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EFFECTS OF ACUTE PHYSICAL EXERCISE AND ACUTE MENTAL EXERCISE ON SIMPLE VISUAL REACTION TIME

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ABSTRACT

Aims: The aim of this study is to investigate the effects of acute physical exercise and acute mental exercise on visual reaction time in healthy medical students. ***Methods:*** We used a simple reaction time task software developed by the researchers to measure the visual reaction times of the subjects. Reaction times of subjects as well as pulse rates were measured on three different occasions: basal (resting), post acute mental exercise and post acute physical exercise. The acute physical exercise was constructed to last for 5 minutes in a way that would double the basal pulse rate of the participant. The acute mental exercise was induced by five minutes of ADD-3 arithmetics. All volunteered physically healthy medical students from four different medical schools in Turkey without red-green color deficiencies were included in the study. ***Results:*** A total of 232 (136 male, 96 female) individuals with a mean age of 20.79 ± 1.42 were included in the study. Differences between basal reaction time and post-physical exercise reaction time; the basal reaction time and post-mental exercise reaction time were found to be statistically significant. Basal reaction time of participants was found to be the key element deriving both post-mental and physical exercise reaction times. Also, one unit increase in the number of ADD-3 problems solved was associated with 0.21 units decrease in post-mental exercise reaction time. ***Conclusion:*** Both acute mental exercise and acute physical exercise can shorten visual reaction time. Our results also indicate that there might be a relationship between arithmetic capability (ADD-3 arithmetics performance) and visual reaction time. ***Keywords:*** Exercise, pulse, reaction time, software

INTRODUCTION

The time between the onset of a sensory stimulus and the consequent behavioral response is called reaction time (RT) (1-4). Since the late 1800s, numerous studies were conducted to have a better understanding of both physiological and psychological aspects of reaction time (1-5). The fundamental classification system was originated from Donders (3) in which he divided tasks into three as simple, recognition (go/no go) and choice response.

Simple reaction time (SRT) tasks consist of stimulus detection and motor execution whereas recognition reaction time tasks composed of stimulus detection, stimu-

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lus discrimination, and motor execution. Choice reaction time tasks consist of stimulus detection, stimulus discrimination, response selection and motor execution (6). Among these three tasks, SRT tasks were considered as the fastest and simplest, while choice reaction time tasks were regarded as the slowest and the most complex (3).

While the effects of physical exercise whether on SRT or on more complex cognitive functions such as long-term memory are extensively studied, work on these concepts remains ambiguous (7-11). In addition, most of these studies focus on the long-term physical exercise rather than acute physical exercise (7-10). However, studies that focus on the effect of acute physical exercise on RTs either differ on when RT task was done (during or after physical exercise) or on outcomes (no effect, facilitation, U-shaped facilitation, impairment) (9). Thus, the need for further investigation arises.

Although certain studies used acute mental exercises such as simple arithmetic to evaluate cognitive functions of participants after or during exercise, there were not many studies that analyzed the effects of acute mental exercise on reaction times (8, 9).

We hypothesize that acute physical exercises that will not exhaust the participants will result in shortening the RT due to possible activation of the sympathetic system. Since SRT tasks are the simplest among other RT tasks physiologically, increased arousal will further shorten the duration of SRT compared to choice reaction time. In addition, participant compliance is expected to be high since they are easier to follow through than other methods which evaluate more complex cognitive functions such as choice, go/no go, memory tasks, etc. We also hypothesize that acute mental exercises that will not drain the attention span of participants will shorten the SRT, not due to sympathetic activation but due to an increase in attention. The aim of this study is to measure the parameters mentioned above in 232 medical students from 4 different universities in Turkey.

MATERIAL AND METHODS

This prospective study was approved by the Scientific Research Ethics Committee of Trakya University School of Medicine (Protocol Code: TÜTF-BAEK 2018/466). Power analysis was conducted prior to ethics approval and the total number of participants needed was calculated as 230.

Measuring Reaction Time

A simple reaction time task software was developed by the researchers to measure the reaction times of subjects. The program starts as a full red screen and when the "start" button is clicked screen turns into green randomly, but at least five seconds after the click. The participant is expected to press "stop" as soon as the screen turns green.

Acute Physical Exercise

The acute physical exercise was designed to last for 5 minutes in a way that would double the basal pulse rate of the participant by using a stationary bicycle or treadmill. All participants were monitored with a pulse oximeter throughout the process and basal and post-exercise pulse rates were recorded.

Acute Mental Exercise

The acute mental exercise was induced by five minutes of ADD-3 arithmetics (12). Basal and post-exercise pulse rates, as well as the number of questions each subject solved, were recorded.

Forms and Tests Prior to Data Collection

All participants were informed about the study and signed informed consent forms. Participants were asked to fill out a physical condition evaluation form to evaluate the safety of acute physical exercise. Ishihara test was also performed by subjects to evaluate for red-green color deficiencies.

Inclusion and Exclusion Criteria

All volunteered physically healthy medical students without red-green color deficiencies were included in the study. Students with Body Mass Index (BMI) of 30kg/m2 or above and students who have any chronic cardiovascular diseases were excluded from the study.

Procedure

Participants were recruited from four different medical schools in Turkey: Trakya University School of Medicine, Okan University School of Medicine, Marmara University School of Medicine and Acıbadem Mehmet Ali Aydınlar School of Medicine. Basal pulse rates and basal reaction times of each subject were recorded. Following this initial step, participants were subjected to acute mental exercise as mentioned above. Acute physical exercise step was done as mentioned above, but on a different day to eliminate the possible effects of acute mental exercise on acute physical exercise or vice versa. Reaction time measurements were repeated for five times for each stage to increase the reliability of measurements. Among pulse rates and reaction times mentioned above, participants' age and gender were also recorded for further evaluation in statistical analysis.

Statistical Analysis

Data was analyzed using R version 3.5.0 (13, 14). Quantile-quantile plots were drawn, and Shapiro-Wilk Normality Test was conducted to check for normal distribution of variables. Normal distribution of pulse rates was observed and differences between each pulse rate group (basal, post-mental and post-physical) were analyzed by Two-Sample T-Test. Non-normal distributions of reaction times were observed and differences between each reaction group (basal, post-mental and post-physical) were analyzed by Wilcoxon Rank Sum Test. Normally distributed continuous variables are presented as minimum, mean, maximum and standard deviation whereas non-normally distributed continuous variables are presented as 1st quartile, median and 3rd quartile. Categorical variables are presented as numbers and percentages. For a detailed analysis of variables that might affect outcomes (variables: age, gender, basal pulse rate, post-physical exercise pulse rate, post-mental exercise pulse rate, number of ADD-3 problems solved; outcomes: post- physical exercise reaction time and post-mental exercise reaction time), linear regression models were built. Residuals of each model were tested for normality and homogeneity. Heavy-tailed distribution on Quantile-Quantile plots was observed and each linear regression model was rebuilt with the assumption of t-distribution of residuals instead of normal distribution. A confidence interval of 95% and p-values less than 0.05 were assumed statistically significant throughout the analysis.

RESULTS

Descriptive Statistics and Hypothesis Testing

A total of 232 (136 male, 96 female) individuals with a mean age of 20.79±1.42 were included in the study. The mean basal pulse rate (BasalPR), post-physical exercise pulse rate (PPhysPR) and post-mental exercise pulse rate (PMentalPR) were calculated as 77.03 ± 9.84, 144.75 ± 19.84 and 80.48 ±10.92, respectively. Differences between mean BasalPR and PPyhsPR, mean BasalPR and PMentalPR, and mean PMentalPR and PPyhsPR were found to be statistically significant ($p<0.01$, $p<0.01$ and $p<0.01$, respectively). Median basal reaction time (BasalRT), median post-physical exercise reaction time (PPhysRT) and median post-mental exercise reaction time (PMentalRT) were calculated as 380.50, 360.80 and 367.70, respectively. Differences between BasalRT and PPhysRT, BasalRT and PMentalRT were found to be statistically significant ($p=0.04$ and $p<0.01$, respectively) whereas differences between PMentalRT and PPhysRT were not statistically significant ($p=0.17$) (Table 1).

Table 1: Descriptive statistics of variables.

	Mean ± SD (min-max)
BasalPR *(bpm)*	77.03 ± 9.84 (50-116)
PPhysPR *(bpm)*	144.75 ± 19.84 (90-200)
PMentalPR *(bpm)*	80.48 ± 10.92 (53-119)
Age *(years)*	20.79 ± 1.42 (17.35-24.77)
BasalRT *(msec)**	380.50 (348.50-423.20)
PMentalRT *(msec)**	360.80 (333.40-401.95)
PPhysRT *(msec)**	367.7 (337.00-404.95)
Gender *[number (%)]*	Male = 136 (58.62) Female = 96 (41.38)

__BasalPR__ = Basal pulse rate, __PPyhsPR__ = Post-physical exercise pulse rate, __PMentalPR__ = Post-mental exercise pulse rate, __BasalRT__ = Basal reaction time, __PPhysRT__ = Post-physical exercise reaction time, __PMentalRT__ = Post-mental exercise reaction time, SD = standard deviation

**non-normally distributed variables are presented as median (1st quartile – 3rd quartile)*

Linear Regression Models

Effects of other variables on PMentalRT and PPhysRT was evaluated by linear regression models. One unit increase in BasalRT was associated with 0.90 units increase in PMentalRT and one unit increase in the number of ADD-3 problems solved was associated with 0.21 units decrease in PMentalRT. Both associations were found to be statistically significant ($p<0.01$, $p<0.01$; respectively). Effects of age, gender, BasalPR and PMentalPR on PMentalRT were not statistically significant ($p=0.91$, $p=0.31$, $p=0.43$, $p=0.73$; respectively) (Table 2).

Table 2: Linear regression analysis results for PMentalRT.

	Estimate	*Std.Error*	*p-value*
(Intercept)	267.12	6.37	<0.01
BasalRT - 262.20	0.90	0.03	<0.01
Age - 17.35	0.12	1.08	0.91
Gender (Female = 1)	-3.22	3.18	0.31
BasalPR - 50	-0.18	0.23	0.43
PMentalPR - 53	0.07	0.21	0.74
NofADD3 - 35	-0.21	0.07	<0.01

__PMentalRT__ = Post-mental exercise reaction time, __BasalRT__ = Basal reaction time, __BasalPR__ = Basal pulse rate, __PMentalPR__ = Post-mental exercise pulse rate, __NofADD3__ = number of ADD-3 problems solved

Minimum values of all continuous variables were subtracted from each value to have a meaningful intercept (eg. Age – 17.35 denotes that minimum age was 17.35, thus 17.35 was subtracted from all participants ages).

One unit increase in BasalRT was associated with 0.78 units increase in PPhysRT and this association was found to be statistically significant (p<0.01). Effects of age, gender, BasalPR and PPyhsPR on PPhysRT were not statistically significant (p=0.72, p=0.27, p=0.81, p=0.22; respectively) (Table 3).

Table 3: Linear regression analysis results for PPhys-RT.

	Estimate	*Std.Error*	*p-value*
(Intercept)	288.34	8.45	<0.01
BasalRT - 262.20	0.78	0.03	<0.01
BasalPR - 50	-0.06	0.23	0.81
PPhysPR - 90	-0.14	0.12	0.22
Age - 17.35	-0.49	1.38	0.72
Gender (Female = 1)	4.60	4.16	0.27

BasalRT *= Basal reaction time,* ***BasalPR*** *= Basal pulse rate,* ***PPhysPR*** *= Post-mental exercise pulse rate*

Minimum values of all continuous variables were subtracted from each value to have a meaningful intercept (eg. Age – 17.35 denotes that minimum age was 17.35, thus 17.35 was subtracted from all participants ages).

DISCUSSION

In this study, a total of 232 medical students from Acıbadem University, Marmara University, Okan University, and Trakya University were included. We found out that differences between mean BasalPR and PPyhsPR, mean BasalPR and PMentalPR, and mean PMentalPR and PPyhsPR are significantly different, but there is no effect of PMentalPR and PPyhsPR on VR time. However, participants who have higher BasalRT, also have higher PMentalRT and PPhysRT.

Red and green colors (stop and go respectively) were used for the simple reaction time task software developed by the researchers. The modern model of color vision states that the first stage of seeing color, the receptor stage, includes the blue, green and red cones (15). Since this stage is the earliest and does not include any cognitive processing, it is thought to be the best approach for measuring simple reaction time. The reason for choosing the color change to be from red to green is because the sensitivity of the red cones is up to 40 times less than the green cones (16). The increase in the sensitivity from red to green allows for more precise measurements. Although studies have shown red color to have shorter reaction times, Blizzard et al. (17) explain that it is caused by "Color Hierarchy" which is due to higher level attentional networks rather than simple reaction time.

We have found the median BasalRT to be 380.50 ms. The average BasalRT varies between 230–295 ms in the literature depending on the participant performing regular exercise, profession, gender and age (18-22). In this research, we have found that gender and age were insignificant in the BasalRT. This might be due to similarities in age groups and exercise habits of participants. Longer median BasalRT can be due to the computers that the developed software was ran on. We aimed to minimize the error by using the same computer for each test for a participant.

It is extensively accepted that regular physical exercise improves RT (10, 22-24). However, the effects of acute physical exercise on RT is studied less. Yerkes et al. (25) discuss that acute physical stress has an inverted U effect when performing cognitive tasks. As the central nervous system is stimulated thus aroused, one's attention narrows and improvements on the cognitive tasks are observed, if the tasks to stimulate the central nervous system are not simple. On the other hand, Duffy et al. (26) stated that overshooting a particular level of stimulation causes the deterioration of psychomotor abilities validating the inverted U relationship.

Literature has defined the optimum exercise as increasing participants heartrates up to 115 beats per minute (27, 28). The participants in our study were asked to run in order to double their BasalPR which had a mean of 77.03 ± 9.84. The mean PPyhsPR was 144.75 ± 19.84. The gap between the exercise and reaction test has also a crucial effect on reaction time. Exercise and high heart rate affect the result only 8 minutes after the exercise has been done (29). The high mean PPyhsPR in the tests indicates that there is no delay of our measurements after the physical exercise which allowed the physical exercise's effects to be reflected on the PPhysRT. We have calculated the median PPhysRT to be 367.70 ms. The visual reaction time of our subjects decreased significantly after acute physical exercise when compared to BasalRT as we have hypothesized.

It has been observed that the body's "fight or flight" response resulted in elevated mental stress (30). Apoorvagiri et al. (31) found that mental stress (not acute) caused a decrease in the VRT whereas mental distress caused an increase. However, we did not come across any studies linking acute mental stress to RT in the literature. In our study, acute mental exercise was induced by five minutes of ADD-3 arithmetics. The median PMentalRT was calculated to be 360.80 ms. The visual reaction time of our subjects decreased significantly after acute mental exercise when compared to BasalRT. This shows that simple repetitive addition process might be enough to cause mental stress, but the relatively short duration of 5 minutes did not cause distress. The mean PMentalPR was calculated to be 80.48 ± 10.92 bpm. The increase was significant compared to BasalPR. This increase in the pulse rate supports the idea of mental stress since the higher pulse rate is achieved without any physical demand. An interesting finding of our study was the relationship between the PMentalRT and the amount of ADD-3 arithmetics performed by the participant. The more problems an individual solved in ADD-3 arithmetics the faster his/her PMentalRT was compared to his/her BasalRT. One unit increase in the number of ADD-3 problems solved was associated with 0.21 units decrease in MentalRT which was found to be statistically significant.

Though we have proved our hypothesis, there are some limitations that should be noted. We used digital software for the measurement of VRT. The performance of the software was dependent on the specifications of the computer it was running on. With four different medical schools and multiple researchers, the standardization was not possible. However, we used the same computer for each test for a participant to minimize the error.

The pulse oximeters were another limitation, they have an expected error of 4% (32). More reliable measurement method such as ECGs used in cardiac stress tests could be used, but it would be inconvenient. We aimed to minimize this error by continuously measuring the pulse and using the same device for each test for a participant. One of the concerns was the repetitive task of measuring the VRT. As Apoorvagiri et al. (31) conclude in their study, reaction time tests are well performed with practice. Thus, we used the mean values of five measurements for each of the BasalRT, PPhysRT, and PMentalRT to eliminate the possible influence of repetition.

As a conclusion, both acute mental stress and acute physical stress can decrease VRT as we have hypothesized. In addition to acquiring results that support our hypothesis, we also discovered that there might be a relationship between arithmetic capability (ADD-3 arithmetics performance), acute mental stress and VRT. Further experiments with various methods are needed to better explain the relationship between acute mental stress and VRT.

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Informed Consent: Written informed consent was obtained from the participants of this study.

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Author contributions: Concept: BK, UG Design: BK, AE, EŞ, UG Supervision: BK, OK, MŞ, GİG Resources: BK, HOİ, FEA, AUM, EA Materials: BK, AE, EŞ, HOİ Data collection and/or processing: BK, AE, EŞ, HOİ, FEA, AUM, EA, HK, CEK, EG, ANG, ET, ST, BT Analysis and/or Interpretation: BK, AE, UG Literature Search: BK, AE, EŞ, HOİ, FEA Writing Manuscript: BK, AE, EŞ, HOİ, FEA Critical Review: BK, AE, EŞ, HOİ, OK, MŞ, GİG

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