Vision Recorder 1.1 Software (Brain Products, Munich, Germany) and stored with a frequency of 500 Hz on the hard disk of a standard Dell XP-laptop PC.

Electroencephalographic Data Analysis

The EEG data were processed using Brain Vision Analyzer 2 (Brain Products, München, Germany). After manual artefact detection, high- and low-pass filters were applied so that a frequency range of 5–60 Hz remained for analysis (time constant 0.0318 s; 48 dB/octave). The EEG data were then segmented into 4-s sections where an overlap of 10% was accepted. A systematic protocol for excluding artefacts was followed. This included careful visual inspection of all EEG data and automated exclusion procedures. An individual component analysis was run on the data to check for eye and jaw movement artefacts. If applicable those were subtracted from the original data. As it is difficult to recognize artefacts in raw signals at or above 5 Hz, data were further checked by spectral analysis. If there was an external interfering signal (e.g., AC/DC at 50 Hz), it would have been present in all channels and therefore made visible by spectral analysis, which was not the case.

Using the integrated sLORETA [14, 15] module in the Brain Vision Analyzer, cortical current densities in the frontal, parietal, and occipital lobes were determined across each 3-min recording

Table 1. Changes in cortical current density ($\mu V^2/mm^4$) before (pre) and after (post) as well as 15 min after (post15) the aerobic exercise and the art class in the frontal, parietal, and occipital lobes

	Lobe	Pre	Post	Post15
Exercise	frontal	–2.84±0.53	–3.46±0.34**	–3.21±0.35*
	parietal	–2.06±0.58	–2.34±0.48**	–2.18±0.55*
	occipital	–0.57±0.10	–0.82±0.34**	–0.72±0.33*
Art	frontal	–3.00±0.46	–3.04±0.32	–3.03±0.28
	parietal	–2.07±0.60	–2.15±0.44	–2.09±0.48
	occipital	–0.67±0.53	–0.66±0.35	–0.60±0.48

A significant effect from pre to post ($p < 0.01$) and pre to post15 ($p < 0.05$) was noticeable after the exercise but not the art class. This effect was independent of lobe. Asterisks mark changes to pre: ** $p < 0.01$; * $p < 0.05$.

interval. Cortical current density defines the electric current caused by neural activity per unit area of cross-section. In general, the unit is microvolts per square millimetre (electrical current in a 2-dimensional area) but in a voxel-based analysis this value needs to be squared so that the unit is squared microvoltsper millimetre to the power of 4. Finally for normalization, data were log transformed using x' = ln(x) [16].

Cognitive Assessment

VERA-3 is a standardized assessment of educational attainment performed in grade 3 throughout Germany. The assessment included tests in mathematics and German (mother language). All pupils of grade 3 were asked to perform the assessment within a given week nationwide. In the German assessment pupils had to read a text for 10 min, followed by 10 comprehension questions to be answered in a time window of 10 min. In the mathematics assessment, pupils had to solve 10 mathematical problems from the current curriculum again in a time window of 10 min. A given number of points was assigned to each as right or wrong answer. The maximum number of points pupils could score (right/wrong) was 23 in mathematics and 18 in German.

The MemoryMatrix® is a game assessing spatial recall that addresses working memory [17], where players have to repeat a visual pattern consisting of tiles organized on the screen. Once a pattern had been reproduced, the number of tiles to be remembered was increased by 1 in every subsequent level. If the player was able to reproduce the pattern the player earned points, which after completion of the game was summed up to a final score and the player would be upgraded to the next level. If the player was not able to reproduce the pattern, the player was downgraded 1 level. The whole game consisted of 15 levels. The game ended by presenting the final score and the final level reached during the game.

Statistical Analysis

Statistical analysis of the EEG data was performed using an analysis of variance integrating the within factors "lobe" (frontal, parietal, occipital), "class" (exercise, art), and "time" (pre, post, post15). A least significant difference test was used for post hoc analysis where appropriate. Multiple post hoc pairwise comparisons were corrected using Bonferroni corrections. The level of significance was set to p < 0.05. Data in this manuscript are presented as 95% confidence intervals.

Statistical analysis on performance in both the German and mathematics components of the VERA-3 assessment (correct answers, wrong answers, processing time) as well as final score and level of MemoryMatrix® were performed using individual analysis of variances integrating the within factors "class" (exercise, art) and "time" (pre, post). Multiple post hoc pairwise comparisons were corrected using Bonferroni corrections. A least significant difference test was used for post hoc analysis where appropriate. The level of significance was set to $p < 0.05$. Data in this paper are presented as 95% confidence intervals. All statistical analyses were performed using Statistica version 7.1 (Statsoft, Tulsa, OK, USA).

Results

During the exercise class, the mean heart rate was 117.3 ± 23.71 b.p.m. with peaks at 182.55 ± 44.72 b.p.m. Comparison of EEG data revealed a significant effect for the interaction of class × time ($F_{2, 26} = 4.93$, $p < 0.05$). Post hoc analysis revealed a significant decrease in activity after exercise ($p < 0.001$) and after 15 min (p < 0.05) following exercise in comparison to the pre-exercise measurement. No changes were obtained for EEG recordings before/after art classes. No further effect of lobe was noticed ($F_{4, 52} = 1.36$, $p = 0.26$; Table 1).

No changes were obtained for VERA-3 components (Table 2) of German (correct: $F_{1, 15} = 0.710$, $p = 0.41$; errors: $F_{1, 15} = 0.06$, $p = 0.81$; processing time: $F_{1, 15} = 4.31$, $p = 0.06$), mathematics (correct: $F_{1, 15} = 0.42$, $p = 0.53$, errors: $F_{1, 15} = 0.36$, $p = 0.56$, processing time: $F_{1, 15} = 0.58$, $p = 0.46$), or for MemoryMatrix® (points: $F_{1, 15} = 4.37$, $p = 0.05$; level: $F_{1, 15} = 0.32$, $p = 0.58$).

Discussion

In this study, cortical brain activity was significantly reduced after attending a sports class while changes were not seen after an art class. Nevertheless, these changes were not accompanied by an increase in cognitive performance as assessed by either the VERA-3 tool or a more game-orientated assessment.

The neurophysiological data obtained in this study confirmed the previous findings that showed a decrease in cortical activity following an exercise session [12, 18]. Whereas previous EEG data showed a decrease in frontal and temporal regions of the brain, there was no lobe effect, i.e. an overall decrease in activity after exercise. A

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Table 2. Results of the VERA-3 assessment for performance in the German and mathematics component of VERA-3 ($n = 16$)

	Before exercise	After exercise	Before art class	After art class
German				
Correct	8.94±3.80	8.31±3.03	8.06±3.57	8.75±4.09
Wrong	8.25±3.71	7.50±2.76	8.44±2.61	8.06±4.30
Processing time, min	12.69±4.67	12.63±3.52	14.94±3.75	12.00±2.63
Mathematics				
Correct	11.06±4.49	10.94±4.92	12.13±3.59	10.69±5.20
Wrong	6.88±2.96	8.06±4.86	6.75±4.09	6.88±4.22
Processing time, min	10.00±0.37	9.75±0.58	9.81±0.75	9.38±1.20
MM				
Points	998.4±89.8	996.3±81.6	965.0±131.3	1,012.2±152.3
Level	8.06±0.68	8.50±0.89	8.06±1.06	8.38±1.15

MM, MemoryMatrix®. Maximal points: German, 18; mathematics, 23.

general model of cortical arousal assumes an increase in arousal and stress to result in a desynchronized cortical state, which is reflected by predominately low-amplitude, high-hertz EEG waveforms [19]. In contrast, slower frequency activity with higher amplitudes is found to be dominant in a relaxed, unstressed condition. Accordingly, the data obtained here can be interpreted as a more relaxed overall cortical state following the exercise class. The fact that no changes were observed after the art class clearly demonstrates an exercise-specific effect.

Interestingly the reported changes were not accompanied by an increase in the standardized assessment of educational attainment as hypothesized [20]. Although many studies in the last few years were able to provide reasonable content for a straightforward effect of exercise on concentrativeness, cognitive function [7], and academic performance [21], a missing effect in this study might be due to the fact that the VERA-3 tests were performed immediately after the termination of the exercise/art class. The personal experience of the study coordinator was that the pupils were very aroused after the exercise class and it was hard to convince them to sit down, stop talking, and start the tests. An assessment of educational attainment is a recall of previously acquired knowledge. Future studies should also concentrate on problem-solving abilities (e.g., creativity) and the effect of exercise on acquiring new knowledge.

Today the curriculum of school physical education is twofold. First, it aims to provide students with appropriate knowledge, skills, and attitudes to lead a physically active lifestyle [22]. Second, school sport aims to offer activities in an environment that is mainly characterized by a lack of physical activity. Whereas representatives of a health-promoting aspect of physical education are mainly concerned about future effects of missing fitness on cardiovascular [23], orthopaedic [24], and metabolic parameters [25, 26], there is increasing evidence concerning a more general effect of exercise. Castelli et al. [5] for example could show a positive relation between fitness and achievements in test performance of mathematics and reading in 3rd- and 5th-grade children. Aerobic fitness was positively correlated with the test results, whereas BMI values were negatively correlated. Coe et al. [6] could show that pupils who reported regular physical exercise outside of school achieved better test scores (mathematics, science, English, world studies) than pupils who reported no further activity outside school. This is in line with a study by Booth et al. [8] as well as results from adult studies showing improved cognitive performance connected to regular exercise [3, 4, 27]. A first reference that these connections could be based on neuroplastic changes caused by exercise was presented by Hillman et al. [7]. Showing a strong improvement in response accuracy, a larger general P3 amplitude, and better cognitive performance, they concluded to crucial changes in the brain's information processing connected to exercise.

Although in general a positive association between physical activity, fitness, cognition, and academic achievement is suggested, findings are not always consistent and need to be further evaluated concerning type, duration, amount, and timing. A good overview is presented by Donelly et al. [28].

One limitation of this study is the low sample size, not necessarily sufficient to detect significant differences in the performance tests.

Conclusions

In this study, cortical activity was reduced after an exercise but not an art class. An effect on cognitive performance was not observed. Hence, the neurophysiological effect of exercise should be further evaluated regarding different kinds of cognitive performance: creativity, knowledge acquisition as well as the outlasting effects of exercise on academic achievement.

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Disclosure Statement

There is no conflict of interest.

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