Evaluating the effectiveness of physical exercise in improving standardized testing performances through attention indices

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Abstract

Introduction: In the United States, standardized tests have risen in prevalence, extending their importance from education placement to employment. Attention is crucial to improving testing performance. Past studies have established that acute, coordinative, aerobic exercise improves attention, which is measured by the D2 Attention Test, emotional analysis, reading time, and eye movement tracking. No studies have drawn connections between physical exercise's quantifiable improvement in attention to improvements in standardized tests; therefore, this study would attempt to do so.

Methods: This study defines attention to be positively related to reading speed and negatively related to the number of eye drifts. High school students were selected to read and answer two reading passages from an SAT (Scholastic Assessment Test) exam, before and after a short 80% intensity run. Their reading times, facial video, and test scores were recorded. Dlib plots the facial landmark and OpenCV tracks movement of the pupil.

Results: Through paired-samples t-tests, this study found out that after exercise, subjects displayed increased reading speed and fewer eye drifts, coupled with increased mean scores.

Conclusion: Thus, this study demonstrated that running, as an acute, coordinative, aerobic exercise, helps increase the testing performance of the SAT reading section by measuring attention. Future research could focus on including head movement as an attention index, replicate the experiment on different standardized tests or exercises, and conduct natural experiments to better simulate real-life conditions to increase applicability.

KEYWORDS
attention, digital image processing, eye movement, physical exercise, reading speed, standardized tests

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1 | INTRODUCTION

Since the 20th century, standardized testing has become an important aspect of the United States’ education system (Himelfarb, 2019). In response to the country’s poor educational outcome among other developed countries, which have greater oversight over testing and curriculum, Congress passed the No Child Left Behind Act in an attempt to regularize education (Benjamin & Pashler, 2015). Specifically, standardized tests, indicators of student academic performance and aptitude, became more widespread to assess the quality of education (William, 2010). A study by the Council of the Great City Schools indicated that in the country’s largest urban districts, students take an average of 112 standardized tests from pre-kindergarten to grade 12 (Hart et al., 2015). Recently, the increasing number of college applicants increased colleges’ reliance on standardized tests to tighten admission under limited resources (Zwick, 2017). The impact of standardized tests goes beyond college admissions: “gatekeepers of America’s meritocracy—educators, academic institutions, and employers—have used test scores to label people as bright or not bright, as worthy academically or not worthy” (Sacks, 2000). Regardless of the tests’ fairness, they impact students’ chances of success.

However, some critics argue that standardized tests are unrepresentative of students’ capabilities (Kempf, 2016). In addition, occasional fluctuations in testing performance could overshadow the cumulative performance of students in class (Wingate & Tomes, 2017). Sievertsen et al. (2016) affirm this statement, arguing that cognitive fatigue can induce a decrease in attentiveness, which causes significant drops in standardized testing performance. Thus, attention can play an essential role in the improvement of standardized testing.

In light of the growing importance of standardized tests, past studies have found physical exercise as a potential method of improving testing performance. Coe et al. (2006) observed that vigorous physical exercise increases academic achievement, which was measured by a national standardized test. Although this correlation has been established, there is a current paucity of scientific research investigating and quantifying attention in explaining how physical exercise leads to improvements in testing performance.

The SAT (Scholastic Assessment Test), a standardized test for reading, writing, and math, has become widespread in U.S. high school education (Zwick, 2004). Recently, the College Board has announced the test’s digital transition by spring of 2024 (College Board, 2021). This study will evaluate the role of attention between physical exercise and standardized tests through the SAT reading test in a digital setting.

2 | LITERATURE REVIEW

2.1 | Physical exercise and attention

To understand how physical exercise improves standardized test scores through the enhancement of attention, it is important to look at the existing body of research on the subject. There has been abundant research suggesting that physical exercise enhances student engage-
effective in evaluating visual speed and accuracy, it only pertains to visual scanning and differs from the line-by-line reading in standardized reading tests (Katz & Carlisle, 2009; Steinborn et al., 2018). In addition, the results of the D2 Attention Test are more “influenced by a skipping strategy than is the concentration performance measure” (Bates & Lemay, 2004, p. 398).

Unlike the research from Spitzer and Hollmann, Budde et al., and de Sousa et al., who studied the effect of physical exercise on attention, some studies focused on how attention is tested. Instead of using the conventional D2 Attention Test, these studies attempted to devise specific indices, such as eye movements, emotional analysis, and reading times, to better gauge attention based on different contexts. Under the context of self-paced reading, Miller (2015) defined attention on reading time and eye movements and provided underlying assumptions. He first established attention as a baseline of comprehension, which affects standardized reading texts, because subjects must concentrate on a piece of text before they could cognitively engage with the text. Miller suggested that attention is the quantity and quality of mental resources dedicated to an object as well as the accompanying behaviors. In eye movement, saccades, or rapid movements, and fixations, or pauses at a particular point, determine attention allocation (Duchowski, 2017). Per Miller, a machine tracks the location of the eye and a computer uses the screen layout to trace the part of the screen that is within the fovea. Morimoto and Mimica (2005) tracked the pupil coordinates for more accurate eye movement tracking. In addition, Miller argued that in the case of self-paced reading, the reading time is positively correlated to attention since subjects fixate on words longer due to the more mental resource devoted to the text. Reading times that are significantly lower than average could indicate that readers skip words or do not fully comprehend. Miller also explained that eye movement tracking could identify words readers skipped or missed, indicating less or a lack of attention dedicated to that portion of the text. Although reading time could be useful in this study, it should be noted that self-paced reading is different from the SAT reading tests, where time is limited.

Azevedo (2015) synthesized from past literature and provided various methods to measure attention, including emotional analysis, feature selection, and eye tracking. The study recommended the triangulation of other sensors and indices for better detection of student engagement and attention. Aslan et al. (2014) used feature selection, including gaze, body posture, and facial points to create a student engagement classification with accuracies up to 85%–95%. However, the study only specified that the students were in a learning environment and failed to address the specific educational context where this model is beneficial. Leelavathy et al. (2020) proposed the use of a built-in laptop webcam to deliver real-time information regarding student engagement in digital learning through emotional analysis and eye movement tracking. After recording, the video was broken down into images and processed through the Haar Cascade Algorithm, which uses edge or line detection to recognize facial features (Viola & Jones, 2001). Additional emotional analysis was added, to match emotion states such as neutral, happy, sad, anger, and surprise to the content of online learning.

Aslan et al. and Leelavathy et al.’s approaches were similar to that of Miller as they did not merely cover the surface-level visual scanning in the D2 Attention Test. In addition, eye movement was accompanied by facial analysis to provide additional details on the focus of attention. Eye movement tracking fits the context of the SAT reading test, where subjects will read line-by-line and produce discernible eye patterns. Although emotional analysis can gauge attention under certain conditions, emotions may be difficult to gauge under standardized testing, which is informative. Furthermore, a lack of attention could mean that participants do not absorb the information, making emotional analysis unfit (Schindler & Bublatzky, 2020).

2.4 | Gap

Research methods from the aforementioned studies provide an evaluation of attention in the context of reading, learning, and test taking. Most of these indices are based on digital image processing, the way of processing and analyzing digital images through computer algorithms and machine learning, to predict and detect the levels of attention (Reddy, 2018). The D2 Attention Test provides little useful information due to its lack of pattern in visual scanning. Emotional analysis is difficult to gauge student attention because standardized tests do not provoke significant emotion and whether students exhibit specific emotions depends on whether students are attentive in the first place. Indices such as eye-movement tracking and reading times provide an appropriate means to gauge attention in reading standardized tests.

Coe et al. (2006) suggested the potential of attention as a link between physical exercise and increased standardized testing performance. Although there has been extensive research on attention indices, there is insufficient research applying them in gauging the effect of physical exercise on attention in standardized testing contexts. This study will attempt to measure attention based on reading time and eye movements. Furthermore, it would evaluate and validate the potential of physical exercise in maximizing standardized testing performances, which is in line with past literature.

2.5 | Hypothesis

This study hypothesizes that the indices of attention, including reading time and eye movements, correlate with performance in standardized tests, which, inferred from past literature, could be improved with acute, coordinative, aerobic exercises.

3 | METHOD

3.1 | Overview

This experiment aimed to show the relationship between physical exercise and improved standardized test performance through enhancing attention. Previous research established that physical exercise
improves attention, but lacks specificity in terms of attention. Therefore, to contextualize the attention used in test taking, indices such as eye-movement tracking and reading time were implemented to accurately gauge student attention, which would then be matched with their test scores. A quantitative research method was implemented to numerically determine the difference in attention and test performance of the test before and after physical exercise.

3.2 | Subject selection

The subjects were selected from high school students in a competitive international high school in Taiwan, where both standardized testing and sports are emphasized. To ensure all subjects have similar effects to physical exercise, they were required to be enrolled in an ongoing sports team, club, or class on a weekly basis. All subjects had given consent to being recorded throughout the experiment, and there were no external incentives in participation to prevent data contamination. Furthermore, this research, which includes collecting human data, has been approved by the Pacific American School High School Institutional Review Board. Before the test, they were given clear instructions on test taking. To minimize the Hawthorne effect, subjects were informed about the intentions of evaluating attention after the experiment (Sedgwick & Greenwood, 2015). After the test, subjects were asked if they have prior knowledge of the passage. If so, the data of the subject would be removed from the study.

3.3 | Standardized testing

The SAT was selected as the standardized test due to its prevalence in high school (Zwick, 2004). The reading section was selected as the line-by-line reading of sentences in paragraphs produces the most discernible pattern to analyze eye movement. Two reading passages were selected from the reading sections of two different Official SAT Practice Tests. Both tests are the first, or literature, passage of the reading section to ensure the similarity of content. The two passages each have 10 different corresponding multiple-choice questions from the practice test. A laptop was used to project the passage and questions, and the answers were marked by the subjects on a separate bubble sheet. Throughout the experiment, the two passages and questions and their orders taken by the subjects were kept the same. The subjects were given a total of 13 min to read and answer the questions since there are five passages in the SAT reading portion to complete in 65 min (College Board, 2020). To ensure that the two passages had similar difficulty, a controlled experiment required subjects to read the passage and answer the questions for both tests. Their scores, the number of correctly answered questions for each passage, were recorded. After the controlled experiment, in the variable experiment, a separate set of subjects were instructed to read and complete the questions for each passage, one before and one after physical exercise. The subjects were told to read the entire passage first before answering the questions to prevent saccades caused by eye movement from the questions back to the passage, which could be interpreted as signs of distraction and shifted attention from the passage (Jonikaitis et al., 2013). The built-in webcam from the laptop and a stopwatch recorded the subjects’ face and reading time, respectively, as they read the passage in both tests.

3.4 | Physical exercise

Physical exercise was the independent variable. Subjects were required to read and complete the questions from two passages, one before physical exercise and one after. Literature established coordinate, acute, and aerobic exercises bring cognitive enhancements, particularly attention (Budde et al., 2008; de Sousa et al., 2018). To maximize the effect of physical exercise on attention, running was selected as an aerobic exercise that requires enough speed and coordination of movement to balance at high, intense speeds (Siddiqui et al., 2010). Before the first test, subjects’ resting heart rates were recorded. Immediately after the first test, subjects were required to conduct exercise for 10 min to be acute as opposed to a long period (Slutsky-Ganesh et al., 2020). Subjects’ heart rates were immediately recorded after the exercise. A 5-min recovery was conducted before the second passage (Cantrelle et al., 2020). Throughout this process, subjects would be supervised by the school physical education teacher to reduce the risk of sports injuries.

Exercise intensity was standardized to ensure similar effects of exercise on subjects. Similar studies on the effect of acute treadmill walking on cognition aimed for 60% intensity (Hillman et al., 2009). The desired intensity for this study is 80%, as suggested by Wang et al. (2013), due to the intensive nature of running. Assessments of heart rate before and after exercise have been recommended as a method for establishing exercise intensity (Liguori et al., 2022). Target heart rate (HRtarget) was calculated through the equation Karvonen and Vuorimaa (1988) established, using maximum heart rate (HRmax), resting heart rate (HRrest), and intensity (% intensity).

$$HR_{target} = (HR_{max} - HR_{rest}) \times \% \text{intensity} + HR_{rest}. \quad (1)$$

Choi et al. (2015) used the following equation to determine the maximum heart rate.

$$HR_{max} = 220 - \text{age}. \quad (2)$$

All subjects’ heart rates after exercise passed the target heart rate.

3.5 | Measuring attention

A stopwatch recorded the reading time of the passage and kept track of the time left for the subjects to complete the test. Due to the word
count difference between the two passages, reading speed was calculated by dividing the number of words by the number of seconds to complete the reading for each passage. Although past research assumed that longer reading time indicates enhanced attention, in the context of standardized tests, which require subjects to efficiently read and absorb information, this experiment evaluated reading speeds such that higher reading speeds indicate attentiveness (Miller, 2015; Coltheart, 1987).

After the two tests, subjects were instructed to scan from the leftmost to the rightmost and topmost to the bottommost edge of the screen, with the camera recording their eye movements. This baseline eye movement would then be compared to subjects’ eye movements during the reading time (Ellis et al., 2011). The previously recorded videos of subjects’ face during the tests were then analyzed. Python programming language was used to conduct digital image processing. The dlib and OpenCV packages were then installed. Dlib detected the frontal face and plotted the coordinates of facial landmarks (Boyko et al., 2011). The previously recorded videos of subjects’ face during the tests were then analyzed. Python programming language was used to conduct digital image processing. The dlib and OpenCV packages were then installed. Dlib detected the frontal face and plotted the coordinates of facial landmarks (Boyko et al., 2011). A pretrained network from Kazemi and Sullivan (2014) was used to detect facial landmarks. Figure 1 shows the diagram of the pupil position relative to the eye. The red two points on the corners of the eye were connected to form a blue, horizontal segment in Figure 1. OpenCV then tracked the pupil position to determine shifts in eye focus (Shang et al., 2019). From OpenCV, the edge of the iris, shown as green segments in Figure 1, could be determined due to the difference in color between the white sclera and the colored iris (Schwarz et al., 2012). The two points on the horizontal segment that intersects the edges of the pupil were marked. The midpoint between these two points, shown as a green dot in Figure 1, produced the horizontal pupil position. A segment perpendicular to the horizontal segment was drawn through the horizontal midpoint. OpenCV was used to differentiate between the iris and the eyelid at the two ends of the vertical segment using color difference. The point of intersection between the vertical and horizontal segment produced two vertical and horizontal subsegments, shown as pink brackets in Figure 1. The ratios of the vertical and horizontal subsegments were calculated. The number of times the horizontal or vertical ratio exceeds the maximum ratios of the baseline eye movements after the two tests was recorded. This number was interpreted as the number of times the eye gaze drifts out of the frame of the laptop, which signifies the shift of attention away from the passage (Zhao et al., 2012).

3.6 | Data analysis

Paired-samples t-tests were used to compare the scores, reading speeds, and eye movements, as this test compares the means of two measurements from the same individual taken at two different times (Student, 1908). Levene’s test was used to ensure equal variance among samples, which is a precondition of the paired-samples t-test (Mandelbrot, 1961). IBM SPSS Statistics was used to conduct these tests.

4 | RESULTS

Table 1 shows the demographic characteristics of the participants. A total of 60 high school students in the international school participated in the research: 30 for the controlled experiment and 30 for the variable experiment with exercise. Since both experiments had samples greater or equal to 30, according to the Central Limit Theorem, the sampling distribution could be approximated to a standard normal distribution (Kwak & Kim, 2017). All of the subjects have signed consent forms. Throughout the experiment, they were supervised by a certified PE teacher. The subjects were all involved in sports teams, clubs, or classes on a weekly basis. Simple random sampling was used within that population; observation of individual participants was independent of that of other participants. There were approximately equal numbers of participants from both genders and age groups.

A paired-samples t-test was conducted to compare the scores of the two tests for the controlled experiment. Three other paired-samples t-tests were conducted to compare the test scores, eye movements, and reading speeds under conditions before and after exercise for the variable experiment. Table 2 summarizes the categories that were compared in the paired-samples t-tests. The results of the paired-samples t-test are shown in Table 3.

The samples are continuous, approximately normally distributed, and do not contain outliers. The samples also passed Levene’s test for homogeneity of variance. For the controlled experiment, the subjects only averaged 0.20000 points more in the first test. The two-tailed p-value was .169, which is less than .05. Thus, there was not a significant difference in the scores for the two tests.

In the variable experiment with exercise, the mean score before exercise was 7.1667, while the mean score after exercise was 8.4333. There was a significant difference in the scores for the variable group. Further analysis of the data shows that there was a significant difference in the number of times the eye movement shifts out of the screen frame during the test before exercise, which had a mean of 2.6333, and the test after exercise, which had a mean of 1.3000. There was a significant difference in the reading speeds for the test before exercise, which had a mean of 3.3356 words per second, and the test after exercise, which had a mean of 4.3913 words per second. As shown in Table 3, the one-tailed p-values of the categories of the variable experiment were all less than .001, indicating significant differences. What follows is the analysis and interpretation of the mean differences and p-values in the paired-samples t-tests.
**TABLE 1**  Demographic characteristic of participants

| Characteristics | Control group | | | Experimental group | | | Full sample | | |
|-----------------|---------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
|                 | n  | %       | N  | %       | n  | %       | n  | %       |
| Gender          |    |         |    |         |    |         |    |         |
| Male            | 15 | 50      | 14 | 46.67   | 29 | 48.33   |
| Female          | 15 | 50      | 16 | 53.33   | 31 | 51.67   |
| Age             |    |         |    |         |    |         |    |         |
| 16 years        | 11 | 36.67   | 10 | 33.33   | 21 | 35      |
| 17 years        | 10 | 33.33   | 10 | 33.33   | 20 | 33.33   |
| 18 years        | 9  | 30      | 10 | 33.33   | 19 | 31.67   |

**TABLE 2**  Paired-samples t-test categories

| Category | Broad categories | Specific categories | First test | Second test |
|----------|------------------|---------------------|------------|-------------|
| 1        | Scores in controlled experiment | Number of correctly scored questions | | Number of correctly scored questions |
| 2        | Scores in variable experiment | Number of correctly scored questions before exercise | | Number of correctly scored questions after exercise |
| 3        | Eye drifts in variable experiment | Number of time eye drifts away from laptop screen before exercise | | Number of time eye drifts away from laptop screen after exercise |
| 4        | Reading speeds in variable experiment | Words per second read before exercise | | Words per second read after exercise |

5  | **DISCUSSION**

5.1  | Data analysis

Since there was not a significant difference between the two test scores of the controlled experiment, it could be inferred that there was no significant difference between the difficulty of the two tests. This shows that two tests were viable in testing the difference in scores and attention indices before and after exercise in the experimental group.

In the experimental experiment, there was a significantly higher number of times participants’ eye movements drift beyond the frame of the screen during the test before exercise. This suggests that during the test, participants’ attention was more susceptible to influence and distraction beyond the passage displayed on-screen; after exercise, participants were more concentrated on their task. This result clearly aligns with the existing literature and claims of Budde et al. (2008), de Sousa et al. (2008), and Spitzer and Hollmann (2013) that physical exercise enhances subjects’ attention through activation in the prefrontal cortex and cerebellum.

In addition, the reading speed of the test taken after exercise was significantly greater than that of the test before the exercise, suggesting that exercise caused participants to more efficiently read and absorb information. Since it has been established in this study that physical exercise causes decreased eye drifts, a sign of inattention, the accompanying increase in reading speed could indicate and be connected to an increase of attention. This qualifies Miller’s (2015) claim that longer reading times indicate enhanced attention only in self-paced reading without limited time.

The results of these two attention indices suggest that participants were more attentive and engaged in test taking after exercise. The enhancement of attention could be reflected in the two scores of the experimental group. The test after exercise had higher scores than that before exercise. This affirms with Sievertsen et al. (2016) and McConaughy et al. (2009) that attention is an integral factor in standardized testing performance. Taken together, exercise caused participants to become more attentive in their tasks, which was accompanied by an increase in test scores. It could be logically confirmed that, in line with the literature, acute, coordinative physical exercises improve standardized test scores through enhanced attention, which was quantitatively measured and correlated by reading speed and the number of eye drifts. This study further consolidates that reading speed and eye movements could be used to correlate physical exercise and testing performance, as well as confirm with past studies that the indices are potential methods to quantify attention. Thus, these results validate the line of reasoning established in the literature, and the hypothesis was proven to be correct.
5.2 | Implications

Since the hypothesis was proven correct, students could learn to better perform in standardized tests. While it should be noted that physical exercise does not necessarily increase students’ maximum testing performance and scores, it has the potential to help students concentrate and engage more attentively with the test to increase their performance closer to their maximum potential. This method could help decrease the fluctuation in an individual student’s performance by decreasing the effects of external distractions (Jonikaitis et al., 2013). Thus, it could help schools more accurately and reliably assess students’ academic performance and aptitude. Students could replicate steps in the exercise experiment, without measuring attention, to evaluate if physical exercise helps improve standardized testing, before official tests. Schools could make it optional for students to access nearby sporting facilities before the test. With the recent announcement from the College Board to digitalize the SAT, this study provides further insight into future test-taking strategies. Since standardized tests were done digitally in this experiment, the method could more realistically simulate that of an actual SAT test, making the results of this study more predictable in the future. Furthermore, this study verified the applicability of the two indices, reading time and eye drifts, in measuring attention.

5.3 | Limitations

However, there are limitations. While the study did use eye movement to gauge and track attention, the study neglected the effect of head movement, one of the indices of attention per Nguyen et al. (2018). The rotation of the face by head movement makes it more difficult for dlib to create a facial landmark and OpenCV to track the pupil movement. If participants’ head position did fluctuate throughout the test, there may be inaccuracies in the detected number of times the eye drifts, thus affecting the measured degree of attention (Wu & Ji, 2018). If the degree of head rotation was large enough to create inaccuracies in eye movement tracking, it could be inferred that the participant’s attention was not focused on the screen, making it a potential factor in the experiment.

Another limitation is the difference in required exercise recovery time for each person. While age and heart rates have been accounted for in exercise intensity for each subject, the recovery time was standardized to 5 min as suggested by Cantrelle et al. (2020) for all subjects. However, resting time could potentially affect participants’ level of attention (Gutmann et al., 2018). Too much resting time could cause the effect of the acute exercise to lessen, but too little resting time could create excessive fatigue for participants, leading to less focus on the tests.
5.4 | Future directions

To address a limitation, future research could include head movement as an index in measuring attention. Similar to how eye movement measures attention, the degree of rotation of the participants’ face could be indicative of where their attention is directed toward. Accounting head movement could also make eye movement more accurate, as specified in the limitations. In addition, future works could evaluate the effectiveness of various attention indices in predicting testing performance. Since this study uses running as an acute, coordinative, aerobic exercise, future studies could explore the effects of other acute, coordinative, aerobic exercises or other physical exercises with different intensities, such as walking as suggested by Hillman et al. (2009), on attention and standardized testing scores. To investigate the applicability of this study in real life, natural experiments could be conducted to compare attention and standardized test results of a class of students right before a physical exercise course and another one right after. Not only does the sample increase, but the results of the natural experiment could also provide suggestions to school curriculums to maximize student performance in standardized testing. Future research could develop on this study and better simulate the standardized tests in the future. Digital tests with formats and lengths more similar to those of the official SATs could be used to better simulate the conditions of a real test. Moreover, since this experiment only used the SAT exam as the standardized test, future research could replicate this experiment with different standardized tests and examine the effect of physical exercise on them.

6 | CONCLUSION

This study affirmed the correlation between physical exercise and standardized test scores, as outlined in the literature, by evaluating and quantifying attention. It demonstrated that acute, coordinative, aerobic exercise could improve subjects’ attention, as suggested by decreased eye drifts and increased reading speed. The improvement of attention was then reflected in the increased standardized test scores after the physical exercise. This study validates the line of reasoning of past works and suggests physical exercise as a potential means to help students maximize their standardized testing performances. Future research could focus on including head movement as an attention index, replicate the experiment on different standardized tests or exercises, and conduct natural experiments to better simulate real-life conditions to increase applicability.

ACKNOWLEDGMENTS

We sincerely thank our teacher Toulouse-Antonin Roy and advisor Horng-Horng Lin for providing constructive guidance on experimental procedures and unwavering support to our research. Furthermore, this paper would not have been possible without the support of the school PE teacher and the student participants.

DATA AVAILABILITY STATEMENT

Data used to support the findings of the study are within the article.

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PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1002/brb3.2800

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How to cite this article: Huang, J., Huang, H., Chang, B., & Ho, J. (2022). Evaluating the effectiveness of physical exercise in improving standardized testing performances through attention indices. Brain and Behavior, 12, e2800. https://doi.org/10.1002/brb3.2800