No difference between taking a five minute general knowledge test online versus on paper in regards to effects on blood pressure, heart rate and beta brain wave frequency

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ABSTRACT:

The purpose of this study was to investigate the physiological differences expressed by college students taking a test on paper versus taking a test online. Physiological responses to testing were measured by taking the frequency of beta waves (a measure of mental effort via electroencephalography), the percent change in blood pressure, and the percent change in heart rate. The three physiological responses were recorded on college students before, during, and after a five-minute paper or online test of general knowledge. We hypothesized that online testing would be less familiar than paper testing, and therefore more stressful, leading to an increased beta wave frequency, a larger increase in heart rate and a larger increase in blood pressure. Results showed that test format was not correlated with a significant difference in the frequencies of beta waves (p-value of 0.16529), blood pressure ($p_{systolic}$= 0.90667, $p_{diastolic}$= 0.11270) or heart rates (multiple values, $p \geq 0.12941$). The data from this study indicates that there are no physiological differences between online and offline testing in college students taking a short general knowledge test. Future studies could examine physiological responses to different test formats, longer tests, or higher pressure examinations (AP, SAT, GRE, etc).

INTRODUCTION:

In an increasingly paperless society, emerging technology makes it possible to learn and to be tested using online technologies. This non-traditional educational style is becoming popular in colleges and schools across the United States. Technologies such as tablets, video screens, and HD projectors are now powerful tools in many classrooms. According to research performed by the Pew Research Center, 96% of students in higher income areas have access to a computer in the classroom for academic use (PEW, 2013).

While there are obvious benefits to such technology, how students react to online examinations versus those on paper remains to be seen. However, testing in general has been shown to be stressful. Previous studies have demonstrated that there is an increase in cortisol levels during exams (Malarkey et al. 1995; Spangler, 1997). Cortisol is a steroid hormone of the sympathetic nervous system that is released when the body is under stress. Cortisol prepares the body for a 'fight or flight' response by increasing heart rate and blood pressure. Both anticipation of examinations and the process of taking an exam can elicit anxiety (Frankenhaeuser et al., 1978). In addition to testing situations causing stress, novel situations can also generate stress; research has shown that individuals have higher stress levels in less familiar situations (Litt et al. 2011). Since the majority of examinations at the University of Wisconsin-Madison (UW-Madison) are given on paper, we expect that students will be less familiar with the online format and show a higher physiological stress response than those taking paper tests.

Based on information from several previous studies, it can be inferred that the frequency of beta waves, measured via electroencephalography (EEG), is a measure of physiological stress. EEG uses electrodes placed on the head to measure electrical impulses that are characteristic of various states of awareness and mental effort. It has also been shown that novice meditators transition from a relaxed state to a non-relaxed state more easily than experienced meditators when presented with visual stimuli; this has been correlated with increased high-frequency EEG rhythms (which may include beta wave rhythms) for the non-relaxed novice meditators and increased low-frequency EEG rhythms for the experienced meditators who maintained their meditative state (Yu-Hao et al., 2014). Our study used EEG to measure beta waves, an EEG-characterizable waveform that is associated with an excited state of the cerebral cortex due to external stimuli (Kremer et al., 2010). Increased beta rhythms occur when an individual is under

a state of alertness or tension, when he or she is engaging in mental effort, or when retrieving memories (Kremer et al. 2010). The frequency range for beta waves can vary between 13 and 30 Hz (Kremer, et al. 2010). Since a stressful test taking situation may be characterized as a non-relaxed state (Obrist, 2007), we infer that there should be an increase in the frequency of beta waves during this time.

Tests of academic performance have been shown to cause transient elevations in blood pressure and heart rate (Conley and Lehman, 2010; Loft et al. 2007). In addition to the fact that cortisol increases during test conditions, heart rate and blood pressure are expected to increase, more-so in the less familiar online test than the paper test.

We investigated the physiological differences expressed by college students taking a 59 question test on paper versus a test online. We hypothesized that students taking a general knowledge test online would demonstrate a higher stress response in the form of a larger increase in blood pressure, a larger increase in heart rate, and a higher frequency of beta rhythms than students taking the same test on paper.

METHODS AND MATERIALS:

Our sample population consisted of upper level college students from UW-Madison. Consent was obtained from all subject participants. Participants were asked to fill out a questionnaire that included information such as sex, age, familiarity with computers, and personal preferences for online versus paper testing. Subjects were randomly divided between the online test, using Google Forms on a Macbook Pro, and paper test experimental groups. Both online and paper tests featured the same 59 fill-in-the-blank questions in the same order. Question topics consisted of history, geography, science, entertainment, sports and math in a

random order with varying levels of difficulty. Participants had five minutes to take the quiz and were allowed to skip difficult questions.

Before testing, baseline blood pressure was measured (OMRON, 10 Series + blood pressure monitor). Electrodes for continuous beta wave frequency and heart rate measurements were applied to the skin according to the Biopac Student Laboratory Manual (Kremer et al. 2010) and non-adhesive pre-wrap tape held the electrodes in place on the head and the wrist. Once electrodes were properly established, the participant was instructed to close their eyes and relax for EEG calibration and baseline readings (Biopac, MP36 model). Once the calibration was complete, the participant was then instructed to begin the quiz and a timer was started for the participant to keep track of time. Beta wave frequency and heart rate measurements were continuously recorded for the duration of the five minute quiz. To minimize performance anxiety, the researchers did not watch the participant take the quiz. At the end of the five minutes, ECG and EEG measurements were suspended and a second blood pressure measurement was taken immediately. Electrodes were removed from the participant and the data was analyzed.

CONTROLS:

The controls were measured on three participants. The positive controls confirmed that the measurements taken during the study were competent. Beta wave frequency was measured while the participant typed the middle row of letters on a keyboard. The participant began typing on the left side of the keyboard and moved towards the right typing every key. The purpose of this exercise was to provided the participant with a mindless task so they were not exerting any mental effort. Next, beta wave frequency was measured by giving the participant five difficult math word problems. The data showed lower beta wave frequencies when the participant was typing than while completing the math problems. Heart rate was measured by having the

participant complete an online game which startled the participant with an unexpected surprise at the end. Measurements were taken before the participant completed the game as well as during the duration of the game. When the startling surprise popped up on the screen, there was an increase in heart rate. A blood pressure reading was measured before and after the participants ran up and down the stairs for three minutes. There was an increase in blood pressure after the participant exercised, confirming that the blood pressure cuff was capable of recording changes in blood pressure.

STATISTICAL ANALYSIS:

To normalize for varying initial heart rates, percent change in heart rate was calculated, and then averages were taken for each test group. Systolic and diastolic blood pressure were calculated as percent changes as well. Average beta wave frequencies were taken for the online and paper test groups. Student t-tests were used to determine statistical significance, defining significance as having a p-value of less than 0.05 and standard deviations were calculated for all means. Boxplots were created using the statistical program R in order to visualize differences between test groups in terms of heart rate, blood pressure (systolic and diastolic) and beta wave frequency.

RESULTS:

The difference in beta wave frequency between online and paper test takers was not statistically significant. The paper test experimental group had an average beta wave baseline frequency of 20.89 Hz +/- 3.20 (one standard deviation). The online test experimental group had an average beta wave baseline frequency of 22.14 Hz +/- 1.82. The difference in baseline frequency between the two groups was not statistically significant with a p-value of 0.16127.

During the course of the test, the paper test takers showed an averaged beta wave frequency of 21.82 Hz +/- 1.67. The online test takers showed an average beta wave frequency of 22.61 Hz +/- 1.39. There was no statistical significance between these experimental values; the p-value was 0.16529 (See Figure 2).

There was also no statistical significance between the blood pressure responses of the two experimental groups. The paper test takers showed a -4.63% change +/- 7.29 in systolic blood pressure after the five-minute test, while the online test takers showed a -4.32% change +/- 6.93. Given a p-value of 0.90667, this was not a statistically significant difference (See Figure 3). For diastolic blood pressure, the paper test experimental group showed an average increase in blood pressure of 3.58% +/- 17.25. The online test experimental group showed an average diastolic change of 4.21% +/- 7.11. The average change in diastolic blood pressure between the two experimental groups was also not significantly different given a p-value of 0.11720 (See Figure 4).

No statistical significance was found between the experimental groups with regards to the physiological response of heart rate. The paper test experimental group had the following average percent changes of heart rate compared to the baseline heart rate throughout the five-minute test: 11.760% increase +/- 12.0 during the first minute of the test; 8.432% increase +/- 10.6 during minute two; 9.835% increase +/- 10.5 during minute three; 10.454% increase +/- 10.7 during minute four; 8.880% increase +/- 10.4 during minute five; -0.606% increase +/- 7.5 at the end of the test. The online test experimental group had the following average percent changes of heart rate compared to the baseline heart rate throughout the five-minute test: 5.619% increase +/- 11.0 during the first minute of the test; 4.751% increase +/- 8.4 during minute two; 7.673% increase +/- 7.3 during minute three; 5.181% increase +/- 7.3 during minute four; 5.155%

increase +/- 8.0 during minute five; 4.190% increase +/- 8.0 at the end of the test (See Table 1). Given that none of the p-values were less than 0.05, there is no statistical significance between heart rate increase of paper versus online testing.

DISCUSSION:

Overall, the difference in physiological responses between online and paper test participants was not statistically significant. Participants in both conditions experienced similar changes in blood pressure, heart rate and beta wave frequency. Online testing had a higher frequency of beta waves in comparison with the paper testing, however the difference was not statistically significant. This suggests that participants in both conditions experienced similar amounts of tension and mental effort.

There was no significant percent change in diastolic or systolic blood pressure. This result confirms the work of previous research which found that academic stress had no effect on diastolic blood pressure, but contradicts their work which found an elevation in systolic blood pressure (Conley and Lehmen, 2010). Blood pressure decreased between the baseline reading and final blood pressure reading. A higher blood pressure before the test could have been due to induced stress from the participants' unfamiliarity with the EEG and ECG wires. The participants also may have had anxiety in anticipation of taking a test, causing elevated baseline measures (Frankenhaeuser et al., 1978). Blood pressure values may have been lower after the test because there were no incentives to do well on the test and participants grew comfortable and less stressed as the test progressed. The similar changes in blood pressure between the two experimental groups suggests that the two groups had similar levels of stress.

Participant heart rates may have fluctuated throughout the exam due to the varying difficulty of test questions; as participants experienced a series of more difficult questions, heart

rate may have spiked or it may have fallen after less-stressful questions. However, there was no statistical significance in the average heart rate response between the online and paper test takers. The similar percent changes in heart rate across both experimental groups suggests that participants in both the online and paper test groups had similar stress levels.

There were no significant differences in the number of questions attempted or in the number of correct responses between the online and paper testing groups (See Figure 6). Although a majority of the participants had a higher familiarity and preference for the paper test (26 of 30 participants preferred paper exams), participants showed similar results in each testing condition. Since there were no significant changes, it can be inferred that test takers will perform similarly between paper and online standardized tests.

This study had several limitations. The sample was a convenience sample from one class at one university. Tests were not taken under standard test taking conditions. The room in which the test was taken had varying noise levels, and there was no incentive to perform well on the test. This could have had an impact on the physiological responses of the participants. For two of the participants in the study, the electrodes measuring heart rate detached from the skin and did not give a complete reading for the entirety of the five-minute test. The heart rate values for these two participants were disregarded.

Future studies could recreate this investigation using more specific parameters to see if the same results are obtained. Giving the test in a silent room may help to minimize variation. More participants from a larger pool other than the Physiology 435 class at UW-Madison could also yield more significant results. Additional steps could examine how stress is experienced among various test formats during tests with a clear incentive to perform (AP tests, ACT, MCAT, etc.). Offering an incentive to future participants may affect overall performance and stress levels.

Perhaps offering a gift card to the participant with the highest score could motivate the test taker to do their best and show a greater change in stress levels. Creating a list with all participant names and scores and telling the participant that their scores will be posted alongside their peers may also make the students want to perform better. Additionally, offering extra credit points or placing the names of students who do well into a drawing for a new electronic gadget could motivate students to perform better. Not allowing a student to skip a question could also increase mental effort and normal stress levels of test taking situations. A focus on differences between gender or different age groups may be a basis for future studies as well.

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TABLES:

	Online		Paper			
Time period	Mean Percentage Change in Heart Rate (+/-1SD)	n	Mean Percentage Change in Heart Rate (+/-1SD)	n	P-value	Significant difference?
baseline to minute 1	5.619 +/- 0.110	11	11.760 +/- 0.120	15	0.19452	No
minute 1 to minute 2	4.751 +/- 0.084	11	8.432 +/- 0.106	15	0.35134	No
minute 2 to minute 3	7.673 +/- 0.073	11	9.835 +/- 0.105	14	0.56853	No
minute 3 to minute 4	5.181 +/- 0.073	11	10.454 +/- 0.107	14	0.17618	No
minute 4 to minute 5	5.155 +/- 0.080	10	8.880 +/- 0.104	14	0.17689	No
minute 5 to final	4.190 +/- 0.080	11	-0.606+/- 0.075	15	0.12941	No

Table 1: Values listed are the means of the percent change of heart rate over time. The values shown were calculated by subtracting the baseline heart rate from the rate for that time period and dividing by the initial value. The values listed are shown plus or minus one standard deviation. Numbers in the "n" column are the number of replicates for each mean; due to technical difficulties with the electrodes, the values fluctuate. Student t-tests were used to compare means, with significance being defined as p less than 0.05. None of the tests showed a significant difference in heart rate between online and paper formats.

FIGURES:

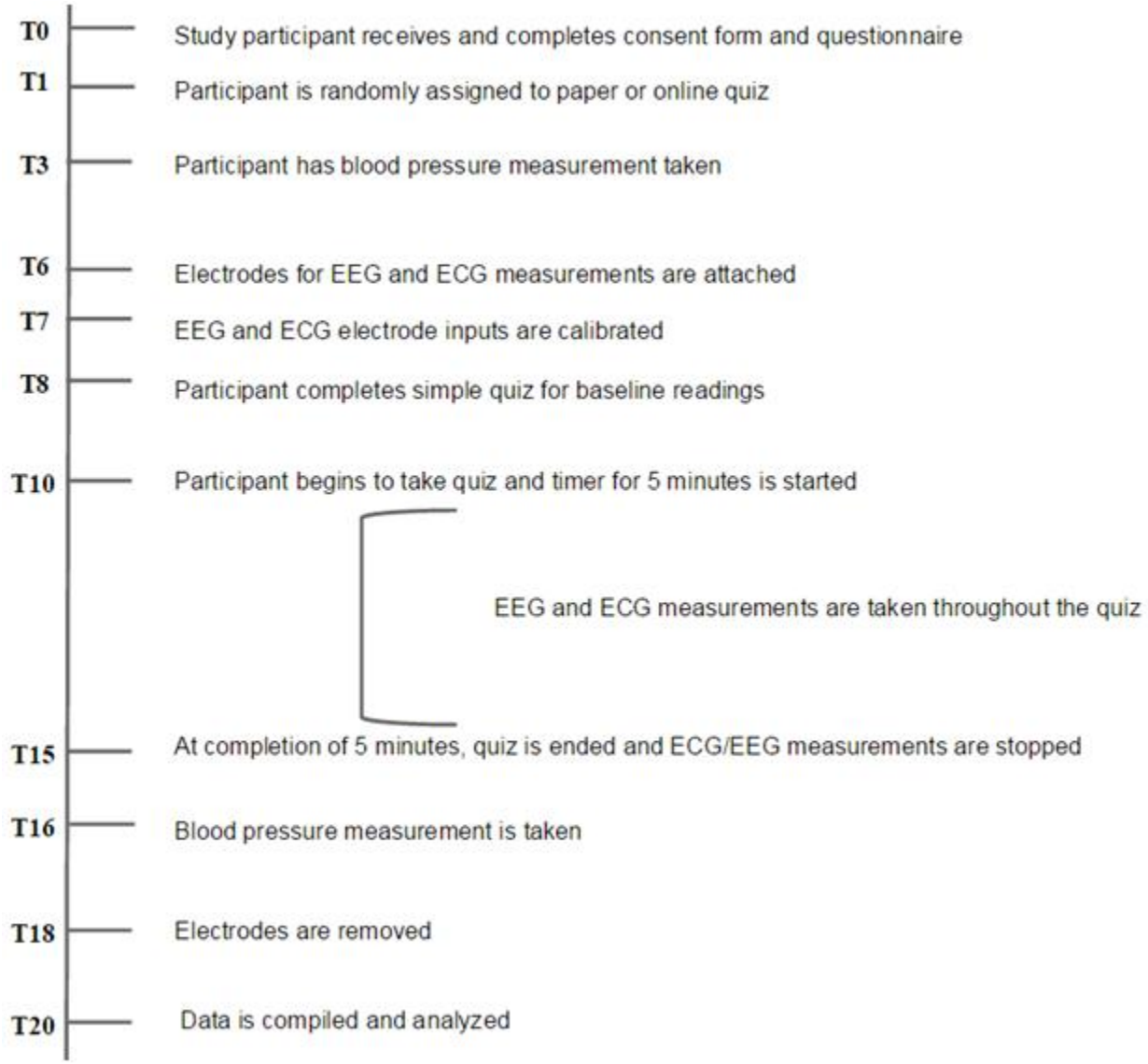

Figure 1: Approximate timeline of experiment outline that was followed for each participant.

(i.e. T1 = 1st minute, T3 = 3rd minute, etc.)

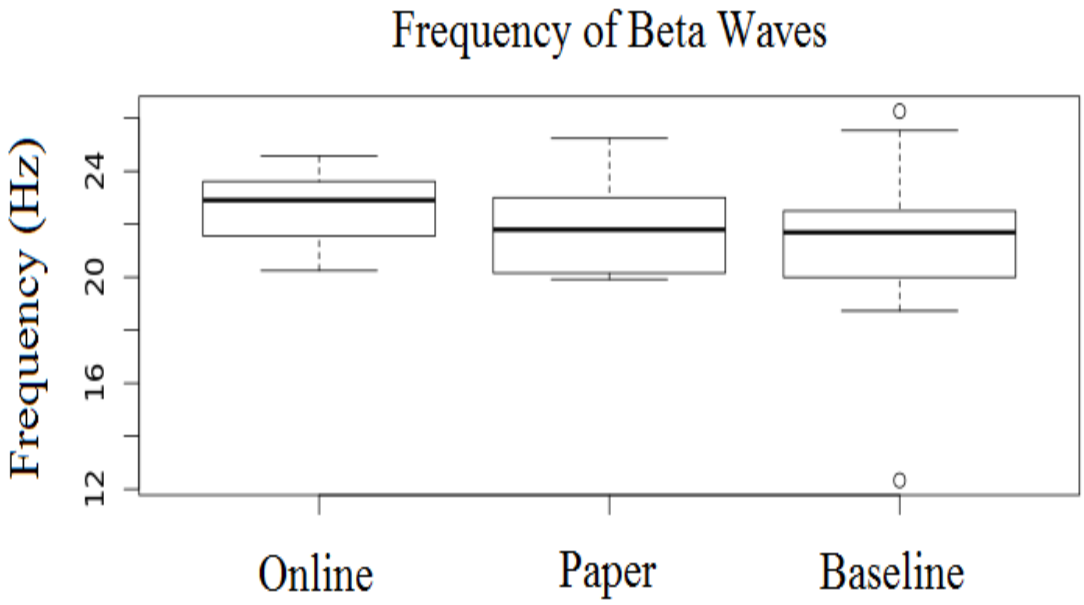

Figure 2: This boxplot visualizes the average beta waves of online and paper test takers versus the baseline beta wave frequency. The circles depicted in the "Baseline" plot represent outlying values. The thick central lines at the center of the plot represent median values, the top and bottom of the rectangle represent the first and third quartiles, and the top-most and bottom-most lines represent the maximum and minimum values. Mean values: online= 22.61 Hz (n= 15); paper= 21.82 Hz (n= 15); baseline= 22.42 (n= 26).

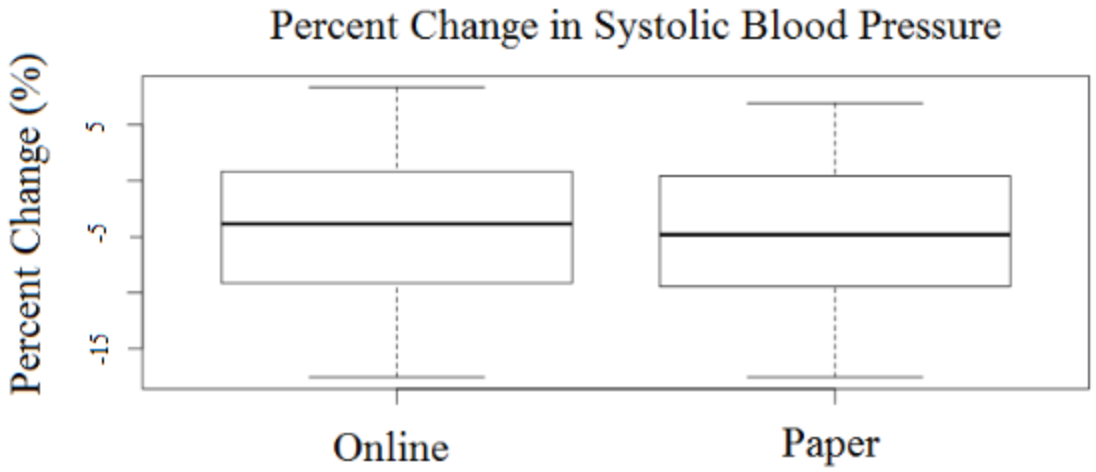

Figure 3: Comparison of percent change in systolic blood pressure of online test takers and paper test takers. Initial systolic pressure was subtracted from final systolic pressure and the resulting value was divided by the initial value to generate percent change. See Fig. 2 for description of box plots. Mean values: online= -4.32% (n= 15); paper= -4.63% (n= 15).

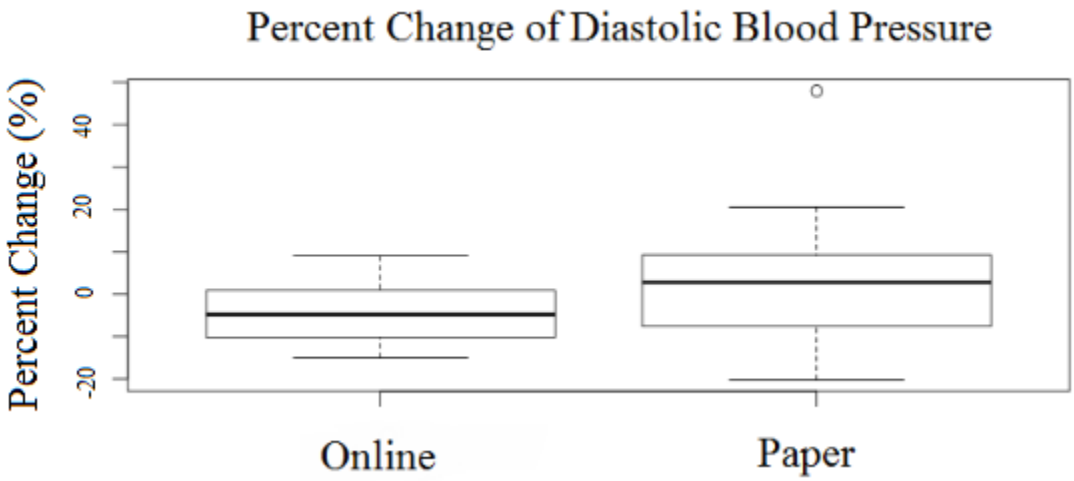

Figure 4: Comparison of percent change in diastolic blood pressure of online test takers and paper test takers. Initial diastolic pressure was subtracted from final diastolic pressure and the

resulting value was divided by the initial value to calculate percent change. See Fig. 2 for description of box plots. Mean values: online= 4.21% (n= 15); paper= 3.56% (n= 15).

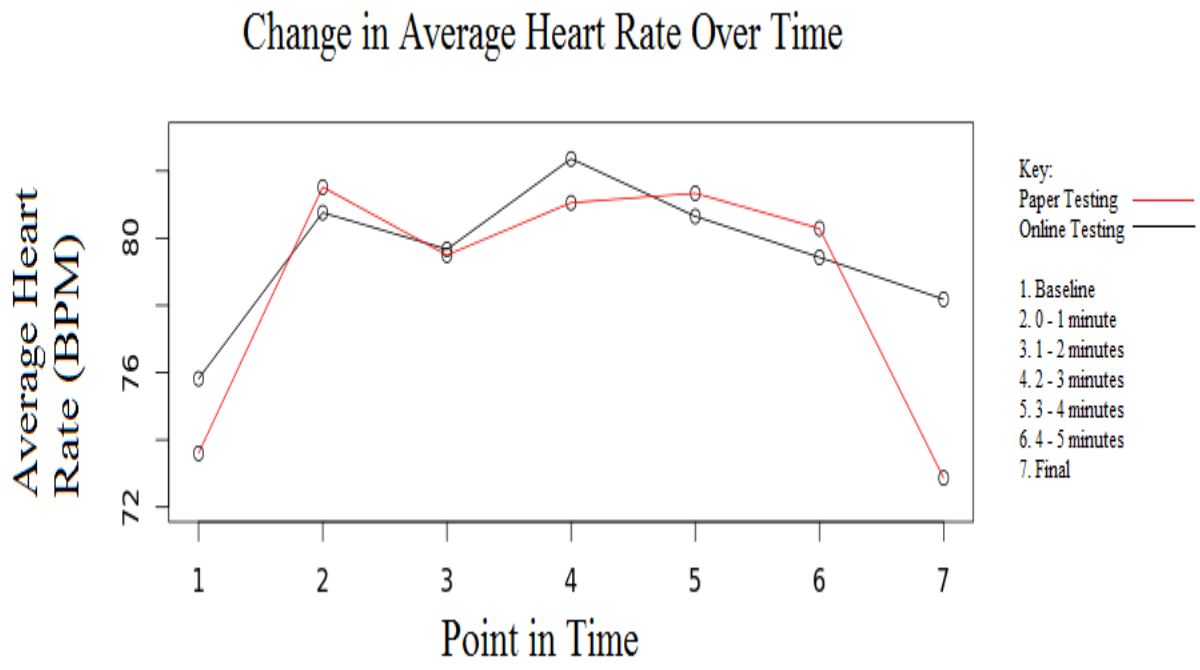

Figure 5: Comparison of average change in heart rate in beats per minute over points in time during online and paper test taking. Note that the y-axis begins at 72 beats per minute, and tops out at 82 beats per minute. All of the average values generated fall between a fairly narrow range (~72 bpm to ~82 bpm).

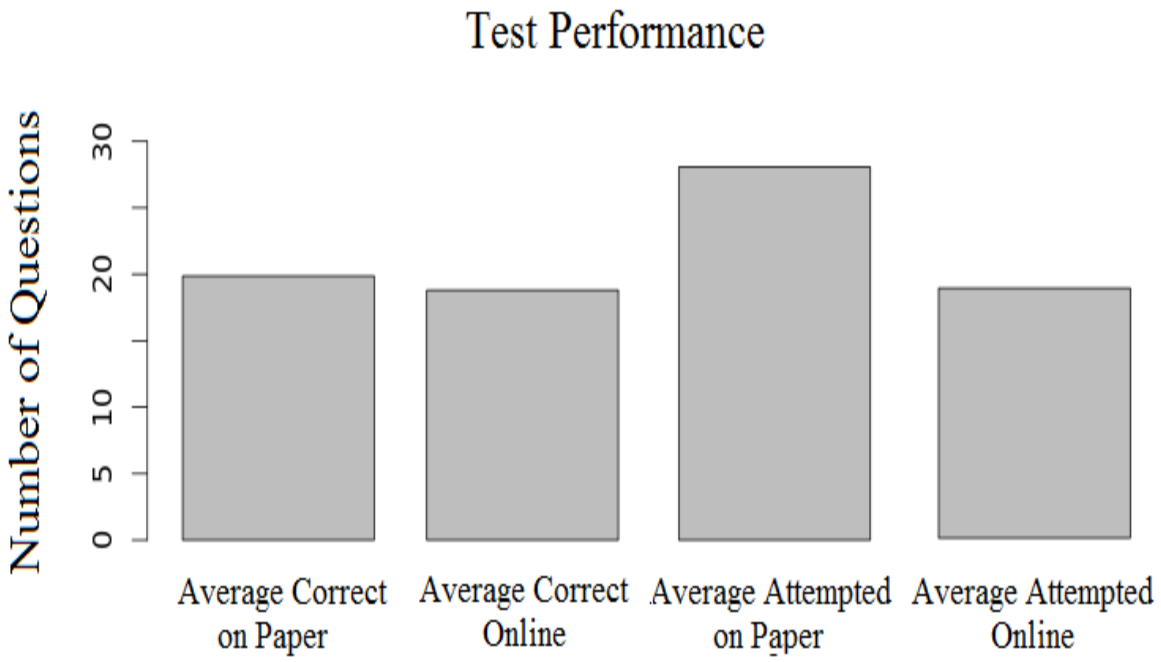

Figure 6: Comparison of average number of correct answers and attempted answers of online test takers and paper test takers.

APPENDIX A: Paper and Online Test Questions

1. What political system was gradually dismantled in South Africa, starting in 1989?
2. Where is the Suez Canal?
3. What chemical element has atomic number 8?
4. What is Bucky Badger's full name?
5. Name the sisters that have dominated women's tennis?
6. What are the first three prime numbers after 10?
7. Who was the 1998 WWE Champion?
8. What is the name of the movie in which the protagonist, played by Brad Pitt, ages backwards?
9. What do we call the white solid hogfat used as a lubricant in cooking?
10. Which animal is the official symbol of the World Wildlife Fund?
11. What do the angles of a triangle always sum to?
12. Who won the FIFA World Cup in 2010?
13. What is the name of the world renowned British physicist that has ALS (Lou Gehrig's disease) and wrote a book titled A Brief History of Time?
14. What sea creature can have an eye measuring 16 inches across, the largest in the animal kingdom?
15. What team won the 2014 World Cup that was held in Brazil?
16. What year marked the beginning of World War I?
17. Which ocean goes to the deepest depths?
18. Who is the author of "The Catcher in the Rye"?
19. What is (4 x 10^-3) / (2 x 10^6) ?
20. What is the last letter of the Greek alphabet?
21. What is 15 squared?
22. What color are superman's shorts?
23. In the NFL, in what US state would you find the Broncos?
24. Which of the 50 states was the last one added to the United States?
25. Which country gave the USA the 'Statue of Liberty?
26. What do you call an angle more than 90 degrees and less than 180 degrees?
27. What is the postal abbreviation for Maine?
28. Who is the Greek god of the sea, usually pictured holding a trident?
29. Who is known for taking a "Midnight ride" and alerting the military of the British approaching before the battles of Lexington and Concord?
30. What continent is cut into two pieces by the Tropic of Capricorn?
31. Name one country that Mount Everest is in.
32. What nationality was the composer Ludwig van Beethoven?
33. Who won Super Bowl XLIX on Feb. 1, 2015?
34. What are the first five numbers of the Fibonacci sequence?
35. What ingredient in fresh milk is eventually devoured by bacteria, causing the sour taste?
36. What year was the University of Wisconsin-Madison founded?
37. Pete Sampras is a famous name in which sport?
38. What's the common term for a cerebrovascular accident?
39. Which team holds the highest number of NHL championships?
40. What tree gives us prunes?
41. What is 35 x 24?

42. What do doctors look at through an ophthalmoscope?
43. What word describes a number system with a base of two?
44. What is the main color of the Chinese flag?
45. What newspaper's motto is: "All the news that's fit to print"?
46. What is the fastest growing plant?
47. What is the square root of 121?
48. In which year did man first land on the moon?
49. In what state would you find Prince William Sound?
50. Who sings "Build Me Up Buttercup"?
51. How many majors has Tiger Woods won?
52. What is the Pythagorean theorem?
53. What was the first planet to be discovered using a telescope?
54. What President was associated with the Watergate scandal?
55. Who was the sixteenth president of the United States?
56. Canberra is the capital of which country?
57. Who was the only actor to win an Oscar after his death?
58. In professional basketball, where do the Hawks come from?
59. Is a shark a fish or a mammal?