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Original Article

The effect of Neurofeedback Training on Working Memory and Perceptual-Motor Development in Athlete Boys

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ABSTRACT

Background: This research aims to study the effect of neurofeedback training on the working memory and perceptual-motor development of athlete boys.
Methods: Thirty athlete boy students of Gorgan province were selected by convenient sampling and participated in the research process. First, a pretest was conducted. All participants had done Wechsler digit span test and Lincoln-Oseretsky perceptual-motor capabilities test. After that, participants were randomly divided into test and control groups. Subjects of the experiment group had 12 one-hour sessions neurofeedback training while the control group subjects received no intervention during this time. Data were analyzed by using multivariate covariance test (MANCOVA) by SPSS 18.
Results: The results of data analysis showed that there is a significant relationship between mean direct and reverse digit span numbers and perceptual-motor development of the experiment group before and after treatment ($P<0.05$) and neurofeedback training has positive effect on the working memory and perceptual-motor development of athlete boys.
Conclusion: Regarding the results of the current research, it seems that neurofeedback training is effective on the working memory and perceptual-motor development of athlete boys; however, more research is required to achieve more definite results about the effective and perpetual effects of neurofeedback on the cognitive function of people.

Introduction

The success of athletes in sport activities depends on their mental and cognitive skills as well as their physical skill level [1]. Different effective factors on the sport performance have been studied by psychologists. One of these factors is working memory [2]. Working memory is a part of neural system which is involved in the cognitive processing and temporary storing of information as well as processing of a wide range of cognitive tasks. Cognitive tasks are processed in several steps and the working memory provides the possibility that the latest form of task is stored in the memory and accessed always [3]. Working memory stores the processes related to the recognition, change and transformations [4]. Researchers believe that working memory is the foundation of our ability for complex thinking and various theories have been introduced for it and the most successful and widely used theory is Baddeley & Hitch multicomponent model. In Baddeley working memory model, working memory has four main components: phonological loop, visio-spatial loop, central executive, and episodic buffer. Phonological loop is responsible for storing and reviewing verbal information. Visio-spatial working memory is the

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place for storing mental images and other visio-spatial information. Central executive acts as an observer who identifies the important information and issues as well as unimportant information [5]. Baddeley added episodic buffer component to this model. This component is a short-term storing system which is placed at the central executive control part and connects phonetic circuit information and visio-spatial plane to each other to form the combined visio-spatial-verbal units based on the time order [6]. Working memory is highly involved in physiological and psychiatric disorders [7] and cognitive abilities of human [8].

Various studies have demonstrated that there is a significant relationship between working memory, sport and physical activity [9]. It seems that some athletes have achieved profitability in sport by high working memory capacity and attentional skills. In this regard, Memmert & Furley indicated that the individual differences in working memory capacity show their effect on the behaviors and reactions of athletes in the intervention conditions which are not dependent on the reasonable reflective behaviors [2]. Controlled processes are caused by central executive component of working memory and when the attention is used in the purposive or indigenous form, controlled process breaks without enough resources (working memory capacity) and improper or unwanted reaction emerges [10].

In addition to working memory, another effective factor on the development of athletes' performance is the development of perceptual-motor skills. Perceptual-motor skills is a set of complex and multidimensional set of development abilities in children which has two main aspects of perception and motion. The quality of motor function depends on the correct perception of an individual and his ability to interpret these perceptions is also dependent on the set of coordinated motor reactions. Perceptual-motor skills are the basis for the development of sport skills [11]. The effective function of perceptual-motor capabilities in the children development field is necessary in three cognitive, emotional and mental-motor aspects and evolutionary trend. On the other hand, the results of many research confirm the interaction of perceptual-motor and development and social development of people [12]. Based on this, the development of mental-motor skills through effective interventions not only improves the mental, cognitive and social development but also leads to the peace of mind, stability and physical capability of a child [13].

Regarding the importance of working capacity and perceptual-motor skills, using the effective interventions is valuable in the improvement of these variables. In this regard, neurofeedback is a new therapeutic method that has been used recently in the medical fields by the psychology, psychiatric and occupation therapy experts. Neurofeedback is the conditioning of electrical function of the brain and promotes the individuals performance to the optimal level [14]. The aim of neurofeedback is normalizing the abnormal neural frequencies by increasing the awareness about electroencephalogram (EEG) patterns [15]. Researchers believe that neurofeedback is a technique which acts according to the electrical activity of the brain during functional conditioning and correcting the disturbed brain wave patterns [16]. In fact, neurofeedback increases the sensorimotor rhythm (SMR) or beta waves in some specific parts of the brain that have no good frequency via operant conditioning. Due to this conditioning, when SMR or beta frequency is increasing, theta waves of the brain reduce in the common points [17, 18]. Neurofeedback can be used for the stimulation or regulation of brain activity [19] as well as some disorders such as epilepsy and ADHD [20, 21] in healthy people [22]. In addition, results have shown that neurofeedback is effective on the cognitive functions of the brain including attention processing and working memory in healthy people and those who have learning disorders [23-25]. The results of Sadeghi et al. study indicated that neurofeedback balance can improve the balance function of children with reading disorder [26].

Regarding what has been said, it seems that neurofeedback has positive effect on the working memory and sensorimotor development of children. However, most studies in this field are conducted on clinical individuals like ADHD and those who suffer learning disorder. Few studies have dealt with the effect of this teaching on healthy people and athletes. Regarding the importance of working memory and sensorimotor development in the success of athlete adolescents, the use of interventions like neurofeedback can be very important to people. In total, by considering the research gap as well as effective interventions importance among the adolescent athletes, this research seeks to answer this question that if neurofeedback training had positive effect on the working memory and perceptual-motor development of athlete boys?

Methods

This is a semi-experimental study with pre and posttest along with the control group. In this research, based on the subject and goal of the research among the athlete boy of Gorgan province in 2017, thirty subjects who continuously participated in the sport clubs in different sports in three days and had inclusion criteria (age between 10 to 14, informed and voluntary intention to participate in the research, family satisfaction, lack of physical and mental disease) were selected by convenient sampling. Then, they were divided into experiment (15 subjects) and control (15 subjects) groups.

Neurofeedback training system was implemented by using the devices equipped with computer system and supervision of the researcher. This tool consists of aProcomp 2 hardware and Thought Technology Ltd software by BioGeraph Infiniti. The device works as follows: based on the therapeutic protocol of 10-20 international system, electrodes stick on the skull of the individual during the training. Generally, two electrodes are placed in the points in which EEG activity has higher deviation than EEG of normal people. An individual stands against the computer and focuses on what the computer shows. When inappropriate activity showed a slight decrease and appropriate activity had slight increase, a sound is heard. At first, variations in the brain waves are transient but by repeating the sessions and gradual changing of the thresholds for preventing improper activity and enhancing healthy brain waves activity by the therapist, the permanent changes become gradually conditioned [27]. The information received by two separate monitors were provided for the experimenter and client. In this state, the client can manipulate the brain wave by the help of the researcher and audiovisual stimulants [28].

Wechsler digit span test for children was used to measure the working memory. This test is a part of Wechsler intelligent test which has been designed in direct and reverse digit spans to measure the working memory of 6-16 years old children. In direct digit span, an experimenter reads randomly a set of one-digit numbers and the subject repeats the numbers with the said order. The numbers at first consisted of two digits and after each time, one digit is added to the numbers such that the maximum chain reaches seven digits. The test is stopped when a subject repeats a set of incorrect numbers for two consecutive times. No feedback is given to the subjects during the test. Performance is scored at the total number of sets with correct remembering. This test is an appropriate tool for measuring short-term memory and attention [29]. Reverse digit span test is also an important tool for evaluating the working memory. The method for treating this test is the direct test span except that the subject would remind the digits in the reverse order. The test is scored as the total number of correct remembering. This tool has been normalized and the results have shown that Cronbach alpha test has reported 0.65 for this test and its validity is 0.83 [30]. Lincoln-Oseretsky Perceptual-motor capabilities was used to study the perceptual-motor abilities. This test has been designed to evaluate the motor capabilities of 5-14 years old children. This test is carried out individually. The total test is comprised of 8 subtests including speed of running and agility, balance, two-lateral harmony, strength, reaction speed, visio-motor control, speed and agility of upper limbs and harmony of upper limbs [31]. The short form of this test includes one subtest and 14 separate sections. This test required reliability and validity such that the validity of Lincoln-Oseretsky test for motor skills of 12 subjects was 90%. The reliability of retest for this set was 0.78 in long form and 0.86 in short form for evaluating the total perceptual capabilities of children. The short form measures the total skills of children and the total score shows the skill of children including hard and soft skills. The researcher has used the short-form of the test [32].

This research was carried out as follows: in two days, all subjects in both groups had pretest which was Wechsler digit span test and perceptual-motor capabilities test individually. Then, subjects of the experiment group had neurofeedback intervention. For providing appropriate condition for cooperation and focus of children, chair, light, and temperature of the room were considered. Twelve neurofeedback training sessions were held twice a week and each session lasted about 1 hour. At the beginning and end of the treatment, base line EEG was recorded with open and closed eyes. All records were done based on 10/20 standard from Fz, F4, F3, O1, Cz canal relative to the head skin and ear auricle. Electrode-skin impedance was less than 5 kohm. The protocol used in this research was increasing SMR, enhancing beta and suppressing theta wave. The experiment group received a feedback which was dependent on their performance. After ending each session, observations and opinions of therapist and his evaluation of the children were recorded on the work sheets and the important points (the level of child cooperation and his cooperation and consciousness) were implemented in the next session. The therapeutic sessions lasted 6 weeks. During the training of the experiment group, the control group received no intervention. At the end of the training sessions, all experiment and control groups' subjects did pretest again. It is worthy to mention that before starting the work in all sessions, things such as necklace, mobile handset (of therapist and client) and other things which may develop disorder in the work were removed. Data analysis was done by using descriptive statistics (mean and standard deviation) and inferential statistics (multivariate covariance analysis (MANCOVA) in SPSS 16.

Results

Based on the demographic information related to the experiment and control groups, 15 participants were in each group and all of them were boys. The mean age of the experiment group was 13.26 and the control group was 12.87.

Mean and standard deviation of pretest-posttest of variables in the experiment and control groups have been presented in Table 1.

Multivariate covariance analysis was used to study the effect of neurofeedback training on the working memory and perceptual-motor development of research subjects; but before the analysis, the normality of data was examined by using skewness and kurtosis of all variables which were in -2 to 2 range; therefore, the data were normal. Results of Leven test for variance homogenization of dependent variables in the groups showed that the direct digit span variance ($F_{1,28}$=1.35, P>0.05), reverse digit span ($F_{1,28}$=1.93, P>0.05), and for agility, balance, strength, speed and agility of upper limbs, response speed, visio-motor control, two-lateral harmony and upper limb harmony ($F_{1,28}$=0.20, 3.46, 0.73, 0.51, 1.42, 2.12, 1.49, 2.92, 1.3, 1.35, P>0.05) is equal in all groups. The results of box test for covariance matrix of dependent variables in the experiment and control groups showed that covariance matrix of dependent variables in the two groups is equal to (Box m=89.79, F=0.99, P>0.05).

After studying the multivariate covariance analysis presumptions, the results of the test showed that there is a significant difference between both groups in dependent variables (direct and reverse digit span and perceptual-motor development components) (Wilks

Table 1: Descriptive statistics of digit span and perceptual-motor development in both experiment and control groups

Variable		Condition	Group	Mean	SD
Digit span	Direct digit span	Pretest	Experiment	5.87	3.24
			Control	6.26	3.33
		Posttest	Experiment	10.53	2.67
			Control	6.53	2.67
	Reverse digit span	Pretest	Experiment	4.33	3.39
			Control	4.53	3.22
		Posttest	Experiment	8.20	2.19
			Control	4.67	3.38
Perceptual-motor development	Agility	Pretest	Experiment	5.80	0.86
			Control	5.53	1.19
		Posttest	Experiment	6.86	0.91
			Control	5.40	1.18
	Balance	Pretest	Experiment	4.26	1.10
			Control	5.53	1.19
		Posttest	Experiment	6.86	0.91
			Control	5.40	1.18
	Strength	Pretest	Experiment	5.66	0.82
			Control	5.53	1.06
		Posttest	Experiment	6.67	1.01
			Control	5.40	0.91
	Speed & agility of upper limb	Pretest	Experiment	5.73	0.80
			Control	5.60	0.91
		Posttest	Experiment	6.86	0.74
			Control	5.73	0.59
	Reaction speed	Pretest	Experiment	5.67	0.97
			Control	5.27	1.03
		Posttest	Experiment	7.13	0.91
			Control	5.86	0.91
	Visio-motor control	Pretest	Experiment	5.26	0.80
			Control	5.66	0.61
		Posttest	Experiment	6.13	0.63
			Control	5.46	0.83
	Two-lateral harmony	Pretest	Experiment	4.26	1.33
			Control	4.20	1.08
		Posttest	Experiment	6.40	0.91
			Control	5	1.13
	Upper limb harmony	Pretest	Experiment	4.20	0.86
			Control	4.13	1.30
		Posttest	Experiment	6.20	0.67
			Control	5.20	1.01

Lambada=0.06, $P<0.0001$, $F_{9,10}=12.94$). The results of inter-subject effects have been reported in Table 2 to study the significant difference of all variables in the experiment and control groups.

Regarding Table 2, F-statistics for all digit span and perceptual-motor development components is significant in 0.01 and 0.05. These findings indicate that there is significant difference between these variables. Regarding the results in Table 1 which indicates the higher mean of the experiment group in the posttest compared to the control group, we can conclude that the significant difference in these variables between the experiment and control groups belongs to the experiment group. Those who were in the experiment group and received neurofeedback had higher working memory and perceptual-motor development compared to the control group who did not receive such a training; therefore, neurofeedback training had a positive effect on the working memory and perceptual-motor development skills of athlete boys.

Discussion

This research was conducted to study the effect of neurofeedback on the working memory and perceptual-motor development of athlete boys. The first finding of this research showed that neurofeedback training has a positive effect on the working memory of experiment group subjects who received neurofeedback training compared to the control group who did not receive this training. In fact, in the posttest step, the experiment group obtained better score in both direct digit span and reverse digit span in the pretest step compared to the control group. This finding can be consistent with the results of the research which showed that neurofeedback training is effective on the working memory and executive actions of athletes and healthy people. Among these results, we can refer to the Hsueh et al. [20], Hsieh & Wang [23], Escolano et al. [24], Dashtbozorgi et al. [25], Boggio et al. [33] and Sepahvand & Oftadehal Movahedi [34] studies.

In explaining the effect of neurofeedback training on

Table 2: Inter-subjects effects of multivariate covariance matrix in digit span and perceptual-motor skills

Variable	Sum of squares	Df	Mean squares	F	Sig	Effect
Direct digit span	69.73	1	69.73	7.21	0.01	0.29
Reverse digit span	111.19	1	111.19	10.67	0.004	0.37
Agility	9.23	1	9.23	8.65	0.009	0.32
Balance	9.91	1	9.91	5.28	0.03	0.23
Strength	8.75	1	8.75	8.01	0.01	0.31
Speed & agility of upper limb	10.97	1	10.97	21.98	0.0001	0.55
Reaction speed	9.36	1	9.36	8.18	0.01	0.31
Visio-motor control	3.01	1	3.01	6.52	0.02	0.27
Two-lateral	13.32	1	13.32	14.39	0.001	0.44
Upper limb harmony	10.71	1	10.71	16.34	0.001	0.48

the working memory, we can refer to the importance of changing brain wave ranges, especially (4-7 Hz) and (15-18 Hz) waves in the high mental and brain functions. The researches indicate that increasing slow brain waves in the different parts of the brain is accompanied with not controlling the impulse and reducing the attention and excitation in the individuals. Therefore, by reducing or suppressing theta and delta wave ranges, we can observe the behavior change, especially excitation and attention in the subjects. As a result, neurofeedback training can help adolescent athletes in regulating the brain wave activity and improve their working memory. On the other hand, human brain can repair itself i.e. the brain has the capability of learning or relearning the self-regulation of brain waves which has an essential role in the normal function of the brain [35]. In fact, neurofeedback training is effective for function by enhancing the self-regulation mechanisms. This system encourages the brain to correct, modify and maintain the appropriate activity by giving feedback to the brain about what an individual has done in the previous seconds and what was the condition of the bioelectric rhythms of the brain. As a result, the brain is requested to manipulate different brain waves by producing some waves and reducing other waves. This will finally lead to the improvement of the working memory [33].

We can also explain that fundamental basis of neurofeedback method is the functional conditioning theory such that if the stimulant (brain wave range) accompanies and enhances with the desired outcome by default (movement of videos or producing sound), it will result in the functional learning. This learning is more effective when it begins from more simple stimulants that receive enhancement, and then moves toward more complex stimulants (like neurofeedback training); therefore, neurofeedback method, as the observing method for presenting information, helps the individual to show appropriate behavior in the future [20]. As a result, with this information, the students learn to change the appropriate behavior in the desired direction, which increases the working memory. Besides, the second finding of the research showed that neurofeedback training leads to the improvement of perceptual-motor skills in the experiment group compared to the control group. In the posttest step, participants of the experiment group had higher perceptual-motor skills compared to the control group who had not received neurofeedback training. These results were consistent with the results of some other research, including Nan et al. [36], Sohrabi Azarpaikan & Torbati [37], Hammond et al. [14] and Sadeghi et al. [26] who showed that the neurofeedback training is useful for perceptual-motor skills development and physical balance of unhealthy people and athletes.

In explaining the effectiveness of neurofeedback on the perceptual-motor skill development, we can refer to the point that changes in the motor behavior can be a sign of changes in the brain. The basis of neurofeedback training, as a therapeutic method, is on the direct change of brain wave and changes in the behavior level can be considered as the consequence of change in the brain waves. In fact, we can say that an attempt to change brain waves by using methods such as neurofeedback leads to the changes in the brain. Every change that occurs in the electrical activity of the brain due to the treatment leads to the reorganization in the bioelectric system and as a result, develops a comprehensive, natural and reflective normalization in the brain which leads to the improvement. On the other hand, since the training has targeted the augmentation of beta wave and suppression of theta wave, and regarding that theta wave is related to the sleepiness, unconsciousness and silence symptoms [36], while the beta wave symptoms are concentration, continuous attention and problem-solving [16], it can be inferred that during neurofeedback training process, theta suppression leads to the reduction in sleepiness and depression. Increasing the consciousness of the central neural system in the cortex leads to the focus on problem-solving processes and more continuous attention to the arbitrary activity. As a result, the individual can control his balance arbitrarily by better dominance on the posture keeping muscles [14]. In fact, by reducing theta wave fluctuations and increasing beta wave fluctuations in the desired defined threshold in the program, cortex and sub-cortex cycles control the motor functions in a more coordinated way. This effect extends due to the consistence in receiving neurofeedback to the conditions without feedback and by this way, the individual experiences more perceptual-motor skills [38].

Conclusion

In summary, the results of this study indicated that neurofeedback training, by affecting the brain waves, cortex and sub-cortex areas related to the cognitive processes and perceptual-motor skills, can lead to the improvement of working memory and perceptual-motor skills of athlete boys. Considering that the working memory and perceptual-motor skills are among the effective factors in the development of athletes, therefore, using methods such as neurofeedback that seems to improve these capabilities is important. However, we should be cautious in generalizing the results of this research, because based on the limitations of the research, the sample of this research was selected from among the boys and there was no follow-up. Therefore, it is suggested to repeat this study with girls and with more participants and observe whether these effects are continuous or temporary. Using follow-up is suitable for this purpose. On the contrary, a motor exercise of more simpler and cheap physical activity may have higher effectiveness than the neurofeedback. Therefore, it is necessary to give neurofeedback training with the control and experiment groups for better decision-making and comparison in order to choose the inexpensive and best technique for individuals.

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