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TIME TO RELAX: NO EFFECTS TO THE STRESS RESPONSE AFTER SHORT-TERM USE OF A BRAIN-COMPUTER INTERFACE

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ABSTRACT: Chronic stress is a significant contributor to emotional distress and a myriad of health issues. Some coping mechanisms for stress and anxiety often have significant barriers preventing people from seeking a remedy. A new home-based treatment method using a brain-computer interface provides people with visual feedback of their affective state. This study compared EEG and Sham Neurofeedback to find if short-term use of a brain-computer interface had any effect on stress. We found EEG Neurofeedback, in the short-term, does not significantly reduce an individual's physiological or psychological stress response to an event-based stressor. One explanation is the participant's self-reported feelings of control of the on-screen object showed no significant differences between groups, which may potentially highlight a design issue in neurofeedback games. Next steps will be to reconfigure the immediate feedback loop to enhance the responsiveness of the application to better match the reported relaxation score from the headset.

INTRODUCTION

Chronic exposure to stress has significant psychological and physiological effects on human beings. Long-term exposure to stress impairs people's cognitive abilities for simple tasks like memorizing a list of words [1], inhibits academic performance in undergraduate students [2], increases the likelihood to engage in procrastination behaviours [3], and can even effect a person's overall health [4]. While stress falls on continuum between positive and negative, the primary focus of this study is the human response to an event that creates a negative or distress response in the brain [5]. Negative stressors are generally unpleasant events and can exceed an individual's coping abilities, resulting in anxiety. For most people, stress is a temporary state that can be easily overcome, but regular exposure to lower-level stress events over time increases the risk of mental and physical health issues [6], largely because the stress response doesn't dissipate immediately following the stressful event. The stressful response can persist in the body and the mind long after the event is over [7], especially if there is no recovery period between events [8]. Without proper intervention, many people experiencing repeated short-term stress events may be subjected to the ill effects of chronic stress and significantly limit their career opportunities due to the typical avoidance strategies enacted by people who suffer from anxiety [9].

Stress and Coping Mechanisms: When faced with a stressful event that exceeds a person's coping ability, some people attend in-person therapy sessions to reduce anxiety [5], [9], [10]. In-person therapy is designed to increase an individual's ability to self-regulate or control their response to stressful emotions [5], [9], [11]. These studies are based on self-reported claims and exclude physiological health markers, thus can only make claims regarding the individual's perception of health versus triangulating the data with physiological health markers, making it difficult to ascertain long-term health benefits. The therapies used in these studies require the active presence of a therapist, which reduces the immediacy of the response and requires active scheduling on behalf of the client. The therapies also don't address new technologies and behaviours that engage individuals, like video games [12]. The negative effects of stress motivate research into developing effective coping strategies through interdisciplinary inquiry. Revised coping mechanisms can borrow from neuroscience, psychology, and technology to establish more immediate mechanisms for reducing the response to predictable stress events (e.g., a public speech, an exam, etc.), incorporate a continuous biometric measure to determine whether or not the treatment is working and implement the motivational elements of game play. If a method can be found to mitigate the effects of predictable stress events and people are motivated to prepare in advance of a difficult conversation, an exam, or a public speech could mean a shift in the approach to therapeutic practices.

Brain-Computer Interfaces: Brain-computer interfaces may be a potential solution to reducing a person's response to stress in the short-term. Several studies have already determined certain brainwaves (EEG) are an effective measure of stress [13], and today, consumer grade EEG devices are becoming increasingly popular. But consumer grade EEG devices in the health and psychology domain is not yet validated and still needs exploration [14].

Amongst today's growing number of brain-computer interfaces, we reviewed two systems that currently address stress and anxiety in a scholarly way: Mindlight and Brainball. Both Mindlight and Brainball use an EEG headset as the main input device to an application. Mindlight is a PC-based game that uses an individual's attentional (beta waves) and relaxation (alpha waves) EEG scores as a means to interact with elements in a game-like environment (e.g., increased attention will turn on a light) [15]. Brainball is a real-world game that

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dynamically moves a physical ball across a table based on the user's neural activity [16]. Mindlight and Brainball depend on a single game to address multiple concerns (attention and stress) and are dependent on a PC-based windows platform or physical objects respectively, limiting its deployment potential. The Mind-full application, on the other hand, is an Android-based system with three 2D games that address different concerns: (1)a warm-up game using a pinwheel, (2) a meditation game using a paraglider visual, and (3) an attention game using stones with an inuksuk visual (i.e., digital representation of a human-made stone landmark). Each game animates an on-screen object (pinwheel, paraglider, or stone) based on the EEG scores of the user and changes the action of the on-screen object based on whether the individual's EEG scores are above or below a predefined threshold of 40. The visualization of neurofeedback in Mind-Full is intended for users to (a) better understand their current affective state by relating the position of the on-screen object to their relaxation levels and (b) over time, learn to self-regulate their stress-related emotions. The hope is with continued use of the device people will develop the ability to self-induce a state of relaxation without the support of any devices. To date both Mindlight and Mind-Full have demonstrated a reduction in anxiety with consistent long-term use [15], [17] but in neither case has a study been completed regarding the effects of short-term use. Brainball did demonstrate a reduction in stress in the short-term, but used a galvanic skin response to measure stress instead of the EEG device and had a limited number of participants [16]. No literature has been found that approaches any type of therapeutic practice from a short-term perspective, which is likely due to the embedded concepts established in psychology regarding habit development and reinforced learning [18]. By incorporating new elements into the therapeutic approach to stress reduction, like gameplay and neurofeedback, researchers have an opportunity to explore all potential uses of EEG Neurofeedback as a therapeutic tool.

The goal of this study was to further explore the potential uses for consumer grade EEG devices and the practical applications for positively altering a person's response to stress in the short-term. Should short-term use of an EEG neurofeedback device reduce the response to stress means that people can use the device in preparation for known event-based stressors (e.g., public speaking event). This study compared EEG neurofeedback with sham neurofeedback to understand if short-term use of a brain-computer interface can reduce the physiological or psychological stress response to an event-based stressor.

Hypotheses: Participants actively controlling an on-screen object using an EEG-based game, Mind-full, will:

H1: have a higher average of relaxation scores during a stressful event as compared to participants who receive sham neurofeedback in the video condition.

H2: self-report increased feelings of relaxation after a stressful event as compared to participants who receive sham neurofeedback in the video condition.

H3: self-report greater feelings of control regarding the on-screen object as compared to participants who receive sham neurofeedback in the video condition.

MATERIALS AND METHODS

Participants: 23 students volunteered for this study, but 1 participant's data was excluded from the analysis due to incomplete data. As such all associated data from the participant is removed. Participants (N = 23) were female (n = 15) and male (n = 8) undergraduate (n = 21) and graduate students (n = 2) from Simon Fraser University between the ages of 18 and 25 (M = 22.1). Participants were recruited via the University research participant system, SONA, as well as through individual undergraduate classes. Each participant was randomly allocated to one of two groups: the video group (n = 9) and the EEG neurofeedback group (n = 14). Each participant was given a choice of compensation in the form of a $15 gift card or course credit. The university's ethics board approved the study and each participant, prior to the start of the experiment, signed an online informed consent form.

Procedure: Participants were randomly allocated to either the EEG Neurofeedback or Video condition with sham neurofeedback, a video recording of someone else playing the Mind-full game. Each participant wore an EEG headset (Neurosky Mindwave Mobile) paired via Bluetooth to a Samsung Galaxy tablet running the Mind-full application throughout the entire session. The EEG headset consists of two pieces: an ear clip to ground the signal and a dry EEG sensor positioned at Fp1; above the left eyebrow on the forehead [19]. The EEG sensor outputs 12 bit raw brainwaves (3 – 100 Hz) with a sampling rate of 512 Hz and EEG power spectrums (gamma, delta, alpha, beta, and theta) every second. This study used Neurosky's proprietary eSense meter, meditation (relaxation is used to differentiate between the event and the EEG data score), which combines raw data from different brainwaves (emphasizes alpha) and converts it into a single

Figure 1 - Participant using the EEG Headset with Mind-Full's Meditation (relaxation) application.

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relaxation score, which updates the tablet every second. A minor delay between the headset and the tablet is estimated to be approximately 16.7 ms. Participants were seated in a chair in a standard-sized office with the tablet mounted on a black frame about 30 cm away from the participant for optimal hands-free viewing (Figure 1). Each participant was asked to focus on two separate games in the experiment: (1) a Baseline practice event, in which participants were asked to relax while watching imagery of a rotating pinwheel and (2) a Meditation event, in which participants were asked to relax while watching imagery of a paraglider gently landing on the earth's surface (Fig 2). Each participant was given access to an internet-enabled MacBook Pro laptop for online surveys as well as a black pen and paper surveys throughout the course of the experiment.

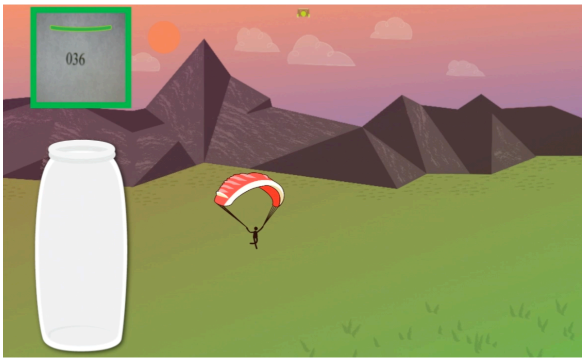

Figure 2 - Mind-full Paraglider App

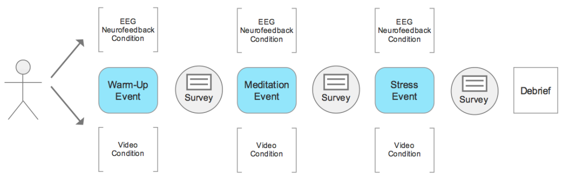

Figure 1 - Image of the two 2 x 3 independent measures design

A 2 (EEG Neurofeedback, Video) x 3 (Baseline, Meditation, Stress) independent measures experimental design was conducted (Fig 3). An independent measures design was selected due to the potential for a learning effect between conditions. The EEG Neurofeedback condition presented the participant with actual visual feedback of their neural activity, essentially connecting the animation of the on-screen object with their neural activity. The video condition was a representation of neurofeedback and presented the participant with an exact replica of the EEG Neurofeedback games withholding only the ability to control the object on-screen based on the neural activity of the user; instead the participant watched a pre-recorded video of the game, referred to as 'sham' neurofeedback. All participants were exposed to three events: (1) a 3-minute Baseline event that level set the data based on personal differences in neural activity, (2) a 10-minute Meditation event that captured the participant's neural activity in a meditative state, and (3) a 3 to 5 minute Stress event containing a math test. The math test was selected as a stressful event based on assessments of math anxiety and findings from a previous EEG study [20]–[22]. Self-report data was collected in-between each of the events, creating a second 2 (EEG Neurofeedback, Video) x 3 (Baseline, Meditation, Stress) independent measures experimental design. At the end of the session, each participant was asked to rate how much control they felt over the on-screen object.

Measures: The dependent variables are (1) continuous EEG data and (2) validated Stress-Trait Anxiety Inventory (STAI-6) to measure each participant's response to the three pre-determined events. EEG data is based on Neurosky's eSense meter parameters[1] and measured on a scale of 0 to 100, with scores between 0 and 40 classified as a non-relaxed state and scores between 41 and 100 as a neutral or relaxed state. The STAI-6 scales are on a scale of 0 to 4, with 0 being relaxed, and 4 being stressed. The STAI-6 has been documented as being both reliable and valid measure of stress [23]. Participants spent about the same amount of time in each activity in the EEG neurofeedback (M = 14:54) and video condition (M = 13:23). One self-reported question regarding the participant's feeling of control was asked at the end of the study in which participants were asked to estimate how much control they felt they had of the on-screen object from 0% to 100%.

RESULTS

This study aimed to discover if people have a reduced response to a stress event after they've actively controlled an on-screen object via a brain-computer interface for 10-minutes. Using two 2 X 3 independent measures ANOVA measuring both continuous EEG data (results per second) as well as self-report scales, this study found no significant differences between those who were actively controlling the object on screen in the EEG neurofeedback condition and those who were watching a video containing sham neurofeedback.

H1: Participants actively controlling an on-screen object using an EEG-based game, Mind-full, will have a higher average of relaxation scores during a stressful event as compared to as compared to participants who receive sham neurofeedback in the video condition.

We hypothesized participants receiving EEG neurofeedback would show higher relaxation scores after being exposed to a stress event. Shapiro-Wilks test indicate non-normal distribution (ps < .01), however since a factorial ANOVA was run, it will compensate for the non-normal distribution. The Levene's Test for unequal variances was not violated (*ps* > .32), but Mauchly's test indicated the assumption of sphericity had been violated $\chi^2(2) = 13.64$, $p = .01$, therefore a Greenhouse-Geisser correction was applied for within

1 http://developer.neurosky.com/docs/doku.php?id=esenses_tm

subject data. A 2 x 3 ANOVA showed a significant difference between the event types $F(1.33) = 5.33$, $p = .02$, η_p^2, = .20. The large effect size of .20 indicates a large difference in the magnitude or size between the events. Post-hoc analysis consisted of pairwise comparisons and found differences between the stress event ($M = 48.61$, $SD = 2.07$) and the main Meditation event ($M = 55.75$, $SD = 1.32$), $p = .002$, as well as between the Stress event and the Baseline event ($M = 56.36$, $SD = 1.20$), $p = .031$ (see Fig 4 for between group means). There was not a significant main effect between the EEG Neurofeedback ($M = 54.36$, $SD = 1.59$) and Video Condition ($M = 53.07$, $SD = 1.27$), $F(1) = .41$, $p = .53$, η_p^2, = .02. There was no significant interaction effect between Event type and Condition, $F(1.33) = 2.01$, $p = .16$, η_p^2, = .09, indicating no differences between the EEG neurofeedback and Video conditions between events. Thus, the first hypothesis is not supported. While both groups showed decreased relaxation scores during the stress event as compared to the Meditation or Baseline event, there were no significant differences between the EEG neurofeedback and Video conditions.

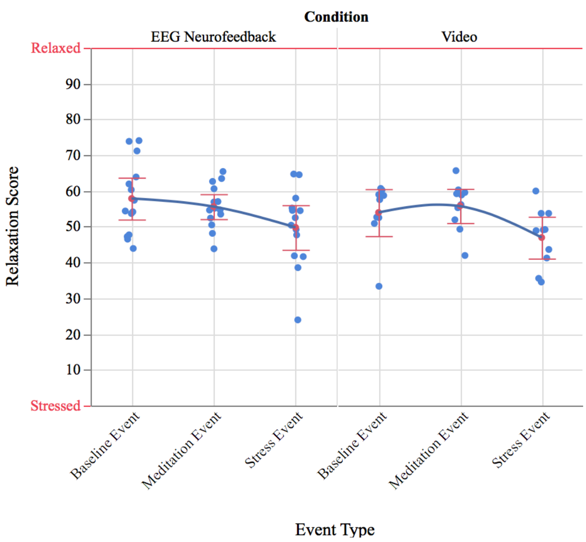

Figure 4 - Mean of EEG data by type of event, separated by video and EEG neurofeedback conditions (95% CI). The blue dots represent the mean score of individual participants.

H2: People actively controlling an on-screen object though an EEG neurofeedback device will self-report increased feelings of relaxation after a stressful event as compared to participants as compared to participants who receive sham neurofeedback in the video condition.

We hypothesized participants receiving EEG neurofeedback would self-report feeling more relaxed as compared to participants receiving sham neurofeedback. Shapiro-Wilks test indicates a normal distribution for all instances ($ps > .25$) except in the 3rd STAI-6 survey in the control group ($p = .02$). Levene's test did not suggest unequal variances for the STAI-6 ($p > .10$) and Mauchly's test indicated no violation in sphericity $\chi^2(2) = 2.13$, $p = .345$. The validated stress scale, STAI-6 ($\alpha = .88$), was considered reliable. A 2x3 ANOVA showed no main effect of conditions on STAI-6, as there were no significant differences between the EEG Neurofeedback ($M = 1.83$, $SD = .16$) and Video conditions ($M = 1.72$, $SD = 13$), $F(1) = .32$, $p = .58$, $\eta_p^2 = .02$. There were no significant differences in the STAI-6 self-report surveys between the 1st survey baseline ($M = 1.77$, $SD = .56$), 2nd survey pre-test ($M = 1.71$, $SD = .51$) and 3rd survey post-test ($M = 1.85$, $SD = .52$), $F(2) = .44$, $p = .65$, $\eta_p^2 = .02$ (see Fig 5 for between group means). There were no significant differences in the interaction between the event and the type of group, $F(2) = 1.61$, $p = .21$, η_p^2, = .07. Thus, the second hypothesis is not supported. There were no significant differences found between the self-reported surveys.

H3: People actively controlling an on-screen object

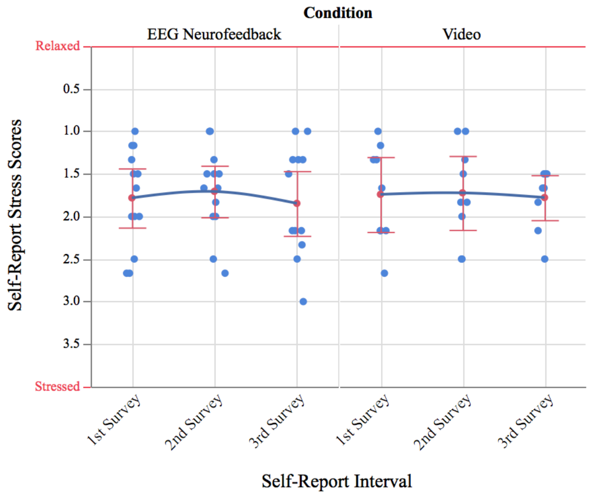

Figure 5 - Mean of Self-Report Surveys by type of event, separated by video and EEG neurofeedback conditions (95% CI). The blue dots represent the mean score of individual participants.

using an EEG-based game, Mind-full, will report greater feelings of control regarding the on-screen object as compared to participants as who receive sham neurofeedback in the video condition.

We hypothesized participants receiving EEG neurofeedback would indicate a greater feeling control of the on-screen object. Four participant's data was excluded due to missing data, leaving 12 participants in the EEG Neurofeedback and 7 participants in the video condition. Shapiro-Wilks test revealed a normal distribution ($ps > .25$) and Levene's test for unequal variances was not violated ($p = .83$). A pooled t-test was run and found no significant differences between the EEG neurofeedback ($M = 44.2$, $SD = .27$) and Video condition ($M = 47.1$, $SD = .29$), $t(17) = .22$, $p = .83$, $\eta_p^2 = .003$ (Fig 6). Thus, the third hypothesis is not supported and participants in the EEG condition did not report greater feelings of control compared to participants in the sham (video) condition.

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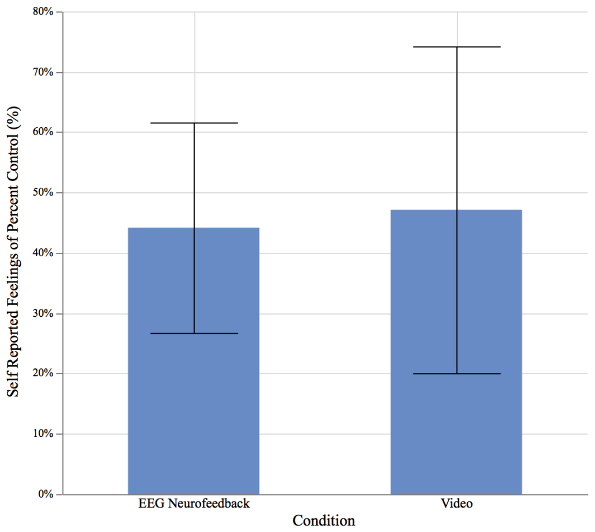

Figure 6 - Mean of self-reported feelings of control of on-screen object in percent by condition (95% CI)

DISCUSSION

This study aimed to discover if people had a reduced response to a stress event (e.g., demonstrated higher EEG relaxation scores) after they've actively controlled an on-screen object via a brain-computer interface for 10-minutes. We found no significant differences between EEG Neurofeedback and video-watching conditions in either the physiological or psychological measures to an event-based stressor.

One possible reason could be that the use of EEG Neurofeedback in the short-term (10 minutes) is insufficient time to train the brain to respond differently to a negative stimulus, as there is no literature studying the short-term effects of brain-computer interfaces on the stress response. In pre- and post- test studies, EEG neurofeedback devices appear to help people learn to self-regulate emotions after 8 weeks of use [17]. But in comparative studies in which there is both EEG neurofeedback and video (sham) neurofeedback, there are no significant differences between the sham and EEG neurofeedback conditions. For example, Mindlight reported that while there was a difference between pre- and post- tests, no differences were found between the treatment and control groups [15], which may suggest that neurofeedback games may be a support mechanism to help people remember to practice meditation skills instead of actively working to retrain the brain.

There is potential that studies using consumer grade EEG devices with Neurosky's proprietary eSense meter may not be an accurate measure of relaxation, however, the math test used in this study did report a significant difference between events, as well as in a previous study [22], indicating the eSense meter is picking up some significant changes in neural activity. It should also be noted that the Neurosky headset may register facial activity (e.g., eye blinks) [24], which may limit the findings of this study, despite Neurosky's claims that the device accommodates for facial movements in its algorithms.

The other possible explanation may be the perceived immediacy of feedback. Both the EEG Neurofeedback and Video group had approximately the same amount of time in relaxation with the only difference being that the EEG Neurofeedback group had active control of the on-screen object. We expected the Video condition with sham neurofeedback to report a lack of control of the on-screen object, and were surprised to find no significant differences between the EEG Neurofeedback and Video (sham) condition. Currently the Mind-full application reports on whether or not the user is above or below a specific threshold of 40, and does not provide immediate feedback to changes in the affective state; users experience a delay between their neural activity and the response from the on-screen object (e.g., object position). For example, the user's relaxation score has to be below 40 to send the paraglider upwards and above 40 to let the paraglider land, which means the user is not aware of the immediate changes to their affective state. Software design guidelines purport the need for users to receive immediate feedback when they perform an action, which may point to an important element that is missing from the user experience design: immediate feedback. Immediate feedback is a critical communication element between the user and the system [25], [26] that impacts an individual's feeling of control over the system. If a sense of control is a factor in neurofeedback games, improving the feedback mechanisms within the application could make short-term use a possibility. The next step will be to reconfigure the immediate feedback loop to enhance the responsiveness of the Mind-full game application to better match the reported relaxation score from the headset.

If feasible, the next study would test the effects of the design change to the system and investigate if the feeling of control is a factor in EEG Neurofeedback systems and short-term use. This study would use an concurrent parallel mixed methods independent measures design with one tablet application with improved immediate feedback (e.g., intervals of 20), one tablet application that utilizes the current parameters (0-40 and 40-100), and a control (video) condition with sham neurofeedback to test the individual feelings of control. A similar stress test would be used to measure their response to stress, followed by a brief interview to understand the participant's perspective on the feeling of control and collect any additional game feedback.

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