Design Evaluations in Educational Settings: A Neuroscientific Study of Incentivized Test/Retest on Student Performance

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To understand the impact of incentivized test/retest scenarios—where students are afforded an opportunity to retest for an incentive—in design education settings, this study examines participants' brain activity using electroencephalography (EEG) during stressful retest situations. This study mimics educational scenarios where students are allowed to retest after a first attempt. Twenty-three student participants were randomly divided into two cohorts: control and experimental. Participants were asked to complete a preliminary questionnaire self-assessing their ability to handle stressful situations. Both cohorts were subsequently asked to complete the typing test and complete an Emotional Stress Reaction Questionnaire (ESRQ), indicating their emotional response during the typing test. The participants were subsequently asked to complete the typing test and accompanying ESRQ a second time. However, prior to the second test, the participants in the experimental cohort were incentivized with a monetary reward for improving their typing speed. This stimulus is used to increase the already stressful situation for the experimental cohort and examine changes in brain activity when the "retest" is incentivized. The results indicate no significant changes in brain activity, emotions, or typing performance for the control group. However, the experimental group showed an increase in EEG sensor activity; specifically, the sensors that control vision and emotion. The experimental group's performance was correlated to their emotional responses, rather than their EEG sensor data. Additionally, the experimental groups' positive emotions were increased for the incentivized typing test. The findings provide recommendations for educational retests practices.

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Introduction

A goal of design research today is understanding human design behavior [1]. Efforts from educators and researchers in learning the potentials of a designer's cognitive and creative thinking have opened the proverbial door for more intervention studies to further understand the complex nature of human behavior and thinking. Intervention studies are conducted in classrooms, occupational epidemiology, and educational institutes aimed at improving individual health and achieving gender equality, diversity, and motivation. The objective of intervention studies is to understand human behavior and understanding of complex brain functions, to develop training modules for improving motivation and increasing performance. Research in human brain plasticity provides evidence on rapid adaptability to complex tasks involving decision-making, memory strength, and cognition. There is a growing need for the application of cognitive neuroscience findings in real-world, educational, and workplace environments. The study of cognitive neuroscience in design education settings may provide insight into the formation of design engineers and benefit educators.

Neuroscience studies on development training are aimed at increasing the understanding of brain functions and performance [2]. Popular studies on training and development, such as London Taxi driver's memory training, leading to modulation of hippocampus's gray volume [3], and increment in brain activities in the prefrontal lobe among meditation practitioners have positively supported the importance of training [4,5]. Training is a well-organized and systematic approach toward improving performance in any controlled environment setting by ethically increasing the potential of the individual or group in said environment. Classroom techniques, such as training students in collaborative learning, project-based activities, group work, etc., have shown a positive impact on learning and development.

Engineering design is synonymous with problem-solving [6], as it is regarded as a twofold activity comprising of identifying the problem and generating the solution for said problem. Engineering design involves conceptual development [7], collaboration [8], computer-aided tool development [9], optimization [10], sustainability [11], human factors, and many other facets. Designer's creativity in problem-solving is the protagonist of the innovation, and yet more than often, it fails to meet the greater demand of empathy [12,13] from the stakeholders. Manufacturing with digital twin technology [14] aims to bridge the gap between product design and emotional response. Electroencephalogram (EEG) data in addition to physical data and emotional feedback aims to benefit smart design and manufacturing. Yet, there exists a gap in understanding how students learn designs and their thinking throughout the learning process. Acquiring a fundamental understanding of the various

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facets of design including designer's thinking [15,16] will benefit the design educators by providing insight into how students respond to various design learning stimuli. The setting for current formal design education is senior capstone design, a culminating design experience for students enrolled in engineering programs.

Educators have used the principle of providing students with extrinsic motivation to impact intrinsic motivation for a more engaging learning environment. Intervention studies in project-based learning environments, such as the senior capstone design course in engineering, targeted at increasing student motivation have shown the importance of training and incentives. In a previous intervention study, the researchers built channels to increase extrinsic motivation (praise and extra-credit) in senior capstone design classroom presentations [17]. The aim of this intervention study was to decrease anxiety, one driving factor of motivation. The instructor of the course and graduate student assistants guided senior capstone design students in developing intrinsic motivation throughout the course by providing opportunities through test/retest training and thus hoping to regulate anxiety and self-efficacy. Test/retest training is a method of providing individuals with an additional opportunity to repeat the activity by incentivizing the repeated task. For example, if the student design team missed the opportunity of understanding how to formulate a problem statement correctly, the instructor would subsequently provide the team a second chance at presenting that information, incentivizing the second opportunity with a bonus point for meeting the requirements before the second, immediately repeated, deadline. This technique not only improves student motivation but also provides opportunities for learning. This paper takes this previous study a step further in examining the impact of the test/retest training from a neurocognition perspective. Using the existing work to understand the impact of intervention studies through cognitive neuroscience provides an added dimension and clarity on the complex workings of human behavior.

Cognitive neuroscience, a branch of neuroscience, offers findings on brain functions to support ethical interventions of altering brain functions and relationships in the betterment of a larger population [18]. EEGs are one of the most effective techniques used to examine and study neural/electrical activity in the human brain. This is achieved by placing electrodes on the human scalp. The electrodes capture micro-electrical charges that take place between brain cells. EEGs have been used for decades in cognitive research for diagnosing epilepsy and sleeping disorders. Further, EEGs are used to study correlations between brain activity and working memory performance in infants, [19,20] and memory performance in toddlerhood [21]. EEGs are used to study overall brain activity to monitor impacts of trauma, addiction, and brain damage.

In this paper, we present an amalgamation of neuroscience, test/retest training, and a reward-based training case study. The content of this paper is based on an initial study presented at the IDETC-CIE 2021 conference [22]. The study was performed in a university setting to understand student performance during a typing test with a control group and an experimental group, from a neurocognitive lens. The experimental group is presented with a reward for best performance. Each of the groups are examined with respect to their neural activity during the typing tests, using an EEG. In addition, immediately following each of the two typing tests, the participants are required to self-evaluate their stress levels during the typing test, using an Emotional Stress Reaction Questionnaire (ESRQ).

Since individual EEGs could not be placed on students during retest design presentation scenarios, we develop a test that is analogous to the stress-induced environment where students are rewarded for making improvements over their original test. We investigate differences in neural activity among participants in the control and the experimental groups and examine the emotional response under a stress-induced environment. This is subsequently examined with respect to the participant's cohort to determine if the test/retest and reward incentives impacted the participant's neural activity or emotions during the second, immediately repeated, retest.

Background

Cognitive psychology is a branch of psychology focused on understanding brain functions and aid in analyzing human brain activities such as language, typing, memory, and abnormalities [23]. In a clinical setting, cognitive psychologists diagnose abnormal brain functions and provide valuable information in the treatment of conditions such as Alzheimer's [24], trauma, memory loss, and other motor disabilities. Advances in neuroscience research have guided advances in the bio-design industry such as the invention of biologically inspired prosthetic hands/legs that use electroencephalography signals to output the triggered command from neurons [25], which impacts roughly 3 million people across the globe [26]. Provided the findings from research, it helps medical practitioners in developing training modules to improve those functions [27].

In experimental settings, cognitive psychologists study the relationship between brain and mind and explain the different functions of the brain in event-related potentials. The two settings serve as the foundations of all neuroscience discoveries and applications. EEG studies are recommended in understanding designers' decision-making and performance. EEGs provide high-resolution data and have the ability to capture cognitive processes in specific brain functions. Traditionally, researchers in engineering have studied engineering behavior in design settings for concept generation, motivation, and decision-making through surveys, interviews, observation, and intervention studies. The addition of neuroscience in design research will provide insights into the cognitive processes of students and engineers at every stage of decision-making [28], hence assisting educators and instructors in increasing student motivation in classroom and performance. Advances in design research among engineers and architects lead to more discoveries in neurocognition and performance [29]. Educators across all disciplines highlight the importance of motivation in engaging classroom environment [30]. Engineering students have reported the value of classroom performance in the overall preparedness for industry and persistence in the program [31]. Studies have shown a 40–60% of retention rate in engineering, [32] which makes this study a small step in contributing to the larger goal of targeting student retention and preparedness for future challenges.

Cognitive training is popularly referred toward improving cognitive functions by training/interventions [2]. The two major approaches to cognitive training can be classified as strategy-based and process-based training paradigms [33–35]. Strategy-based training involves task instruction and applications. Process-based training is more focused on practice/repetition. In this study, we focus on process-based training, where the participants are asked to complete a test in under one minute and subsequently repeat the same test. This is termed as test/retest training in this study. The control group were administered two typing tests with no incentive to improve during the repetition; the experimental group is incentivized to repeat the typing test with improved performance for a reward of $100.

The first typing test can be linked to the preparatory practices that are used in research and real-world settings to prepare candidates for optimal performance under high-stress conditions. Research shows negative effects including increased anxiety and decreased performance in stressful environments [36–38]. Preparatory practices have long been used in medical and clinical settings to reduce the negative effects of stress and indicated promising outcomes [39]. For example, medical doctors practice verbal preparation with their patients before important surgeries and operations to reduce anxiety. Studies have also shown the positive impact of written and verbal preparations used in psychotherapy groups [40]. However, there is not enough evidence of the same results outside of medical settings. A study by Olson examined the impact of preparatory information on speech anxiety outside a clinical setting; however, the results indicated no overall significant change [41]. All high-stress environments share similar characteristics. Some examples include muscle tension, anxiety, increased heart rate, and so on. experienced by individuals under stressful conditions [42]. Therefore, while stressful situations may differ in nature, they produce similar responses and characteristics. The adaptability to those environments may change from person to person. The routine stressful tasks response is different from emergency stressful tasks. Huey and Wickens coined this change in stressor as a transition event [43].

Our previous research has shown that senior capstone design presentations can be regarded as one such stress-inducing environment for students, with the requirement of biweekly presentations to industry clients and instructors. It has also shown a decrease in presentation anxiety and an increase in performance at the end of the course, inferring the impact of repetition and preparedness garnered throughout the course [44,45]. Incentives can be intrinsic and extrinsic, both considered motivation-specific processes leading to desired behavior/outcome of the task. This type of cognitive intervention can be studied from a neuroscience perspective to gain insights into the event-related brain function.

With performance incentive systems, rewards can be conditional to the standards of performance [46]. With the adamant of research in reward-based performances, studies highlight two important topics: improving performance [47] and changes in intrinsic motivation [48]. The authors of this study have previously contributed to understanding student motivation in mechanical design courses [49]. The idea of improving motivation and student performance with rewards is controversial [48]. Educators have expressed mixed opinions on the use of rewards in educational settings to increase motivation and performance. Studies have also shown the negative impact on performance when the reward is larger than the task [50]. Important research in rewards and behaviors has shown the change in adult behavior, and the change in value motivation can be correlated to the monetary reward and its impact on performance [51–53]. It has also been identified that an adult tends to spend more physical and mental resources on a task given a bigger monetary reward [54]. Adults can optimize and strategize their actions toward the reward, thus making this study important in understanding the complex working reward-based performance.

Electroencephalography. The human nervous system is made up of the brain, spinal cord, nerves, and ganglia. The nervous system controls the body's response to internal and external stimuli. It is comprised of two main types of cells: neurons and glia. The basic function of neurons is to convey information across various parts of the nervous system. Neurons transfer this information in the form of electrical and chemical processes. Electroencephalogram or EEG is an imaging technique administered to read electrical activity within the brain, commonly referred to as brain waves. EEGs can be categorized under a safe experimental procedure with minimal discomfort caused to the participants.

Brain waves are categorized under four main groups depending on their frequencies: beta, alpha, delta, and theta. Beta (>13 Hz) waves are the most commonly and frequently observed among adults and children [55]. Beta activities are relatively fast and predominate the wave frequencies in the brain [56]. Alpha (8–13 Hz) is commonly observed in the normal awake EEG recordings. It is associated with memory functions [57]. Theta (4–8 Hz) rhythms are associated with drowsiness and early stages of sleep. Delta (0.5–4 Hz) is dominant in deep sleep state [58].

The four categorized lobes in the brain are occipital, temporal, parietal, and frontal. The occipital lobe is responsible for visual processing in the brain. It determines the concept of color, depth, height, facial recognition, and formation of memory visuals [59]. The temporal lobe is associated with the main functions in the brain: emotions, visual recognition, and audio processes. The parietal lobe plays three important roles: integration of information from sensory modalities, integration of memory and information from the sensory world, and integration of the individual internal state with sensory information. The role of this integration is to provide feedback to the muscles, eyes, limbs, head, etc. The frontal lobe is divided into three main regions: the primary motor region, the premotor region, and the prefrontal region. Frontal regions are associated with planning, guidance, and evaluation of behavior. Frontal regions are also associated with emotional functioning, decision-making, and judgment. The frontal lobe is responsible for a varied range of activities including motivation, regulation of dopamine, and personality.

In this paper, we examine participants' neural activity during a typing test. Research has shown the activation of brain regions such as the left superior parietal lobule, the left supramarginal gyrus, and the left premotor cortex in experiments measuring typing and writing [60]. It has been found that motor skills, such as typing, involve numerous cognitive processes in clinical studies [61–63]. Researchers have extensively studied and analyzed the human brain under chronic stress conditions. Advances in neuroscience research help in training individuals to overcome stress and brain dysfunctions.

Research Method

Twenty-three students, aged 16–22 years old, participated in the EEG experiment study. The students had varied educational backgrounds in STEM-based majors; however, none of the participants had formal typing training. Out of 23 study subjects, 12 were randomly assigned control group and 11 under the experimental group without prior information on the participant's background. The experiment takes place in a design laboratory setting at the university. An EEG device is administered to collect data on event-related potential activities. Additionally, participants take a stress survey after each trial of the typing test. None of the participants had received formal typing training, nor are they provided any information about the study prior to it being conducted. The experiment is conducted in a controlled environment; there is no change in the lab setting throughout the duration of the experiment. Each participant completes the typing test individually, to eliminate additional distractions. Further, participants are advised not to consume any stimulants (coffee/tea/energy drinks) across the duration of the study. Natural light in a lab setting was used instead of artificial light.

This quantitative study is an amalgamation of EEG data and survey responses collected from participants. In this section, we introduce the EEG device and the experimental setup for performing the typing test for the control and experimental cohort participants. We chose the use of a typing test for this study, as it provides a combination of multiple motor and cognitive functions. This preliminary study aims to provide a foundation for future, design specific, and neuroscience studies.

Experiment Design. The EEG experiment takes place in two groups: the control group and the experimental group. None of

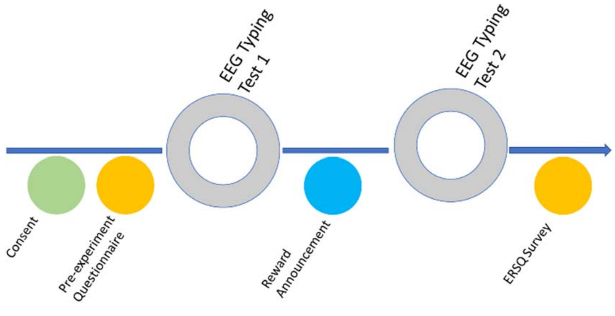


Fig. 1 EEG Experiment

Fig. 2 Study subject setup

the participants were trained specifically beforehand. The randomly selected participants follow the sequence of events as shown in Fig. 1. This is completed in a single, individual session, to eliminate distractions during the typing activity. Once the sequence starts, the participant does not leave the room until all tests and surveys are completed and data are collected. The study begins with a human consent form, followed by a pre-experiment survey. Upon completion, the participants are briefed about the typing test and EEG setup administered by the researchers (shown in Fig. 2). Each participant subsequently completes the first typing test (T1) while EEG and heart rate data are collected. Upon completion of the first typing test, each participant completes a stress response (ESRQ) survey self-assessing their stress levels during T1. Here is where the sequence of events diverge between the control and the experimental group: (a) the participants in the control group subsequently take the second typing test (T2), with EEG and heart rate data being recorded, and complete a second ESRQ survey thereafter to end their participation; (b) prior to a participant's second typing test in the experimental group, the researchers inform them that the participant that increases their typing speed the most will receive an award at the end of the test. The experimental group is subsequently administered the second typing test, followed by the ESRQ stress response survey, similar to the control group. For both groups, the second typing test is administered immediately following the completion of the first test and ESRQ survey.

An Institutional Review Board (IRB)-approved human consent form was given to participants upon arrival. The consent form signed by participants stated no health risk, however, indicated the possibility of experiencing minimum stress throughout the experiment, which varied based on the individual. The consent form was followed by a pre-experiment questionnaire. This pre-experiment questionnaire was administered to collect demographic information of the participants. The questionnaire consisted of questions on gender, age, and a Likert scale rating on daily stress levels. The participants scored on a scale of 15, poor to excellent, on items such as how well they handle stress, how often they experience stress and the impact of their daily stressors on their wellbeing.

Typing Test. In an ideal research setting, students would be equipped with an EEG during a design test/retest situation. However, due to the intrusive nature of EEGs and their immobility, we devised an incentivized test/retest scenario that mimics the stress of design presentations. Further, presentations involving the participant speaking could not be performed as the movement of muscles in the human face could alter the EEG readings. Thus, the authors devised a stressful environment that afforded a test/retest opportunity without requiring participants to speak or use their facial muscles.

The participants take part in a one-minute typing test twice during the experiment. The typing test is available online on TypingTest.com [64]. For the one-minute typing test, the website offers eight options for typing: Easy Text, Medium Text, Difficult Text, Tricky Spelling, Blind Spelling, Story Typing, Themed, and Professional. From the eight options, the researchers selected the story typing option beforehand for the participants. The story typing category further has seven options to select from. The researcher chose two of those options for the participants: Aesop's Fable and Tigers in the Wild. The control group and the experiment group participants complete both the typing tests. If a participant's first typing test is Tigers in the Wild, the second test is Aesop's Fable, or vice-versa. This is specifically designed so that the participants cannot "recall" their first typing test during the second test and do not know what they will be expected to type prior to either of the two tests.

Electroencephalogram Measurements. The EEG device was positioned on all participants before starting the EEG test. The researchers in this study had received prior formal training in administering the EEG device. The EEG device used in this study is a mobile EMOTIV Epoc+. This device has 14 channels recording brain neural activities. The channels are spaced with a standard International 10–20 location method with a sampling frequency of 256 Hz. The channels targeting the designated hemispheres are AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4 [65]. This device used a sequential sampling method with a single ADC. The alternating current (AC) coupled device has a built-in digital fifth-order sinc filter. The motion sampling capacity of the EMOTI Epoc+ is 128 Hz. The EMOTIV EEG is shown in Fig. 3(*a*), the spatial position of the electrodes is shown in Fig. 3(*b*), and a heatmap (one type of output) of the neuroactivity

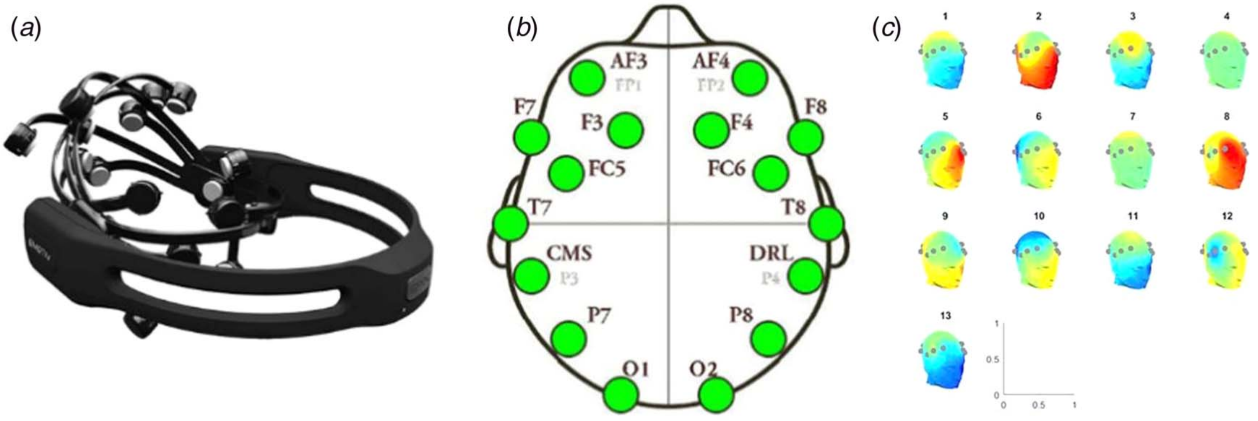


Fig. 3 (*a*) EMOTIV EEG headset, (*b*) spatial mapping of electrodes, and (*c*) heatmap of neuroactivity [65] during stimuli In Fig. 3(*c*). Odd numbers refer to the left hemisphere and even numbers refer to the right hemisphere. O, P, T, C, and F denote the occipital, parietal, temporal, central, and frontal lobe, respectively.

F8 surrounding area is associated with emotion regulation. F7 and F8 are considered important for impulse control and metabolic activities, cognition, and self-control. They are also referred to as control centers [66]. Working memory is associated with the prefrontal cortex area. F7 is associated with verbal and behavior, F8 with social inhibitions. F8 regulates emotions such as anger, joy, and happiness. Amygdala is responsible for communication with this region of the brain. F4 and F3 are associated with motor planning [67]. F4 is typically associated with left hemisphere motor planning activities. O1 and O2 are associated with visual processing in the brain. P7 and P8 of the parietal lobe are associated with somatosensory perception, spatial representation, and tactile perceptions. This refers to the physical sensory movements with a conscious perception such as touch, pressure, pain, etc. AF3 and AF4 are associated with the management of cognitive and executive decision-making. Temporal lobes, T7 and T8, are associated with the perception of biological motions. FC5 and FC6 are also associated with executive tasks and emotional resources on a given task. Common Mode Sense (CMS) and Driven Right Leg (DRL) are the reference channels primarily used to provide high-quality readings by reducing noise. External factors such as low blood sugar, flashing lights, caffeine, and hair products may interfere with the EEG test results.

Emotional Stress Reaction Questionnaire. The Emotional Stress Reaction Questionnaire [68] is used in this study to record the emotional responses of the participants at two instances during the study: after the first and after the second typing tests. The ERSQ questionnaire was designed for the participants to answer the emotional response in less than 60 s, therefore not extending the time between the two trials of the test (to ensure a test/retest situation). The ESRQ consists of 14 emotional words: indifferent, relaxed, pleased, glad, alert, focused, concentrated, energetic, concerned, uncertain, heated, mad, and angry. Student participants were asked to rate each emotion on a Likert scale of 1–4. T-tests analysis is performed on the recorded responses to determine differences between the two tests, as well as differences between the two groups of participants.

Analysis. The analysis performed will investigate the impact a “test/retest” situation has on the participant’s brain activity and the impact of incentivizing the second test for the experimental cohort. The goal of the study is to determine, through the use of an EEG, the change in brain activity and performance (measured in words per minute) between a participant’s first attempt and second attempt of a one-minute typing test. The typing test is intended to induce a stressful situation for the students as they attempt to perform well. Two statistical analyses are conducted to correlate and compare the typing performance and brain activity data: T-tests and regression analyses. T-tests are conducted between the two groups of participants (control versus experimental), as well as within cohorts (T1 versus T2), to determine if statistically significant differences existed in their brain activity during the typing test. Linear regression is used to determine the impact of the participant’s negative emotions on their typing speed for each of the tests. The analysis utilizes Akaike’s Information Criterion (AIC) to find the best fit model since correlations may be multilevel [69]. In this study, statistical significance is considered at $\alpha < 0.05$; however, $\alpha < 0.10$ is maintained for discussion purposes.

The overarching goal of the study is to determine, if differences in brain activity exist in the test/retest situation, what part of the brain this activity occurred in and what information this could tell us about the participant’s reaction to the ability to retest immediately.

Table 1 T1 Typing speed *t*-test results

Typing speed	Control	Experimental
Mean	40.25	32.17
Variance	337.5	117.9
Pooled variance	227.7	–
t Stat	1.312	–
p-Value	0.203	–
t Critical	2.074	–

Table 2 T1 Comparison of positive emotional score

Positive emotions	Control	Experimental
Mean	17.42	18.33
Variance	12.27	9.333
Pooled variance	10.80	–
t Stat	−0.683	–
p-Value	0.502	–
t Critical	2.074	–

Results

The goal of the study is to determine the impact of a “test/retest” policy when participants are exposed to a stressful situation to mimic design test/retest scenarios. An EEG is used to monitor the participant’s brain activity during two trials of a one-minute typing test.

First, it was necessary to determine if inherent differences existed between the two cohorts of participants. A *t*-test was performed to examine both cohorts’ typing speed on the first test, to ensure that one cohort was not naturally superior at typing to the other. Increased typing ability in one of the cohorts could result in naturally lower anxiety in our simulated “stressful situation.” Table 1 shows the results of the *t*-test exhibiting that there was not a difference between the two groups ($p = 0.20$).

Additionally, it is necessary to view the differences in the two cohorts’ positive and negative emotion scores (using the ESRQ) during the first typing test to determine how each of the participants reacted to the initial test. Similarly, a *t*-test was used to examine the participants’ reactions in the first stressful situation. Tables 2 and 3 show the positive and negative emotional scores, respectively.

Table 3 T1 Comparison of negative emotional score

Negative emotions	Control	Experimental
Mean	11.58	12.42
Variance	19.90	8.447
Pooled variance	14.17	–
t Stat	−0.542	–
p-Value	0.593	–
t Critical	2.074	–

Table 4 *t*-Test comparison of F4 (T1)

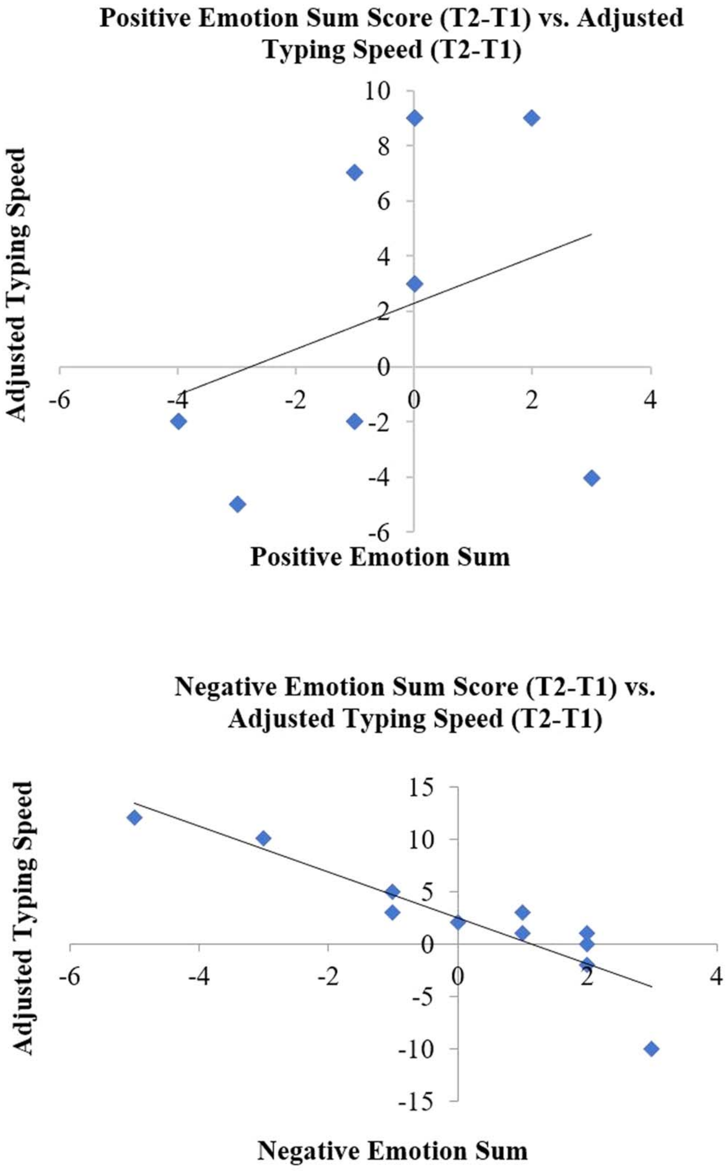
F4 Probe	Control	Experimental
Mean	4222	4206
Variance	316.1	626.7
Pooled variance	464.0	–
t Stat	1.884	–
p-Value	0.073	–
t Critical	2.080	–

Table 5 Experimental O2 sensor *t*-test

O2 Sensor	T1	T2
Mean	4150	4153
Variance	17.02	37.67
Pearson correlation	0.252	–
t Stat	−1.485	–
p-Value	0.084	–
t Critical	1.812	–

Table 6 Experimental FC6 sensor *t*-test

FC6 Sensor	T1	T2
Mean	4149	4155
Variance	308.4	201.9
Pearson correlation	0.741	–
t Stat	−1.704	–
p-Value	0.059	–
t Critical	1.812	–



	Coefficients	Standard Error	t Stat	P-value
Intercept	1.172	0.902	1.299	0.230
Positive Emotion	0.568	0.267	2.130	0.066
Negative Emotion	-2.079	0.291	7.147	9.74e-05

Fig. 4 Experimental group emotion sum values versus adjusted typing speed

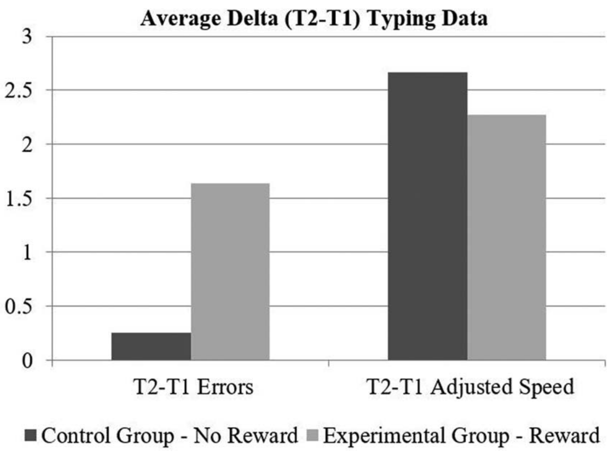


Fig. 5 Change in typing data between trials

Table 7 Control group typing speed (WPM)

Typing speed	T1	T2
Mean	46.33	49.25
Variance	426.9	425.1
Pearson correlation	0.975	–
t Stat	−2.224	–
p-Value	0.048	–
t Critical	2.200	–

As shown in the tables, neither the positive ($p = 0.50$) or negative ($p = 0.59$) emotional scores differed between the control and experimental cohorts during the first test. This indicates that neither of the two groups were well suited for the situation emotionally.

Provided that the data showed no significant difference in the participants' natural typing ability or emotional scores, a t-test assuming equal variance was performed between the two groups' EEG data during the initial typing test (T1) to determine if significant differences in brain activity occurred between the two groups during their first attempt at the typing test. Of the 14 different probes, none of the differences between the two groups were found to be significant; however, one sensor was maintained for discussion—F4 Right Hemisphere Frontal Lobe—producing a p-value = 0.073. Additionally, as previously outlined, significance was not found between the two groups' positive, negative, or total ESRQ scores during the first typing test. Table 4 shows the t-test comparison of F4 for the first test. Therefore, the groups of participants were not significantly different in their abilities, emotions, or performance during the first typing test. This indicates that all of the participants responded similarly to the initial test, providing a baseline for the retest scenario.

Paired t-tests were completed on each individual group to determine if significant differences existed between the two typing tests (T1 to T2). It is interesting to note that none of the probes produced a statistically significant difference in the control group. Recall, the control group was exposed to a test/retest scenario *without* an incentive. However, the experimental group produced two p-values ($p < 0.1$) that were maintained for discussion purposes. The O2 and FC6 sensors produced p-values of 0.084 and 0.059, respectively. As shown in Tables 5 and 6, both the O2 and FC6 mean values increased between the two tests for the incentivized, experimental group. Linear regression was also performed to determine which (if any) of the sensors correlated to the participant's performance on the typing test. Further, an AIC analysis was also performed using to determine the best fit model. However, for the experimental group, it was found that the participant's adjusted typing speed was not correlated to any of the sensor data; rather, the participant's performance on the test was dictated by their *emotional scores*. This information is shown in Fig. 4.

Table 8 Experimental group typing speed (WPM)

Typing speed	T1	T2
Mean	36.64	40.55
Variance	157.9	170.1
Pearson correlation	0.942	–
t Stat	−2.952	–
p-Value	0.014	–
t Critical	2.228	–

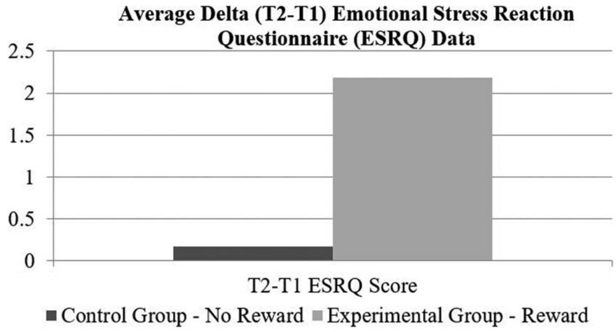
Therefore, the participant's typing data were further examined to determine if there were any statistically significant changes between tests for the two groups of participants. Figure 5 shows a comparison between the two groups' change in typing errors and typing speed between the first and second typing tests.

In the control group, the typing errors, adjusted typing time (with errors considered), and emotion scores (positive, negative, and overall) were found to be insignificant between typing trials. However, the control groups' typing speed (overall speed not considering errors made) was found to increase, with significance. This is shown in Table 7. This same phenomenon was found to be true for the experimental group of participants, as well. This is shown in Table 8.

However, both groups of participants' adjusted typing speed (considering errors and accuracy) were not found to have a significant change between trials. This indicates that, while both groups of participants did significantly increase their typing speeds, they were also making more errors and did not significantly improve between trials.

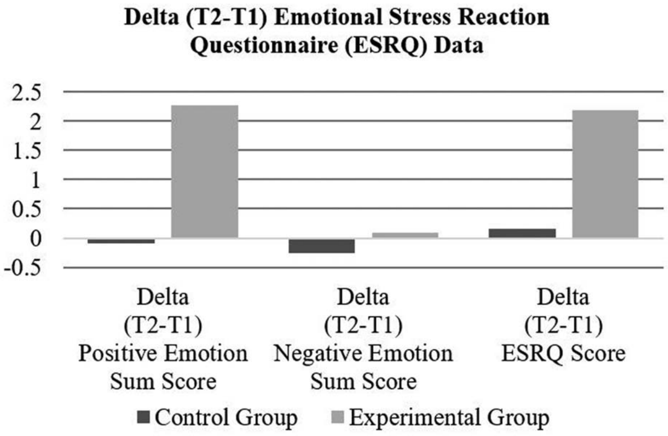
The analysis of the ERSQ questionnaire indicates the neutral response from the two groups upon completion of typing test 1 (T1), with no significant differences between the control and experimental groups' positive or negative emotions. However, one interesting finding was that the overall emotional score (determined via the survey given after the typing test) increased significantly during the second typing test for the experimental group that were offered a reward. The overall change for the control and experimental groups is shown in Fig. 6. It is important to note that this is the overall change in emotion, examining the change in both positive and negative emotion scores.

To further investigate this information, the control and experimental groups change in positive and negative emotion scores were viewed individually. This is shown in Fig. 7.



	Control	Experimental
Change in ESRQ	0.167	2.182

Fig. 6 Average change in ESRQ



	Positive Emotion		Negative Emotion		Delta Emotion	
	Control	Experimental	Control	Experimental	Control	Experimenta
ΔESRQ	-0.083	2.182	-0.250	0.091	0.167	2.182

Fig. 7 Overall change in ESRQ data

Table 9 Paired *t*-test for positive emotion of experimental group between tests

Positive emotion	T1	T2
Mean	17.91	20.18
Variance	7.891	15.36
Pearson correlation	0.737	–
t Stat	−2.845	–
p-Value	0.017	–
t Critical	2.228	–

As Fig. 7 shows, the experimental group that was offered a reward before the second typing test experienced a sizable increase in their positive emotions (also a small increase in their negative emotions) during the second typing compared to the first. The positive emotion was found to increase significantly on the second typing test ($p = 0.017$) for the experimental group, shown in Table 9. Their negative emotion did increase slightly as well, but this was not found to be significant.

Discussion

In this paper, we analyze the neural activity comparison between a control group and experimental group of participants during a one-minute typing test. We infer that the designing and typing tasks share some common attributes such as precision, decision-making, planning, efficiency, and many more. Hence, typing task was chosen for this study to mimic design presentation test/retests scenarios. The control group's participants were administered two, one-minute typing tests with no reward for improvement. Conversely, the experimental group was also administered two, one-minute typing tests with a reward of $100 gift card for best performance at the end of the second typing test.

There were no significant differences in EEG data between the two typing tests for the control group of participants. This indicates that similar brain activity occurred during the first and the second test for the group that was not offered an incentive to retest. However, in the experimental group, there was an increase in activity in the O2 and FC6 sensors, at $p < 0.1$, which is maintained for discussion purposes. This interesting finding aligns with other research [70] that suggests senior college students who are given incentives to retest will outperform those who are not incentivized. The ability to observe this difference through neuroactivities is unique and provides insight into the potential source for the difference.

The O2 sensor showed an increase between the two tests for the experimental group, upon announcement of a reward for the retest. The O2 region of the brain is responsible for visual processing in the brain. Therefore, this suggests the participants increased their attention in an effort to increase their accuracy and performance on the second, incentivized test. This is backed by findings that increased saccadic eye movement has been observed upon reward expectation in neuroscience studies [71]. The same can be inferred in the findings of this paper, where the typing test involves vision accuracy, and announcement of a reward therefore increases activation in the O2 sensor.

The FC6 sensor showed an increase between the two tests for the experimental group. FC6 is in the frontal/central lobe and associated with the executive and emotional resources. This suggests that the participants have an increased physical and emotional response when the test is incentivized. Other studies have also reported an extra expense of emotional and physical resources among adults when incentives are presented; this emotional and physical expenditure is also shown to increase when the monetary incentive is increased [54]. The results showing changes in the FC6 stressors in the experimental group indicate the impact of a reward on their emotions in the second typing test.

From a design education standpoint, the results suggest that when students are incentivized to retest their design demonstration, typically in the form of a presentation, they perform better than their unincentivized counterparts. This finding suggests that students may not make concentrated efforts (as indicated by the brain activities observed in the O2 and FC6 regions in the incentivized results) to improve if not incentivized to do so. If retests are only beneficial when incentives are offered, there may be value in intentionally evaluating original submissions meticulously with the intention of students attempting a retest to improve their grades. While this may seem like an aggressive approach to student evaluation, the experimental groups' participant's positive emotions increased with significance ($p = 0.017$) on the second typing test. This implies that students that participated in the incentivized retest felt better during the retest than during their initial typing test. Thus, students may benefit from performing a retest but will require an incentive to do so.

The design education recommendations of this study suggest that students should be implored to perform test/retests as part of their formal evaluation process. While students should not be forced to perform a retest, the option should be provided with an incentive (for instance, earning back missed points). By doing so, students place a greater concentrated effort toward improved performance which leads to positive emotions toward their activity.

Conclusion

The goal of the study is to determine the neuroscientific impact of providing students with a incentivized test/retest scenario in design presentations. Due to challenges in performing EEG studies during design presentations, a typing test is used to examine the effectiveness of using an incentivized "test/retest" scenario to improve participants' performance during stressful situations. The participants were divided into a control group and an experimental group, where the experimental groups' second trial was incentivized. The participants' brain activity was detected using an EEG and compared to their emotional response surveys and typing performance during each of the typing tests.

The results show that there were no significant changes in brain activity, emotions, or typing performance for the control group of participants (no reward offered). However, the experimental group showed an increase in O2 and FC6 sensor activity, controlling vision and emotion, respectively. The experimental participant's performance was also found to be correlated to their emotional responses, where their positive emotions were increased significantly during the second typing test, even though their performance did not increase.

Overall, this indicates that an incentivized retest has a positive impact on a participant's emotions, which shows promise for future design education intervention studies where students are allowed to complete a retest of a design activity. The recommendations of this study for design educators are to provide students with an option to exercise a test/retest with an incentive. Students should not be forced to perform a retest, but incentivized to do so as part of their formal evaluation process. To accomplish this, students must see value in attempting a retest, so educators must develop evaluation rubrics with the intention of a retest in mind.

Conflict of Interest

There are no conflicts of interest.

Data Availability Statement

The data and information that support the findings of this article are freely available online.[2] Data under embargo.

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