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Effect of Treadmill Exercise on Fluid Intelligence in Early Adults: Electroencephalogram Study

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***Abstract*—**Fluid intelligence declines along with age, but it can be developed. For this reason, increasing fluid intelligence in young adults can be possible. This study examined the effects of a two-month treadmill exercise program on fluid intelligence. The researcher designed a treadmill exercise program to promote cardiorespiratory fitness. Thirty-eight healthy voluntary students from the Boromarajonani College of Nursing, Chon Buri were assigned randomly to an exercise group (n=18) and a control group (n=20). The experiment consisted of three sessions: The baseline session consisted of measuring the VO_2max, electroencephalogram and behavioral response during performed the Raven Progressive Matrices (RPM) test, a measure of fluid intelligence. For the exercise session, an experimental group exercises using treadmill training at 60 % to 80 % maximum heart rate for 30 mins, three times per week, whereas the control group did not exercise. For the following two sessions, each participant was measured the same as baseline testing. The data were analyzed using the t-test to examine whether there is significant difference between the means of the two groups. The results showed that the mean VO_2 max in the experimental group were significantly more than the control group ($p<.05$), suggesting a two-month treadmill exercise program can improve fluid intelligence. When comparing the behavioral data, it was found that experimental group performed RPM test more accurately and faster than the control group. Neuroelectric data indicated a significant increase in percentages of alpha band ERD (%ERD) at P3 and Pz compared to the pre-exercise condition and the control group. These data suggest that a two-month treadmill exercise program can contribute to the development of cardiorespiratory fitness which influences an increase fluid intelligence. Exercise involved in cortical activation in difference brain areas.

***Keywords*—**Treadmill exercise, fluid intelligence, raven progressive matrices test, %ERD of upper Alpha band.

I. Introduction

FLUID intelligence (Gf) is the capacity to think logically and solve problems in novel situations, independent of acquired knowledge [1], [2]. Fluid intelligence is critical for a wide variety of cognitive tasks. It is considered one of the most important factors in learning. Moreover, it is closely related to professional and educational success [3]. Fluid intelligence advances rapidly in early and middle childhood, continues to increase, though at a slow rate, until early adolescence and reaches asymptotic values in the mid-adolescence to late-adolescence stage, after which it begins to decline [4], [5]. Unfortunately, the decline of fluid intelligence begins in early adulthood at the start of one's career, and therefore, it is important to address it early on, rather than wait to try to improve the situation later in life. Nowadays, more people are taking an interest in increasing fluid intelligence because it may be possible to improve.

During the past several years there has been growing a scientific and public interest in the effect of physical activity, and in particular cardiovascular exercise on cognitive maintenance. Human fitness training studies find a positive relationship between aerobic exercise and cognitive function [6], [7]. In addition, a prospective cohort study showed that low levels of physical activity were a risk factor for poor performance on a measure of fluid intelligence [8]. From those researches, we can see the relationship between physical fitness and fluid intelligence. The randomized clinical trial study has shown that participants (aged between 58 and 77 years) in the aerobic group taking part in the fitness training program demonstrated a significant increase in cardiovascular fitness and improvement in the plasticity of the aging brain, when compare to the control group [9].

A neuroimaging approach provides a characterization of neural bases of fluid intelligence. It is born out of a network of cortical areas. This network is described as the parieto-frontal integration theory, or P-FIT. The P-FIT model is related to a brain network that primarily involves frontal and parietal lobes. The levels of intelligence are the reflection of how efficient the frontal- parietal networks process information [10]. Studies assessing activation of the whole brain via various brain imaging techniques and analysis of electroencephalogram (EEG) have mostly shown that brains of people of higher intelligence work more efficiently than those of less intelligent individuals. It means that brighter individuals use only single or a very small number of cortical derivations during cognitive performance. This phenomenon is referred to as neural efficiency [11].

There are various measures adopted to assess fluid intelligence. For example, RPM test requires participants to identify relevant features based on the spatial organization of an array of objects and then select the object that matches one or more of the identified features [12].

In recent years, researchers have adopted methods to study the relationship between brain activity and intelligence. Various parameters of oscillatory EEG activity are investigated with regard to their sensitivity to task related effects. In particular, the quantification of event-related desynchronization (ERD), which has proved a useful and appropriate method to measure the cortical activation during cognitive performance. It is based on the fact that the amount of alpha power decreases during cognitive activity compared

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with a resting state. The ERD of alpha band activity reflects an increased excitability level of neurons in involved cortical areas [13], [14].

According to the studies of benefits of exercise on cognition, there are no studies which investigate the effect of exercise training, which is one way to achieve physical fitness, on fluid intelligence. This study investigated whether aerobic exercise training improves fluid intelligence in young adults using the ERD of alpha band activity– a neuroelectrical index – during perform RPM test.

II. METHOD

A. Participant

The sample was recruited from students of Boromarajonani College of Nursing, Chon Buri, Thailand (aged between 18 and 28 years, with a mean age of 23). All of the participants were right handed, not athletic and exercised less than twice a week, did not have a history of cardiovascular or neurological disorders, and had normal or corrected to normal vision. The participants were paid for their participation in the EEG session. They gave informed consent prior to the experiment, and the protocol was approved by the Human Subjects Committee of the College of Research Methodology and Cognitive Science, Burapha University. Forty participants were assigned randomly to the exercise group and the control group.

B. Cardiorespiratory Fitness Assessment and Exercise Training Program

Maximal oxygen consumption (VO_2 max) was measured using a graded exercise test (GXT) on a Monark Ergomedic 828 E Exercise test Cycle. The GXT was performed on the stationary bicycle, which determines the VO_2 max by estimating oxygen consumption from the heart rate. All participants were measured before and after exercise training session.

Aerobic exercise training depends on three parameters, which are: frequency intensity and duration [15]-[17]. In this study, an exercise program of 40 minutes of treadmill at 60 % to 80 % of maximum heart rate three times a week for three months was implemented. The program protocol includes a five minute warm–up, 30 minutes of moderate–intensity exercise, which is defined as 60 % to 80 % of maximum heart rate, and five minutes of cool-down activities.

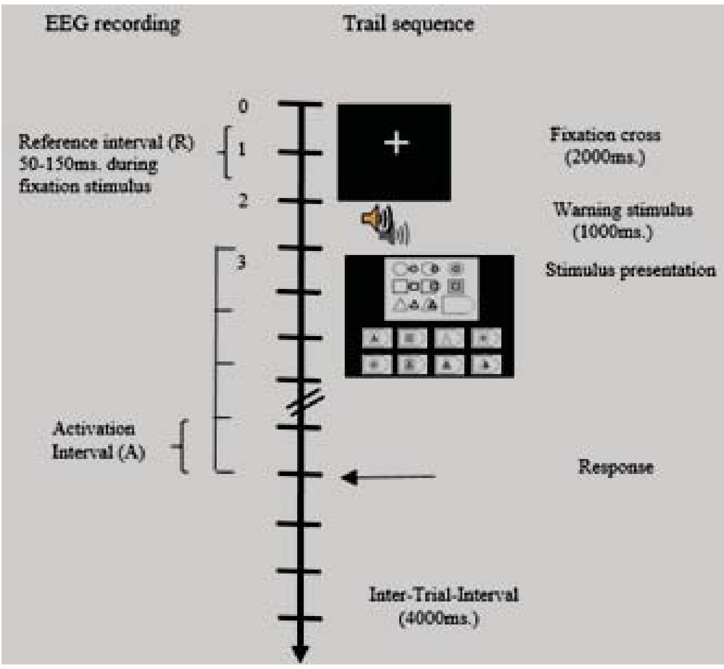

Fig. 1 Schematic display of an example item of RPM test and relevant of EEG intervals

C. Experiment Task

RPM were originally developed by John C. Raven Back [12]. This test consists of five sets (Set A to Set E), with 12 items per set. Set A and the first half of Set B measured the perceptual process, while the second half of Set B and Sets C to E measured the analytic process. The RPM test designed all the problems for intelligence tests to be based on five basic types of rule, including constant in a row, quantitative progression, figure addition or subtraction, distribution of 3 values, and distribution of 2 values. Each problem might have combinations of different rules or different instances of the same rule. RPM test requires participants to identify relevant features based on the spatial organization of an array of objects and then select the object that matches one or more of the identified features. In this study, RPM test traditional version was transfer performance to computer by using SuperLab 4.5 MCST program. In this task, participants were shown a stimulus on a computer screen. Each of the tasks took 60 seconds to complete and was deleted from the screen after participant pressed the response pad to select an answer. The answers were collected in the Cedrus Viewer of SuperLab program. The scoring procedure of this task was based on correct answer. Test-retest reliability was 0.78.

D. EEG Recording

An EEG was recorded with Ag/AgCl electrodes located in an electrode cap in 15 positions (according to the international 10-20 system; a ground electrode was located on the forehead and the reference electrode was placed on the right ear. To register eye movement, one electrode was placed below the outer canthus of the right eye. The EEG signals were filtered between 0.5 Hz and 30 Hz; an additional 60 Hz notch filter was applied to avoid power line contamination. Electrode impedances were kept below 10 kΩ. Trigger signals for the stimulus presentation and the responses were also recorded. All signals were sampled at a sampling frequency of 250 Hz.

E. Procedure

Healthy young adults were selected using a self-report questionnaire, as well as measuring heart rate and blood pressure. The participants of the study matched this selection criterion. The experiment consists of three sessions: baseline, exercise training, followed by a two-month training session. The baseline session consists of measuring cardiorespiratory fitness, EEG and behavioral response during the Raven progression matrices test. In the exercise sessions, the experimental group exercised on a treadmill at 60 % to 80 % maximum heart rate for 40 minutes, three times per week, whereas the control group did not participate in the training program. After two months of exercise training, both groups returned to take part in the same baseline testing. In the baseline session, the VO_2 max of each participant was measured. After one week, the participants were invited to the laboratory to measure fluid intelligence by recording EEG levels during the RPM test. The participants were seated in the EEG recording room. Each EEG trial started with a two-minute EEG sequences under resting condition with eyes closed. Participants then opened their eyes and were presented with a fixation cross on the screen, which lasted for two seconds, which was followed by an auditory warning stimulus. After three seconds, the test stimulus was presented and the participants were expected to respond as fast and accurately as possible. The stimulus disappeared from the screen immediately after the participants responded. Each response was followed by an inter-trial interval of four second. (See Fig. 1)

F. EEG Analysis

For reasons given in [18], the frequency border of the analyzed alpha band was determined individually for each participant using the peak EEG frequency in the alpha band (the so-called Individual Alpha Frequency, IAF) as an anchor point. The frequency bands obtained by this method are termed by the Klimesch's group. Three different frequency windows with a bandwidth of 2 Hz each were defined: lower1 alpha band (L1= [IAF-4Hz] to [IAF-2Hz]), lower2 alpha band (L2= [IAF-2Hz] to IAF) and upper alpha band (U= IAF to [IAF+2Hz]). In this study, ERD is analyzed in the upper alpha band because this alpha band has consistently shown correlations with individual differences in intelligence and is related to intelligence [11].

Only correctly solved trials were included in ERD analyses. To calculate ERD, an interval between 0.5 seconds and 1.5 seconds during the presentation of the fixation stimulus was taken as the reference interval (R). The individual reaction time (RT) interval was divided into four timeframes of equal length and the last of these periods served as the activation interval [19]. The formula to calculate %ERD is (1).

$$\%ERD = ([R-A]/R) * 100 \quad (1)$$

Positive %ERD value indicates a decrease in alpha power (cortical activation or desynchonization) and negative %ERD values indicated increases in alpha power (cortical deactivation or synchronization, ERS).

G. Statistical Analysis

The accuracy scores of RPM, upper alpha %ERD of the experimental group were compared with the control group using an independent t-test.

III. Results

A. Behavioural Data

For the pre-training session, no significant difference of VO_2 max was recorded between the experimental group and the control group. The mean VO_2 max in the experimental group after the exercise training session was significant more than the control group ($p<.05$). When comparing the behavioral data, it was found that the accuracy scores of RPM TEST in the experimental group after exercise training session were significantly higher than the pre-exercise session (t_{17}= -8.7, $p < .01$) and the control group who did not exercise (t_{36} = 5.26, $p < .01$) (see Fig. 2). The reaction time for giving correct answers in RPM test for the experimental group was significantly higher than the pre-exercise session and the control group. When comparing simple items and difficult items between the pre-exercise session condition and the post-exercise session condition in the experimental group, the results were (t_{17}= 1.99, $p < .05$) and (t_{17}= 2.36, $p < .05$), respectively. A comparison was made between simple items (t_{36} = -4.07, $p < .01$) and difficult items (t_{36} = -1.92, $p < .01$) for the experimental group and the control group (Fig. 3).

B. EEG Data

The %ERD of upper alpha power in the experimental group after exercise was significantly higher than pre-exercise condition for P3 (t_{17}= -8.88, $p <.05$), Pz (t_{17}= -7.94, $p <.05$). When comparing the %ERD of upper alpha power between the experimental group and the control group, it found that %ERD of upper alpha power in the experimental group after exercise was significantly higher than the control group for P3 (t_{36} = 2.36, p <.05), Pz (t_{36} = 2.14, p <.05) (Fig. 4).

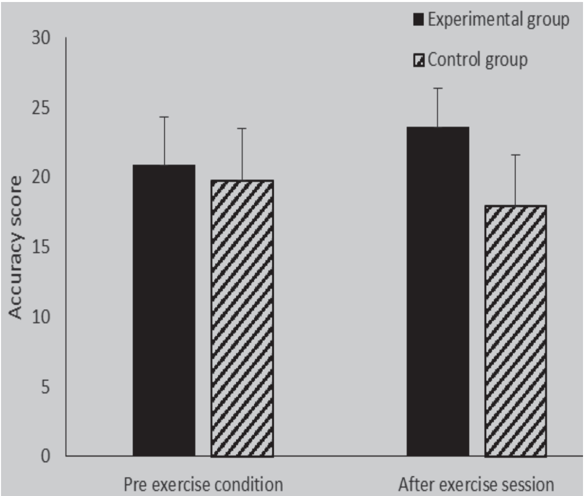

Fig. 2 The mean accuracy scores of RPM test, separately for experimental group and control group

IV. Discussion

This research has shown that aerobic exercise training had a greater positive effect on fluid intelligence. After two months of treadmill exercise training, the experimental group has improved performance on RPM relative to the control group, and they performed faster and more accurately. Mean VO_2 max in the experimental group after the exercise training sessions was significantly more than the control group. Thus, this program can improve cardiovascular function.

Considerable evidence, from both behavioral data, the accuracy scores of RPM test in the experimental group after a two-month treadmill exercise training session were significantly higher than the control group. The reaction time for giving correct answers on the RPM test both for simple and difficult items in the experimental group were significantly higher than the control group. These data are in agreement with the research that studied the relationship between cardiovascular fitness and cognitive function, which revealed that lower levels of aerobic fitness in children was associated with longer reaction time (RT) and decreased accuracy response, while active children were not behaviorally different than either adult group [20].

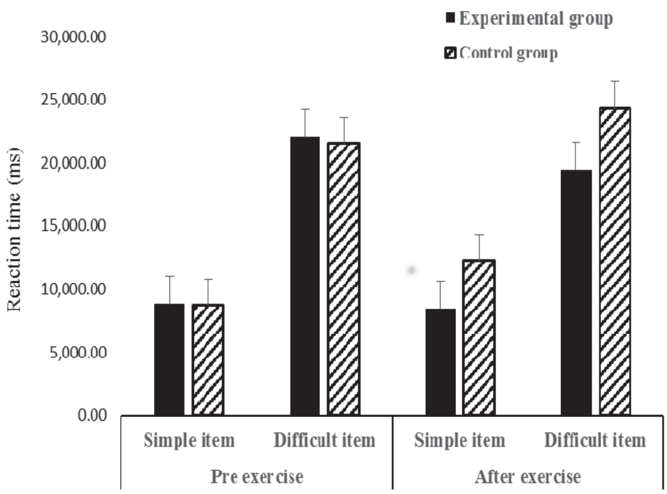

Fig. 3 The mean reaction time of RPM test, separately for experimental group and control group

There is evidence that the alpha rhythm recorded represents the neurophysiology mechanisms directly related to individual differences in information processing in the human brain [18]. This study has shown that the score on RPM test correlated positively with alpha rhythm frequency. The study also found that %ERD of upper alpha band activity (10 Hz to 13 Hz) decreased during RPM test. Cortical activation was quantified by analyzing the ERD, based on the fact that the amount of alpha power decreases during cognitive tasks (an activation interval) compared with a resting state. The ERD of alpha band that decreased reflected an increase in the excitability level of neurons in the involved cortical areas, which may be related to an enhanced information transfer in the thalamo-cortical circuits [18], [21]. Therefore, ERD decreases cause %ERD to increase. This study indicated that %ERD of upper alpha band activity in the experimental group post-treadmill exercise training as higher than pre-training.

Despite many studies examining the effect of exercise training on cognitive function, no study has addressed the effect of exercise training on fluid intelligence in early adults. Although there was research study about benefit of exercise on intelligent but it focused on chronic obstructive pulmonary disease (COPD), not early adults. Additionally, fluid intelligence was evaluated by using the standard paper- and pencil administered version of RPM test [22]. In this research, a short-term program of two-month duration was implemented to improve fluid intelligence and study brain activity by EEG recording.

These results were interpreted in terms of neural efficiency. According to the evidence from the study, higher intelligent brains seem to be characterized by more efficient brain function, indicated by less overall and/or more focused activation during cognitive activity [23], [24]. These findings have been explained in the so-called neural efficiency hypothesis: Participants performing a complex task well may use a limited number of brain circuits and/or fewer neurons, thus requiring minimal glucose use, while poor performances use more circuits and/or more neurons [25].

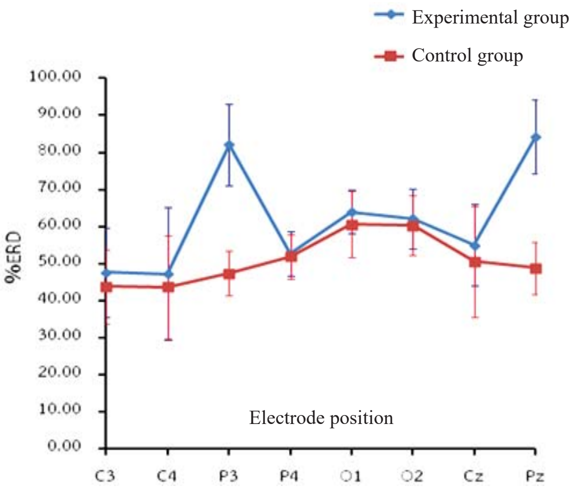

Fig. 4 The mean %ERD of Upper alpha band power, separately for the experimental group and control group

Comparing the pre-exercise condition and the control group, our findings indicate a significant increase in the percentages of ERD of upper alpha band activity in P3 and Pz, located in an electrode cap, and which demonstrate the location of parietal lobe. These findings are in agreement with the research that found a significant interaction between the parietal lobe area and fluid intelligence. From the parieto-frontal integration theory of intelligence (P-FIT) presented by Jung and Haier, the parietal lobe plays a role in the management of information and transmission of information to the frontal lobe [10]. In addition, the study has found that people with normal intelligence have more activity in the parietal lobe than other parts of the brain when participating in the RPM test [26].

Recently, several research studies structure the network of the brain using the diffusion imaging method, which is a new application for studying the anatomy of the brain in vivo. The researches have shown that people with high intelligence had short path lengths between the neurons of the parietal lobe which represented fast transmission through the network of the brain [27], [28]. In addition, the study also shows the relation between intelligence and the arrangement of the physical structure of the neurons that link to other parts of the brain which leads to greater efficiency in the transmission of information [29]. The other study also revealed that the transformation of physical structure in each part of the brain differs according to genetic and environmental factors. Besides, it indicates that environmental structures have more efficiency in altering function of the parietal lobe than genetics [30]. Thus, the treadmill exercise training given in this study may increase the effectiveness of short path lengths between the neurons in the parietal lobe of the research participants.

Animal model studies have provided much insight into the effect of exercise on brain function at the biological level. Exercise has multi-dimensional effects on brain function, including activating the brain plasticity mechanism and increasing neurogenesis [31]. One of key molecules that mediated brain plasticity is brain derived neurotropic factor (BDNF). One study showed that the level of BDNF in the blood increased after four weeks of continuing exercise. After one to two weeks, the level of BDNF in the blood decreases because BDNF is diffused into the brain [32]. These substances alter physical structure and the function of synaptic plasticity in the parietal lobe. Therefore, the increase in %ERD in the parietal lobe after aerobic exercise may be result from an increased production in BDNF.

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