2022

The effects of acute aerobic exercise on motor cortex activation and piano performance

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THE EFFECTS OF ACUTE AEROBIC EXERCISE ON MOTOR CORTEX ACTIVATION AND PIANO PERFORMANCE

A Thesis Submitted

in Partial Fulfillment

of the Requirements for the Designation

University Honors

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May 2022

This Study by: Maya Deuso

Entitled: The Effects of Acute Aerobic Exercise on Motor Cortex Oxygenation and Piano Performance

has been approved as meeting the thesis or project requirement for the Designation

University Honors

5/5/2022	Dr. Terence Moriarty
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Abstract

Previous research has shown that an acute (single) bout of aerobic exercise performed immediately before a fine motor task can improve the performance of that particular task as well as alter motor cortex (M1) activation. However, the intensity of exercise may influence the extent of motor skill acquisition and M1 activation. The primary aim of the current investigation was to compare the impact of moderate-intensity training (MIT) and high-intensity interval training (HIIT) on whole-body motor skill acquisition via a piano task. We also aimed to determine if M1 activation was a potential mechanism for any changes in piano performance. Nine participants (F = 7, M = 2) completed a control, MIT, and HIIT trial followed by a whole-body piano task in a randomized order. M1 activation (as measured by the difference in oxyhemoglobin and deoxyhemoglobin (Hbdiff)) was measured by functional near-infrared spectroscopy (fNIRS) during the post-exercise piano task. The results show that piano performance scores were significantly higher following MIT, but not HIIT, compared to control. M1 activation was significantly higher following HIIT, but not MIT, compared to control. These results suggest that MIT may be the optimal intensity of exercise to prime the nervous system for enhanced performance of a whole-body motor skill, while higher-intensity exercise may be most optimal to increase M1 activation. These findings suggest that similar exercise protocols may also be effective in improving the performance of other activities of daily living (e.g., woodworking, painting, showering, and shooting a basketball). This study also highlights the need to explore the longer-lasting effects and mechanisms associated with whole-body motor priming.

Introduction

It is widely known that regular exercise has a variety of benefits, including lowering blood pressure, lowering resting heart rate, and lowering cardiovascular disease risk (Nystoriak & Bhatnagar, 2018). Even a single bout of exercise can produce benefits. For example, an acute bout of aerobic exercise has previously shown to improve motor learning and motor skill acquisition in both healthy and clinically diseased populations (Nepveu et al., 2017; Ploughman et al., 2008; Snow et al., 2016; Statton et al., 2015). This concept, known as "exercise priming," relates to the use of acute aerobic exercise, prior to or after a cognitive or motor task, to possibly alter brain activation and increase the likelihood of downstream cognitive or motor skill retention (Moriarty et al., 2019; Roig et al., 2012; Statton et al., 2015; Swarbrick et al., 2020). That said, there is a wide variety of methodologies in each study related to this topic. Studies typically focus on either motor learning (a relatively permanent improvement in the performance of a skill) or motor skill acquisition (the initial development of a skill), with a few studies investigating both areas (Mang et al., 2014, 2016; Roig et al., 2012; Snow et al., 2016; Statton et al., 2015; Swarbrick et al., 2020). Additionally, the structure of each study protocol varies in the placement of the motor skill; some require participants to complete the motor skill following the exercise bout, while others place the motor skill before the exercise bout. The present study aimed to investigate motor skill acquisition, rather than motor learning, when the motor skill was completed after the acute exercise bout. Additionally, this study used a piano task as the studied motor skill because it is a whole-body skill representative of an activity of daily living, similar to woodworking, painting, showering, and shooting a basketball.

The existing literature presents inconclusive results regarding whether low-, moderate-, or high-intensity exercise is most optimal for motor skill improvements. In terms of motor skill acquisition, Mang et al. (2016) and Roig et al. (2012) found no acquisition improvements following an acute bout of high-intensity exercise. Meanwhile, two studies conducted by Snow et al. (2016) and Statton et al. (2015) showed improved motor skill acquisition following an acute bout of moderate-intensity exercise. In terms of motor learning, Thomas et al. (2016) found larger improvements in motor learning following a high-intensity exercise bout compared to a moderate-intensity exercise bout. However, Swarbrick et al. (2020) did not find any motor learning differences between the high-intensity and moderate-intensity exercise groups. It is important to note that Swarbrick et al. (2020) is the only current study to our knowledge that utilizes piano performance as the motor task. Most other studies utilize computer tracking tasks controlled by a mouse or joystick, which may not capture the complex nature of motor tasks performed during activities of daily living. At first glance, these results suggest that HIIT may be optimal for motor learning while MIT may be optimal for motor skill acquisition. However, studies comparing HIIT to MIT report no between group differences for both motor skill acquisition and motor learning (Baird et al., 2018; Swarbrick et al., 2020; Wanner et al., 2020). The aims of the current study were to investigate the effects of moderate-intensity training (MIT) and high-intensity interval training (HIIT) on motor skill acquisition using piano performance as the motor task.

The mechanism that promotes improvements in motor skill acquisition is also unknown. Previous studies have investigated neurotrophin levels, genetics, and neural activation as potential mechanisms, but the results are inconclusive (Mang et al., 2014, 2017; Skriver et al., 2014). One such mechanism that may tell us more about the connection between motor skill performance and a prior exercise bout may be the activation of the motor cortex (M1). This is measured using functional near infrared spectroscopy (fNIRS), which detects oxyhemoglobin and deoxyhemoglobin in the M1. Xu et al. (2020) found significant improvements in pre-motor area oxygenated hemoglobin during a table-setting task (action observation task) following acute moderate-intensity exercise (15-min cycling at 65% VO_2max). This increase in oxygenated hemoglobin following an acute bout of aerobic exercise may translate to improved motor skill acquisition. To our knowledge, however, the relationship between motor skill acquisition and M1 oxygenation following an acute exercise bout has not been extensively studied. Therefore, the present study aims to investigate M1 oxygenation as a potential mechanism for any changes in motor skill performance.

Purpose

The purpose of the current study is to investigate the effects of HIIT and MIT on piano performance and M1 oxygenation. Exercise priming may be beneficial in improving the acquisition of a variety of other motor tasks, including woodworking, painting, showering, and shooting a basketball. It is important to note that the intent of the current study was not to assess the effects of acute aerobic exercise on motor skill learning, but rather post-exercise motor skill performance. We will also explore if other exercise stress markers (i.e., blood lactate, heart rate, and rating of perceived exertion) are related to any changes in piano performance.

Literature Review

Introduction

While it appears that aerobic exercise may improve cognitive and laboratory-based motor task performance in humans, it is less well known if enhancements with exercise transfer in to improved performance during tasks of daily living (e.g., piano performance). Aerobic exercise may facilitate improvements in performance outcomes via improved neuropsychological mechanisms. Increasing brain activation through aerobic exercise may perhaps lead to better performance and/or retention of such motor skills. This technique has been shown to be beneficial for both healthy and clinically diseased populations (Nepveu et al., 2017; Ploughman et al., 2008; Snow et al., 2016; Statton et al., 2015). It is important to note that in practice, priming is generally performed prior to cognitive or motor task performance, but some studies have also used this technique post-training (Ferrer-Uris et al., 2017; Roig et al., 2012). Additionally, the optimal intensity of exercise for motor performance benefits is largely unknown.

Efforts to understand the neuropsychological mechanisms by which motor skill performance may be enhanced following an acute bout of aerobic exercise have been unsuccessful. Various articles investigate whether this effect is caused by genetics, neurotrophins, or neural activation, but the results are inconclusive (Mang et al., 2014, 2017; Skriver et al., 2014). Here, we focus on motor cortex (M1) activation during the piano performance task as a potential mechanism for exercise priming.

Motor Task Type

Previous research has demonstrated the effectiveness of exercise priming on motor skill acquisition and learning in both healthy and clinical populations using various computer-based motor tasks. These tasks include target selection using a mouse, visuomotor tracking of a sine wave curve using a force transducer, and visuomotor target tracking using a finger joystick (Mang et al., 2014, 2016; Snow et al., 2016; Statton et al., 2015). For example, Statton and colleagues (2015) found that in a healthy population, an acute bout of 30 minutes of moderate-intensity (at 65%-85% VO_2 peak) running facilitated the improvement of motor performance during acquisition of a visuomotor computer tracking task but did not influence the longer-term learning of this motor skill. Similarly, research investigating exercise priming typically uses closed-environment single-limb motor tasks (Ploughman et al., 2008; Rosenfeldt et al., 2021). For example, a study in Parkinson's Disease patients utilized a tablet task in which the finger is used to track targets (Rosenfeldt et al., 2021). Therefore, in both healthy and clinical populations, it appears that the motor tasks administered are not representative of typical motor skill tasks that take place during activities of daily living. Every day, whole-body motor skill tasks are much more complex than computer-based or simple object movement motor tasks due to factors including timing, balance, multi-sensory feedback, and the use of multiple body parts. Examples of tasks of daily living include brushing one's own hair, riding a bicycle, writing, and painting. There is very little research exploring the effects of exercise priming on these complex types of motor skill acquisition. Furthermore, only one study has investigated the effects of an acute bout of aerobic exercise preceding a piano performance task on motor learning (Swarbrick et al., 2020). While this study yielded a positive correlation between an acute bout of high-intensity interval training (HIIT) and piano performance, more research must be conducted to investigate the relationship between exercise priming and whole-body motor learning tasks, such as piano performance.

Exercise Intensity and Mode

While there is limited research investigating the effect of exercise intensity on motor skill acquisition, many studies have investigated its effects on motor learning. However, the optimal intensity of an acute bout of aerobic exercise to induce improved motor learning is still unknown. Typical research studies involve high-intensity bouts of aerobic exercise to investigate whether this produces improvements in motor learning (Mang et al., 2014, 2016; Roig et al., 2012). For example, Mang et al. (2016) conducted a study with 16 young, healthy participants showing that a single bout of high-intensity cycling improves motor learning using a computer target selection task. Two of these studies also investigated motor skill acquisition using a computer tracking task with a mouse or joystick, with exercise either preceding or following the motor task. The results of these two studies showed no improvements in motor skill acquisition for the high-intensity (three sets of 3-minute high-intensity cycling interspersed with 2-minute low-intensity cycling) aerobic exercise groups (Mang et al., 2016; Roig et al., 2012). However, high-intensity exercise is not always feasible or safe for clinical populations. For this reason, recent studies have started to investigate whether low or moderate-intensity exercise produces similar motor performance benefits (Snow et al., 2016; Statton et al., 2015; Swarbrick et al., 2020; Thomas et al., 2016). Thomas et al. (2016) found larger improvements in motor learning following high-intensity aerobic exercise, compared to moderate-intensity aerobic exercise. In terms of motor skill acquisition, both Snow et al. (2016) and Statton et al. (2015) found improvements in motor skill acquisition (computer tracking using a joystick or force transducer, respectively) immediately following an acute bout of moderate-intensity (60% VO_{2max} and 65-85% HR_{max}, respectively) aerobic exercise. Other research did not find any significant differences in motor skill acquisition and/or learning based on intensity level and yielded inconclusive results regarding whether a certain intensity is more optimal than other intensities of exercise for exercise priming (Baird et al., 2018; Swarbrick et al., 2020). Swarbrick et al. (2020) assigned their 25 healthy participants to complete a bout of either HIIT (three 3-min bouts at 90% watt max alternated with 2-min bouts at 60% watt max) or low-intensity interval training (three 3-min bouts at 12% watt max alternated with 2-min bouts at 8% watt max) followed by several different retention tests. Notably, this is the only study presently found that utilizes piano performance for the motor task. The results concluded that there were no differences in motor learning between the low-intensity and high-intensity groups at the one hour, one day, and one-week retention tests (Swarbrick et al., 2020). Therefore, the role of exercise intensity in the observed motor skill acquisition and learning benefits following exercise priming is still largely unknown.

The role of exercise mode as it relates to exercise priming is also unknown, as current research on this topic is very limited. One study examined the effects of three different exercise modes on motor skill performance and did not find any significant differences between the groups (Thomas et al., 2017). This study assigned its 40 participants to complete a 45-50-minute bout of either strength training, circuit training, hockey, or rest. The results showed similar increases in motor skill performance across all three exercise groups from the one-hour retention test to the one-day retention test. The authors believe that motor performance benefits produced by exercise depend on the physiological stimulus of the exercise bout rather than the exercise type (Thomas et al., 2017). Therefore, there is currently no evidence to suggest a certain exercise mode would diminish the effects exercise priming has on motor performance and we should place more importance on the intensity of exercise.

Potential Mechanisms

Research has been conducted to explore potential mechanisms for the effects of an acute bout of aerobic exercise on motor skill performance, but the body of literature fails to come to a consensus as to why acquisition improves. One possible mechanism is the increase in brain derived neurotrophic factor (BDNF) immediately following exercise. BDNF is a protein involved in increasing neuroplasticity in the brain (Mang et al., 2014; Moriarty et al., 2019; Skriver et al., 2014). It is crucial for various cognitive functions involved in learning and memory, including long-term potentiation, which may directly benefit M1 function (Mang et al., 2014; Moriarty et al., 2019; Skriver et al., 2014). However, most studies do not find a correlation between increases in BDNF following exercise and increased cognitive function, potentially due to the extremely limited amount of time BDNF remains elevated after the termination of exercise (Mang et al., 2014; Skriver et al., 2014). Mang et al. (2014) studied the correlation between exercise-induced increases in serum BDNF and motor learning in a group of eight healthy females and eight healthy males. This study found a significant increase in BDNF immediately following the acute exercise bout, but this was not associated with any motor learning improvements observed in the study (Mang et al., 2014). Another chemical with potential implications on motor learning following exercise is lactate. Lactate increases markedly with exercise and plays an important role in the survival of neurons and axonal myelination (Skriver et al., 2014; Taubert et al., 2015). However, more research is needed to explore this relationship because lactate may only be producing benefits due to the increase in other neurotrophins it causes, such as BDNF and norepinephrine (Taubert et al., 2015).

Additionally, genetics may play a role in explaining why motor learning improves following an acute bout of aerobic exercise. There is currently only one study that explores genetics as a possible mechanism and it suggests that the dopamine D_2R may correlate with motor learning improvements following exercise (Mang et al., 2017). This study combined results from two previous studies for a total of 32 healthy participants. Participants practiced the computer tracking or target selection task immediately following either a 20-minute bout of high-intensity interval cycling or 20 minutes of rest. All participants then completed a 24-hour retention test. The results show that aerobic exercise enhanced motor learning in glu/glu homozygotes of the DRD2/ANKK1 genotype, but not lys allele carriers. There was no effect on motor skill acquisition in either gene variant (Mang et al., 2017).

Finally, brain blood flow may play a significant role in exercise priming. Although global brain blood flow remains relatively stable during acute exercise, there may be a shift in resources from areas of cognitive function to areas required for motor control. The intensity of the exercise bout will likely influence the level of blood flow to certain regions of the brain. For example, research has shown that prefrontal cortex oxygenation increases with increasing exercise intensity until high-intensity exercise is achieved (approximately 80% of maximal intensity), at which point prefrontal cortex oxygenation levels begin to decrease (Moriarty et al., 2019; Rooks et al., 2010). Perhaps it is at this point that blood flow is redirected to the M1 for maintenance of motor control. In addition, Park et al. (2021) report higher cortical activity on all brain regions (including the M1) while walking following HIIT compared to moderate-intensity continuous exercise during a fine motor-cognitive dual-task (digital trail-making-test) in healthy young adults. That said, cerebral oxygen levels remain elevated for 20-30 minutes after the termination of low and moderate-intensity exercise, which may correlate with the improvement in motor learning that also occurs after an acute bout of low-to-moderate-intensity aerobic exercise (Moriarty et al., 2019). For example, Xu et al. (2020) found that there were significant improvements in pre-motor area oxyhemoglobin during a table-setting task (action observation task) following acute moderate-intensity exercise (15-min cycling at 65% VO_2max) in healthy college-aged participants. In summary, acute aerobic exercise appears to promote motor skill acquisition and learning but the specific mechanism behind exercise priming is still unknown. Therefore, researchers are continuing to investigate the influence of acute aerobic exercise as a primary driver of motor skill enhancement in both healthy and clinical populations.

Hypotheses to Be Tested

Hypothesis 1: An acute moderate-intensity bout of aerobic exercise will improve performance on the piano task.

Rationale: Snow et al. (2016) and Statton et al. (2015) both observed increased motor skill acquisition following an acute moderate-intensity bout of aerobic exercise.

Hypothesis 2: An acute high-intensity bout of aerobic exercise will not improve performance on the piano task.

Rationale: Mang et al. (2016) and Roig et al. (2012) conducted studies using high-intensity aerobic exercise and observed no subsequent improvements in motor skill acquisition.

Hypothesis 3: An acute bout of moderate-intensity aerobic exercise will increase motor cortex (M1) oxygenation levels.

Rationale: Research has shown that M1 oxygenation increases during a fine motor task following acute moderate-intensity aerobic exercise (Xu et al. 2020).

Hypothesis 4: An acute bout of high-intensity aerobic exercise will increase M1 oxygenation levels.

Rationale: Park et al. (2021) *report higher cortical activity on all brain regions (including the M1) while walking following HIIT compared to moderate-intensity continuous exercise.*

Methodology

Participants

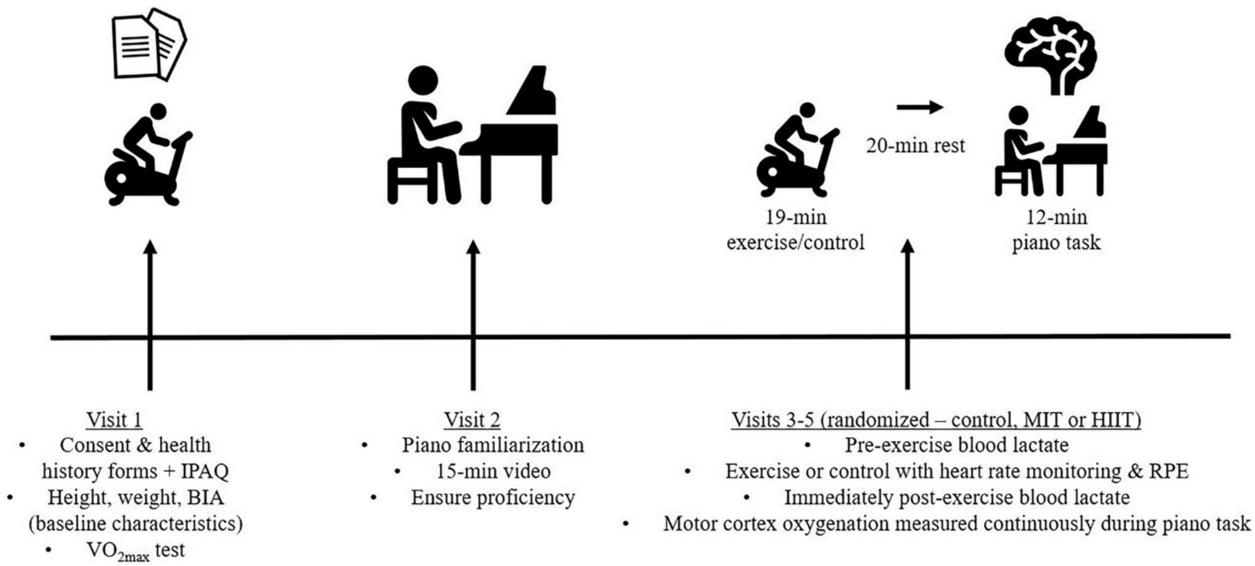
Nine (male = 2, female = 7) participants volunteered to participate in this study, all of whom were undergraduate students at the University of Northern Iowa. All participants had successfully completed their first semester of MUS 1470 Group Piano for Music Majors with a grade of a C or higher and were currently enrolled in their second semester of the same course. The study protocol was approved by the University of Northern Iowa Institutional Review Board prior to the first trial. All study procedures were completed during the fall semester of 2021 in the Exercise Physiology and Music Performance Laboratory at the University of Northern Iowa. Similar environmental conditions were maintained for all trials and all trials took place at the same time of day (± 2 hours). All risks, benefits, and procedures involved in this study were outlined to each participant and a health history questionnaire was completed before signing a consent form. Subjects reported no known cardiovascular, pulmonary, or metabolic disorders and had no known history of psychiatric illness or neurologic brain disease.

Study Protocol

The study protocol consisted of five trials, each separated by at least 48 hours: 1. VO_{2max} test, consent form, health history form, and International Physical Activity Questionnaire (IPAQ); 2. pre-recorded piano performance familiarization and review of piano concepts; and the following randomized trials 3-5. moderate-intensity training (MIT), high-intensity interval training (HIIT), or a control trial. The protocol is outlined in **Figure 1** below.

Figure 1

Study Protocol



Note. BIA = bioelectrical impedance analysis. HIIT = high-intensity interval training. min = minutes. MIT = moderate-intensity training. VO_{2max} test = maximal oxygen consumption test on a cycle ergometer. From "Acute Aerobic Exercise-Induced Motor Priming Improves Piano Performance and Alters Motor Cortex Activation" by Moriarty et al., 2022, *Frontiers in Psychology*, 13. https://doi.org/10.3389/fpsyg.2022.825322.

Baseline Measures

Following completion of the health history and consent forms, each participant also completed an IPAQ. Each subject's height (nearest 0.1 cm) and weight (nearest 0.1 kg) were measured using a stadiometer and scale, respectively. These measures were used to calculate each subject's body mass index (BMI). In addition, body fat percentage was determined using bioelectrical impedance analysis (BIA) (InBody 720).

Following the completion of all paperwork and initial anthropometric measurements, a VO_{2max} test was conducted on an electronically-braked cycle ergometer (Lode, Groningen, The Netherlands). This test began with a brief, self-selected warm-up before being connected to a metabolic cart (Parvomedics, Sandy, UT, USA) and Polar™ heart rate monitor (V800, Polar Electro Inc., Woodbury, NY, USA). This allowed for the continuous measurement of oxygen consumption, carbon dioxide production, and heart rate. Participants were instructed to maintain 70-80 revolutions per minute (RPM) throughout the test and workload was increased every 3 or 4 seconds (15-watt ramp for females beginning at 30 watts and 20-watt ramp for males beginning at 40 watts) until the participant's RPM dropped below 60 or subjects reached volitional fatigue. Participants were instructed to notify the researcher immediately if they experienced any dizziness, faintness, or chest pain. Following the completion of the VO_{2max} test, the data was analyzed to determine whether the subject reached their true VO_{2max}. Achievement of this required two of the following four criteria to be met: heart rate within ±10 bpm of age-predicted maximal heart rate, Respiratory Exchange Ratio (RER) > 1.15, a plateau in VO_2 with continued increases in workload, or Rating of Perceived Exertion (RPE) > 17. Each participant's workload in watts and VO_{2max} was then used to calculate appropriate high- or moderate-intensity levels for each of the subject's randomly assigned exercise protocols.

Piano Protocols

Familiarization. During the piano familiarization phase, participants were first asked to watch a 15-minute pre-recorded instructional video that demonstrated tasks similar to those utilized in this study. They were required to demonstrate understanding of the tasks before they were allowed to practice piano exercises similar to what would be required of them later in the study. The piano performance tasks used later in the study consisted of a combination of the following: two sight-read pieces consisting of treble and bass clef notations, transposition of piano pieces, one sight-read open score, and the performance of various vocal warm-up exercises.

Motor Task. Each piano performance task took place following the completion of the randomized exercise bout or control trial, and the additional 20-minute rest period. Each participant was instructed to silently review each musical piece for 30 seconds and make notes on it as needed. They were then given an additional 30 seconds to practice the piece freely. Following the conclusion of the practice period, each participant performed the piece in full and was scored out of 100 by three piano teachers. All teachers were blinded to the participants' assigned randomized trial. Each piano performance trial was approximately 12 minutes in duration.

Exercise Protocols

MIT and HIIT Trials. The MIT and HIIT exercise trials were both 19 minutes long and used intensities based upon the participant's VO_{2max} from the first visit. The MIT trial consisted of a 2-minute warm up at 30% intensity (workload in watts at 30%VO_{2max}) followed by 15 minutes of continuous cycling at 50% intensity and a 2-minute cool down at 30% intensity. The HIIT trial consisted of an identical warm-up and cool-down, with the interval phase in the middle. The interval phase lasted 15 minutes and consisted of five alternating cycling bouts as follows: a 1-minute cycling bout at 85-95% intensity (workload in watts at 85-95%VO_{2max}) followed by 2 minutes of recovery at 40% intensity. Heart rate and RPE were recorded at the end of the warm-up and every 3 minutes after for all MIT and HIIT trials. RPE was collected using the Borg scale (6-20). A blood lactate measurement was also taken at the beginning and end of every randomized trial. Following the completion of the exercise bouts, participants completed a 20-minute rest period before beginning the piano performance task. Motor cortex (M1) activation was measured continuously using functional near infrared spectroscopy (fNIRS–

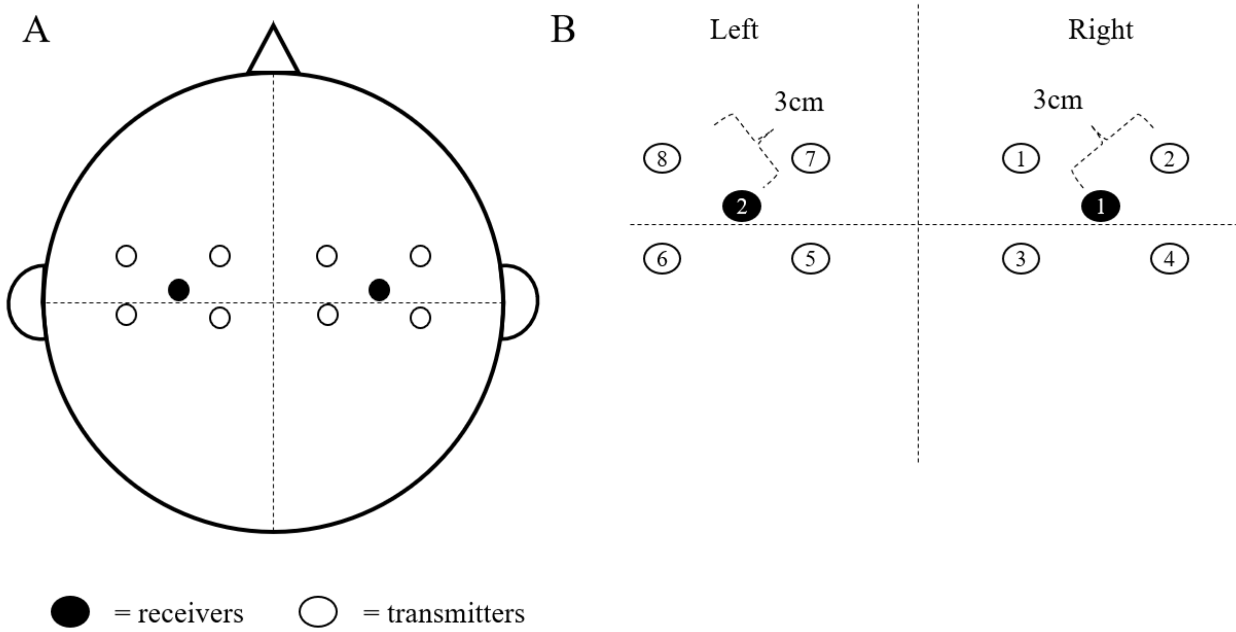
Octamon, Artinis Medical Systems–8-channel setup) throughout the 12-minute piano performance phase of each trial.

Control Trial. Participants randomly assigned to the control trial were instructed to sit quietly for 19 minutes, which is the same duration as the exercise trials. Following this initial period of rest, participants completed another 20-minute rest period identical to the exercise trials before beginning the piano performance task. During both rest periods, subjects were not allowed to use any electronic devices and were instructed to limit communication with all members of the research team who were present in the room.

Functional Near Infrared Spectroscopy Recording. Functional Near Infrared Spectroscopy Recording (fNIRS) was used during all piano performance tasks to measure M1 oxygenation. The device measures activation by detecting changes in oxyhemoglobin and deoxyhemoglobin in the M1. The system is a portable, wireless, and non-invasive optical system (OctaMon+, Artinis Medical Systems). It consists of 8 channels that utilize two wave-lengths (760 and 850 nm) and a sampling rate of 10 Hz. Four transmitters were placed over the right hemisphere (1-4) of the M1 and the other four were placed over the left hemisphere (5-8) of the M1 (see **Figure 2**). Additionally, one receiver was placed on each hemisphere of the M1. Within each hemisphere, the transmitters were configured in a square, and each transmitter was placed 3 cm away from the receiver in the center of the square. All transmitters and receivers were held in place by a neoprene head cap. All measurements were filtered using a 0.1 Hz lowpass filter to remove any noise.

Figure 2

fNIRS Positioning



Note. Placement of the 8 transmitters and 2 receivers covering the motor cortex (M1). (**A**) shows a superior view of this configuration on the head. (**B**) shows the measurement between each transmitter and its corresponding receiver, as well as the placement of all transmitters and receivers in relation to the midline. From "Acute Aerobic Exercise-Induced Motor Priming Improves Piano Performance and Alters Motor Cortex Activation" by Moriarty et al., 2022, *Frontiers in Psychology*, 13. https://doi.org/10.3389/fpsyg.2022.825322.

Whole Blood Lactate Measurement. Immediately following the termination of exercise in each exercise trial, a droplet of blood was collected using a portable, automated blood lactate analyzer to measure blood lactate concentration (Nova Biomedical, Waltham, MA, USA). All blood droplets were collected from the participant's earlobe. Two samples were collected after each trial and an average was calculated.

Statistical analysis

All results are expressed as means ± SD. A one-way ANOVA with repeated measures was used to analyze changes in the M1 and differences in piano performance scores between trials (control, MIT, HIIT). Post hoc Tukey analysis was performed when main effects were detected. Data were analyzed using GraphPad Prism 9. Intraclass Correlations (ICC) were calculated for each piano performance trial and categorized using the following guidelines: < 0.5 = poor; $0.5 – 0.75$ = moderate; $0.75 – 0.9$ = good, and > 0.9 = excellent.

Results

Demographics

The average age, weight, height, body composition, BMI, VO_{2max}, IPAQ, months of musical training, and major GPA for all participants, as well as separated by gender with classifications, are displayed in **Table 1**. As a group, the average age was 18 ± 1 years and the average weight was 73.8 ± 13.9 kg. The average body fat percentage for the participants in this study was 30.1% ± 14.2%, while average BMI was 25.9 ± 5.8 kg.m^2. Data from the VO_{2max} tests resulted in an average aerobic fitness of 32.4 ± 9.7 ml.kg.min^{-1}. The IPAQ reported a group average of 2,093 ± 1660 MET-mins/week.

A significant main effect ($p < 0.01$) was observed between all trials for all exercise intensity indicators (RPE, HR, %HRmax, blood lactate) and these averages are displayed in **Table 2**. The indicators were all higher ($p < 0.01$) following the high-intensity interval training (HIIT) trials compared to the moderate-intensity training (MIT) and control trials. Additionally, the indicators were higher ($p < 0.01$) following the MIT trials compared to the control trials.

Table 1

Participant Demographics. (Mean ± SD)

Characteristic	All Participants (9)	Males (2)	Females (7)
Age (years)	18 ± 1	18.5 ± 0.7	18.4 ± 0.5
Weight (kg)	73.8 ± 13.9	67.4 ±1.5	75.6 ± 15.4
Height (cm)	169.3 ± 7.5	178 ± 0	167 ± 7
Body fat (%)	30.1 ± 14.2	11.6 ± 4.0 (good*)	35.4 ± 11.0 (very poor*)
Body mass index (kg.m^2)	25.9 ± 5.8	21.3 ± 0.5 (normal*)	27.3 ± 5.9 (overweight*)
VO_{2max} (ml.kg.min^{-1})	32.4 ± 9.7	47.2 ± 7.4 (good*)	28.2 ± 4.7 (fair*)
IPAQ (MET-min/week)	2093 ± 1660	2946 ± 41	1850 ± 1834
Months of musical training	32.6 ± 38.5	66 ± 85	23 ± 17
GPA	3.63 ± 0.27	3.85 ± 0.22	3.55 ± 0.23

Note. cm = centimeters. GPA = grade point average. IPAQ = International Physical Activity Questionnaire. kg = kilograms. $kg.m^2$ = kilograms per square meters. $ml.kg.min^{-1}$ = milliliters per kilogram per minute. VO_{2max} = maximum volume of oxygen consumed.

* Classifications are based on ACSM's Guidelines for Exercise Testing and Prescription (American College of Sports Medicine, 2018).

Table 2

Exercise Intensity Measurements. (Mean ± SD)

Measurement	Control	MIT	HIIT
Duration (min)	19	19	19
RPE	6 ± 0	12.4 ± 1.2**	15.4 ± 1.2**$^{\#}$
HR (bpm)	84 ± 12.1	146 ± 11.2**	171 ± 8.1**$^{\#}$
$\%HR_{max}$	44 ± 7	76 ± 7**	89 ± 4**$^{\#}$
Blood Lactate Concentration (mmol/L)	1.0 ± 0.1	2.7 ± 1.0**	5.1 ± 1.1**$^{\#}$

Note. bpm = beats per minute. HIIT = high-intensity interval training. HR = heart rate. HR_{max} = maximal heart rate. min = minutes. MIT = moderate-intensity training. mmol/L = millimoles per liter. RPE = rating of perceived exertion.

**Statistically higher than control, $p < 0.01$. $^{\#}$Statistically higher than MIT, $p < 0.01$.

Piano Performance

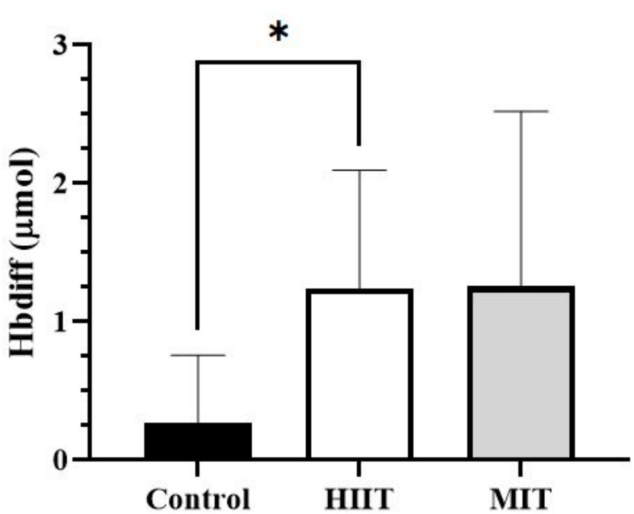
Piano performance scores were significantly higher following the MIT trial (89.7 ± 7.8), but not the HIIT trial (87.6 ± 9.1), compared to the control trial (79.6 ± 13.5, $p < 0.05$). However, there was not a significant difference between piano performance scores following MIT trial (89.7 ± 7.8) and HIIT trial (87.6 ± 9.1, $p > 0.05$). Intraclass Correlation (ICC) was calculated for all piano performance trials to determine if all three music teachers were producing similar scores for the same trial. The ICC was excellent for both the MIT (0.942) and HIIT (0.962) trials, and good for the control (0.895) trial.

Motor Cortex (M1) Oxygenation

The fNIRS system was used to record the difference in oxyhemoglobin and deoxyhemoglobin (Hbdiff) in the M1 throughout all piano performance tasks. The fNIRS data for 3 subjects was unusable, and has therefore been removed from the analysis. The usable data for the remaining 6 subjects is reported as preliminary data. The results reveal a significantly higher Hbdiff during the piano performance task following the HIIT trial (1.24 ± 0.85 μmol), compared to the piano performance task following the control trial (0.27 ± 0.49 μmol, $p < 0.05$) (see **Figure 3**). There were no significant differences in Hbdiff when comparing the piano performance tasks following the MIT trial (1.25 ± 1.26 μmol) and control trial (0.27 ± 0.49 μmol, $p > 0.05$).

Figure 3

Motor cortex (M1) hemoglobin differences (Hbdiff) following control, moderate-intensity training (MIT), and high-intensity interval training (HIIT) conditions.



Note. M1 hemoglobin difference (Hbdiff) was significantly higher following high-intensity interval training (HIIT) compared to control ($p < 0.05$). MIT = moderate-intensity training. N = 6. From “Acute Aerobic Exercise-Induced Motor Priming Improves Piano Performance and Alters Motor Cortex Activation” by Moriarty et al., 2022, *Frontiers in Psychology*, 13. https://doi.org/10.3389/fpsyg.2022.825322.

Discussion

The purpose of this study was to investigate the role of exercise intensity in motor priming. We utilized a whole-body piano task for the motor skill and investigated motor cortex (M1) activation as a potential mechanism for any changes in piano performance. The results of this study show higher piano performance scores following moderate-intensity training (MIT) compared to the high-intensity interval training (HIIT) and control trials. Additionally, M1 activation was found to be elevated during the piano performance phase of the HIIT trial, but not the MIT trial, compared to the control trial. Therefore, the results suggest that MIT may be a more beneficial exercise type than HIIT when trying to improve motor skill acquisition. Further, the increased activation in the M1 reported by the preliminary fNIRS data after the HIIT trials did not result in improved piano performance.

Previous studies have investigated the role of an acute bout of aerobic exercise before performing a motor task, finding evidence that supports the positive effects of exercise priming (Ploughman et al., 2008; Rosenfeldt et al., 2021; Snow et al., 2016; Statton et al., 2015; Swarbrick et al., 2020). The present study investigated whether exercise intensity plays a role in this relationship. The results align with several previous studies that suggest MIT is the optimal intensity for improving motor skill acquisition (Snow et al., 2016; Statton et al., 2015). The results of the present study also agree with previous studies that found no improvements in motor skill acquisition following HIIT (Mang et al., 2016; Roig et al., 2012). The mechanism explaining the difference between the effects of MIT and HIIT is currently unknown, but various theories exist. One potential mechanism explaining this is the idea that HIIT may have produced greater post-exercise fatigue than MIT, resulting in more difficulty performing the piano task and lower piano performance scores following HIIT. Similarly, fitness level may play a role in the effects of motor priming. Previous research has demonstrated that lesser fit individuals likely experience larger effects from exercise, and therefore have a greater potential for motor priming, compared to those of excellent aerobic fitness (Li et al., 2019). The results of this study should only be applied to individuals of "fair-good" aerobic fitness. Additionally, the role of cognitive function in piano performance may provide insight to the difference in piano performance scores between MIT and HIIT. Required cognitive processes in piano performance include working memory, visual processing, the translation of visual information into motor instructions, and the ability to read ahead in the music before the hands arrive at that point (Herrero & Carriedo, 2019; Rayner & Pollatsek, 1997). It is also widely known that the prefrontal cortex plays a vital role in cognitive function. Accordingly, several studies have explained that prefrontal cortex oxygenation increases at submaximal exercise intensities up to 80% of VO_{2max}, at which point it begins to decrease (Moriarty et al., 2019; Rooks et al., 2010). Perhaps the elevated prefrontal cortex oxygenation at submaximal exercise intensities is improving cognition, resulting in higher piano performance scores following MIT. Meanwhile, the decrease in prefrontal cortex oxygenation at higher exercise intensities may be impairing the cognitive component of piano performance, resulting in no significant improvement in piano performance scores following HIIT.

As mentioned, the present study observed elevated M1 oxygenation during the piano performance phase following HIIT trials, but not MIT or control trials. The research studies conducted by Moriarty et al. (2019) and Rooks et al. (2010) also provide a potential explanation for the M1 activation results of the present study. Perhaps the decrease in prefrontal cortex oxygenation at 80% VO_{2max} and above correlates with the redirection of oxygen to the M1. This would result in elevated M1 activation during the piano performance phase following HIIT trials, but not MIT or control trials. The results of the present study also align with the findings of Brümmer et al. (2011). This study recorded EEG measurements of the brain at various times throughout a progressive bicycle test. Results showed increasing M1 activation with increasing exercise intensity, likely in an effort to help sustain the motor activity being performed (Brümmer et al., 2011). While these theories provide various potential explanations for the results of this study, they all require further exploration.

Limitations

There are several limitations to consider in this study. First, the sample size (N = 9; 2 males, 7 females) is small. Future studies should use a larger, more representative sample size with relatively equal groups of males and females, more racial diversity, recruitment from more than one university, and more diverse fitness levels. Another limitation is that only six participants' fNIRS data could be used in this study. Previous studies utilizing fNIRS technology have reported similar issues, due to darker hair pigmentation, greater hair density, larger skull thickness, and varying distances between the skull and M1 (Haeussinger et al., 2011; Mcintosh et al., 2010). Finally, it is important to note that the mean piano performance scores for the MIT and HIIT trials were very similar, but the standard deviation was larger for the HIIT trials. Therefore, the piano performance scores for the HIIT trials were not significantly higher than the control trials due to the large standard deviation. Similarly, motor cortex activation levels were very similar for the MIT and HIIT trials, but the standard deviation was too large for the MIT trials to be considered significant. A larger sample size would have likely decreased these standard deviations, making the piano performance scores significant for the HIIT trials and M1 activation levels significant for the MIT trials.

Conclusion

Previous studies have shown that an acute bout of aerobic exercise performed immediately before a fine motor task can improve the performance of that particular task. However, the optimal intensity of exercise and the mechanism behind these effects are currently unknown. The aim of the present study was to investigate the effects of HIIT and MIT on piano performance and M1 oxygenation. The results showed improved piano performance following MIT trials only, suggesting that exercise intensity is related to subsequent motor task performance. This study also found increased M1 oxygenation following the HIIT trials only, suggesting that exercise intensity is related to M1 oxygenation. These results as a whole suggest that increased M1 activation is not associated with improved piano performance. Additionally, this study suggests that moderate-intensity exercise is the optimal intensity for motor skill acquisition. This is an important finding, as moderate-intensity exercise is often more feasible for untrained individuals and clinical populations. Exercise priming using moderate intensity exercise may be applied in the real-world to other activities of daily living, such as woodworking, painting, and shooting a basketball, in order to improve the rate at which acquisition occurs. Additionally, moderate intensity exercise may be used in exercise priming with clinical populations to help them re-learn activities of daily living, such as showering and brushing one’s own hair. Further research is still necessary to investigate the neurophysiological mechanisms associated with whole-body motor task performance improvements. Additional studies must also be conducted using a larger, more representative sample size in order to confirm these findings.

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