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Reaction Time as a Measure of Neuroplasticity after Aerobic Exercise

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Research Project submitted in partial fulfilment of the requirements for Masters of Education

(M.Ed.)

Kinesiology Graduate Specialization

School of Human Movement, Sport, and Leisure Studies

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### **Abstract**

Until the 1960s it was commonly-assumed in neuropsychology that the adult human nervous system was hard-wired and had extremely limited capacity to change. Recently research has demonstrated that this earlier assumption was not accurate and that the adult human nervous system indeed is quite plastic and in a state of continuous change. Further, physical exercise has been demonstrated to promote positive effects on the adult human nervous system as a result of increased blood flow and modified neurotransmitters and neurotrophins. These effects are hypothesized to improve the synaptic connectivity and promote neurogenesis, both of which are believed to play an important role in neural plasticity. The most commonly-used approaches to monitor neural plasticity have included the use of MRI images and measuring changes in levels of certain neurotransmitters in the brain. These approaches are expensive and not affordable to most physical activity researchers. The purpose of this study was to determine whether measures of simple and choice reaction time (SRT; CRT) could provide evidence of increased neural plasticity that has been documented to occur following moderate intensity aerobic exercise. I hypothesized that both SRT and CRT would decrease following moderate intensity aerobic exercise which might indicate improvement in neural plasticity compared to a control puzzle group. I assigned male and female volunteers (n=11), ages 18-30 years old, randomly to either an exercise group or a Sudoku puzzle-solving (control) group. I measured SRT using a computer software three times: pre-exercise/puzzle-solving (30 minutes), immediately post-exercise/puzzle-solving, and delayed (3 hours) post exercise/puzzle-solving. The between group independent variable was the intervention (either puzzle-solving or moderate aerobic exercise on a bicycle ergometer) and the within-subject (repeated measures) variable was the time of administration of pre-post-delayed-post reaction times (repeated measures) while the dependent

measure was the simple reaction times (SRT) in milliseconds. The statistical analysis method used was a mixed factorial ANOVA. No significant differences in simple reaction time were discovered between the two groups or within the times of testing reaction time and no significant group by time interaction occurred. I concluded that one of four rationale could explain the lack of significant differences and have discussed the rationale in greater detail in the paper. I recommend the future replication of this study with a much larger sample size to increase the statistical power to detect differences as well as improving the consistency of the protocol and methods used in the study plus the addition of using choice reaction times or other valid measures of neural plasticity

### **Introduction**

Until the 1960s it was a common textbook knowledge in neuropsychology that the adult nervous system is rather hard-wired and had probably a rather limited capacity to change (Hötting & Röder, 2013). Nowadays, many research papers have showed that, this knowledge was not right and human brain is in a state of continuous change. Plasticity is neither transient nor unique to developing organisms. However, as we develop the neural system stabilize once we achieve or reach optimal patterns of function. Stabilization decreases the system capacity to adapt but doesn't eliminate it (Stiles, 2000)

The term 'neuroplasticity' has multiple definitions. All these definitions do have some commonalties which fall into three categories: 1) process, 2) adaptation, and 3) organization. In terms of process, neuroplasticity describes the dynamic structural and behavioral changes that occur within the nervous system. Adaptation is defined as the system ability to adapt or recruit different resources in response to some external demand (Stiles, 2000). Organization: the process of plasticity is a systematic process, which is a product of interaction between the brain structures

and the environment. According to Hötting & Röder (2013), “neuroplasticity refers to acquiring new skills after damage to the nervous system and/or as a result of sensory deprivation” (p.2244).

Reaction time (RT) is the elapsed time between the presentation of a sensory stimulus and a subsequent behavioral response (Shelton & Kumar, 2010). Reaction time reflects or measures the level of neuromuscular coordination in response to visual or auditory stimuli. Simple reaction time (SRT) can be determined when an individual is asked to press (or release) a button as soon as a light or sound appears (Shelton et al., 2010). SRT indicates that the brain has processed and decoded the sensory stimuli and initiated the appropriate motor action in response to that sensory input. Thus, any increase in the RT may indicate an impairment or disruption in the cognitive processing or sensory information processing or in the initiation of the execution of motor behavior.

Reaction time is the slowest among persons who have suffered cerebrovascular accidents and stroke followed by brain damage. Also, reaction time has an 86% accuracy in prediction of disease related mental decline. Thus, RT is frequently used as an index of central nervous system functioning and it implicates information processing time (i.e., sum of time for stimulus perception and preprogramming of the response prior to the execution of the desired action) (Ozyemisci-Taskiran, Gunendi, Bolukbasi, Beyazova, 2010)

Exercise has many positive effects on the nervous system. According to Hötting & Rotter, (2013) “aerobic exercise improves blood flow, increases the secretion of neurotransmitters and neutrophins. Neutrophins are a group of proteins that regulate neural survival, development, function, synaptic function and synaptic plasticity” (Huang & Reichardt, 2001, p.1). These effects improve the synaptic connectivity and promotes neurogenesis, which are believed to play an important role in enhancing neural plasticity. Moreover, aerobic exercise is believed to directly

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enhance neural plasticity by “increasing brain driven neurotrophic factors (BDNF), Insulin like growth factor one (IGF-1,) stem cell proliferation, growth hormone (GH) and mitochondriogenesis. Exercise also may induce neurogenesis by decreasing HR, systolic and diastolic blood pressure, increasing cerebral artery flow velocity, and vascular growth” (Archer, Svensson, & Alricsson, 2012, p. 295). BDNF is a protein that plays an important role in growth, cell differentiation, neural development, increasing resistance to damage and improving the survival of neurons. Also, BDNF is used as a measure or an indicator of exercise effects on injured neurons (Jeon & Ha, 2015). According to Jeon & Ha (2015) “insulin-like growth factor 1 (IGF-1), one of the factors involved in BDNF expression, is known to mediate regulation of genes involved in BDNF-related neurogenesis, and it is involved in the growth and differentiation of neuron units of the brain” (p.737).

In a study where the functional brain changes after trauma were studied, the researchers identified 10 principles of experience-dependent neuroplasticity: “Use it or lose it, use it and improve it, specificity, repetition matters, intensity matters, age matters, salience matters, time matters, inference and transference” (Kleim & Jones,2008, p.227). Physical exercise can partially reverse some of the brain damage after trauma. This exercise effect could be attributed to anti-apoptosis, anti-inflammatory, decreased depression, anxiety and stress effects of exercise. According to Archer et al (2015), exercise may promote neural plasticity by “increasing growth hormone, stem cell proliferation, mitochondriogenesis, and brain-derived neurotropic factors. Moreover, it promotes angiogenesis by increasing cerebral artery flow velocity and vascular growth” (p.295).

Neuroplasticity also may result in a maladaptive behavior consequences. The exercise effect of reorganization on the central nervous system could result in an undesirable form of

reorganization. For example, reorganization of somatosensory and motor areas has been reported to be accompanied with focal dystonia (Hötting & Rotter 2013). So, the mechanism that causes improvement in performance could cause maladaptive effects. Therefore, the course of neuroplasticity should be monitored closely and carefully. Monitoring neuroplasticity on daily bases is an unachievable task, because the most commonly used methods to monitor plasticity is MRI which is very expensive and non-handly device.

Based on this recent literature findings related to exercise and neuroplasticity, I hypothesized that I should expect to observe a decrease in reaction times following moderate aerobic exercise either immediately or during the period up to 3 hours after exercise compared to the pre-exercise reaction time as well as compared to a non-exercise control group.

## **Method**

### **Participants**

Participants in this study included 11 Bowling Green State University students. Participants included 11 males between the ages of 18 and 28 years with an average age of 20.91 years and standard deviation of 2.43 years (see Table 1). All participants in this study were volunteers who completed informed consent forms that contained information about the purpose of the study, procedures, benefits and risks of participation, voluntary participation, contact information of the researchers, and the institutional review board (IRB). Participants were informed that they could withdraw without penalty and in order to assure no pre-existing conditions, a pre-participation health screening questionnaire assessed the self-reported health status of the participants. The questionnaire included questions about history of any heart diseases, operations, asthma, diabetes, smoking, medications, blood pressure and

musculoskeletal problems that would limit physical activity. The existence of any condition would have eliminated the participant from the physical exercise group in the study.

**Table 1** Ages of participants in each group.

	Exercise	Sudoku	Sample
Mean	21.5	20.2	20.91
S.D	3.39	0.84	2.43
Number	6	5	11

The table shows the difference in average age of participants in each group, standard deviation and the average age of both groups combined together. \*Note SD= Standard Deviation.

### Measures

Reaction Time Measurement v.1.0 software by Cognaxon was used to measure the simple reaction time (SRT), the movement time (MT), and total response time (TRT). SRT, MT and TRT were all used in the analysis of the results of this study. Initially, choice reaction time (CRT) was intended to be measured, but problems with the software prohibited its use.

### Procedures

As participants arrived at the research site, they were asked to have a seat and read the informed consent. After the investigator answered any questions, they signed the informed consent and then completed the pre-participation screening questionnaire which they also signed. Participants were assigned simple code numbers using the order in which they were tested. Participants with odd numbers were assigned to the aerobic exercise group and participants with even numbers were assigned to the puzzle-solving group. The researcher asked the participants if they have any questions or concerns about participation in the study.



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When the first participant arrived, he was assigned to the aerobic exercise group after he completed the informed consent, the health survey, and the investigator answered any questions. A Cardio Sport Start2 heart rate monitor was used to measure each exercise participant's resting heart rate (RHR). RHR was measured three times while seated and the average was used as the baseline resting heart rate. The reaction time software was installed on a Dell Inspiron 5520 laptop and a Logitech M 185 wireless computer mouse was used to conduct the SRT trials. The participant was allowed to do as many practice SRT trials as he needed to get accustomed to the software and mouse; then each participant completed 25 trials of SRT.

The RT software displayed the following instructions at the start of every trial: "Press left mouse button. Keep left mouse button pressed until a white circle shows up. Then release the left mouse button and press right mouse button as quickly as you can."

Participants took approximately 3 minutes to finish the 25 trials. After finishing the trials the results were copied to an Excel spreadsheet and the participant then began either the exercise or puzzle-solving intervention. Each member of the exercise group pedaled on the Monarch cycle ergometer (MONARK Ergo medic Model 828 E) after the seat was adjusted so the participant's knees are not hyperextended. Exercise participants were asked to maintain a target exercise heart rate of approximately 50% of his heart rate reserve (HRR) as calculated by the standard formula.

### **Formula 1** Calculation of heart rate reserve (HRR)

*1) Max HR = 220 - age, 2) Resting HR reserve = Max HR - Resting HR, 3) Resting HR Reserve X 0.50 (percentage of Max HR) and 4) Target HR = (product of the third formula) + resting HR.*

Immediately Upon completing 30 minutes of cycling exercise at the 50% heart rate reserve, a post-test SRT test of another 25 trials was conducted. The participant was then asked to return

approximately 150-180 minutes later at which time he completed the second delayed post-test SRT test, again for 25 trials.

When the second participant arrived, he was assigned to the puzzle-solving group after he completed the informed consent, the health survey, and the investigator had answered any questions. Then, participant two was asked to have a seat to do the pre-SRT time test after which he was asked to start working on a Sudoku puzzle for 30 minutes. Standard Sudoku puzzles were copied from <https://worksheets.theteacherscorner.net/make-your-own/sudoku/>. Upon working on the Sudoku puzzle for 30 minutes, the second participant was asked to do the post-puzzle-solving SRT test. Upon completing the 25 SRT trials and having the SRT values entered into the Excel spreadsheet, the participant was asked to return again in 150-180 minutes for the third, delayed SRT measurement. Subsequent participants (i.e., #3 through #11) were tested using protocols identical to the first two as described above.

### **Statistical analysis**

All statistical analyses were calculated or conducted using SPSS version 22 software. Box's test of equality of covariance matrices was used to check the assumption of homogeneity of covariance across the groups using  $p < .05$  as a criterion. Levene's test of Equality of Error Variances was used to determine whether variances of each variable were equal across the groups.

A two-factor, mixed effects factorial Analysis of Variance (ANOVA) (2 (groups) x 3 (time periods)) with repeated measures on the second factor was used to analyze the main effects between group and time factors as well as any groups by time interaction for mean SRT (see Table 4).

## Results

The results of the statistical analysis using the factorial ANOVA revealed no significant main effect differences in SRT between intervention groups nor differences in SRT among the three time periods. In addition, no significant group x time interaction effects were discovered (Table 4 and Figure 1).

**Table 1.** Descriptive statistics of SRT, MT and TRT

Group		SRT		MT		TRT	
		Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
Pre	Exercise	415.08667	49.246530	92.1800	56.250882	484.54667	84.511758
	Sudoku	446.57600	123.476549	104.7680	93.099166	551.34400	191.920433
	Total	429.40000	87.072521	97.90182	71.360203	514.90909	139.718921
Post	Exercise	379.46667	22.121348	63.56000	50.100839	443.02667	65.728487
	Sudoku	430.56800	105.244217	92.76000	38.327995	523.32800	133.686665
	Total	402.69455	73.398913	76.83273	45.554355	479.52727	105.202638
Post3	Exercise	387.83333	87.709402	57.67333	48.211185	445.50667	103.283559
	Sudoku	399.56000	57.840802	89.95200	51.249386	489.51200	97.326286
	Total	393.16364	72.264770	72.34545	49.969159	465.50909	98.238674

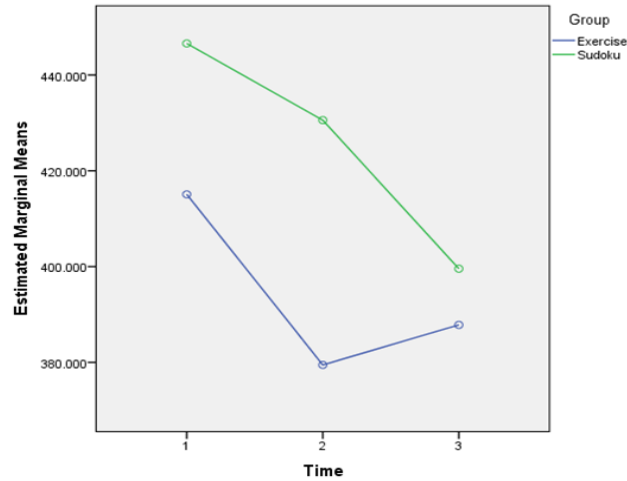
The table shows the changes in mean and standard deviations of SRT, MT and TRT across the three time measurements.

The repeated measures ANOVA showed that our results were statistically insignificant. The tests of within subject's contrasts had two levels/ sources (Time and Time by group). At the Time level, the F value was 2.684 with a P value of 0.136 at 2 degrees of freedom. The time by group test yielded an F value of 0.551 with a P value of 0.477 at 1 degree of freedom.

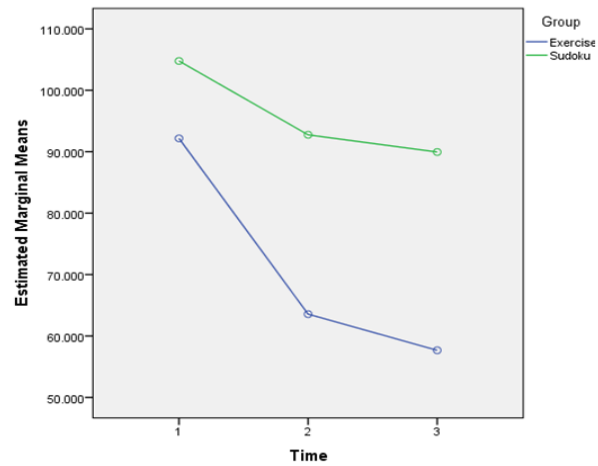
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Box's test of equality showed a significance value of 0.06. Levene's test of Equality of Error Variances showed the following significance values at the pre, post and 3 post measures respectively .194, .020, .580.

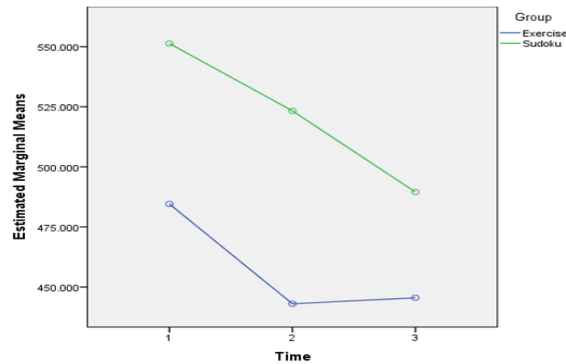
**Figure 1** Changes in reaction time between two groups across three occasions



**Figure 2** Changes in movement time between two groups across three occasions



**Figure 3** Changes in the Total Response Time between two groups across three occasions



### Discussion

Box's test of equality of covariance matrices concluded a significance value of 0.006, which indicates that the observed covariance matrices of the dependent variables aren't equal across groups. This means that there was a significant inequality in covariance among the groups. Levene's test of equality of error variances concluded significance values of .194, .020, and .580 at the pre-test, post-test, and 3-hour delayed post measures, respectively. Levene's test results indicated that the variability in group's conditions is about the same except at the immediate post-test measurement. The significance value of 0.020 at the post measurement reflects that variances on the post-test SRT were significantly different. Levene's and Box's test significances values indicated that we had a lack of standardization of the way we administered the test which may explain the high variability between and within the groups mean simple reaction times, represented by high standard deviation values (Table 1).

While, the first impression of Figure 1 would seem to indicate differences between groups and likely a group x time interaction, the combination of large standard deviations (due to differing procedures by participants) and very small sample sizes in the two groups reduced the statistical

power that could have discovered significant differences if they existed. Significant differences did exist between the covariance matrices which also indicates there are problems with the data regarding how participants responded. I believe that if I had a larger sample and had done a pilot test to standardize procedures better, the standard deviation of mean reaction times would have decreased and I might have had more statistical power to find statistically significant differences if it really existed.

According to Wohlwend, Olsen, Håberg & Palmer, 2017, “Reaction time changes seem to account for most of exercise’s observed effects on cognition” (p.1). The direction of these changes remains unpredictable or unclear. In other words, research studies that observed the relation between reaction time and exercise have concluded divergent results. Wohlwend et al (2017) suggested that the differences in results between studies could be attributed to duration, intensity of exercise, exercise modality, and timing of assessments. I do not believe that the case all the time, particularly in this study.

In Keita, Hayashi, Sakai, Yahiro, Tanaka, and Nishihira’s study (2017) reaction time after moderate intensity cycling was reported to be shorter than reaction time following light exercise and flankers’ task (cognitive task). The results of the Keita et al study contradicts with the findings of our study. According to Keita et al. (2017), “RT encompasses multiple components of the stimulus response relationship such as stimulus evaluation, response selection, and response execution, whereas P3 latency (brain potential) is thought to reflect stimulus evaluation time and is generally unrelated to response processes “(p.361). However, we believe that the high variation and lack of consistency of our results could be attributed to the lack of standardization of how participants performed the reaction time test and insufficient number of pilot studies.

## **Limitations**

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The participants in our study were not native English speakers, which might have affected the participant's abilities to understand the software and puzzle instructions that were written in English. Reaction time software familiarization trials were conducted before starting the test, although some participants still reported difficulty following the instructions. Also, all participants in the puzzle group had never seen or tried a Sudoku game, which made the task more cognitively and mentally demanding. I think that might explain the change in reaction times in the puzzle group. Moreover, if the participant hit the button twice the software automatically doubled the reaction time, which resulted in high standard deviations among participants and groups. I used a visual stimulus delay interval ranging from 1000 MS to 10000 MS was too broad and likely introduced extra error. Also, many participants used two fingers for reaction time (release the button) and a different finger to press (movement time). This practice made it more likely for the total reaction time to be meaningless. Furthermore, sometimes the software reported a zero value for movement time, which is technically not possible! Finally, the very small sample sizes in the two groups reduced the statistical power that could have discovered significant differences if they existed.

I recommend that future studies use multiple measures including simple reaction time, choice reaction time, and electro encephalography (EEG) to measure whether cognitive and/or plastic changes occur in the nervous system after exercise. In addition, further research should compare results from each measure to the others to conclude if one measure is more sensitive or valid to predict neuroplasticity after exercise. Also, larger samples (e.g., greater than 20-30/group) of different ages should be considered in future studies. Further the directions for performing the reaction time and movement time tasks need to be better standardized so that increased objectivity and reliability of the measures can be assured.

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## Appendices

### Appendix A Informed consent letter

#### Reaction Time as a Measure of Neural Plasticity after Moderate Exercise/Problem Solving

##### INFORMED CONSENT

My name is Ahmed Mostafa, a graduate student in the School of Human Movement, Sport, and Leisure Studies at Bowling Green State University. I am conducting a research study for my Masters project which is investigating whether moderate exercise and/or working puzzles for 30 minutes impact how quickly people respond to a light. I am hopeful that you may volunteer to participate.

I affirm that I am at least 18 years old and don't have any known health issues. If I agree to voluntarily participate in this study I have been told I will either pedal a stationary bike for 30 minutes or spend 30 minutes solving puzzles and to take a simple reaction time test three times. I have been told that I will not receive any incentives for participating in this study, but it may benefit science by helping researchers to learn more about how some activities may affect brain functioning. I know that my voluntary participation may or may not benefit my physical fitness or general health, but it is highly unlikely to harm it. There are no known risks to solving puzzles. The risks from 30-minutes pedaling on a stationary bike are similar to those I might experience in riding my own bicycle or going to the Student Recreation and Wellness Center to exercise (e.g., lift weights, walk/run on a treadmill or stepper, walk or swim) for 30 minutes. A remote possibility exists of adverse changes to blood pressure resulting in dizziness, fainting, or rarely a heart arrhythmia if there is a pre-existing condition. I have been informed a risk of minimal delayed-onset muscle soreness may exist, especially if I am not a daily exerciser. Every effort will be made to minimize these occurrences by completing the health questionnaire, warming up before exercise, and by monitoring my condition during and shortly after exercise.

I am aware that my identity will remain completely confidential through the use of a code number instead of my name and that the information which is obtained in this study will be treated as confidential and not be released or revealed to any person. I also know that my participation is completely voluntary and that I may withdraw from participation at any time without any consequence and that deciding to participate or not has no impact on any relationship I have with BGSU or the investigator. I realize that it is my obligation to inform the researchers if any symptoms of dizziness, shortness of breath, or chest or leg pain should develop.

I will receive exact instructions regarding the type of activity (either stationary bicycling or puzzle solving) and the three response time tests I will perform on the computer. My participation is limited to a single day and will require only about 45-60 minutes spread over a 4-hour period. Between the short computer tests, I will not be required to remain in the laboratory testing room or in the building.

The investigator, Ahmed Mostafa, has answered all my questions and he can be contacted at phone (419-351-1020) or email [mostafa@bgsu.edu](mailto:mostafa@bgsu.edu). Dr. Stephen Langendorfer is Mr. Mostafa's advisor and he can be reached at (419-372-7595) and [slangen@bgsu.edu](mailto:slangen@bgsu.edu). If I have questions or concerns about my rights as a research participant, I may contact the Chair of the Institutional Review Board (IRB) (419-372-7716) or email [orc@bgsu.edu](mailto:orc@bgsu.edu) .

---

Participant's name (printed)

---

Date of birth

---

Participant's signature

---

Today's date

## Appendix B

### Health questionnaire

#### AHA/ACSM Health/Fitness Facility Pre-participation Screening Questionnaire (*modified*)

Assess your health status by marking all true statements

History You have had:

- \_\_\_\_\_ a heart attack or heart surgery
- \_\_\_\_\_ cardiac catheterization coronary angioplasty (PTCA)
- \_\_\_\_\_ Pacemaker/implantable cardiac defibrillator
- \_\_\_\_\_ Heart rhythm disturbance (e.g., atrial fibrillation)
- \_\_\_\_\_ heart valve disease
- \_\_\_\_\_ heart failure
- \_\_\_\_\_ heart transplantation
- \_\_\_\_\_ congenital heart disease

Symptoms:

- \_\_\_\_\_ You experience chest discomfort or pain with exertion.
- \_\_\_\_\_ You experience unreasonable breathlessness
- \_\_\_\_\_ You experience dizziness, fainting, or blackouts
- \_\_\_\_\_ You take any heart medications

Other health issues:

- \_\_\_\_\_ You have diabetes
- \_\_\_\_\_ You have asthma or other lung disease
- \_\_\_\_\_ You have burning or cramping sensation in your lower legs when walking short distances
- \_\_\_\_\_ You have musculoskeletal problems that limit your physical activity.
- \_\_\_\_\_ You have concerns about the safety of exercise
- \_\_\_\_\_ You take prescription medication(s).
- \_\_\_\_\_ You are pregnant or think you may be pregnant.

**If you marked any of the above statements in this section, please immediately consult your physician or other appropriate health care provider and you are excused from participating in my study.**

#### Cardiovascular risk factors

- \_\_\_\_\_ You smoke, or quit smoking within the previous 6 months.
- \_\_\_\_\_ Your blood pressure is >140/90 mm Hg.
- \_\_\_\_\_ You do not know your blood pressure.
- \_\_\_\_\_ You take blood pressure medication.
- \_\_\_\_\_ Your blood cholesterol level is >200 mg/dl.
- \_\_\_\_\_ You do not know your cholesterol level.
- \_\_\_\_\_ You are physically inactive (i.e., you get <30 minutes of physical activity on fewer than 3 days/ week).
- \_\_\_\_\_ You are >20 pounds overweight

**If you marked two or more of the statements in this section you should consult your physician or other health care provider and probably should not participate in my study.**

\_\_\_\_\_ None of the above

**If you mark “none of the above,” you should be able to participate safely in this study without concern or needing to consult your physician or other appropriate health care provider**

Modified from American College of Sports Medicine and American Heart Association. ACSM/AHA Joint Position Statement: Recommendations for cardiovascular screening, staffing, & emergency policies at health/fitness facilities. *Medicine and Science in Sports and Exercise* 1998:1018.

## Appendix C



spread sheet.xlsx