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ORIGINAL ARTICLE

Effects of a video game based aerobic training program on aerobic power and executive functions in cerebral palsy: a pilot study

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Purpose: In this study we aimed to determine how aerobic training program will affect executive functions and cognition in individuals with spastic cerebral palsy (CP).
Method: We applied a game based aerobic training program for 12 weeks to 10 individuals (3 girls, 7 boys) with spastic CP whose ages ranged from 10 to 18 years. Training program consisted of some aerobic exercises like running, step up and down stairs, jumping, and an interactive video game. Before and after the training program, we measured their aerobic power using a cycle ergometer. We also evaluated their attention and executive functions with the Cancellation Test and Simon Test.
Results: After a 12 weeks aerobic training program, aerobic power levels of the participants increased significantly. (Aerobic power; pre-training: 30.2±9.7 $mL.kg^{-1}.min^{-1}$ post-training: 32.3±9.8 $mL.kg^{-1}.min^{-1}$) ($p<0.05$). There were significant improvements in the Cancellation Test. The number of overall correct marks increased while the number of skipped targets decreased (correct marks; pre-training: 225.3±9.5-posttraining: 233.5±5.4) (skipped targets; pre-training: 14±9.5-posttraining: 6.7±5.6) ($p<0.05$). There are improvements in the Simon Test too. While number of the total responses increased, total reaction time and reaction time of the correct responses decreased, but these changes were not statistically significant ($p>0.05$).
Conclusion: Our study showed that, video game based aerobic training program positively affected aerobic power levels of individuals with spastic CP. At the same time, cognitive functions such as attention and executive scores also demonstrated a significant increase. This has led to the idea that thew aerobic training program can improve some cognitive functions.
Keywords: Cerebral palsy, Aerobic exercise, Executive functions.

Serebral palside video oyun tabanlı aerobik eğitim programının aerobik güç ve yürütücü işlevler üzerindeki etkileri: pilot çalışma

Amaç: Bu çalışmanın amacı, aerobik eğitim programının, spastik serebral palsili (SP) bireylerde aerobik güç ve yürütücü işlevler üzerinde etkilerini araştırmaktı.
Yöntem: Çalışmaya yaşları 10-18 arasında değişen 10 spastik SP'li birey (3 kız 7 erkek) dahil edildi ve 12 hafta boyunca video oyunu temelli aerobik eğitim programına dahil edildiler. Eğitim programı, koşma, merdiven inip çıkma, zıplama gibi aktivitelerden ve interaktif bir video oyunundan oluşmaktaydı. Aerobik gücü değerlendirmek için Astrand Bisiklet Ergometresi Testi; dikkat ve yönetici işlevleri değerlendirmek için Simon Testi ve İşaretleme Testi eğitim programı öncesinde ve sonrasında uygulandı.
Bulgular: Eğitim programı sonucunda SP'li bireylerin aerobik güç düzeylerinde artış saptandı (Aerobik güç: eğitim öncesi: 30,2±9,7 $mL.kg^{-1}.dk^{-1}$, eğitim sonrası: 32,3±9,8 $mL.kg^{-1}.dk^{-1}$) ($p<0,05$). Benzer sonuçlar İşaretleme Testinde de sağlandı ($p<0,05$). İşaretlenen doğru sayısında artma; atlanan hedef sayısında da azalma gözlendi. Eğitim öncesi testte doğru sayısı 225,3±9,5, eğitim sonrası testte ise 233,5±5,4 oldu ($p<0,05$). Atlanan hedef sayısı eğitim öncesi testte 14,7±9,5; eğitim sonrası testte ise 6,7±5,6 oldu ($p<0,05$). Simon Testi'nde toplam doğru sayısında artış, toplam tepki süresi ve doğruların tepki süresinde azalma gözlense bile fark anlamlı değildi ($p>0,05$).
Sonuç: Bu sonuçlar, video oyunu temelli aerobik eğitim programı spastik SP'li bireylerin aerobik güç düzeylerini olumlu yönde etkilediği görüldü. Aynı zamanda dikkat ve yürütücü işlevler gibi birtakım bilişsel işlevlerin skorlarında da anlamlı artış gözlendi. Bu da aerobik eğitim programının, birtakım bilişsel işlevleri geliştirebileceğini düşündürmüştür.
Anahtar kelimeler: Serebral palsi, Aerobik egzersiz, Yürütücü işlevler.

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Cerebral palsy (CP) is an unprogressive neurodevelopmental disorder. Early lesions occurring in the central nervous system cause this disorder. The main symptoms are muscular weakness, abnormal muscle co-activation, involuntary movements, weak selective voluntary motor control, spasticity, contractures and weak balance. Motor disturbances are frequently accompanied by sensory, cognitive, perceptive, behavioral and communicative deficits and seizures.[1]

Some disturbances in cognitive functions may be expected to occur in individuals with CP, according to the lesion in the brain. Extensive lesions in white matter tracts may be the cause of inefficient information processing which is effective in some cognitive functions.[2] Attention and executive dysfunctions may be observed as a result of periventricular white matter lesions in the anterior and parietal region. Lesions of the basal ganglia, thalamic system, or both of them together, may affect executive functions as well as focused attention. Memory disorders are observed in many groups of developmental diseases.[3,4] This is due to lesions of neural structures supporting memory such as the basal ganglia, capsula interna or hippocampus, or to problems in coding which develop secondarily to primary perceptive disorders. Some cortical (lateral surfaces of the parietal and temporal lobes) and subcortical (capsula interna, thalamus, basal ganglia) areas fed by the central cerebral artery are believed to support focused attention and motor executive functions, language functions and memory.[5-7]

Due to certain problems in the musculoskeletal system, individuals with spastic CP have a less active life style compared to their healthy peers. This leads to a decrease in the individual's aerobic fitness, social participation and quality of life. Physical activity levels of individuals with CP are lower in comparison to normal individuals of the same age.[8,9] Exercise is known to have significant effects on the well-being of the cardiovascular system and musculoskeletal system. Physical activity is reported to provide improvement in some cognitive parameters, reinforce memory, facilitate learning, enable neurogenesis, and protect the nervous system from damage and neurodegenerative diseases.[10] By means of these studies three important hypothesis have been proposed how aerobic activity enhances executive functions: a) It increases oxygen saturation and angiogenesis in brain regions associated with the tasks.[11,12] b) It raises the quantity of brain neurotransmitters, such as serotonin and norepinephrine.[13] c) It enables the expression of some neurotrophins such as brain-derived neurotrophic factor, insulin-like growth factor 1, basic fibroblast growth factor.[14]

The effectiveness and reliability of aerobic exercise and its optimal duration, intensity, frequency in individuals with CP has not been completely determined due to lack of scientific data. This is because there are limited numbers of studies which prove that aerobic exercise training improves aerobic fitness in individuals with CP. It is considered that individuals with spastic CP may also benefit from the positive effects of aerobic exercise and the cognitive functions may be improved; thus these hypotheses have been proposed: a) Aerobic training program will increase aerobic power in individuals with spastic CP. b) Aerobic training program will provide positive effects on attention and executive functions in individuals with spastic CP.

METHODS

In line with these aims, individuals with CP, receiving specialized education and rehabilitation in a rehabilitation center in İzmir, were selected to participate in the study according to these inclusion and exclusion criteria stated below.

Inclusion criteria:

1. Being an individual with spastic CP (hemiplegia or diplegia) within the age range of 10-18 years, classified as level 1 according to Gross Motor Function Classification System (GMFCS).

2. Have the ability to receive simple verbal instructions.

Exclusion criteria:

1. Having a circulatory and/or respiratory problem which may negatively affect aerobic exercise.

2. Having neurological or ortopedic surgery (including Botulinum toxin injection) within the last 6 months.

3. Having a chronic disease that is contraindicated to do aerobic exercise.

All the subjects were done a check-up from hospital. It is confirmed that the participants had no contraindications to do aerobic exercise. According to these criteria eleven individuals were chosen. One of them is excluded because he could not complete the cycle ergometer test. The participants were classified according to GMFCS by a physical therapist. They had not been using any assistive devices. All participants had been continuing their weekly physical therapy and academic lessons throughout the aerobic training. The participants, who use glasses, wore their glasses throughout the cognitive tests. The participants were evaluated before and after the training program, with some tests, as an indication of aerobic power, attention and executive functions. All participants and their families were informed about this study and an informed consent form was signed. Ethical approval for this study is given by the Dokuz Eylul University Ethics Committee (2012/13-14).

Measure of aerobic capacity

Before the aerobic training program, the participants' height, weight and body mass indexes were recorded and then their aerobic powers were measured with a cycle ergometer test (Monark Ergomedic 839E, Sweden, B50026-0609, 2008). Participants were requested to cycle against a specific load for 6 minutes and their heart rate was recorded at the end of each minute. After the final heart rates and workloads were recorded the values were placed in the formula used for indirectly estimating maximal oxygen consumption; the rate of oxygen consumption per kilogram was calculated.[15]

Evaluation of executive functions

Cancellation Test: The paper, on which participants made cancelations, was secured on the table with a tape. Then the participants were requested to mark the same form on the paper that was shown to them then disclosed within a short amount of time. Cancellations were carried out in a row on four separate pieces of paper comprised of regular letters, irregular letters, regular shapes and irregular shapes. At the end of the test, duration, number of correct and incorrect targets and number of skipped targets were recorded.

Simon Test: This test was applied on computer. A red or blue circle appears in different locations; on the center, right or left side of the computer screen. Participants were requested to ignore the location and only to press the left key when the red circle appeared and press the right key when the blue circle appeared. When all the circles were completed, the number of correct and incorrect responses and reaction times were automatically recorded on the computer.

Training program

Aerobic training program was carried out twice a week for a total of 12 weeks. Each session lasted 45 minutes. Session started a five-minute warm-up. Then functional exercises were carried out for 10 minutes and Sony Playstation 3 Move Fitness game was played for 25 minutes. In the last 5 minutes of the session cooling exercises were carried out. Exercise intensity was set to correspond to 60-70% of heart rate. Warming up and cooling programs were comprised of 5 minutes of running at a smooth pace. The 10 minute functional exercises consisted of running, jumping, short distance sprinting, negotiating stairs, running to reach a target while jumping over or under hurdles. In the following 25 minutes of the aerobic training interactive games, selected from the game console, were played. To ensure that this activity provided a sufficient level of aerobic work, heart rate was monitored and the intensity of the exercise was adjusted to be between 60% and 70% of maximal heart beat rate. In this game program there were games such as boxing, collecting points from different directions by jumping and lifting the arms, bending down to get a basketball and throwing it into the net, lifting arms to break plates coming from different directions and breaking glass by boxing.

Statistical analysis

Kolmogorov-Smirnov test is used to understand how the data is distributed. If the data distribution is normal Paired sample t-test is used. If the data is not normal Wilcoxon signed rank test is used. These tests were carried out to determine if there was a significant difference in aerobic power levels before and after the aerobic training program. Differences in the sub parameters of the Cancellation test (number of correct targets, skipped targets and incorrectly marked targets,

total number of mistakes and visual search duration) and sub parameters of the Simon test (total number of correct responses, total reaction time, total reaction time for correct responses) before and after the training program were evaluated with paired sample t-test. A value of $p<0.05$ was accepted to be statistically significant.

RESULTS

Eleven individuals with spastic CP aged between 10 and 18 were recorded, selected according to the inclusion and exclusion criteria of the study. One is excluded because he could not pedal on the cycle ergometer test. Three of the 10 participants had hemiplegic CP, seven had diplegic CP. The participants' genders, ages and body masses and their levels according to GMFCS before and after the training program are presented in Table 1.

Submaximal cardiorespiratory responses following bicycle ergometer: The mean values of the participants' maximal oxygen consumption and maximal oxygen consumption per kilogram before and after the training program are presented in Table 2. First absolute aerobic power on the bicycle ergometer test before the aerobic training program (mean. 1.62±0.63) was observed to significantly increase after the training program (mean 1.79±0.64) [$t(9)=-3.013$; $p<0.05$]. Oxygen consumption per kilogram on the bicycle ergometer test significantly increased on the last test (mean 32.39±9.82) compared to the first test (mean 30.29±9.75) [$t(9)=-2.33$; $p<0.05$].

Cognitive function: Following the aerobic training program there was a positive improvement in both the Simon test and the Cancellation test. The improvements were not found to be statistically significant on the Simon test, but the increase in the correct number of cancellations and the decrease in number of skipped targets on the Cancellation Test were statistically significant (Table 3 and 4).

Table 1. Participants' gender, age, body mass and GMFCS levels.

			Body mass (kg)		
Participants	Gender	Age (years)	Pre-training	Post-training	GMFCS Level
1	Male	15	41	42	1
2	Male	18	64	63	1
3	Male	13	70	71	1
4	Male	14	75	78	1
5	Male	15	64	67	1
6	Male	10	25	26	1
7	Male	10	35	36	1
8	Female	18	70	71	1
9	Female	16	43	43	1
10	Female	14	77	83	1
Mean±SD		14.3±2.7	56.4±18.6	58.0±19.6	

Table 2. Participants' maximal oxygen consumption and maximal heart rate during bicycle ergometer test before and after the aerobic training program.

	Pre-training	Post-training	
VO_2(L.min^{-1})	1.62±0.63	1.7±0.6	*
VO_2(mL.kg^{-1}.min^{-1})	30.29±9.7	32.3±9.8	*
Heart rate (beat.min^{-1})	153.3±15.2	148.9±13.4	

* $p<0.05$.

Table 3. Simon Test results before and after the training program.

	Pre-training	Post-training
Total number of correct responses	115.40±22.71	119.50±13.64
Total reaction time (ms)	1091.85±947.74	792.33±317.74
Total reaction time for correct responses (ms)	1117.91±1007.31	794.42±323.59

Table 4. Cancellation Test results before and after the training program.

	Pre-training	Post-training	
Number of correct cancellations	225.3±9.55	233.5±5.48	**
Number of missed targets	14.7±9.55	6.7±5.63	**
Number of incorrectly cancelled letters and shapes	11.1±21.13	6.7±10.96	
Total number of errors	25.8±20.24	13.4±8.79	
Visual search time (sn)	1100.6±825.25	1020.2±717.34	

** p<0.01.

DISCUSSION

After the aerobic training program, the aerobic power levels of the individuals with spastic CP was elevated; according to the improvements in performance on the Cancellation and Simon test, considerable progress was observed in some cognitive functions such as attention, sustained attention, memory and impulse inhibition.

We found an increase in aerobic power after twelve weeks of video game based aerobic training. Participants exercised at a moderate intensity (60% to 70% of maximal heart rate) twice a week and each session lasted 45 minutes. There are some studies similar to ours that found improvements in aerobic power at different exercise intensity, duration and frequency. In a study conducted by Ake Lundberg et al, 14 individuals with CP were subjected to a 6-week training program comprised of running, jumping, and calisthenic exercises. After the training program the individuals' heart rates declined, blood lactic acid concentrations decreased, heart volume increased on average 5% and oxygen consumption was elevated after the same submaximal load.[16] These positive effects on aerobic capacity in children with CP have received support from other studies too.[17-20] In line with our study it can be concluded, from the above studies, that a specific duration and intensity of aerobic exercise can increase aerobic fitness in individuals with spastic CP.[16-20] Considering all of these studies, the aerobic training program which needs to be applied to increase aerobic power in individuals with spastic CP should mainly be of moderate intensity. Although the data obtained is insufficient, training programs designed to increase aerobic capacity in individuals with CP should take place at least 1-2 sessions per week and progress gradually thereafter, as adaptations occur.[21]

Another main finding was the improvement in some cognitive functions. We used the Simon Test from the PEBL Battery, and the Cancellation Test because they are easy to apply for individuals with cerebral palsy. The improvements measured by these tests showed that the training program we applied may lead to positive improvements on cognitive functions. Both improved aerobic power levels and improvements in cognition may be due to moderate intensity of game based aerobic training. Interactive video

games and functional aerobic training requires more attention and visual perception. This video game based aerobic training may also lead to brain oxygenation and brain regeneration, resulting in improved attention and executive functions. In our study it is shown that interactive video games may be used to develop aerobic power, and that these games may be used to improve attention and executive functions. One controversial part of our study is that this enhancement in cognitive functions may be related to academic lessons. However these academic lessons may be considered to be an ongoing process, both before and after the study. So these improvements in cognition may therefore be considered independently. One limitation to our study, we did not evaluate the hand functions and usage of some drugs before and after the study because the spasticity of the hand could affect the reaction times of Simon Test and usage of some antiepileptic and antispastic drugs may affect perception.

For cardiorespiratory fitness, the American College of Sports Medicine recommends regular, purposeful exercise that involves major muscle groups and is continuous and rhythmic in nature. The types of activities includes running, step-ups, climbing stairs, cycling, arm ergometer exercise, propelling a wheelchair, and swimming, which should be tailored to the specific condition of the included participants.[21] We applied a functional aerobic training program to participants. In addition to functional exercises, we also included an interactive sports game, in order to increase motivation and participation of the individuals. Interactive video game based training program in our study is important in respect to the increase it provides in aerobic capacity. Along with the positive changes to aerobic fitness, this type of exercise training also results in increases in mobility capacity.[17,20] We did not measure the individuals' mobility and functional capacity. Future studies should be done if there was a link between aerobic fitness, cognitive improvements and motor function.

Aerobic exercise training using functional activities or in combination with strength training or anaerobic training, results in significant increase in cardiorespiratory endurance.[17,20] Much of the exercise training effects to cardiorespiratory fitness and mobility capacity are lost during the first 4 months after the training while cognitive gains remain.[17] So, aerobic training should be done throughout lifespan for cardiorespiratory and functional gains. Cognitive tasks should be added to the training program so cognitive gains could increase.

Limitations

Our study was unfortunately confined to a limited number of participants, therefore may be carried out in the future with larger populations comprising participants of a wider cerebral palsy subgroups and age range.

Conclusion

In conclusion, a video game based aerobic training program may enhance aerobic power and some cognitive skills such as attention and executive functions in individuals with CP. The interactive video games may also improve aerobic capacity if they are carried out as moderate intensity exercise. Numerous studies should be carried out to determine the optimal mode, duration and frequency of exercise. Also, the exercises placed in the training program comprising some cognitive tasks should be investigated in respect to whether they may provide further improvement in cognitive functional skills.

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