Effects of NeuroBike Cycling on EEG Brain Activity and Mathematical Performance: An Intervention Study.

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Abstract

The general purpose of the study was to promote the research on effects of physical activity on mathematical performance and brain functions, which is of particular interest regarding children's education as well as for all adults. Several studies have identified an influence of cycling on cognitive processes and brain activity. In the present study, we investigated effects of cycling training on a special bicycle on spontaneous EEG brain activity and on mathematical performance of young adults. Participants performed different interventions (special bicycle - NeuroBike, common bicycle, daily activity) in a two-week intervention with three 20-minute training sessions per week. Spontaneous EEG was recorded before and after each training condition at rest as well as during different mathematical tests (algebra, arithmetic, geometry) before and after the two-week intervention. Behavioral data show reduced mathematical performance in geometry after the NeuroBike and common bicycle intervention in comparison to daily activity. EEG data reveal increased temporal and occipital theta power, occipital alpha power, and parietal and occipital beta power after the two week intervention without acute influence of NeuroBike cycling at rest. Repeated NeuroBike training lead to increased frontal power in all frequency bands as well as temporal theta and alpha power during algebra performance. The results indicate that continuous training on a NeuroBike fosters a beneficial brain state for learning at resting state, but does not lead instantaneously to an optimum brain state for active spatial processing in mathematical problem solving.

Keywords: brain functions, motor control, physical activity, cognition, mathematic performance

Introduction

Effects of bodily activity on cognition have been studied for several decades and are meanwhile widely accepted (Colcombe & Kramer, 2003; Cox et al., 2015; Esteban-Cornejo, Tejero-Gonzalez, Sallis, & Veiga, 2015; Etnier et al., 1997). However, the influence on the specific brain activation patterns is barely examined. Previous research though shows a positive effect of general physical activity on cognition and brain activity. Thus few studies identified an influence of cycling on cognitive processes, concerning brain activity and mathematical performance partially (Crabbe & Dishmann, 2004; Etnier & Sibley, 2003). Henz, Schöllhorn and Oldenburg (2013) found increased alpha, beta as well as gamma activity during minor physical activity in processing different mathematical tests. But the main research is still limited on the analysis of executive functions in relation to physical activity. Further studies showed an influence of executive functions as working memory and inhibition on mathematical performance (Barrouillet & Lepine, 2005; Bull & Scerif, 2001; Passolunghi & Siegel, 2001; Swanson & Kim, 2007).

Up to now, most studies mainly focus on the effect of aerobic exercise like cycling, running and walking that are dominated by endurance and mainly repetitions of movement, on brain activity. This study uses the approach of analyzing a coordinative demanding exercise with high variety, and its effects on cognition. The NeuroBike is a kind of an instable bicycle with high coordinative demand applied in sports therapy and sports training. We assume cycling the NeuroBike requires certain executive functions as inhibition, high mental flexibility, and attentional control as a consequence of the specific, flexible frame of the bicycle,. An improvement in these functions is assumed to be advantageous for mathematical performance as well. The expected balance movement is similar to the cross-coat of humans due to the joint in the center of the bicycle frame and should lead to positive effects on brain functions according to the manufacturer. In the present study, we investigate effects of training with this NeuroBike on spontaneous EEG brain activity and on mathematical performance (algebra, arithmetic, geometry) as a representative of the assessment of cognitive performance. Furthermore we compare these abilities with the impact of common bicycle training and following non-physical daily activity. We suspect according to the high coordinative demand of the NeuroBike a special influence on brain activity and mathematical performance.

Methods

Participants

The sample of 36 healthy volunteers, all students aged between 20 and 28 (mean 24±2 SD) years, was divided into three groups, equal in number as well as intra-group equal in gender. Subjects gave their written informed consent for study participation. All participants fit the neurologically necessary condition of the same handedness to compare brain activity (Serrien, Ivry, & Swinnen, 2006; Sun & Walsh, 2006) and right-handedness was selected as a study participation criterion for economic reasons. Volunteers were classified as neurologically healthy. No neurological impairment or related medical pre-existing conditions were mentioned. The physical or cerebral activity influencing substances (Zschocke & Hansen, 2012) have not been consumed at least 24 hours before the measurement dates. With one exception, caused by an injury outside the study framework, all participants completed the destined study design.

Participants were coded with numbers for anonymity of personal data. As an instruction volunteers were requested to refrain outside study participation from any physical activities demanding coordination and especially from cycling with a common bicycle throughout the intervention period.

Study design and procedure

The study was conducted at the sports institute of the Johannes Gutenberg University of Mainz. With a pre-post-test design the effects of three independent training groups were investigated. EEG brain activity and mathematical problem-solving competence were chosen as measurement parameters for cognitive performance dependent on different training groups. Secondary criteria, which may affect cognitive functions, were the subjective state, determined by assessing physical and mental effort, and the quality of cycling management. The measurements were carried out under laboratory conditions.

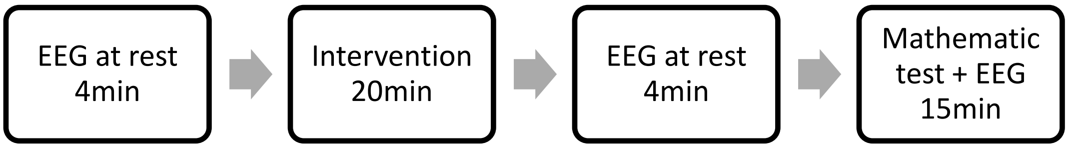
One group, that was training on the NeuroBike, and two control groups, characterized by training on a conventional bicycle and by the pure pursuit of physically inactive everyday activity, determined the three groups of participants with group-dependent differences in content as well as in number of appointments.

According to Frenzel (2004) an average time of 14.7 minutes is needed in order to obtain a very first cycling skill of the NeuroBike (Schöllhorn et al., 2005). Therefore all participants of the NeuroBike group started with two practice sessions of 20 minutes on different days for acquiring sufficient cycling ability on the NeuroBike. Practice was based on the concept of explorative learning (Steiner, 2013). Afterwards cycling ability was tested by passing five laps in a self-designed slalom course through documentation of lap time, various cycling errors, and heart rate. The conventional bicycle group was also obliged to undergo this cycling test before starting the two-week period of measurement. Measurement data of participants, who didn't pass this test, were excluded from further evaluation. Overall four participants of the NeuroBike and three of the common bicycle group were suspended. The daily activity group required no additional appointment.

Within the two-week intervention period the NeuroBike and common bicycle group completed six training sessions of 20 minutes cycling in the course. The first and last session included the pre- and post-test, measuring EEG brain activity and mathematical performance. The daily activity group was just supposed to underlie the pre- and post-test and in between to pursue their common, everyday activities. As non-physical daily activity, watching a TV series for 20 minutes was chosen. The current subjective state of every participant was measured each session by means of a questionnaire containing the individual assessment of physical and mental effort as well as the grade of wellbeing, concentration, sleep, and the last recent activity before the test.

The procedure of each test (Figure 1) was defined by the measurement of spontaneous EEG activity for four minutes with eyes open just before and after the intervention session of 20 minutes at rest. Afterwards mathematical performance was assessed during 15 minutes with simultaneous EEG brain activity measurement.

Figure 1. *Pre- and post-test procedure*



Apparatus

Intervention

The NeuroBike, a common bicycle, and a known sitcom available as DVD were applied for intervention. The NeuroBike (Figure 2) is a kind of an instable bicycle applied in sports therapy and sports training. The balance movement during cycling is similar to the cross-coat of humans due to the hinge-joint in the center of the bicycle frame (instead of the moveable handlebar in common bicycles) and leads according to the manufacturer to positive effects on brain function.

Figure 2. *NeuroBike*

The NeuroBike and the common bicycle were similar in wheel size (26 inches), brakes and adjustability of seat height. The only difference laid in the number of gears (single-gear NeuroBike and multi-gearbox of the common bicycle). To avoid potential influence of differences in resistance on analysis, a single gear of the common bicycle was chosen, which corresponded to the one of the NeuroBike. Two different episodes of the sitcom were shown on a computer to the third group, while the relevant participants watched them sitting on a common chair with headphones with constant volume.

Cycling course

The course of physical exercise was especially set up for this study, since no validated, especially suitable course for NeuroBike cycling was available. The course was inspired by recommendations of a project “limits for absolute unfitness to drive with cyclists” (Daldrup et al., 2014) and cycling instructions of the NeuroBike manufacturer. The course was divided into four main elements. These include goals to drive through in an oval arrangement, slalom driving through gates and shields in irregular distances as well as a straight, long slim alley. In order to reduce adaptational effects and minimize emerging boredom, the cycling direction had to be changed each lap.

Participants were instructed to cycle the course as quickly and safely as possible. According to the varied course the use of executive functions was considered to be maintained constantly. Individual cycling ability was quantified by means of the average time per lap, fastest and slowest lap as well as average cycling errors of three different types (foot, obstacle-, omission-errors). A foot-error was defined as any contact with a foot to the ground. Any contact with the bicycle or body to an obstacle was identified as an obstacle-error. Omitting an obstacle of the course was declared as omission-error.

Electroencephalography

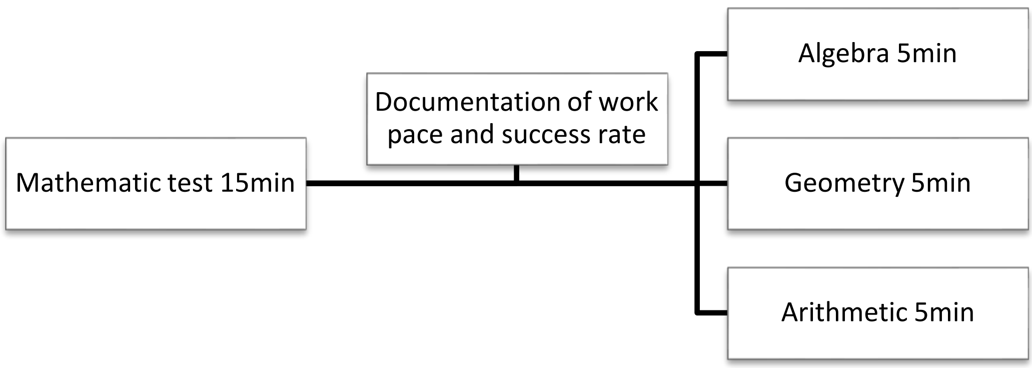
Spontaneous resting electroencephalography (EEG) was assessed by the EEG-system Micromed SD LTM 32 BS with a sampling rate of 256 Hz and recorded by the international 10-20 system using 19 electrodes. At pre- and post-test, EEG was recorded before and after the training session at rest, and during the mathematical tests. For all EEG measurements a homogeneous and low impedance of the electrodes in all points was sought. Spectral power densities were calculated for the theta (4-7.5 Hz), alpha (8-13 Hz), alpha1 (8-10 Hz), alpha2 (10-13 Hz), beta (13-30 Hz), beta1 (13-15 Hz), beta2 (15-21 Hz), beta3 (21-30 Hz) and gamma (30-70 Hz) band. The conduction of brain activity was unipolar with grounding on the nose. Furthermore, a bipolar electrooculogram was applied. Additionally, an electromyogram was recorded for monitoring the activity of the neck and shoulder muscle activity. Data were recorded by means of the SystemPlus Evolution software. Data were band pass filtered (0.008 Hz to 120 Hz).

Mathematical Tests

The test of mathematical performance is mainly based on the one Henz, Schöllhorn and Oldenburg (2013) used in their study for the analysis of the relation between minimal physical activity and brain activity. The other few existing validated tests in German language to measure mathematical performance of young adults (Jasper & Wagener, 2013; Lienert, Hofer, & Beleites, 2014) were according to the destined processing time and type of tasks not appropriate to the remaining study design.

Overall performance in mathematics (Figure 3) was divided into the performance in the subareas algebra, geometry and arithmetic. This was assessed before and after the intervention by a multiple-choice PC test. For each subarea a processing time of five minutes was set to solve as many tasks as possible by mental effort only. The tests demanded solving linear equations with two-sided variables (Filloy, Rojano, & Puig, 2008), using spatial ability (Birkel, Schein, & Schumann, 2002) and mental arithmetic (Padberg, 2007). The chronological arrangement of the three subareas was evenly distributed over all participants in order to ensure independence of the processing sequence. For each subarea the number of correct and total solved tasks, pace of work, and success rate of the subareas was determined.

Figure 3. *Setting of the Mathematic Test*



Heart Rate Measurement

Heart rate was monitored at rest right before and during the intervention by a Polar H7 heart rate sensor connected via Bluetooth to an iPad Air as a control variable. The strain on the cardiovascular system between the bicycle and NeuroBike group was compared in order to control the exhausting level that can influence brain activity and cognitive performance (Coe et al., 2006; Hillman et al., 2008).

Mental and Physical State

Mental and physical exertion, based on subjective expression of the participants, was documented before and after every session. This was operationalized using a numerical rating scale with an even division of the values from 0 as low to 10 as high exertion. Out of this information an additional variable was created signifying the changes of each exertion type between assessment times. Therefore a values range from -10 to 10 existed in which the negative values described a decrease and positive values an increase in effort.

Data Analysis

Throughout the analysis, a significance level of five percent (P <0.05) was determined. The recorded measurements of brain activity were statistically analyzed by EEGLAB, an add-on of the software MATLAB. All other measured data were entered into the statistical software SPSS and subjected to selected statistical tests. All variables were tested on standard normal distribution by Shapiro-Wilk-test. Descriptive statistics were generated for every sub-region of analysis (Table I).

Physical Intervention

Data of the movement-time course and the heart rate were evaluated via ANOVA with repeated measurement. A six-step within-subjects factor corresponding to the number of intervention events was created with the experimental group as between-subjects factor.

Mental and Physical State

First, the subjective conditions of all three groups were analyzed in a pre- and post-test comparison. Using analysis of variance with repeated measurement, changes in the mental and physical effort of the pre- and post-test were evaluated with the number of measurement times corresponding the double within-subjects factor.

Furthermore the sensitivities of the two physically active treatment groups according to the course management was analyzed by means of ANOVA with repeated measurement for all six measurement points followed by a post-hoc test with Bonferroni alpha correction.

Mathematical Performance

Homogeneity of mathematical performance data at the very beginning of the study was proven by the Kruskal-Wallis test. For analyzing intergroup differences within the three mathematical subareas due to the two-week intervention period, ANOVA with repeated measurement was applied using a double within-subjects factor and the experimental group as between-subjects factor. In addition post-hoc test was used with Bonferroni correction. To examine changes in movement groups the t-test for dependent samples was applied in the sub-region geometry. Non-normally distributed data of the partial areas algebra and arithmetic were analyzed by Wilcoxon-test.

Evaluating Individual Characteristics

The variables 'age', 'last activity right before each session', 'general well-being', 'sleep of the previous night' and 'current concentration' were analyzed by the Kruskal-Wallis test differentiating between experimental groups. Data of the 'last activity right before each session' was scaled in three categories, a) cognitively and b) physically demanding as well as c) without request.

Electroencephalography

Spectral analysis was used for assessment and interpretation method of EEG data (Zschocke & Hansen, 2012). For each EEG frequency band, theta, alpha, beta and gamma, as well as the respective sub-bands power density spectra of the EEG signal has been created by Fast-Fourier-Transformation. Furthermore, an independent component analysis (ICA) was conducted via EEGLAB. Recurring artefacts such as eye closing and eye movement as well as muscle artefacts of muscle activity (EMG) were filtered by reducing interference-prone components. After visual inspection of the complete recordings individually occurring, abnormal interferences of the electric potential have been eliminated. For statistical examination the analysis of variance included post-hoc test with Bonferroni correction was conducted.

Results

Table 1. *Descriptive statistics of selected variables*

		NeuroBike		common bicycle		daily activity
N		7		9		12
Age (years)		25.8 ± 1.0		23.7 ± 1.5		23.7 ± 2.1
Gender (n)						
Males		5		4		6
Females		3		5		6
Well being		2.8 ± 0.3		2.8 ± 0.2		2.8 ± 0.3
Sleep last night		2.5 ± 0.4		2.6 ± 0.4		2.5 ± 0.6
Concentration		2.5 ± 0.3		2.6 ± 0.4		2.5 ± 0.5
Last activity (%)						
cognitiv		29.4 ± 33		18.5 + 19.3		29.2 ± 39.6
physical		14.6 ± 27.2		24.2 ± 27.6		20.8 ± 33.4
without request		56.0 ± 39.7		57.3 ± 30.2		50.0 ± 42.6
Mental and physical state (x ≤ ±10)						
mental effort	Pre	1.6 ± 2.1		0.7 ± 2.3		-1.2 ± 1.9
	Post	3.3 ± 2.6		2.9 ± 1.5		-0.7 ± 1.7
physical effort *	Pre	3.7 ± 1.6		2.4 ± 2.6		-1.5 ± 2.2
	Post	3.7 ± 2.1		5.1 ± 1.2		-2.5 ± 2.2
Movement intervention						
Heart rate (bpm)						
at rest	Pre	69.6 ± 11.9		71.4 ± 14.2		
	Post	67.7 ± 8.3		64.6 ± 15.0		
exercise	Pre	134.6 ± 19.3		145.9 ± 22.5		
	Post	137.6 ± 15.3		153.6 ± 14.8		
Lap time (s) **	Pre	47.2 ± 5.8		31.3 ± 3.3		
	Post	31.6 ± 1.6	**	27.1 ± 2.2	**	
Fastest lap (s) **	Pre	38.1 ± 5.0		28.3 ± 3.0		
	Post	28.0 ± 2.1	**	24.9 ± 2.3	**	
Slowest lap (s) **	Pre	80.3 ± 9.7		40.0 ± 5.4		
	Post	45.0 ± 7.2	**	31.9 ± 3.8	*	
Cycling errors (n per lap)						
Overall **	Pre	5.6 ± 3.4		0.1 ± 0.1		
	Post	0.7 ± 0.3	*	0.1 ± 0.1		
foot-errors **	Pre	4.9 ± 3.2		0.0 ± 0.0		
	Post	0.3 ± 0.2	*	0.0 ± 0.0		
obstacle-errors**	Pre	0.7 ± 0.3		0.1 ± 0.1		

	Post	0.3 ± 0.1 *	0.1 ± 0.1	
omission-errors	Pre	0.1 ± 0.1	0.0 ± 0.0	
	Post	0.1 ± 0.0	0.0 ± 0.0	
Workpace (n)				
Algebra	Pre	23.6 ± 11.4	22.0 ± 12.3	21.2 ± 11.7
	Post	29.7 ± 15.3 *	28.33 ± 14.5 *	27.8 ± 13.9 *
Geometry	Pre	8.3 ± 2.5	8.3 ± 2.6	7.9 ± 4.4
	Post	11.1 ± 4.2	11.2 ± 3.7	11.8 ± 5.0 *
Arithmetic	Pre	15.1 ± 5.5	13.3 ± 2.7	14.5 ± 4.6
	Post	18.0 ± 4.0	16.3 ± 4.6	16.4 ± 5.6
Success rate (%)				
Algebra	Pre	74.9 ± 17.7	75.8 ± 16.2	76.7 ± 12.4
	Post	77.1 ± 11.7	81.2 ± 6.1	75.8 ± 12.4
Geometry	Pre	38.9 ± 18.6	32.1 ± 26.0	34.5 ± 23.4
	Post	50.9 ± 25.2	43.6 ± 26.8	42.8 ± 17.7
Arithmetic	Pre	74.6 ± 20.3	66.4 ± 20.1	72.8 ± 13.7
	Post	74.6 ± 13.1	66.7 ± 15.0	73.6 ± 12.4

Note: mean ± SD; * p<0.05, ** p<0,001; * after parameter signify intergroup difference; * after certain value signify intragroup difference between pre- and post-test.

Movement Intervention

The statistical results show no significant intergroup difference in heart rate at rest (F (2,968) = 0.350, P = 0.787) as well as during movement intervention (F (5) = 1.413, P = 0.230). In all speed parameters (average lap time F (2,367) = 28.905, P < 0.001, η^2 = 0.674; fastest lap F (1,898) = 14.246, P < 0.001, η^2 = 0.504; slowest lap (F (2,927) = 10.145, P < 0.001, η^2 = 0.420) highly significant differences appeared with much better values for the common bicycle group. Also all parameters related to errors during the bicycle rides (overall errors F (1,287) = 14.849, P = 0.001, η^2 = 0.515; foot-errors F (1,292) = 14.851, P = 0.001, η^2 =0.515; obstacle-errors F (1,967) = 8.490, P = 0.001, η^2 = 0.378), except omission-errors, displayed highly significant differences.

As a result of the two-week intervention period highly significant intragroup effects were determined within the NeuroBike group in speed parameters (average lap time F (2,080) = 55.753, P < 0.001, η^2 = 0.903; fastest lap F (1,404) = 41.593, P < 0.001, η^2 = 0.874; slowest lap F (5) = 16.093, P < 0.001, η^2 = 0.728). The bicycle group showed highly significant intragroup differences (average lap time F (2,030) = 16.550, P < 0.001, η^2 = 0.674; fastest lap F (2,119) = 11.598, P = 0.001, η^2 = 0.592; slowest lap F (1,841) = 6.408, P = 0.011, η^2 = 0.445). With regard to the error parameter only the NeuroBike group cared, except the omission errors, for a significant decrease (overall errors F (1,284) = 11.483, P = 0.008, η^2 = 0.657; foot-errors F (1,292) = 11.348, P = 0.008, η^2 = 0.654; obstacle-errors F (1,662) = 7.695, P = 0.012, η^2 = 0.562) following the two-week intervention.

Mental and Physical State

In pre- and post-test comparison no significant difference in mental effort has been identified between groups (F (2) = 1.209, P = 0.315). Based on the post-hoc tests with Bonferroni correction highly significant differences between the NeuroBike as well as common bicycle group and the daily activity group were determined (P < 0.001), but no statistical differences between the movement-intensive experimental groups (P = 1.00). The analysis of physical exertion displayed a significant difference between the common bicycle, NeuroBike and daily activity group (F (2) = 3.690, P = 0.039, η^2 = 0.228) with similar group-specific results as already presented in mental effort.

The evaluation of subjective condition throughout the exercise period of time revealed no significant difference in mental effort (F (5) = 0.262, P = 0.932) as well as in physical exertion (F (2.676) = 2.344, P = 0.095) between movement groups.

Mathematical Performance

Algebra

There was no significant difference of measured parameters in Algebra between treatment groups in the pre-test (pace of work H (2) = 0.079, P = 0.961; success rate H (2) = 0.084, P = 0.959) and due to the two-week intervention period (pace of work F (2) = 0.024, P = 0.976; success rate F (2) = 0.699, P = 0.506). Within every group a significant increase of pace of work was determined (NeuroBike Z = -2.205, P = 0.027, r = 0.833; common bicycle Z = -2.524, P = 0.012, r = 0.841; daily activity group Z = -2.848, P = 0.004, r = 0.822). There were no significant differences of success rate within the individual test groups.

Geometry

The analysis of the pre-test showed with respect to pace of work and success rate no significant intergroup differences (pace of work H (2) = 0.265, P = 0.876; success rate H (2) = 0.165, P = 0.921). Following study participation no significant difference between groups was seen compared to the pace of work (F (2) = 0.243, P = 0.786) and success rate (F (2) = 0.072, P = 0.931). Within experimental groups no significant differences were found according to the two-week training, except the daily activity group, who could achieve only a significant improvement in pace of work (t (11) = - 3.600, P = 0.004, r = 0.735).

Arithmetic

No significant intergroup differences were detected in the pre-test (pace of work H (2) = 0.519, P = 0.771; success rate H (2) = 0.822, P = 0.663) as well as after study participation (pace of work F (2) = 0.495, P = 0.615; success rate F (2) = 0.023, P = 0.977). In pre- and post-test analysis the NeuroBike group missed narrowly a significant increase in the pace of work (Z = -1.951, P = 0.051). The other two groups obtained no significant changes. Success rate didn't lead to a significant difference in any test group.

Participant Characteristics

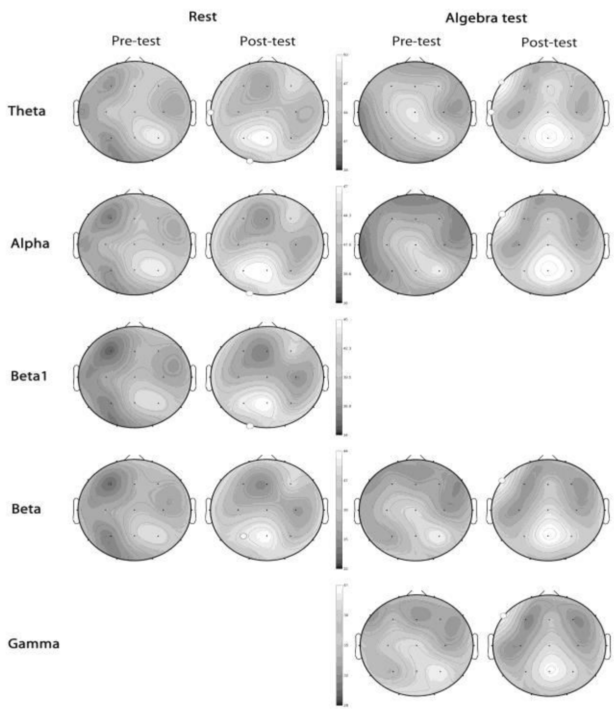
Statistical analysis yielded a non-significant effect of age between experimental groups (H (2) = 1.928, P = 0.381). Generally welfare (H (2) = 0.301, P = 0.860), the evaluation of last night's sleep (H (2) = 0.313, P = 0.855) and the ability to concentrate (H (2) = 0.589, P = 0.745) led also to no significant differences between experimental groups. Analysis of the last activity identified also no significant intergroup differences in the different test populations (cognitively demanding H (2) = 0.426, P = 0.808; physically demanding H (2) = 1.495, P = 0.473; without any effort H (2) = 0.079, P = 0.961).

Electroencephalography

EEG data revealed significantly increased temporal theta power, occipital theta, alpha and beta1 power and parietal beta power ($P < 0.05$ each) after the two-week intervention without acute influence of NeuroBike cycling at rest (Figure 1).

Acute NeuroBike training caused a reduction of frontal theta, alpha and beta power in the pre-test as well as frontal and temporal theta, frontal beta and gamma power in the post-test. No significant changes in acute influence of NeuroBike training as a result of the two-week intervention were observed. Repeated NeuroBike training led to significant increased frontal power in all frequency bands and temporal theta power during algebra performance (Figure 1). There was a reduction of temporal beta3 and gamma power in geometry just as a reduction of temporal, parietal, occipital and frontal gamma brain activity in arithmetic performance.

Figure 4. *EEG spectral power changes (divided in frequency bands) of NeuroBike intervention without acute influence at rest (left) / while Algebra-test (right). White colored circles show significant differences (P < 0.05) compared to the pre-test. Scale unit* μV^2



Discussion

The analysis of participants' characteristics provided in all individual criteria no significant differences, in consequence a possible influence of these characteristics on behavioral data and EEG brain activity is not suspected. Behavioral data show slightly reduced mathematical performance in geometry after the NeuroBike and common bicycle intervention in comparison to daily activity. In addition, EEG data indicate reduced brain activity in all frequency bands just after movement intervention. Evoked mental fatigue may be a consequence of high demands on concentration and attention skills during course cycling. Measured heart rate during training session just as physical effort testifies no significant differences between the intervention groups.

Increase of theta, alpha and beta activity at unaffected rest after the two-week intervention indicates a positive effect of NeuroBike training on brain activity. No differences in pre- and post-test comparison of brain activity after acute cycling suggest a persistent effect of NeuroBike training, which though might be related to a continuous cycling learning process based on steady improvements in cycling speed and errors. EEG during mathematical test shows a dissonant effect on brain activity. Continuous NeuroBike training seems to be beneficial in objective related cognitive processes like equations solving (higher absolute power), but negatively associated with spatial abilities (decreased beta and gamma activity) and mental arithmetic (decreased gamma activity). In comparison to the studies of Henz et al. (2013) and Crabbe and Dishmann (2004), which both present beneficial effects of bodily movement on brain activity, but used different study designs of type, duration and intensity of physical activity, there is no conformity with regard to the results of this study. The effect on cognition appears to be dependent of the certain kind of exercise, defined by type, duration and intensity of physical activity.

Conclusions

The analysis of the results has occupied an influence of NeuroBike training on mathematical problem solving expertise and EEG brain activity. Training on the NeuroBike seems to cause a brain state conducive to learning and receptivity under resting conditions. The impact, based on the mathematical performance, varies according to the respective underlying test requirements. Behavioral data of mathematical solving skills is to some extent even indicated with a tendency negative impact due to NeuroBike training. It can be deduced that NeuroBike training does not cause a brain state level appropriate for productive solving of mathematical tasks. To confirm these assumptions follow-up studies should be carried out using the NeuroBike with accompanying, targeted extensive analysis of learning processes and different cognitive practices. Therefore it would be convenient to examine the effect of NeuroBike training in children during school lessons and compare the influence on following cognitive performance dependent of various school subjects. Furthermore, the durability of an acute effect of practice sessions on brain activity as an overtime sustained effective training result has to be discussed. The present results show a relationship between specific physical activity and cognition, and that the influence on cognitive processes is partially fostered. This was achieved using a new, according to the literature not yet closely investigated movement device, which was initially unknown for the participants and required coordinative demanding movements. Further research is going to evaluate the effect of NeuroBike cycling as a cognitively enabling instrument. Hence not only endurance but also coordinative demanding physical activity may effect cognitive processes. In summary, even if the present results are ambiguous, further research of different kinds of physical activity promise a great potential of interesting investigations of the influence on cognition.

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