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The effectiveness of the *Mind-Full* neurofeedback system for cueing sustained attention

Abstract

Attentional issues are among the leading mental health challenges in North America today. Options to improve attentional abilities include pharmacological remedies as well as self-regulation (e.g. mediation, inward focus). However, the acquisition of self-regulation skills is not always easy. Neurofeedback-based systems have been shown to facilitate the learning of such techniques among children and adults, and technological advances like personal electroencephalogram (EEG) devices are making this type of treatment an increasingly affordable and viable option. Current research has focused on the benefits of using neurofeedback-based systems over an extended period of time. However, there remain at least two gaps in the literature. First, it is unclear whether neurofeedback-based training also has an *immediate* effect on attention. Second, researchers are unsure how many sessions are necessary for learning to take place. In this experiment, I help fill these gaps by exploring the short-term impact of a single neurofeedback-based session on sustained attention using a between-subjects experiment with 22 adults. Participants were3 exposed either to a functional neurofeedback-based game ("*Mind-Full*") or shown a sham treatment of a prerecorded video of the game. I hypothesized that participants using the functioning neurofeedback-based system would perform better on a test of sustained attention ("SART") than those who simply watched the video. Further, I anticipated that those using the game would have higher EEG attention levels as measured by the headset and would self-report higher attention levels. Results indicate that

Keywords: *neurofeedback, attention, self-regulation, mindful, sustained attention*

1 Introduction

Attentional issues are among the leading mental health challenges in North America today (Kooij, 2013). These difficulties are closely associated with stress and often have negative impacts on self-esteem, productivity, and well-being (Barkley & Fischer, 2011; Prevatt, Dehili, Taylor, & Marshall, 2015). Although pharmacological remedies can be effective (Kooij, 2013), a less invasive strategy is the use of self-regulating techniques (Tang et al., 2007). These include deep breathing, inward focus, and meditation. However, the acquisition of self-regulation skills is not always easy. There are many approaches to facilitate learning self-regulation; and research has shown neurofeedback-based systems to be particularly useful in the acquisition of these skills (Budzynski, 2009).

Interventions involving electroencephalogram (EEG) neurofeedback technology have been in practice for several decades (Lubar, 1991). Through the observation of real-time brain activity, children and adults can better understand their mental state and learn to adjust it (Gruzelier, 2014). Studies have demonstrated that neurofeedback-based training can be especially effective in developing individuals' sustained attention (T. Egner & Gruzelier, 2004; Tobias Egner & Gruzelier, 2001) which Manly et al. (Manly et al., 2001, p. 1066) define as the "capacity to maintain a particular processing set over time." Until recently, much of this research was confined to laboratory settings due to the costly and sensitive nature of the equipment. However, with the advent of commercially available personal EEG devices, brain activity can now be monitored using a relatively inexpensive headset and mobile device (Rogers, Johnstone, Aminov, Donnelly, & Wilson, 2016). Studies using this new technology have shown to be effective in helping individuals learn to self-regulate (Antle, Chesick, Levisohn, Sridharan, & Tan, 2015; Chen & Huang, 2014).

Self-regulation skills improve with practice. Accordingly, much of the existing research reveals the positive effects of neurofeedback-based systems on individuals' attentional abilities over extended periods of time (i.e. multiple sessions, spanning several weeks) (Tobias Egner & Gruzelier, 2001; Fuchs, Birbaumer, Lutzenberger, Gruzelier, & Kaiser, 2003). This long-term focus contributes to two gaps in the literature and in our applied knowledge. First, as Gruzelier (Gruzelier, 2014) notes, we do not know how many sessions are required for neurofeedback-based learning effects to take place. For example, Egner and Gruzelier (T. Egner & Gruzelier, 2004) describe a 10-session regimen to test improved attentional abilities, whereas Vernon et al. (Vernon et al., 2003) use an 8-session design. Repeated exposures may be sufficient for treatment effects, but there is no evidence to suggest they are necessarily more efficacious than a single exposure. In this study, I am interested in better understanding whether treatment effects are apparent after just one treatment session (without subsequent sessions). Second, it is unclear whether neurofeedback-based systems can have an *immediate* effect on sustained attention. For example, Vernon et al. (Vernon et al., 2003) studies treatment effects 4 weeks after initial exposure. Training with a neurofeedback-based system for several weeks may improve attentional abilities, but such a research design is time consuming and may be impractical in some real-world settings. In this study, I measure the outcome variable immediately following treatment, as opposed to days or weeks afterward. In this way, I aim to improve our knowledge of whether treatment effects are apparent in the short term. On a theoretical level, this study hopes to improve our understanding of the relationship between neurofeedback systems and attention – specifically, the conditioning effect of treatment frequency and duration.

This research builds on previous work using the neurofeedback-based game *Mind-Full*. *Mind-Full* is a mobile application that was developed for use with children who have experienced trauma or have attentional issues. Using commercially available EEG headset technology, *Mind-Full* provides real-time feedback on user's stress and attention levels and rewards them for achieving customizable thresholds (Antle et al., 2015). It consists of three unique games (further discussed in section 2.2). By practicing these *Mind-Full* games in a controlled environment, users have been shown to improve their self-regulation over time (Antle et al., 2015). To investigate the immediate effectiveness of *Mind-Full* in the short term, I compare two groups: one that used the real game, and one that received a sham treatment. I hypothesize the following results:

H1: *Participants using the Mind-Full neurofeedback-based game for a period of 10 minutes will make fewer errors of omission in a test of sustained attention (SART) than participants who observe the game without functioning neuro-feedback.*

H2: *Participants who use the Mind-Full neurofeedback-based game will make fewer errors of commission in a test of sustained attention (SART) than those who view it without functioning neurofeedback.*

H3: *Participants who use the Mind-Full neurofeedback-based game will have higher average attention brainwave scores during the intervention than participants who view it without functioning neurofeedback.*

H4. *Participants who use the Mind-Full neurofeedback-based game will self-report higher attention levels than participants who view it without functioning neurofeedback.*

2 Methods

2.1 Participants

A total of twenty-three students from Simon Fraser University's undergraduate and graduate population voluntarily participated in this study (9 male). Participants received compensation either in the form of course credit or a $15 gift card. Ages of participants ranged from 18 to 25 (M=21.7). 3 participants reported having been previously diagnosed with an attentional disorder (ADHD/ADD). One individual described their symptoms as severe, and also scored highly on a pre-treatment Attention-Related Cognitive Errors Scale (ARCES) (Cheyne, Carriere, & Smilek, 2006). This participant's data was removed from the analysis, bringing the final sample size to 22. This study was approved under the course ethics for IAT 802. All participants completed an informed consent form prior to taking part in the experiment.

2.2 Stimuli and Apparatus

The *Mind-Full* game system consists of a NeuroSky Mindwave Mobile headset (figure 1), connected wirelessly to a 10" Samsung (Android) tablet. The headset has a single sensor that rests on a user's forehead above their left eyebrow, and an ear clip which acts as a reference point to help reduce environmental noise ("NeuroSky," n.d.). Information relating to electrical impulses in the user's brain are transmitted in real-time via Bluetooth to the tablet. The incoming data consists of raw Alpha, Beta, Gamma, Delta, and Theta brainwave measurements, as well as algorithmically generated attention and meditation scores. Depending on which game the user is playing, an animation is triggered when the attention or meditation score is greater than a predefined threshold (figure 2). This feedback allows users to visually recognize when their brain activity changes, and rewards them with game tokens when this mental state is maintained. The game allows users to customize the threshold level, increasing the difficulty as they become more adept at controlling it over time. For the purposes of this experiment all thresholds were left at their default setting.

Participants were seated at a table for the duration of the session. An easel was placed on the table approximately 72cm from the participant. During the calibration and treatment stages of the experiment, a tablet was placed on the easel for the participant to view. For the calibration activity, the treatment group's tablet contained the *Mind-Full* application "Pinwheel game". During treatment, the tablet contained the *Mind-Full* application "Stone Game". The control group were shown pre-recorded videos of another person's game play of both games. They had no control over the animation.

Two measures of attention were used in this study. The Sustained Attention to Response Task (SART), as well as a survey based off of Millisecond's Mind Wandering Probe ("Sustained Attention to Response Task (SART)," n.d.). The SART is an updated version of Strub and Black's "A" Random Letter Test (Lezak, 2004). Participants sit at a computer while random numbers between 0-9 flash on the screen at a rate of 1 per second. Users are asked to press the spacebar every time a number that is not their target number appears. This test allows the observation of both errors of omission (i.e. not pressing the spacebar when a non-target number appears) as well as errors of commission (i.e. pressing the spacebar when the target appears). Minimizing errors, therefore, requires participants to remain focused for the duration the task. The code for this measure was obtained from Millisecond ("Sustained Attention to Response Task (SART)," n.d.) and was run locally on a MacBook Pro using Inquisit software.

Figure 1. NeuroSky Mindwave Mobile headset promotional photo, and demonstration of correct sensor placement.

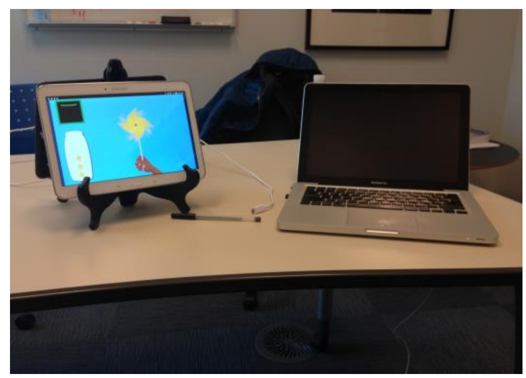

Figure 2. Participant's Workstation.

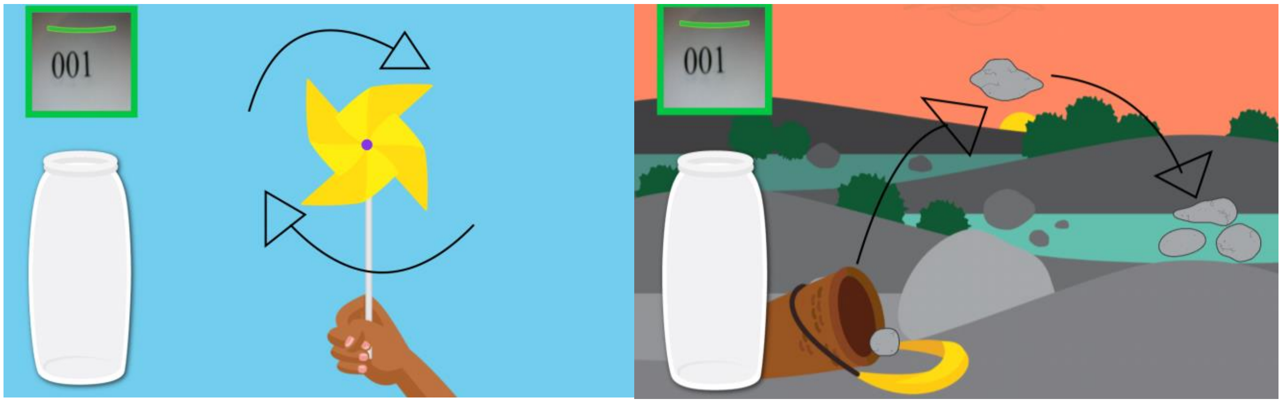

Figure 3 Screenshots of the *Mind-Full* Pinwheel and Stone Games. Arrows indicate the direction of the animation triggered when the thresholds are crossed. Video of the Stone Game can be found at the following URL: https://vault.sfu.ca/index.php/s/dAupz3oy6zR4Fcb

2.3 Procedure

Participants were randomly allocated into one of two conditions, treatment (n = 12) or control (n = 10). Neither group was told explicitly that they could control the game with their brain activity, rather they were asked to focus and to "see if you can control it." Both groups followed a similar procedure. First, the participants entered the lab, and were asked to sit at a table. Depending on scheduling, participants would either do the experiment alone, or with one other participant in the room (whose progress was blocked from view). Next, participants would complete the informed consent form and a demographics questionnaire. To ensure consistent instructions across sessions, a video was pre-recorded and played on a laptop.

Participants were then fitted with the NeuroSky headset, and used the *Mind-Full* Pinwheel relaxation game for two minutes to ensure a good connection; this process took longer when the headset required additional adjustment. To get a sense of whether participants experience significant attentional issues they were asked to complete an ARCES assessment. Next, participants completed a SART, looking for the target number 3, followed by a brief survey to assess their self-reported focus in the moment. Next they used the *Mind-Full* stone game for 10 minutes, followed by a second identical survey. Finally, they repeated the SART, this time looking instead for the target number 5; and completed a third, identical survey. At the end of the study, participants completed a questionnaire asking them about the experience, and if they have faced any anxiety or attentional issues in the past. A debrief was then held with each participant.

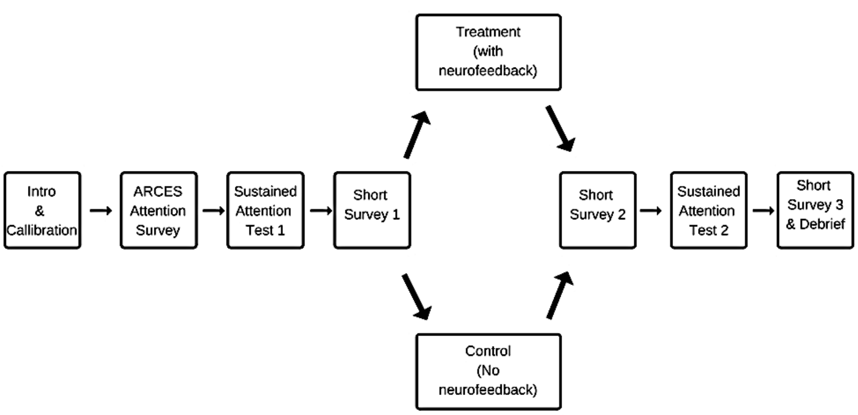

Figure 4. Experiment study design and measurement administration time points.

2.4 Experimental Design

This study had a 2 condition (neurofeedback condition: on, off) between-subjects design. Participants were randomly assigned to one of the two conditions. The experiment was a single session long and took approximately 40 minutes to complete. There were four dependent variables: SART errors of omission; SART errors of commission; average brainwave attention scores during the intervention; and responses to self-report surveys. Data for the SART and self-report attention survey were collected before and after the Mind-Full intervention (pre and post test points) and the self-report attention survey was also collected after final SART (post-SART test point) (as shown in Figure 4). The brainwave data was collected during the Mind-Full intervention.

2.5 Data Analysis

Assessment of the first two hypotheses was done using the SART score as an independent variable (pre and post-treatment). Hypothesis three uses the Average Attention Brainwave Index as a within-factor independent variable. The final hypothesis is testing the effects of Self-reported survey of attention score and using it as the independent variable. In the upcoming sections, we are going to provide test results for each of the four hypotheses.

3 Results

In this section we provide the result of the experiments based on each hypothesis and discuss about what this data means for each of these hypotheses.

3.1 H1: Errors of Omission

A two-way repeated-measures ANOVA was conducted for SART scores. We observe that there is a noticeable change between the pre-test omission error scores of the treatment group (*M* = 1.58, *SD* = 1.38) and their respective post-test error scores (*M* = 0.42, *SD* = 0.52) which indicates that the treatment is somehow affecting the participants and making them better. At the same time, there is an increase in error scores of the control group from before the experiment (*M* = 3.60, *SD* = 4.90) compared to after the experiment (*M* = 5.90, *SD* = 8.13) (see **Figure 3**).

There was no significant effect on the Time variable, $F(1,20) = 0.69,\ p = 0.42, \eta^2 = 0.03$. There is a significant interaction effect on SART omission scores, *F*(1, 20) = 6.25, *p* = 0.02, $\eta^2 = 0.238$, which proves that we can successfully refute the null hypothesis. Running a follow-up univariant ANOVA shows that this significant change is caused by applying the treatment to the participants (Treatment as a variable), $F(1,40) = 7.348, p = 0.10, \eta^2 = 0.155$ which shows that a considerable amount (because of the high effect size) of changes in SART scores (DV) are caused by the application of the treatment on the participants.

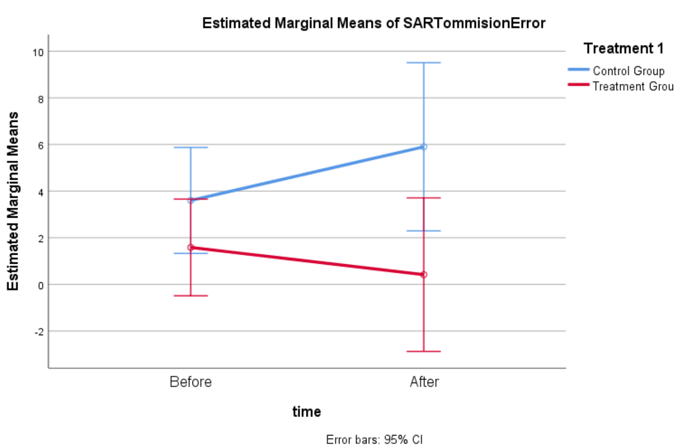

Figure 3 - Estimated marginal means of the SART scores for omission error

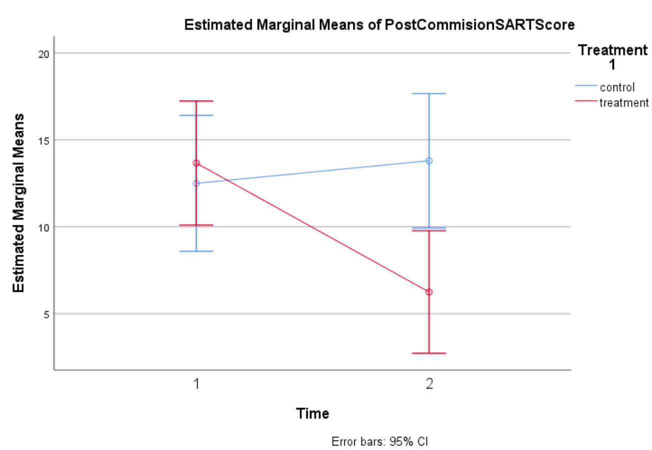

Figure 4 - Estimated marginal means of the SART scores for commission error

3.2 H2: Errors of commission

A two-way repeated-measures ANOVA was conducted for SART scores of commission error. As we can see in **Figure 4** that there is a noticeable change between the pre-test commission error scores of the treatment group (M = 13.67, SD = 5.82) and their respective post-test error scores (M = *6.25*, SD = 5.40) which indicates that treatment is somehow affecting the participants and making them better at making commission errors. Compared to the treatment group, the control group has not changed significantly in terms of pre-test scores ($M = 12.50, SD = 6.06$) and post-test scores ($M = 13.80, SD = 6.37$), these participants have actually became slightly worse in terms of commission error.

We can see a significant effect on the Time variable, $F(1, 20) = 8.93,\ p = 0.007, \eta^2 = 0.31$. There is, also a significant interaction effect on SART commission scores F(1, 20) = 18.14, p = 0.000, $\eta^2 = 0.48$ which proves that we can successfully refute the null hypothesis. Running a follow-up univariant ANOVA (to analyze the effects of Time variable) shows that this significant change is caused by applying the treatment to the participants (Treatment as a variable), $F(1, 40) = 9.50, p = 0.004\ , \eta^2 = 0.19$ which shows that a considerable amount (because of the high effect size or *eta square* variable) of changes in SART scores (DV) are caused by the application of treatment on the participants.

3.3 H3: Average Attention Brainwave Index

Based on **Figure 5**, we can see that in each minute of the experiment, the average attention brain index of the treatment group is higher than that of the control group. Index values for the control group ($M = 46.5, SD = 7.88$) seems to be lower than those of treatment group ($M = 51.29, SD = 7.88$) but we must bear in mind that the difference is quite small and the standard deviation of brainwave indices for both of these groups are quite the same.

Analyzing the within-subject effects of the indices shows no significant effect for Time variable, $F(9, 180) = 1.15, p = 0.33, \eta^2 = 0.05$. We also could not find any significant interaction effect, $F(9{,}180) = 0.384, p = 0.942, \eta^2 = 0.02$. These pieces of evidence, combined with a lack of significance for the between-subject variable of Treatment ($F(1, 20) = 2.41, p = 0.14, \eta^2 = 0.11$) shows us that despite a seemingly different index value for each minute, there is not enough difference between the two groups to support this hypothesis. It also disproves any interaction between treatment and the indices.

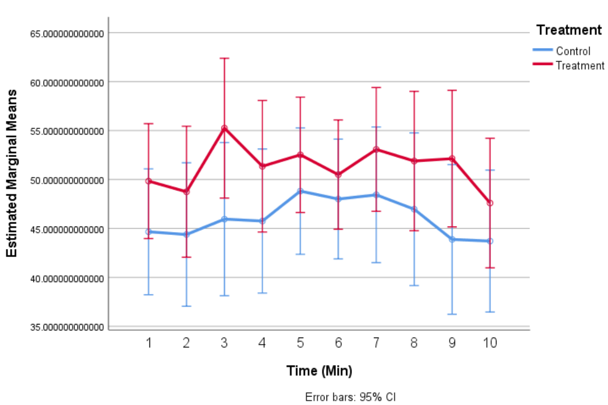

Figure 5 - Estimated Marginal Means of Average Attention Brain Index

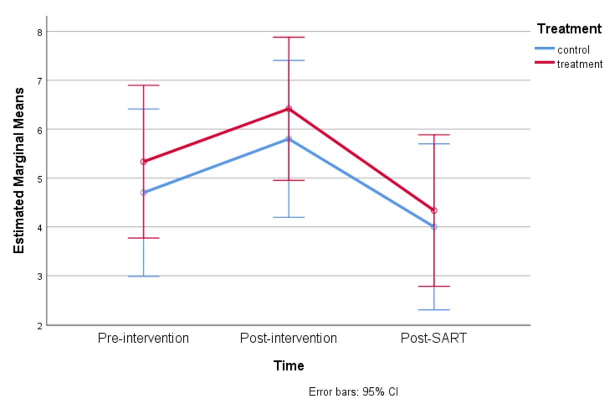

Figure 6 - Estimated Marginal Means of Attention Self-report Score

3.4 H4: Self-report Survey

Based on what we can see in **Figure 6**, it seems that the self-reported scores of the treatment group before the experiment ($M = 5.33, SD = 2.77$) is lower than after the experiment ($M = 6.42, SD = 2.50$) and then it goes up in post-SART scores ($M = 4.33, SD = 2.81$). This set of scores for the control group follows the same pattern for pre-intervention ($M = 4.70, 2.36$), post-intervention ($M = 5.80, SD = 2.34$), and post-SART ($M = 4.00, SD = 2.26$). The scores for the control group seem to be lower than the treatment group, but we need to test to see if any of these changes bear any significant effect.

Using an ANOVA test shows us that time is having a significant effect ($F(2, 40) = 3.42, p = 0.042, \eta^2 = 0.15$) on the results. However, there is no significance in interaction ($F(2, 40) = 0.03, p = 0.975, \eta^2 = 0.001$). Based on this data we cannot find enough evidence to support this hypothesis. Also, if we take a look at the pairwise comparisons, we can see that there is a significant difference in self-report scores between post-intervention and post-SART.

4 Discussion

Previous works have shown that participants can improve in learning self-regulated skills by long-term usage of *Mind-full* (Antle et al., 2015). However, the existence and magnitude of the immediate effect of this technology on users have remained unexplored. Using a series of short experiments for measuring SART scores, we found out that exposure to this treatment (Mind-full game) can have a noticeable impact on improving users' measured attention scores. Here we also encounter an interesting observation; not using the treatment for the control group has somehow diminished the users' attention scores. This effect can be the result of an anticipation factor in the control group. It means that their score is justified by their anticipation of getting worse as a result of a lack of treatment. However, there is not enough data to prove or refute such a hypothesis, and it can be the subject of follow-up or future studies.

There is also strong evidence to suggest that the users' commission error rate directly correlates to the reception of this mindful treatment. Participants showed improved attention scores in terms of commission error rates, and based on our data and the effect size of the treatment; we can say these improvements were mostly caused by the application of our treatment.

The experiment results for average brain wave index measurement show that users are seemingly affected by the application of the treatment, but further analysis disproves any correlation between the two. There is not enough evidence to support such a relation between these two factors.

Finally, this study shows that we cannot state that self-reported attention values are affected by exposure to the treatment. Although a careful analysis of the results shows that users' self-reported attention is being affected by the treatment, just after the SART score collection compared to after the treatment. This can suggest that the SART score collection tests or the passing of time could have a potential effect on the users' self-reported attention values. We do not have enough data to support or refute such a claim. Thus it would be an interesting question to be addressed by future studies.

5 Conclusion

Our collected evidence implies that using a mind-full activity such as the Mind-full game has a positive effect on participants' systematically measured attention score (in this case, SART). The game immediately affects these attention scores and improves them in the users. The lack of sufficient data, though, prevents us from generalizing this to every other attention score (e.g., EEG measured ones). Conducting this experiment with other attention measures and scales is suggested, as we might be able to reach a data census with SART scores. We were unable to find enough evidence to suggest that it had an immediate impact on their self-reported attention. Therefore, we suggest using different scenarios and a larger participant pool (with more variation) in order to reach any meaningful conclusion about self-reported attention.

Based on the presence of specific significant effects, we can also suggest using a qualitative measure to obtain a better view of the participant's mindset and their true self-reported attention.

6 Acknowledgments

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7 References

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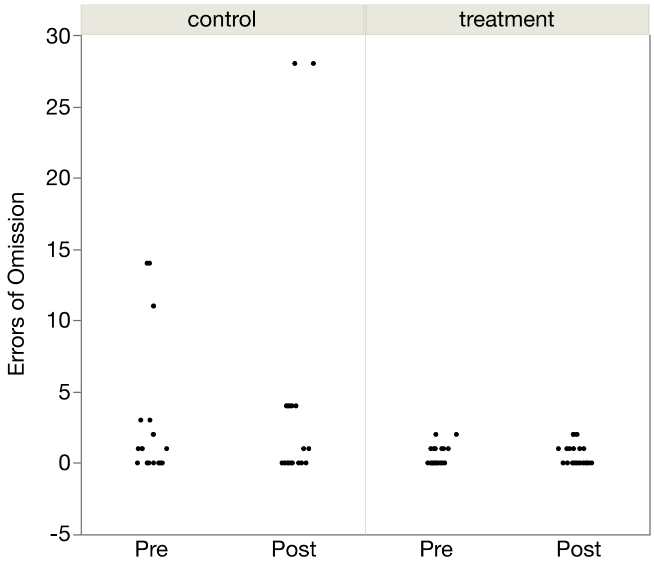
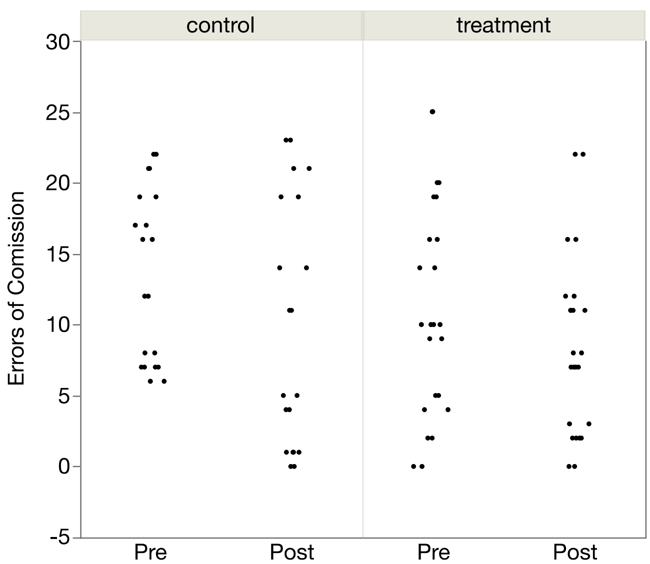
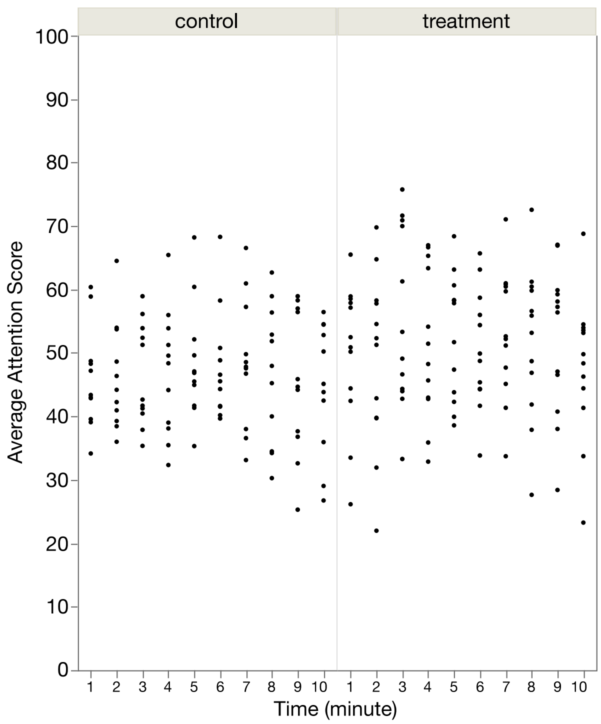
Appendix



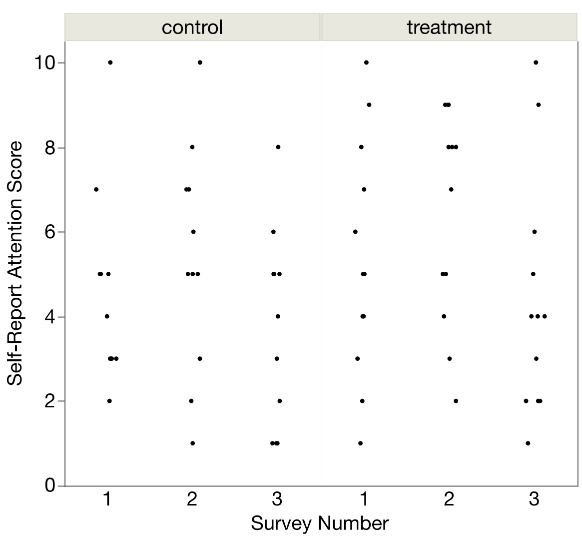
Appendix 1. Raw data plot for errors of omission pre/post treatment



Appendix 2. Raw data plot for errors of commission pre/post treatment



Appendix 3. Raw data plot for participants’ average brainwave attention score during treatment



Appendix 4. Raw data plot of participants’ self-report attention score