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Original Article

The Effect of Acute Aerobic Exercise on Working Memory Among Female Students of Bingham University, Nigeria

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ABSTRACT

Researches have showed that participation in a physical activity is associated with increased performance across a variety of tasks involving attention, cognition, and memory. The present study aimed at investigating the effects of aerobic exercise on working memory in non-athletic female students of Bingham University. A total of 53 participants who completed the physical activity readiness questionnaire (PAR-Q) were considered for this study. The study was conducted in three days, with day 1 being the baseline testing. Participants completed an N-back working memory task before the start of aerobic exercise. They were then required to perform an aerobic exercise on the treadmill for 10 min; and after which, were made to perform the N-back working memory task again. The same procedure was carried out on days 2 and 3. All data were analysed using analysis of variance at $p<0.05$. A significant ($p<0.001$) increase in total false alarm was observed in subjects after exercise and on days 2 and 3 compared to the first day before exercise. There was significant decrease in reaction time after the exercise, and on days 2 and 3 of the study as compared to the first day at $p<0.001$. This study has shown that acute aerobic exercise improved working memory in the female students' population.

Keywords
Aerobic exercise, N-back, Working memory, Reaction time, Acute

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INTRODUCTION

The effect of exercise on various domains of cognitive function is still a well-sorted and current field of research with respect to neuroscience, cognitive psychology, exercise science, and clinical medicine. The cognitive portion of the human brain that is responsible for processing and storing incoming information simultaneously (Gray et al. 2017) for the performance of a task in the near future is known as working memory. It involves having a coordinated behavior during active multiple goals, as well as manipulating and updating information (Nyberg and Eriksson 2015).

Several theories of working memory have been proposed, but the most significant of them all is the multicomponent model of working memory (Baddeley and Hitch 1974) that consists of three subunits; a central executive and two domain-specific stores. The stores are responsible for the retention of visuospatial and phonological materials; on the other hand, the central executive is involved in range of regulatory functions such as attention, control of action and solving problem (Levin 2011). The central executive also supervises the integration of information and coordinates the "slave system" (phonological loop and visuospatial sketchpad) which maintains short-term information. The phonological loop stores and prevents the decay of phonological information by refreshing it in a rehearsal loop. The visuospatial sketchpad on the other hand, stores visual and spatial information, constructs, manipulates and represents them on mental maps (Weiten 2013).

Many modifications have been made on working memory theories with respect to specific mechanisms within (Baddeley 2012). Inhibitory processes that serve to protect disruption of activated memory traces have been proposed (Engle 2002; Kane et al. 2007). Some other models suggested that working memory represents long-term memory in an activated state by integrating short- with long-term memories (Cowan 1999; Oberauer 2002). There also exist other theories which involves updating (Ecker et al. 2010; Schmiedek et al. 2014), set shifting and rational binding (von Bastian and Oberauer 2013), as well as fluid intelligence (Engle et al. 1999).

The existence of the central executive in working memory has been opposed by more recent models; rather the updating function which involves the ability to replace stored information by new upcoming ones (Rey-Mermet et al. 2017). Stored information are also maintained in a stable manner, by shielding it from unwanted distractions form the environment. There is usually conflict of flexibility and stability in updating and maintenance of information. This is because incoming information can be relevant and could trigger updating, or irrelevant and should be inhibited. Therefore, a modulatory mechanism is needed to control both functions (Rac-Lubashevsky and Kessler 2016). An input-gating mechanism which shields the maintained information and enables stability is a theory that is used to replace the control mechanism. Closing the gate enables stability while opening it represents updating of new relevant information (Kessler and Oberauer 2015; Chatham and Badre 2015). This gating mechanism is controlled by neuronal process which releases dopamine from the prefrontal cortex as well as the basal ganglia (O'Reilly and Frank 2006).

Some areas in the brain make up vast network that influences working memory. These areas includes: the frontal and parietal lobes, hippocampus, thalamus, the inferior central gyrus as well as the anterior cingulate gyrus (Gutiérrez-Garralda et al. 2014). Behavior disorders and social difficulties have been associated with impairments of working memory (Engle et al. 1999), which could in turn affect the quality of life.

Cognitive function and brain health has been shown to improve after aerobic exercise (Padilla et al. 2014). Voss et al. (2010) reported that there was increase in functional brain connectivity such as frontal executive network and default mode network as well as improvement in executive function after a one year regimen of aerobic exercise. Memory decoding and gray matter volume in the cingulated and prefrontal cortices has been linked to physical activities (Floel et al. 2010). A meta-analysis study has reported that moderate intensity exercise enhanced working memory processing speed (McMorris et al. 2011). Also, Roig et al. (2013) indicated that acute moderate-intensity exercise had much more influence on working memory and short term memory.

N-back task is a working memory test that involves the continuous sequences of stimuli which is presented in the form of images or letters and displayed one after the other. The individual will determine if the present stimulus is similar to the one displayed in (1,2,3) trials beforehand (Courtney et al. 2023). Despite the array of studies on the influence of exercise on the brain, there have been quite some discrepancies in results of several studies in working memory through updating task. Thus, the effect of acute aerobic exercise on working memory still remains uncertain. The accuracy of the modified Sternberg and N-back task improved after moderate- intensity acute aerobic exercise (Pontifex et al. 2009; Weng et al. 2015). In yet another report, acute moderate-intensity exercise did not improve reaction time and accuracy in the N-back task (Gothe et al. 2013; Li et al. 2014). It was however suggested that these discrepancies could be due to inter-individual differences in working memory function (Sibley and Sian 2007). Though it has not been fully established if inter-individual difference influences working memory via updating task after aerobic exercise, this study therefore, investigated the effect of aerobic exercise on female students with average academic performance. Thus, it is hypothesized that working memory could be improved after acute bout of aerobic exercise using an updating task.

MATERIALS AND METHODS

Participants

A total number of sixty-seven female students were recruited to participate in this investigation, of which fifty-three were aged 16 – 25 years with averagely good academic performance, were fit to partake in the study. Each participant filled a physical activity readiness questionnaire (PAR-Q) which was designed to provide pre-activity screening and to detect potential risk factors that might be triggered by participating in the acute exercise. It was ensured that those with acute infection/critically ill, neurological diseases, athletes and those involved in vigorous physical activity were excluded in this study. The study protocol was reviewed and approved by Bingham University Research and Ethical Committee ((BHU/REC/18/H003)

Experimental Protocol

This study was conducted in two phases: In the first phase, the participants were made to undergo a screening exercise where questionnaire was administered; and body weight and height were measured. Their blood pressure and pulse rates were measured to ascertain if they were fit enough to partake in the exercise. They were made to do a pre-test training of the N-back task.

The test had two phases: after being certified fit to participate, each participant was made to undertake the N-back updating task (as described subsequently), after which the N-back task proper was done and recorded to get the baseline of their working memory.

They were then made to use the treadmill at a speed of 6 mph and later adjusted to 8 mph. This bout of aerobic exercise was conducted for 10 min. After the exercise, each participant was made to observe a rest of 5 min. and then undertook the N-back task. On days two and three, the participants were made to perform another acute bout of exercise on the treadmill, allowed to relax for about 5 min. before performing the N-back task.

N-back Task
The N-back task is a go/nogo working-memory performance task. The single N-back task was used for this study, and this utilized visual cues as its stimulus. In this task, the participants were shown a sequence of stimuli, which was a sequence of yellow shapes displayed over a black background (Jaeggi et al. 2010b). They were made to indicate if a displayed stimulus fulfilled n-values as follows:
For N=0, N=1, N=2 and N=3 trials, if the displayed shapes were similar to the presented, it was said to be a target. The participants were required to respond by pressing the key "A" on the computer. In case where the presented stimulus was not similar, the participants were expected not to respond. In each trial, the shapes were presented for 500 msec. and a waiting time of 2000 msec. before presenting the next shape in the sequence. Thus, the timeline for a participant to respond by pressing "A" for target stimulus was 2500 msec.

Statistical Analysis
Descriptive statistics were presented as means ± standard deviations. Normality of the data was tested with Shapiro-Wilk. Repeated measure ANOVA was used to test for significant difference between N-back groups across physiological parameters. Where statistical significance is attained, post hoc test was conducted by means of Bonferroni's. Statistical significance was set at $p < 0.05$ and all statistical tests were two-sided. All statistical analyses were performed with Statistical Package for Social Sciences (IBM SPSS Incorp., USA) version 26 for Windows.

RESULTS

The anthropometric characteristics of the sample population showed that the mean weight of subjects was 64.3 ± 9.88 kg (minimum weight of 44 kg and a maximum weight of 95 kg). The mean height was 160.36 ± 7.03 cm (minimum height of 147 cm and maximum height of 179 cm). The mean Basal Metabolic Rate (BMI) was 20.05 ± 2.92 kg/m2. Since the BMI of the participants were within the normal value range implying that the subjects were physically active.
The blood pressure and pulse rate of the subjects increased significantly ($p<0.001$) after aerobic exercise compared with before the exercise, as shown in Table 1. On the other hand, there was no significant change in the diastolic blood pressure after an active bout of aerobic exercise. However, the pulse pressure increased significantly ($p<0.001$) after the exercise.
In the working memory of the subjects using the N-back test, there was a significant increased ($p<0.001$) total false alarm (TFA). There was also a significant decreased ($p<0.001$) reaction time of the subjects. VDV: is the proportion of the Total Hit Target (THT) and Total False Alarm (TFA). The VDV showed that the THT decreased significantly $p<0.001$ to the omission error (TFA) (Table 2).

DISCUSSION

This present study on the effect of acute aerobic exercise on working memory was performed among non-athletic female students of Bingham University, who were subjected to 10 min. of aerobic exercise each day for three days. On the first day, a baseline test was performed which sought to check some cardiovascular parameters as well as their baseline working memory index. The results from this study showed significant increased systolic blood and pulse pressures after aerobic exercise as compared to the baseline pre-exercise value. This increase in systolic blood pulse pressures could be due to the fact that these parameters were measured 5 min. after the exercise. The increase in pulse rate in this study agrees with the findings of Barros et al. (2021), who reported increased heart rates of subjects after bouts of aerobic exercise.
This study is in agreement with the report of the Centre for Disease Control (1996) on blood pressure changes after aerobic exercise. It was stated that mean arterial blood pressure increased in response to dynamic exercise, and which is largely due to increase in systolic blood pressure. The systolic blood pressure increased linearly to about 200 – 240 mmHg with increasing rates of work. The increase is due to the resetting of the arterial baroreflex to a higher pressure and without this reset, the body would experience arterial hypotension during intense activity (Rowell 1993). It is expected however, that after two to three hours, the blood pressure should fall below the pre-exercise resting level (Isea et al. 1994). On the contrary, Barros et al. (2021) reported decreased systolic blood pressure in normal individuals after exercise, which agrees with other

Table 1: Blood pressure and pulse rate of the sample population

	1	2	3	4		
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	F	*P*
Systolic BP (mm Hg)	121.56 ± 10.30[a]	146.71 ± 14.54[b]	142.21 ± 14.76[b]	141.31 ± 14.75[b]	58.45	<0.001
Diastolic BP (mm Hg)	73.21 ± 10.28	74.98 ± 12.02	74.42 ± 9.89	75.60 ± 9.60	0.90	0.444
Pulse rate (beats/min)	82.66 ± 10.31[a]	115.55 ± 19.66[b]	109.85 ± 14.79[b]	109.96 ± 14.41[b]	60.18	<0.001

1: Pre-exercise, 2: After exercise day 1, 3: After exercise day 2, 4: After exercise day 3
Means with different superscripts are significantly different at $p<0.05$

studies (Pinto et al. 2006; Cardoso et al. 2010; Perrier-Melo et al. 2020). The decrease in blood pressure reported could be due to post exercise recovery: This post exercise hypotension could be due to the intensity, volume or duration of the exercise (Brito et al. 2018; Fonseca et al. 2018). It is stated that exercise longer than 25 min. and more intense than 50% of oxygen consumption reserve (VO2R) could result to more hypotensive responses (de Brito et al. 2018).

Table 2: Result of working memory in sample population using the N-back test

	1	2	3	4		
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	F	*P*
THT	34.85 ± 9.55	33.96 ± 9.73	34.70 ± 9.88	31.45 ± 11.36	2.41	0.089
TFA	4.64 ± 4.09[a]	4.96 ± 6.80[b]	7.02 ± 11.61[b]	15.06 ± 16.32[b]	15.56	**<0.001**
VDV	2.52 ± 0.72[a]	2.47 ± 0.72[b]	2.31 ± 1.11[b]	1.39 ± 1.65[b]	17.32	**<0.001**
RT $x10^6$	1.28 ± 0.40[a]	0.90 ± 0.31[b]	0.89 ± 0.23[b]	0.94 ± 0.36[b]	18.89	**<0.001**

1: Pre-exercise, 2: After exercise day 1, 3: After exercise day 2, 4: After exercise day 3
Means with different superscripts are significantly different at P <0.05.
THT: Total Hit Target, TFA: Total False Alarm, VDV: ratio of THT to TFA, RT: Reaction Time

It has been recorded that exercise bouts leads to high energy expenditure which tends to attenuate the effect of exercise on the duration and magnitude of blood pressure (Jones et al. 2007; Fonseca et al. 2018). This is attributed to the role of the central baroreflex on post exercise hypotension, and is elicited through the action of vascular smooth muscle (myogenic tone) (Phan et al. 2022) and afferent fibres of the muscles (Halliwill et al. 2013) which tend to reset the blood pressure at a higher level. At the end of exercise, the baroreflex resets to a lower level due to decreased sympathetic activity, which in turn leads to a reduction in blood pressure (Chen and Bonham 2010; Halliwill et al. 2013).

In the working memory task, there was a significant decrease in the reaction time and a significant increase in the TFA. This implies that the acute bouts of aerobic exercise improved the working memory of the subjects. The reaction time in our study was shortened after the aerobic exercise compared to pre-exercise. This shorter reaction time observed in this study could be due to increased arousal level which was triggered by the exercise. During exercise, the sympathetic nervous system becomes activated which leads to increased phasic release of catecholamine. Catecholamine has been reported to improve cognitive performance and could consequently enhance working memory activity (McMorris 2021). The improvement in cognitive function is due to brain the plasticity changes associated with aerobic exercise (Erickson and Kramer 2009; Voss et al. 2013).

The results from our study is in conformity with that of Chen et al. (2016), who reported an improvement in the working memory of children exposed to acute bouts of aerobic exercise. Erickson and Kramer (2009), Chang et al. (2012) and Chen et al. (2016) also reported that working memory improved after exercise. The report of Keita and Ryuji (2019) tend to agree with our findings of shorter reaction time, although their report had a higher hit target contrary to the present result. Working memory shows a significant improvement after simple aerobic exercise (Ludyga et al. 2016; Chang et al. 2012). This improvement is more profound after some moment of delay than immediately after the exercise (Chang et al. 2012). A study has also shown that healthy adults with low cognitive performance can benefit greatly from acute bouts of aerobic exercise. This claim is however not uniform amongst individuals (Sibley and Sian 2007).

In N-back test, it is expected that the reaction times should increase while accuracy decreases with respect to increased task difficulty in N values (Harvey et al. 2005; Miller et al. 2009; Schmidt et al. 2009). In this study, the reaction time decreased while the TFA increased after exercise indicating that the higher the reaction time, the higher the number of errors. These findings are in agreement with the report of Carter et al. (1998) and Jaeggi et al. (2010a).

Working memory have a wide spread mapping in various areas of the brain such as the cerebral cortex (frontal, parietal, occipital and temporal lobes) and subcortical areas like the amygdala, cerebellum, hippocampus and the thalamus (LaBar et al. 1999; Diwadkar et al. 2000; Osaka et al. 2004 Owen et al. 2005). Chen et al. (2016) reported that N-back task is suitable for working memory test and that certain areas of the brain such as the bilateral superior parietal and left inferior parietal lobes, left hippocampus, and bilateral cerebellum are activated during aerobic exercise. The improvement in working memory has been reported to be due to the plasticity changes that come with aerobic exercise (Erickson and Kramer 2009; Voss et al. 2013). Also, larger bilateral hippocampal volumes in high-fitness children has been shown to improve memory task (Chaddock et al. 2010). Li et al. (2014) showed that aerobic exercise activates the brain, which in turn may have improved the working memory of the young female students.

Conclusion

In conclusion, this study showed that acute aerobic exercise can improve working memory in young individuals by decreasing the reaction times and increasing the total false alarm of the subjects. These data therefore extend the body of knowledge indicating the changes associated with acute aerobic exercise. The study was also able to show increased systolic blood and pulse pressures after exercise.

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Conflict of Interest
None declared.

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Authors' Contribution
SEO and AMD designed the research work and wrote the final version of the manuscript, MO and SEO carried out the research work, while MJM and SJI assisted in writing the manuscript.

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