Experimental observations of the effects of physical exercise on attention, academic and prosocial performance in school settings

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1. Introduction

German school authorities do not place much emphasis on physical exercise although it is known that concentration improves, and stress and aggression decrease through exercise. We performed three experimental observations (EO) implemented in everyday school settings to investigate the effects of physical exercise on attention, academic and prosocial performance. In the first EO we examined the effect of a long-term exercise intervention on these variables in 6th grade students at a single primary school. In the second EO, the same design was replicated at four different schools. In the third EO the effect of a weekly jogging lesson was examined. Compared to control classes with regular lessons results indicate that implementation of exercise had positive effects on concentration and social behavior, and that academic performance was not compromised replacing lessons by sports. In the light of these results, physical exercise should play a bigger role in school children’s daily curriculum.

One part of the brain, the prefrontal cortex (PFC) is often discussed as being important for the ability to learn. Located right behind the forehead, the PFC is most certainly in charge of governing our behavior when confronted with new input. It can be divided into regional subdivisions that are connected to all the sensory systems, the motor and limbic system as well as structures that are important for reward, motivation and memory [14]. As Miller and Cohen explain, the PFC is a collection of interconnected neocortical areas that are in contact with most parts of the brain. The PFC is activated when something unusual happens in an otherwise normal situation. Spotting new relations, attending to and evaluating important events, and decision-making are important functions of this part of the brain. Storing information about goals and appropriate behavior according to context as well as the ability to inhibit the impulse to do something that might be fun at the moment but does not lead to achievement, constitutes one of the primary general function of the PFC [1,19].

Furthermore, neural pathways in the PFC are important for cognitive control since they store general rules that are needed for goal-directed behavior, comparing external information (something that happens right now) with internal information (past experience, learned and acquired over many years). Miller and Cohen go on explaining how the ability to inhibit acquired information in the face of an unusual instruction is also a feature of the PFC [19]. Since there are so many unpredictable problems that a person may experience, it seems unlikely that a neural pathway exists for every single problem. Rather, neurons in the PFC seem to form new pathways and build different connections as they are needed, an ability referred to as neuroplasticity. The PFC allows a
person to stay on-task, think about and hold information that one has just heard or read in mind, and think about something from different perspectives. Taken together, these abilities are often summarized by the term executive function [10].

Having well developed executive functioning is crucial for a student in school when he has to focus on a task. He must reason about the task and at the same time suppress the urge to engage in conversations with peers next to him. In everyday life, executive functions make the adaptation to quickly changing environments and situations possible. Inappropiate behavior is inhibited while the execution of a goal-directed plan is facilitated [14]. In general, executive functioning in young children has been found to correlate with academic achievement, health, income and (negatively) with addiction and criminal behavior later in life [20].

Another important factor for learning with an overall positive effect on neurons is the neurotrophin brain derived neurotrophic factor (BDNF), a member of the neurotrophin family of signaling proteins that modulate nerve cell growth [4,26,30]. BDNF, produced and released by glutamatergic neurons, is the only neurotrophin that is broadly abundant in the hippocampus and the adult forebrain. BDNF crosses the blood-brain-barrier in both directions and is stored in the periphery in platelets. Several positive effects of BDNF on neurons have been described to date and they shall briefly be described here.

Berchtold et al. [2] conducted a study examining the effect of exercise on BDNF and memory in mice using a radial-arm water maze. For three weeks, one group of mice had access to running wheels in their cages, while the other group did not. Subsequently, all the mice underwent “cognitive training” by being placed in a radial-arm water maze containing a hidden platform in one of the arms. As it turned out, animals who had exercised on the running wheels prior to the cognitive training made fewer errors in repeatedly finding the hidden platform than did sedentary mice. Emphasizing that “[…] BDNF in particular is emerging as a central molecule mediating benefits of exercise on cognition [… “], Berchtold et al. additionally analyzed the degree to which exercise increased the BDNF protein in the brains of another set of mice. Here, again, one group of mice had voluntary access to running wheels for a time period of three weeks while another group of mice did not have running wheels in their cages. BDNF protein levels were measured immediately after three weeks of exercise, after one week of no running wheels and no exercise and after two weeks of no running wheels and no exercise. The level of BDNF was increased in mice immediately after the exercise period. During the two following weeks of no exercise, the BDNF level declined [2].

Furthermore, BDNF increases, via the expression of a protein, the quantity of neurotransmitter vesicles that are transported close to the synaptic gap. This implies that the neurotransmitter can be released more frequently [4]. In addition, BDNF plays a crucial role in brain lactate metabolism and thereby further enhances neuronal functioning [28,25].

In humans, a study in eight healthy athletes looked at the BDNF levels after both a 10-minute moderate exercise interval and a subsequent ramp incremental cycle ergometry to exhaustion of about the same time. Rojas Vega et al. found that BDNF levels measured in the periphery before and after the moderate exercise interval did not differ. However, the researchers found an augmented BDNF level immediately after the athletes had completed the exercise to an exhaustion level [26].

In another 2006 study in Germany by [29], the effect of relaxation or engagement in aerobic or anaerobic exercise on cognitive performance was tested in 27 healthy male subjects. On three different days that were at least one week apart, subjects were assigned to three different experimental conditions: (A) Remaining sedentary for 15 min. (B) Engagement in low levels of physical activity for 40 min. (C) Engagement in intense physical activity by sprinting twice for three minutes with a two minutes break in between. After these activities, all subjects were required to learn fictional vocabulary words. The authors concluded that the speed of learning was significantly faster after the intense sprinting intervention than after the sedentary or the low physical activity conditions: students who had sprinted twice for three minutes learned 20 percent faster than students who had been sedentary or exercising at low intensity. Blood samples were gathered at three different time points: before and after the exercise took place and immediately after the vocabulary studying intervention. The BDNF serum level rose under all three conditions, the rise was the greatest and statistically significant in the high intensity program [29].

Taken together, the studies on BDNF and its role in the nervous system suggest that there is a link between exercise and a higher level of BDNF and a link between BDNF and improved performance on cognitive tasks. Through exercise and play, executive functions develop and BDNF is synthesized and released. Both factors are crucial for learning and memory, activities that are vitally important in schools where students have to focus on tasks, pay attention, think critically and acquire new knowledge and skills.

How can this new knowledge about PE and positive effects on school related behaviors be applied? Since schools have to be attended by every child, they provide an excellent opportunity for universal physical activity.

On the basis of the evidence presented so far, the effect of extra exercise lessons versus normal lessons on academic performance and prosocial behavior was tested in three different experimental observations. The first observation took place at a single school with 44 participating students. The second observation was a replication of the first observation with the only difference that it took place at four schools and engaged 148 students. In the third experimental observation, all the fifth grade students of a single school (48 students) participated. All the experimental observations took place at German primary schools (German: Hauptschule).

2. Experimental observation 1: effect of early morning exercise on social behavior and academic performance (single school).

This experimental observation was conceived to investigate the effect of extra weekly exercise lessons on students’ social and academic performance in a school setting. Two sixth grade classes were part of the observation; the intervention class received extra exercise lessons whereas the control class did not receive such exercise lessons. We hypothesized that extra exercise classes would change the students’ social behavior, self-perception, and academic performance. Therefore, academic grades in mathematics, German, and English language from both groups were compared at baseline (after fifth grade) and at post-test (after the first half-term of sixth grade). The teacher who taught both classes in German filled out a form before and after the study period that captured students’ behavior and academic skills in the classroom.

2.1. Method

The intervention class consisted of 24 students (mean age= 12.5 years; 9 female) and the control class of 20 students (mean age= 13 years; 7 female). The intervention class received three weekly extra exercise lessons during the first hour of the school day during a four month period (36 exercise lessons were accomplished). Two of these weekly exercise lessons took place in the Gymnastic hall of the school with three playing fields: here, the students were grouped into six teams of three to four players and played either
basketball (field one) or soccer (field two) or one of several possible other games (such as Hockey or Handball; field three) for ten minutes; then, the teams rotated to the next field, and then a third rotation took place. The third exercise lesson took place in the aula of the school: a hip–hop instructor was hired and the children were given a dancing lesson. The exercise lessons lasted for 30 min each, where after the children were given time to change clothing. Thus the duration of the entire intervention lasted for 45 min, i.e., the time period of a regular German school hour. During this time, the control class received English, German, or mathematics lessons according to the regular plan, i.e., the extra exercise lessons were performed en lieu of the regular school program.

Both classes filled out the d2 test of attention [5] before and after the intervention took place. This test consists of 14 lines with 47 characters each. Each character is either the letter d or p, marked with one, two, three or four dashes above or below each letter. The subject is given 20 s for each line with the task to cross out only those d’s that have two dashes attached to it. A d with more or less dashes or the letter p is not to be crossed out. The four main variables are total number of items processed, the number of errors made, the percentage of errors made in the test, and the concentration performance. Of these variables, the concentration performance was of most relevance to us.

2.2. Results and discussion

The Teachers’ list for social and studying behavior (German: Lehrereinschätzliste für Sozial- und Lernverhalten) [24], comprised of ten subscales, was filled out by the same German teacher for each student at pre- and post-testing. A repeated measures analysis of variance (ANOVA) with group as the between subjects factor and time (pre/post) as the within subjects factor revealed a significant interaction of both main factors (\(F(1,36) = 6.85, p = 0.01\)) for the subscale accurateness while studying. The intervention classes’ behavior had improved after the intervention period while scores for this item decreased in the controls. Furthermore, the intervention class outperformed the control class numerically in the d2 test of attention before and after the intervention period while statistical significance was not met. A repeated measures ANOVA on German grade with main factors group and treatment showed a significant interaction \((F(1,33) = 4.87; p = 0.03)\). German grades in the intervention class were slightly better at post-testing whereas the German grades in the control group worsened (see Fig. 1). This experimental observation revealed that early morning exercise instead of normal school lessons had either no effect (in math or English) or a positive effect (on social behavior and the German grade).

3. Experimental observation 2: effect of early morning exercise on social behavior and academic performance (four schools)

The obvious limitation of the first experimental observation was its small sample size of 44 students only. Therefore the second experimental observation followed the same design with intervention and control class, and was carried out at four primary schools. The primary school of the first experimental observation was not part of the second experimental observation.

3.1. Method

At the beginning of this observation, 148 students from 8 classes got involved. However, the school administrator of one school did not allow, contrary to previous verbal agreement, the evaluation of the children’s school grades for privacy issues. Therefore, even though the children and the teachers at this particular school participated in the observation throughout the intervention period, the most important dependent variable could not be measured.

Of the remaining group, 88 children completed the d2 test of attention before and after the intervention period. There were 55 students in the intervention group (mean age = 12.4 years; 22 female) and 33 students in the control group (mean age = 12.3 years; 12 female). Again, the exercise lessons were scheduled during the first hour of the school day. At one school, the exercise classes could not be scheduled within the usual timetable: the Gym hall was shared with another school and therefore always in use. Here, “zero hour” was invented for the duration of the study period: the class teacher and the students of the intervention class began their school day 45 min earlier on three days of the week. On these days, the students were not given any homework.

A total of 30 exercise lessons were conducted during the intervention period. In addition to the d2 test of attention, data on school grades in German, English and mathematics were gathered at pre- and post-testing. Furthermore, the Teachers’ list for social and studying behavior was completed by the class teachers of the intervention and control classes. Additionally, regular interviews with the teachers were conducted to see whether they noted any differences in the behavior of the students. Height and weight measurements were obtained through which the body-mass index was individually calculated. The conductor of the experimental observation interviewed each student at pre- and post-testing. In this interview, information on screen time, homework time and time spent outside of the school with extra sport was gathered.

At each school, two university students were hired to carry out the exercise lessons. The exercise lessons only comprised of games that could be played with three or four members on each team. In general, the same design was used as in the first experimental observation. During the exercise lessons, a teacher was present for insurance reasons.

3.2. Results and discussion

A repeated measures ANOVA revealed a significant interaction of both main factors group and time \((F(1,86) = 7.01, p = 0.01)\); see Fig. 2). The post-to-pre difference was greater in the exercise than in the control group, indicating that the exercise increased overall concentration performance more than the control condition.

For math there was a significant main effect over time \((F(1,63) = 6.28, p = 0.015)\) and a significant group by time interaction \((F(1,63) = 15.825, p < 0.001)\); see Fig. 3). The control group’s
math grades worsened whereas the exercise group’s math grades got better after the three months intervention time period.

The academic achievement in the school subjects German and English did not differ significantly. Both the Teachers’ rating scale for social and studying behavior and the regular interviews with the teachers involved in the study revealed that the prosocial behavior of the students in the intervention group changed positively, e.g. they were more eager to help other classmates. Such behavioral changes were not observed in any of the control classes.

The interviews conducted with each participating child revealed no differences between both groups as regards time spent with homework or screen-time. It is worth noting that 45% of all children stated in the interview that they do not exercise outside of the school during the afternoon at all.

The body-mass index was obtained and each child was categorized into one of five groups (overweight, upper range of the normal weight range, normal, lower range of the normal weight range, underweight). There were no BMI differences between the two groups and there were no differences at pre- and post-testing. Yet, it turned out that at pre-testing 28% of the students were overweight and 27% were in the upper range of the normal weight range. At post-testing, 25% of the students were overweight and 30% were in the upper range of the normal weight range.

Students in the intervention group in this experimental observation had either less homework or less regular lessons in the school subjects of math, German and English than the control group. Yet, the outfall of regular studying time or conversely the additional exercise time had (again) either no or positive effects on academic achievement and prosocial behavior.

4. Experimental observation 3: effect of early morning jogging (single school)

The first and the second experimental observation revealed that 6th grade students benefit from early morning exercise. The main problem in allowing for more exercise at all the participating primary schools is the shortage of Gym halls: schools either shared their exercise space with another school or they had only one single Gym hall. So even if the school authorities were willing to give students more time to exercise within their timetables, there would be no room to actually carry out the exercise lessons.

So, once the question whether children benefit from exercise was positively answered, the next question arose: How can this finding be implemented into a normal school curriculum? In a third experimental observation, jogging around a school was explored as one possible way to exercise all students together at the beginning of the school day.

4.1. Method

Fifty three 5th grade students (mean age = 11.6 years; 21 female) were part of this observation. The school organized heart rate monitors so that the students could run at their individual paces. The conductor of the experimental observation explained to the students how the gadgets work and at which pace they should be running, e.g. at 150 b/pm. The students ran around the school building, which is surrounded by trees. The path does not run next to streets, which means that the children were not exposed directly to car pollution while running. One loop around the school is 400 m long. Since the path is not equipped with a roof, the children could only run outside when the weather allowed for running.

The children ran around the school on one day per week (Thursdays); no specific parameters were evaluated. However, the conductor of the experimental observation interviewed the class-teachers regularly.

4.2. Results and discussion

The experimental observation period consisted of four months (March–June) with a total of 13 jogging lessons taking place. The jogging class had to be canceled once due to rainy weather.

The observation was not funded at all, which means that the conductor of the experimental observation was the only external person who explained the students at which pace they had to jog and how to wear the heart rate monitors. Even though most children liked the idea of seeing how fast their hearts were beating especially through running, it was very difficult for one person alone to organize and manage the proper usage and handling of the monitors.

The teachers reported that the children were generally more concentrated and focused after the jogging intervention. It was also noticed that most children had to learn what “jogging” means, namely neither sprinting nor standing but running at a constant pace that allows for talking. It was also noticed by the teachers and the conductor of the experimental observation, that most children learned very quickly at which pace they needed to run in order to maintain a steady running rhythm. No negative observations were made.

5. General discussion

Why should physical exercise be introduced in the daily schedule of school children?
Firstly, a recent metaanalysis of studies on physical activities and academic achievement published by the Centers for Disease Control and Prevention (2010) concluded that physical activities either led to increased academic performance or had no effects, but in no case led to negative effects on academic achievement: “[…] Eleven of 14 studies found one or more positive associations between physical education and indicators of cognitive skills and attitudes, academic behavior, and/or academic achievement. Overall, increased time in physical education appears to have a positive relationship or no relationship with academic achievement. Increased time in physical education does not appear to have a negative relationship with academic achievement […].” [7]

Secondly, due to a sedentary lifestyle in industrialized countries, mainly caused by time spent in front of screen-media and the consumption of junk food, an increasing number of children are overweight or even diagnosed as obese [21]. These relationships are discussed in a recent policy statement by the American Academy of Pediatrics. The authors conclude: “[…] Media clearly play an important role in the current epidemic of childhood and adolescent obesity. The sheer number of advertisements that children and adolescents see for junk food and fast food have an effect […]” [9].

Thirdly, exercise benefits the brain in different ways: aerobic exercise improves executive functioning in the short and in the long term [3]. Animal studies [2,15] as well as human studies [26] confirm that the neurotrophin BDNF is produced and released through running.

Fourthly, studies on the relationship between physical exercise and concentration performance have been conducted in school environments. In two studies the d2 test of attention was used: in the first one, Budde et al. [6] demonstrated in a pre- post-controlled study design that teenagers did significantly better in this concentration test after they had engaged in 10 min of coordinative exercise versus a normal sport lesson. In the second one, Moser [22] conducted a study in which students either had a math lesson, an art lesson, or an exercise lesson during the 5th hour of the school day. Then, in the 6th hour of the school day, three different concentration tests (at the beginning, the middle and the end of the 6th hour) were performed. It turned out that concentration performance in the third test, i.e. at the end of the 6th hour, was the highest if the previous lesson had been the exercise lesson. After the math lesson, performance in all three tests was lowest.

For these four reasons, the experimental observations were carried out: the authors were interested to find out how big the impact of extra exercise lessons would be. School grades were the most important dependent variable. It was shown that academic performance either improved or remained the same in the intervention groups in the first and in the second experimental observation, whereas the grades in the control groups either remained the same or worsened. Both experimental observations did not reveal negative effects of exercise on academic performance. The d2 test of attention was furthermore used as a dependent variable in the first and second experimental observation: with the small sample size (44 students) of the first experimental observation, only positive trends towards higher concentration performance in the intervention class were observed. These trends became significant with the increased sample size (88 students) of the second experimental observation. Also evident in Fig. 2 is a slight increase in concentration performance in the control group. It would be interesting to find out whether a group that would receive neither exercise nor normal lessons would also demonstrate changes in concentration performance because it is usually the case that control groups in intervention studies do not receive any treatment. With respect to the present experimental observations, it is however difficult to implement such a condition because this would imply that one group of students had to receive less weekly lessons, which is most likely not in accordance with statutory provisions for German school authorities.

In addition, our data on physical parameters (BMI) has to be discussed in the light of data presented by the Robert Koch institute [17] on this issue: this institute revealed in a nation-wide survey that 15% of German children are overweight; researchers of that institute reported that they found that children from households with a lower income were more likely to be overweight, yet, they did not reveal how much more likely the children were. Data on the income per household of the children involved in the experimental observations presented here were not acquired. However, it was noted by teachers and the researcher that children often did not wear proper sport shoes or sport outfits. This may indicate that many children in this experimental observation were of a lower socioeconomic status which would serve as a possible explanation for why more than 50% of the children in the second experimental observation were either overweight or in the upper range of the normal weight range.

Regular interviews with the class teachers revealed that behavioral problems with students that led to parents–teacher meetings occurred more frequently in the control classes. These data could not be quantified, as each school has its own way of dealing with disordered conduct and disrupted behavior. One teacher of an intervention class described that all her students accepted each other with all their peculiarities, which had not been the case before the intervention had started.

Finally, the experimental observations described here show that it can be difficult to work scientifically at a school: teachers and students become ill and therefore cannot complete a testing series, and teachers sometimes are not willing to comply with a scientific design. But, even though schools are a scientifically unfriendly environment in this respect, it is nonetheless possible to conduct experimental observations. These are needed because only through such experimental observations the positive effect of a treatment such as exercise can be confirmed. Now the next step must lay in the establishment of daily exercise in schools.

References


