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Original Research Article

Impact of a Short-Duration Exercise Program on the Speed of Sensorimotor Integration and Processing

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Abstract:

Background: Exercise exerts multifaceted effects on the human body, including potential impacts on cognitive function and psychomotor speed. Existing research suggest that effects on these dimensions is quite ambiguous. Reaction time has emerged as a simple, non-invasive and reliable marker of the speed of sensorimotor integration and processing and even cognitive functions. It has been validated in numerous studies. However, literature on the effect of exercise on reaction time remains inconclusive. This necessitated the present study.

Objectives: The study was done with the objective of ascertaining the effect of a short-duration exercise program, comprising both isometric and isotonic contractions, on visual and auditory reaction times in young adults. It also sought to quantify the change observed.

Methods: A descriptive, observational study was conducted on 60 healthy young adults. Visual and auditory reaction times were recorded using a multiple-choice reaction time apparatus before and after the exercise session. Exercise intensity was graded based on post-exercise heart rate. The data was analyzed using SPSS. Before-after comparison of mean values was done with paired t-test. Linear regression was used to quantify the change and find out factors which could consistently predict the outcome in terms of percentage of change in the reaction times.

Results: Both visual and auditory reaction times significantly decreased after exercise. The average decline in Visual (VRT) and Auditory (ART) Reaction times were approximately 18% and 21% respectively. Baseline reaction times and exercise intensity both were significant predictors for ART and together accounted for 40% of the decrease. In VRT, only baseline values emerged as a significant predictor contributing to 24% of the variance.

Conclusion: Short-duration exercise significantly improves psychomotor processing speed, as evidenced by reduced reaction times. Exercise intensity significantly affects the auditory reaction times. This improvement is likely mediated by mechanisms such as enhanced cerebral blood flow, faster neural transmission, and improved cognitive function.

Keywords: Exercise, Reaction time, psychomotor speed, sensorimotor integration, Cognitive function.

Introduction

Exercise has manifold effects on the human body. It is well documented over years of research that exercise impacts almost all systems of the body. [1-3] It is not merely the cardiorespiratory and metabolic adjustments which aim to harmonize the kinetics of oxygen supply and consumption in the exercising muscles, exercise also brings about various changes in the nervous system and even the immunological profile of the subjects. [4-6] Studies show that exercise causes an increase in cognitive functions as manifested by faster speed of processing executive tasks given to the brain. [7] Both short-term and long-term exercise can enhance cognitive functions, particularly, working memory, attention window and the ability of multiple object tracking. [8,9] However, some studies also suggest that exercise might have a dual effect on the psychomotor system, causing varying effects in different areas of the brain. Repeated muscle activity as seen in exercise can lead to the phenomenon of central fatigue. [10] There is a decrease in voluntary activation of the muscles from the cortex, i.e., reduction in the number and discharge rates of the motor units recruited at the beginning of a contractile activity. Some researchers have also observed intracortical inhibition of motor activity resulted in central fatigue caused by various factors such as Renshaw cell inhibition. [11,12] Psychomotor speed was also found to be affected during conditions overtraining suggesting further that there are possible mechanisms by which cognitive processes could be negatively affected.[13]It is thus obvious from the existing corpus of scientific evidence that the effect of exercise on the speed of psychomotor processing and cognitive efficiency is ambiguous. Some studies show that exercise makes the process faster, probably due to an increased blood supply to the brain [14] or probably due to a facilitatory conditioning effect on the neural pathways used over and over during repeated activity. [15-17] On the other hand, physiological mechanisms which can have the opposite effect have also been described in the medical literature. This formed the basic premise of the present study. Measurement of reaction time was taken as the index of peed of sensorimotor integration and processing.

Reaction to a particular stimulus is a purposeful and voluntary motor response to a stimulus or event that can be discerned at the level of consciousness. It involves both the arms of the nervous system, i.e., the central nervous system and the peripheral nervous system. The performance of a motor task in response to a particular stimulus involves an orderly sequence of neural activities comprising perception of the task by the cerebral cortex, analysis of the same and generation of an appropriate response, followed by its execution. Motor activity itself is a three-tier activity involving cortical areas concerned with idea of the response, planning and programming and finally execution. [1-3] The whole process therefore amalgamates the sensory nervous system, cognition and the motor nervous system. Reaction time (RT) is defined as the time between application of stimulus and the appearance of response. [3,18]

In other words, it is the time taken in neural processing from perception of the stimulus to the voluntary execution of task. [19-21] It is known that the minimum delay across a single synapse is 0.5 milliseconds. [3] Therefore, reaction time can as an excellent reflection of sensorimotor integration, integrity of neural pathways and speed of nerve conduction. Its validity and reliability have been tested and established in various studies. A long reaction time signifies decreased performance. [22-24] Because recording of reaction time involves alertness, concentration and swift voluntary action, it has also been proposed as a marker of cognitive efficiency. [25] As such, the literature on the effect of exercise on reaction time is not conclusive and studies on Indian population are limited. [26-29] The present study was therefore carried out with the objectives of recording the visual and auditory reaction time of young adults and how it gets affected by a short-duration exercise having both isometric and isotonic type of muscle contractions.

Materials and Methods

A descriptive, observational study was conducted with 60 healthy young volunteers, from both the sexes, in the Department of Physiology, Himalayan Institute of Medical Sciences from January 2021 to September 2021.

Sample Size Calculation: The sample size was calculated using G-power (version G*Power 3.1.9.2) which is a widely accepted, validated and reliable software used for computation of sample size. [30,31]Considering α-error probability as 0.05, power of the study as 0.95 and effect size as medium (0.5) as per existing statistical conventions of Cohen, the requisite sample size for two-tailed, before-after statistical comparison using paired t-test was found to be as 54. [32,33] For ease of statistical analysis, we recruited a higher number, i.e., 60 subjects for the study. Convenience sampling technique was used to select the subjects. Prior approval was obtained from the Institutional Ethics Committee (vide letter no HIMS/RC/2020/163) and informed consent was taken from all the subjects before starting the study. The data obtained has been dealt with strict confidentiality and used for the said research only.

Selection criteria: The inclusion criteria were young adults, 18-25 years old and who were willing to perform isometric and isotonic exercises for short duration. Participants were excluded from the study if they had impaired vision, impaired hearing or any musculoskeletal conditions involving the upper limb like deformity, fracture, etc. Similarly, those who had a history of smoking, alcoholism or intake of any drugs like sedatives, anxiolytics, sympathomimetics, anti-psychotics, anti-histaminics, etc. were also excluded. Those who were suffering from diabetes, neuromuscular, neurological or psychiatric diseases or complaining of anxiety were also excluded from the study as all these factors could act as confounding factors.

Methodology:

a. Recording of Reaction Time: Reaction Time was recorded using Medicraft Multiple Choice Apparatus for audio visual reaction time (Model No. 653MP/008, Manufactured by Medicraft Electro Pvt. Ltd., Lucknow, Uttar Pradesh, India) which has a provision of recording both visual and auditory stimuli of different frequencies and wavelengths. Before recording, the apparatus was shown to the subjects, the concept of simple reaction time was explained and a demonstration of the procedure was given. The subjects were instructed to press the appropriate response key when they detect and perceive the stimulus. The subjects were asked to avoid stimulants like coffee and tea 12 hours before the procedure. Once ready, the subjects were instructed to keep the index finger of the dominant hand at the same distance from the response key throughout the test and press the response switch as soon as they perceived the stimulus. A single monochromatic visual stimulus (a green-colour light) and a single medium-range frequency auditory stimulus were used for all the subjects to maintain uniformity. The time taken from the application of the stimulus to response to stimulus is displayed on a five-digit digital chronoscope of the device which has a resolution to the nearest 0.001 seconds. The lowest of three such recordings were noted as the Visual Reaction Time (VRT) and Auditory Reaction Time (ART) of the subject respectively. Recordings were repeated once again after the exercise session. These resting values acted as controls against which the effect of exercise was compared.

b. Isometric exercise: Isometric contraction was performed using a Hand Grip Spring Dynamometer (INCO Instruments & Chemicals, Pvt. Ltd., Ambala, Haryana, India). The participants were asked to place their hand on a table maintaining an angle of 90° of flexion at the elbow. Then, they were asked to squeeze the handle of the dynamometer with their maximum strength. A contraction sustained for at least 3 seconds was taken as a valid recording. Their maximum strength was denoted as T_{max}. Subjects were asked to maintain a contraction at half of their T_{max} (50%) for minimum 5 minutes or complete fatigue whichever was earlier.

c. Isotonic exercise: Isotonic contraction was performed by lifting fixed weights. The subjects were asked to lift up weight of 1.5 kg- 2 kilograms with their hand by flexing the elbow joint causing isotonic contraction of the muscles for minimum 5 minutes or complete fatigue whichever earlier. The weight was kept fixed for a particular subject during the exercise duration.

d. Grading of intensity of exercise: Exercise intensity was graded on the basis of the pulse rate obtained after exercise. Pulse rates up to 100 beats/ min was categorized as mild, 101-125 beats/min was categorized as moderate, 126-150 beats/ min was categorized as severe and > 150 beats/min was categorized as very severe grades of exercise. [34]

Statistical Analysis: Data was analyzed with SPSS version 17 (Manufactured by SPSS Inc., Chicago, USA). Descriptive statistics were used to express the mean values of the parameters. Independent sample t-test was used to compare the difference in the variables between males and females. Paired t-test was used to compare the mean reaction times before and after exercise. Linear regression was used to quantify the amount of change with possible predictor variables. The goodness of fit of the model was ascertained by calculating the coefficient of determination (R^2). P-value less than 0.05 was considered statistically significant.

Results

The visual and auditory reaction times of the participants as well as their pulse rate before and after exercise are shown in Table No. 1. There were no significant differences in these parameters between the two sexes, suggesting good comparability of the subjects. Both the visual and auditory reaction times showed a statistically significant (p-value < 0.05) decrease after exercise.

The pulse rate significantly increased after exercise suggesting the exercise done by the participants had a significant effect on their bodies. Figure No. 2 shows that out of 60 participants, 24 participants performed mild, 32 participants performed moderate and 4 participants performed severe grades of exercise. The average reductions were about 18% in VRT and 21% in ART. The figure shows a consistent decrease in both the visual and auditory reaction times with the intensity of exercise, with 27.5% and 32.6% decrease in them respectively in severe intensity of exercise.

Out of the two, the effect was more relatively pronounced in auditory reaction time except for mild exercise. Table No. 2 shows the results obtained on linear regression quantifying the amount of change that can be attributed to the baseline values and intensity of exercise obtained by the participants. The F-statistic for both the outcome variables was found to be statistically significant (p-value < 0.05) suggesting that this model was a good fit for the variance in the observations.

About 24% of the variance in VRT could be attributed to the baseline VRT and 40% of the variance in ART could be attributed to the effect of baseline ART and intensity of exercise taken together as revealed by their coefficient of determination (R^2).

Table 1: Visual and auditory reaction times and pulse rate of the subjects

Subjects	Baseline (before exercise)		After exercise		Comparison of effect (P-value) #
	Mean ± S.D.	Inter-group comparison (P-value) *	**Mean ± S.D.**	Inter-group comparison (P-value) *	
Visual Reaction Time (seconds)(VRT)					
Males (N= 30)	0.246 ± 0.114	0.928	0.199 ± 0.067	0.923	**0.001**
Females (N= 30)	0.248 ± 0.094		0.200 ± 0.068		**0.000**
Average (N= 60)	0.247 ± 0.104		0.200 ± 0.067		**0.000**
Auditory Reaction Time (seconds)(ART)					
Males (N= 30)	0.191 ± 0.105	0.092	0.149 ± 0.105	0.346	**0.034**
Females (N= 30)	0.237 ± 0.103		0.161 ± 0.050		**0.001**
Average (N= 60)	0.214 ± 0.106		0.155 ± 0.050		**0.001**
Pulse Rate (beats/min)					
Males (N= 30)	84.7 ± 13.37	0.294	107.80 ± 14.04	0.532	**0.000**
Females (N= 30)	81.13 ± 12.69		105.60 ± 13.05		**0.000**
Average (N= 60)	82.92 ± 13.05		106.70 ± 13.48		**0.000**

*** Comparison of means by independent sample t-test, # Comparison of means by paired t-test, Level of significance of p-value: < 0.05.**

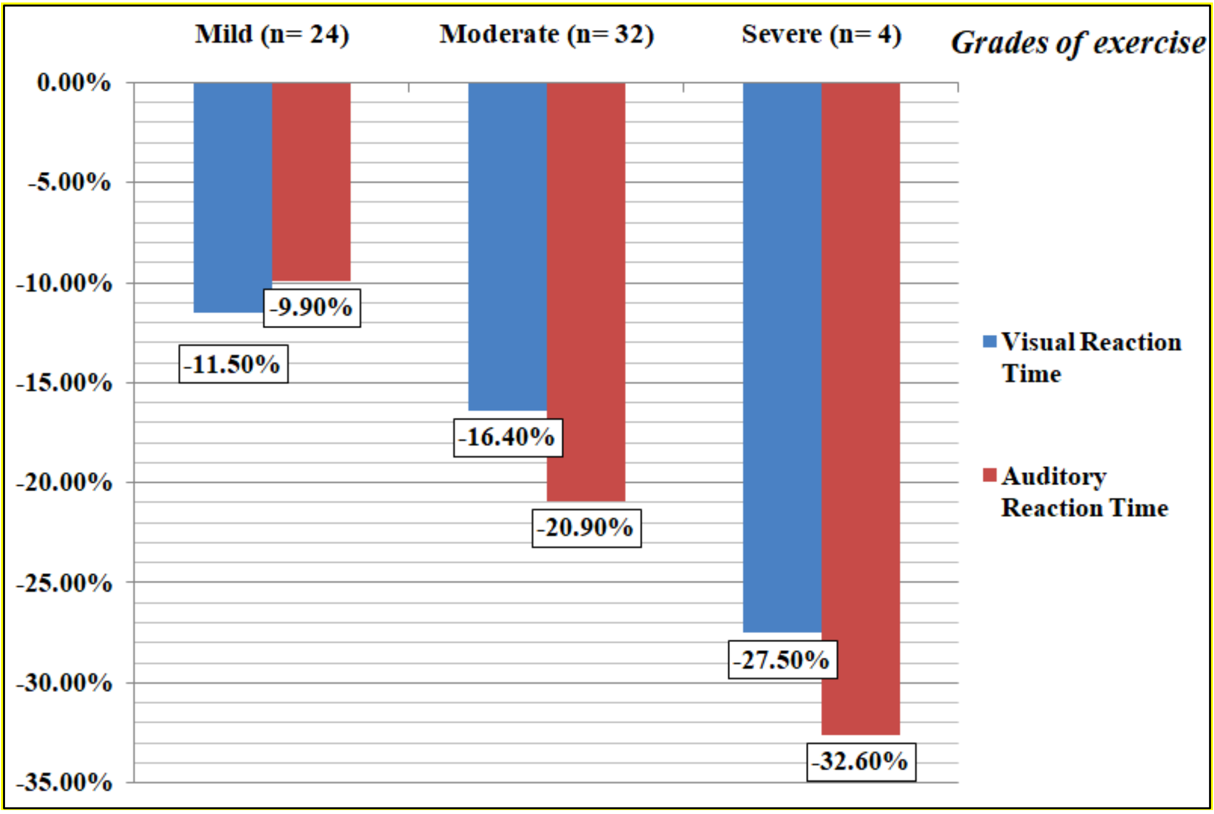

Figure- 1: Amount of decrease observed in the reaction times in various grades of exercise

Table 2 : Regression coefficient and constant for the percentage of change observed in Visual Reaction Time (VRT) and Auditory Reaction Time (ART) with baseline values and percentage of change observed in pulse (N=60)

Outcome/ dependent variable	Independent Variables/ predictors	β coefficient	95% CI	p-value	Regression model summary	Adjusted R^2
Percentage change in Visual Reaction Time (VRT)	Constant	11.683	-1.55 to 24.91	0.082	F (2,57) = 10.340, **p=0.000**	0.240
	Baseline VRT	-94.675	-137.20 to -52.15	**< 0.001**		
	Percentage change in Pulse rate	-0.112	-0.32 to 0.09	0.272		
Percentage change in Auditory Reaction Time (ART)	Constant	32.470	14.31 to 50.63	**0.001**	F (2,57) = 20.557, **p= 0.000**	0.399
	Baseline ART	-196.362	-258.73 to -134.0	**< 0.001**		
	Percentage change in Pulse rate	-0.255	-0.56 to 0.049	**0.048**		

Outcome/ dependent variable: Percentage change in VRT and ART separately. Predictor/independent variable: Baseline values, percentage change in pulse rate. F-statistic obtained on regression, numbers in parentheses represent degrees of freedom. Level of significance of p-value: < 0.05.

Discussion

Determination of reaction time is a simple, convenient and yet reliable index of testing the speed of neurological processing, which by default also indicates the integrity of the neural pathway. It is also a reflection of physical agility of an individual. Reaction time is recognized as a reliable marker of higher cognitive functions for example attention, concentration, decision-making for a voluntary movement, etc. [22,35,36] In the present study we recorded the simple visual and auditory reaction times of young adults as a surrogate marker of the sensorimotor integration and psychomotor processing and observed the effect of short-duration exercise program on it.

The mean resting Visual Reaction Time (VRT) and Auditory Reaction Time (ART) of our participants were 0.247 ± 0.104 s and 0.200 ± 0.067 s respectively, i.e. 247 ms and 200 ms respectively. Our findings are in close consonance with the values reported by Jain A et al. who observed a VRT of 247 ms and ART of 228 ms. [37] Lower values as compared to our study were found by Welford AT who reported a VRT of 190 ms and ART of 160 ms. [22] Thompson et al.reported VRT and ART of approximately 180–200 ms and 140–160 ms respectively. [38] On the other hand, higher values were observed by Chandak PR and Makwana J. They reported a VRT of 365 ms and ART of 341 ms. [39] There could be multiple reasons behind these variations. Difference in the mean age of the participants, ethnic variations in study groups, method used for reaction time measurement like psychometric and computer-based software, electrophysiological techniques could contribute to these differences. There were no significant differences between males and females in the present study. Similar findings were also reported by Hanumatha S et al. [40]On the other hand, Jain A et al. and Nikam LH and Gadkari J reported significantly longer reaction times in females relative to males. [37,41]

In the present study, it was also found that both visual and auditory reaction times significantly decreased after exercise. Similar effect was also observed by Garg M et al. with aerobic exercise irrespective of gender. [23] A similar study by Ahmed MA et al. comparing the effects of isometric and isotonic exercise revealed that exercise led to significantly lesser reaction times in the subjects. [42] Nighute S et al. and Roche et al. also reported similar findings. [43, 44] Similar effect of exercise on reaction time was also documented in a variety of study settings involving athletes, [45-47] basketball players and sportspersons. [48-49]

The present study, additionally, also attempted to quantify the change and explore factors which could predict the outcome of exercise which have not been done by most authors. There was a decrement of approximately 18% and 21% in VRT and ART respectively. Greater change was seen with higher intensity of exercise. In case of VRT, only baseline value was a consistent predictor and it contributed to 24% of the decrease. In case of ART, baseline values and intensity of exercise both were significant predictors and together contributed to 40% of the changes. The effects could be attributed to improved concentration and alertness, faster motor response processes like motor unit recruitment. Moderate to high intensity exercise has also been shown to increase cerebral blood flow leading to higher supply of necessary nutrients such as oxygen and glucose which in turn could fasten cognitive functioning like alertness and decision-making. [50] Faster processing in the central nervous system was identified to be the cause of faster reaction time in athletes. [51]

Functional MRI based studies have also showed that exercise enhances brain activation patterns in prefrontal lobe, supplementary motor cortex and even hippocampus all of which are brain areas associated with working memory, attention and decision-making aspects. [52] Roberts and Pallier in 2001 had proposed that reaction time comprised of two components: Pre-movement time (time taken to perceive and process a stimulus and initiate a response) and Movement Time (time taken in actual execution of the response). [53] The above effects suggest a possible facilitation of the premovement time which could lead to reduced reaction times.

Conclusion

This study provides evidence that exercise for as much as ten minutes involving both isometric and isotonic contractions significantly improves psychomotor processing speed in young adults. There was an average reduction of 18% in VRT and 21% ART approximately. Baseline reaction times and exercise intensity together accounted for 40% of the observed decrease in auditory reaction time. In VRT, only baseline values emerged as a significant predictor contributing to 24% of the variance. These findings suggest that exercise enhances neural processing and sensorimotor integration through mechanisms such as improved cerebral blood flow, faster neural transmission, and enhanced cognitive function. Intensity of exercise affects the auditory reaction times.

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