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Abstract: Purpose: To subjectively and objectively measure workload and performance levels among radiation oncologists performing computerized performance test (BrainPrint®) before and after introducing neurofeedback as measurable intervention. Methods: Eight subjects (4 attending and 4 residents) were recruited for this pilot study. Workload associated with information processing was assessed subjectively using the NASA Task Load Index (NASA-TLX) instrument, and objectively using electroencephalography (EEG) data analysis. Performance was subjectively assessed using flow-state survey, and objectively assessed based on time-to-test completion and performance-based errors (# of incorrect clicks during test). Statistical differences in pre- vs. post-intervention scores of i) NASA-TLX, time-to-test completion, and performance-based errors were tested using matched pairs t-test; ii) perceived performance as quantified by the flow-state survey using Wilcoxon signed-rank test; and iii) and pre vs. post temporal lobes EEG changes that were acquired during a continuous performance test using analysis of variance (ANOVA). Results: Analysis indicated significant reductions in subjective workload (NASA-TLX: p-value=0.01); significant improvements in objective workload as quantified by EEG (increases in Theta power: p-value<0.01) and reduction in high-Alpha/low-Beta power: p-value<0.01) suggesting improved information processing performance; and significant improvements in subjective performance (flow-state survey: p-values<0.001). No significant differences were found in objective continuous performance test measures (time-to-test completion, and performance-based errors; p>0.05). Conclusions: Results suggest that neurofeedback could be considered as an intervention to reduce workload and improve cognitive performance, which is of particular importance for radiation oncology physicians during treatment planning tasks where concentration and situational awareness for long periods of time are often necessary.

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November 30, 2014

Dear Editor-in-Chief,

I am thrilled to submit this manuscript aimed at relating neurofeedback as a means to reduce workload and improve information processing during provider-computer interactions.

I hope that your review committee looks favorably upon our manuscript. Please let me know if you require any additional information.

Sincerely,

Lukasz Mazur, Ph.D.

***Title Page (With Author Details)**

Neurofeedback as a Means to Reduce Workload and Improve Performance during Provider-Computer Interactions

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Running Title: Improving workload and performance.

Summary: Results suggest that neurofeedback could be considered as an intervention to 'optimize' information processing abilities for radiation oncology physicians.

Conflicts of Interest

Bill Scott is the CEO and co-founder of BrainPaint®. This study was supported in part by the University of North Carolina (UNC) Health Care System. We want to express our gratitude for their support.

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Neurofeedback as a Means to Reduce Workload and Improve Performance during Provider-Computer Interactions

Abstract

Purpose: To subjectively and objectively measure workload and performance levels among radiation oncologists performing a computerized performance test (BrainPrint®) before and after introducing neurofeedback as a measurable intervention.

Methods: Eight subjects (4 attending and 4 residents) were recruited for this pilot study. Workload associated with information processing was assessed subjectively using the NASA Task Load Index (NASA-TLX) instrument, and objectively using electroencephalography (EEG) data analysis. Performance was subjectively assessed using flow-state survey, and objectively assessed based on time-to-test completion and performance-based errors (# of incorrect clicks during test). Statistical differences in pre- vs. post-intervention scores of i) NASA-TLX, time-to-test completion, and performance-based errors were tested using matched pairs t-test; ii) perceived performance as quantified by the flow-state survey using Wilcoxon signed-rank test; and iii) and pre vs. post temporal lobes EEG changes that were acquired during a continuous performance test using analysis of variance (ANOVA).

Results: Analysis indicated significant reductions in subjective workload (NASA-TLX: p-value=0.01); significant improvements in objective workload as quantified by EEG (increases in Theta power: p-value<0.01) and reduction in high-Alpha/low-Beta power: p-value<0.01) suggesting improved information processing performance; and significant improvements in subjective performance (flow-state survey: p-values<0.001). No significant differences were found in objective continuous performance test measures (time-to-test completion, and performance-based errors; p>0.05).

Conclusions: Results suggest that neurofeedback could be considered as an intervention to reduce workload and improve cognitive performance, which is of particular importance for radiation oncology physicians during treatment planning tasks where concentration and situational awareness for long periods of time are often necessary.

INTRODUCTION

The successful practice of radiation oncology requires physicians to perform a series of computer-based tasks (e.g. image segmentation, treatment planning, plan review). The tasks require cognitive skills to support the processing of diverse types of information including text (e.g. clinical notes), quantitative data (e.g. laboratory measures), and medical images. The information processing and associated workload demands on radiation oncology physicians are considerable, especially when subjected to time pressures.

Suboptimal performance of radiation oncology physicians can lead to errors and the possibility of patient harm. Indeed, errors are estimated to occur in up to ≈ 5% of the > 600,000 patients receiving RT per year in the US; with serious/lethal events occurring ≈ 1 of 1,000-10,000 patents. [1] A reasonable fraction of these errors/events have been associated with several of these computer-based tasks. [2-5]

Such workload/cognition/performance-based issues are not unique to medicine, or radiation oncology. In several other settings, neurofeedback has been suggested to improve cognitive skills [6-7], including aviation (in work done by NASA: National Aeronautics and Space Administration), surgery, sports, dance, and musical performance. [8-12] Interestingly, many of the cognitive skills that neurofeedback has been shown to enhance are quite similar to the computer-based tasks integral to a radiation oncologist's practice. [1-2]

In this pilot study, we examine the effect of a neurofeedback protocol designed to help radiation oncologists to better regulate their information processing demands, with goals of reducing their workload and improving performance. Efficient information processing is of particular importance for radiation oncology physicians during RT planning efforts where concentration and situational awareness for long periods of time are often necessary. Thus, by virtue of task demands and the extreme adverse consequence of error, RT physicians can be considered as ideal subjects to evaluate the potential benefits of neurofeedback.

METHODS

Subjects: Eight subjects (4 attending and 4 residents) from a large teaching hospital were invited by the principal investigator via email and in person to participate in the study. The email message included the consent form describing the purpose, objectives, procedures and potential risks of the research study. All subjects were given ample time to make an informed decision regarding their participation in the study. Prior to experimental engagement and after the consent was obtained, a member of the research team provided a brief study orientation session for participants describing the simulated clinical environment and data collection methods. Participants were encouraged to ask any questions they may have had at any time. The study was approved by the hospital's Investigational Review Board (IRB). Subjects received $160 for participation in the study.

Neurofeedback Alpha/Theta/Beta intervention: The intervention consisted of eight neurofeedback sessions over a four-week period (on average two sessions per week) targeting cortical Alpha/Theta/Beta activity in both temporal lobes at location C5 and C6 as described by the international 10-20 system of electrodes placement. [13] The duration of each session was 28 minutes. The Alpha/Theta/Beta protocol was divided into four separate seven-minute training periods: C5 Alpha/Theta, C5 Beta, C6 Beta, and C6 Alpha/Theta. The inhibit frequencies for C5 and C6 Alpha/Theta were 2-4 Hz and 15-30 Hz while the reward frequencies were 5-7 Hz and 8-11 Hz. As Alpha dropped 30% below threshold a high frequency tone dropped in pitch and volume. As Theta increased by 60% above threshold a lower tone increased in pitch only. The inhibit thresholds were set to stop all sounds as these frequencies increased by 20% above threshold. For the Alpha/Theta protocol, all thresholds were reset if they remained beyond their respective thresholds for one minute. Inhibit frequencies for Beta C5 and Beta C6 were 1-12 Hz and 22-30 Hz while the reward frequency was 15-18 Hz. For Beta training, the thresholds were set to stop the sounds when 1-12Hz and 22-30Hz increased above threshold by more than 20%. Rewards were set so the Beta generated a tone as it increased above threshold by 60%. All sensors were references to linked ears. All sessions were done with eyes open.

Specifically, each session started with instructions for the physicians to remain relaxed and still for approximately 20-40 seconds as BrainPaint® software gathered baseline measures for the reward and inhibit frequencies. During protocols, when rapid increases in the 1-12Hz and 22-30Hz frequency ranges were 30% greater than the amplitudes recorded during the baseline period, participants were warned by the software via verbal and visual feedback about potential excessive movement or muscle tension. After three such warnings the software paused the protocol to ensure the quality of data collection during neurofeedback. We noted no pauses to protocols during our neurofeedback sessions. Further, to ensure quality neurofeedback sessions the BrainPaint® system displayed a bar graph that was proportionately more green than red when the reward conditions were being met and more red than green when the reward conditions were not being met. For each protocol, the software tracked the longest number of seconds for which the graph remained more green than red. When subjects noticed the graph turning all red and eventually light blue (increased 4-levels in red) they were instructed to click the right mouse button (as an indication of attentiveness), which would cause the graph to drop back to all green and maintain its increasing number of seconds of ‘hold’ time. This allowed the software to adaptively recognize an individuals’ own levels of EEG activity as they were attentive. This method allowed researchers to quantify average hold times by session, permitting the examination of subjects’ ability or willingness to participate with the training. Subjects averaged approximately 400 seconds (with 420 seconds being the theoretical maximum) of hold time per protocol by the third session indicating that they were engaged during the intervention.

Computerized performance test: A BrainPrint® test, which is a computerized continuous performance test, was administered pre- and post- to the neurofeedback intervention. This test acquires two channels of raw EEG at C5 and C6 while subjects respond to go/no-go style stimuli. They were presented with 3 letters (L, R, and P; Figure 1), two of which required a response and one required an inhibition of a response. Subjects held a two-button mouse in two hands with their left and right thumbs over the two respective mouse buttons. When subjects saw the letter “L” they were to press the left and when they see an “R” they press the right button. When they saw the “P” they paused for that individual’s current average response time until the next letter appeared. All letters were generated randomly. Any response instantly generated a beep and presented the next letter within 30 milliseconds. A correct response advanced the two inch letter one pixel to the right towards a visible finish line. An incorrect response moved the letter ten pixels to the left away from the finish line. The test required 600 correct responses to cross a finish line, if no errors were made. The actual game required a pretest of 100 correct responses. Subjects were asked to be as fast and accurate as their abilities allowed.

Insert Figure 1 Here

Data Collection

Both subjective and objective data on workload and performance were collected during the computerized performance tests (i.e. pre- and post-neurofeedback Alpha/Theta/Beta intervention).

Subjective workload assessment: Following each computerized performance test, study participants completed the National Aeronautics and Space Administration Task Load Index (NASA-TLX) instrument to assess workload. [14] In summary, the NASA-TLX is based on a multi-dimensional rating procedure that considers six dimensions (Mental, Physical, and Temporal Demands; Frustration; Effort; and Performance) to yield a global workload score between 0 and 100.

Objective workload assessment: During each computerized performance test, EEG-based data was collected with a 2-channel recording in left (C5) and right (C6) temporal lobes using international 10-20 system of electrodes placement using the BrainPaint® system. The raw EEG was sampled at 256Hz. The artifact threshold was set for 100 microvolts. All sensors were references to linked ears.

Objective performance assessment: Individual performance was assessed objectively based on efficiency (time-to-test completion) and performance-based errors (number of incorrect clicks).

Subjective performance assessment: Following each computerized performance test subjects self-assessed their performance using a slightly modified flow-state survey with 28 items using 5-level Likert scale (1-strongly disagree, 2-disagree, 3-neutral, 4-agree, and 5-strongly agree; Figure 2). [15] The flow state survey assessed the psychological experience of undergoing the computerized performance test using following nine validated scales (Figure 2): 1) *Autotelic experience*: A feeling of being in efficient ‘flow’; 2) *Clear goals*: A feeling of certainty about what one is going to do; 3) *Challenge-skill balance*: A feeling of balance between the demands of the situation and personal skills; 4) *Concentration on task*: A feeling of being really focused; 5) *Paradox of control*: A feeling of good performance without conscious effort; 6) *Unambiguous feedback on performance*: A feeling of control (everything is going according to plan); 7) *Action-awareness merging*: A feeling of automaticity about one's actions; 8) *Transformation of time*: A feeling that time can be seen as passing more quickly, more slowly, or there may be a complete lack of awareness of the passing of time; 9) *Loss of self-consciousness and transformation of time*: A feeling of engagement with the activity. When in 'flow', physicians were expected to perform at optimized level of workload and performance.

Insert Figure 2 Here

Data Analysis

Subjective workload assessment: Differences (pre- vs. post-intervention) in NASA-TLX scores were assessed using matched pairs t-test.

Objective workload assessment: EEG data were processed using EEGLAB. [16] Major muscle artifacts and electrode pop were manually removed. Data were high-pass filtered at .05Hz, segmented into three-second epochs and submitted to automatic artifact detection and rejection algorithms. To standardize the total amount of EEG data for analysis, each subject's data from the computerized performance tests were divided into the first and last 2 minutes of the pre- and post- neurofeedback training. Each group (pre- and prost-) was run through independent component analysis (ICA) and components were clustered within each group. A fast Fourier transform (FFT) was run between 3 and 45 Hz in 100 steps with a tapered window to assess power in each frequency band with statistically corrected within-subject permutations using ANOVA at $p < 0.05$.

Objective individual performance assessment: Differences (pre- vs. post-intervention) in time-to-test completion and performance-based errors were assessed using matched pairs t-test.

Subjective individual performance assessment: Differences (pre- vs. post-intervention) in flow-state scales were assessed using the non-parametric Wilcoxon signed-rank test to compare the sizes of the differences in number of positive responses (subjects indicating 'positive' change; 'agree' and 'strongly agree') to the sizes of the differences in number of negative responses (subjects indicating 'negative' change; 'disagree' and 'strongly disagree' responses).

RESULTS

Subjective workload assessment: The mean difference in NASA-TLX was 12 (pre=52; post=40). A matched pairs t-test indicated a statistical significance difference in subjective workload (t=3.22, df=6, p-value=0.01; Figure 3A). At the individual dimension levels the matched pair t-test indicated statistical significance difference only in mental demand (mean difference=28; pre=67; post=39; t=2.99, df=6, p-value=0.02; Figure 3B).

Insert Figure 3A and 3B here.

Objective workload assessment: Significant power increases in the initial Theta frequency band were detected [first 2 minutes; 5-7Hz; ANOVA with permutations, p-value<0.05; Figure 4]. Significant power reduction over time in the high-Alpha/low-Beta frequency band was detected [last 2 minutes; 13-14Hz; ANOVA with permutations, p-value<0.05; Figure 4]).

Insert Figure 4 Here

Objective individual performance assessment: The mean difference in time-to-test completion was 0.1 minutes (pre=9.1; post=9.0) and the mean difference in performance-based errors was 0.9 errors (pre=10.1; post=9.2; out of 600 correct responses required to complete the test assuming no errors). Matched pairs t-test indicated no significant difference for either objective performance assessment (p-values>0.05).

Subjective individual performance assessment: The mean difference in positive vs. negative differences in responses to the flow state survey was 2.4 (positive=3.6; negative=1.2). The Wilcoxon signed-rank test indicated a significant difference in perceived performance as measured by the flow-state survey (S=148.5, df=27, p-values<0.001). At the individual scales the Wilcoxon signed-rank indicated significant differences in perceived performance (p-values<0.001) except for the *loss of self-consciousness and transformation of time* scale.

DISCUSSION

Subjective and objective measures of workload and performance were collected from radiation oncologists performing a computerized performance test before and after eight 28-minute sessions of neurofeedback training. Subjectively, radiation oncologists indicated a significant decrease in workload as quantified by the NASA-TLX global score, with mental demand being the only dimension indicating significant reduction. Objectively, the EEG data analysis indicated statistically reliable power increases in Theta frequency band and power decreases in high-Alpha/low-Beta. These increases in the Theta with reduced high-Alpha/low-Beta under identical task-load (pre- vs. post-intervention) suggest diminished arousal and enhanced information processing. Our results remain in line with previous research on neurofeedback training as a viable method for improving cognitive skills. [6-13, 17-20] For example, while studying 16 subjects performing computer-based flight simulation tasks researchers found that tasks with high load required significant increase in Theta power (dominated by a sharp peak in the spectra in the theta 6–7Hz range) and significant power decrease in the Alpha (8–12 Hz) frequency band. [20]

Subjectively, radiation oncologists perceived significant improvements in their performance as quantified by the flow-state survey, with significant results in all measured scales except *transformation of time*. Objectively, we found no significant differences in the computerized performance test as quantified by the time-to-test completion or by the mean difference in performance-based errors. This was to some degree an expected result because significant improvements in computerized performance test (time and errors) in healthy subjects are rarely realized (as most healthy subjects can complete the BrainPrint® pre-test relatively quickly with relatively low number of errors). The reliability of the effects on workload with this protocol is strengthened by findings that, on average, participants showed strong engagement during neurofeedback training sessions.

This pilot study has several limitations. First, our sample size was small sample size. We recruited eight physicians (representing ≈75% of the physicians that see patients at this center), and gathered data from seven of these, with one subject not able to complete the study due to scheduling issues. Given the intensity of the training needed (eight sessions, each 28-minutes in length), a modest number of patients is common in these types of pilot studies. Second, we did not have a control group. However, it is unlikely that power increases in Theta frequency band and power decreases in high-Alpha/low-Beta between the pre- and post-neurofeedback intervention were due to learning/familiarity with computerized performance tests, as prior studies of this type do not report significant improvements in control groups. [7,9,11-13] These limitations could be minimized in the future with greater numbers of subjects from different clinics and inclusion of a control group in order to better isolate the effect of the intervention on the outcome measures.

Third, the NASA-TLX instruments and flow-state survey might not be the best methods to subjectively measure workload and performance respectively during the computerized performance test (BrainPrint®). Future studies could consider using multiple instruments and measures to provide more robust results and protect against potential interpretive errors. Nevertheless, the NASA-TLX instrument and state-flow surveys are currently the most well accepted methods to perform such assessments. Furthermore, future studies could consider evaluation of clinical scenarios (i.e., treatment planning tasks) in addition to computerized performance tests.

Fourth, one of the practical difficulties in running the study was the availability of the radiation oncologists to fit the neurofeedback sessions into their busy schedules. This caused some subjects to receive three neurofeedback sessions per week and not two per week as intended. This could have negatively affected the training by creating temporal demands on the radiation oncologists (coming to the lab during their busy days) and therefore introducing additional stress and anxiety during training sessions. We tried to address this issue by scheduling the 'extra' training session per week using an additional day, thus avoiding multiple sessions on the same day.

Nevertheless, despite the limitations, it might be useful and innovative to further examine the effect of neurofeedback as means to lessen workload and improve the cognitive skills of radiation oncologists. If this sort of intervention proves useful, it might be reasonable to incorporate neurofeedback into ongoing training for radiation oncologist. In addition, it might be reasonable to structure some of the work that radiation oncologists are already performing in the electronic environment to be presented to them in such a way as it itself can serve as a neurofeedback exercise. In this manner, there would not be any extra “work/effort” involved, but rather radiation oncologist would be having training as they were doing their routine work.

To the best of our knowledge, this is the first study to show subjective and objective evidence for reduction in workload in radiation oncologists by means of neurofeedback. Radiation oncology physicians will continue to be stretched by the increasing reliance on computer-based tools in the clinical environment. The data shown here support for the notion that neurofeedback could be considered as an intervention to help ‘optimize’ cognitive information processing leading to improved quality and safety of patient care.

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Figure Legends

Figure 1: Illustrations of BrainPrint® Test.

Figure 2: State-flow survey with 9 scales and 28 questions.

Figure 3: A) NASA-TLX (Global) scores of the computerized continuous performance test (BrainPrint®) administered pre- and post- to the neurofeedback intervention. B) Mental demand scores (1 of 6 dimensions of NASA-TLX instrument) of the computerized continuous performance test (BrainPrint®) administered pre- and post- to the neurofeedback intervention.

Figure 4: Power spectra for the first and last 2 minute of the pre(top)- vs. post(middle)-, computerized performance test with bottom graphs representing the p-value (log scale) calculation.

Figure 1

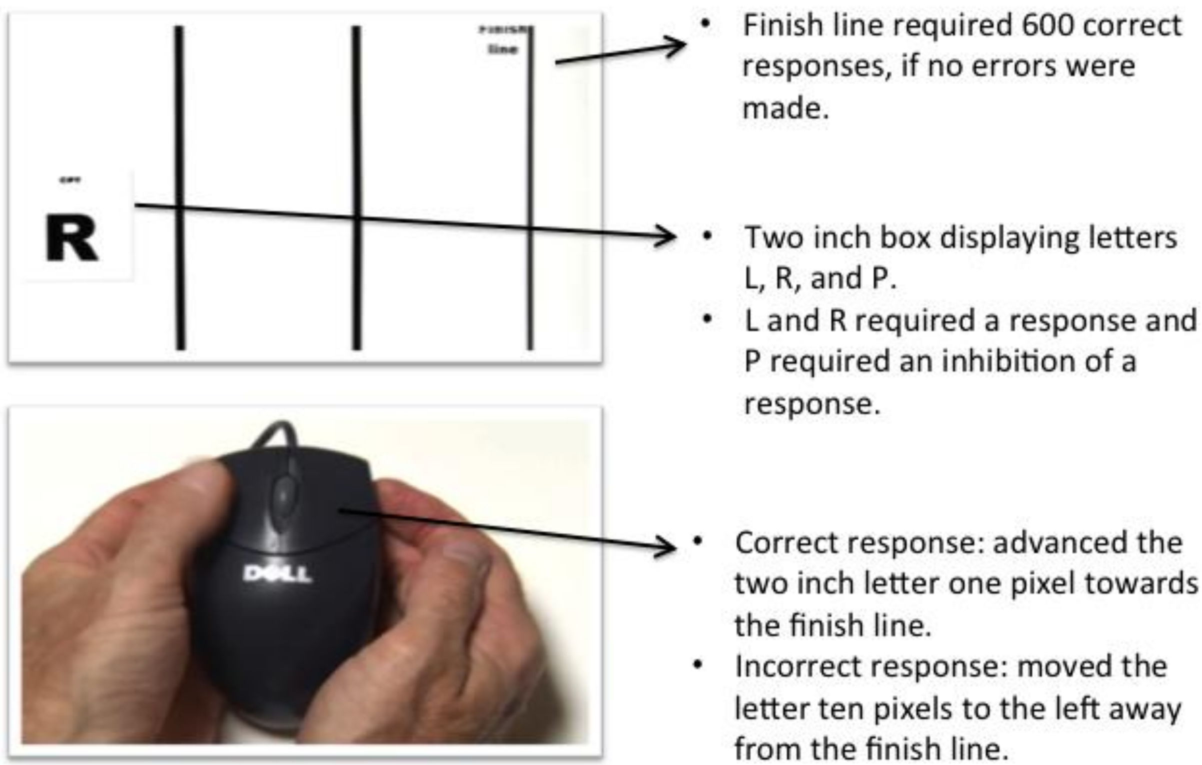

• Finish line required 600 correct responses, if no errors were made.
• Two inch box displaying letters L, R, and P.
• L and R required a response and P required an inhibition of a response.
• Correct response: advanced the two inch letter one pixel towards the finish line.
• Incorrect response: moved the letter ten pixels to the left away from the finish line.
R

Figure 2

#	Autotelic Experience
36	My overall experience was improved
8	My overall experience was more enjoyable
8	My overall experience left me feeling better
	Clear Goals
2	I knew more clearly what level of concentration I wanted to achieve
21	I had a stronger sense of how to achieve the desired level of concentration
28	I felt I was able to sustain the desired level of concentration more easily
	Challenge-Skill Balance
16	I felt more competent to achieve the desired level of concentration
1	I was more aware of my level of concentration
9	I was able to deal with task demand challenges more easily (distractions, noise, info in multiple records, etc.)
	Concentration on Task
17	I found my concentration to be improved
4	My concentration was more focused
11	I was able to sustained my concentration more easily
	Paradox of Control
24	I felt more in control of my ability to think and solve problems
30	I felt more in control of what I was doing
5	I felt I could control my emotions more easily
	Unambiguous Feedback on Performance
33	I had a better idea of how well I was performing by the way I was performing
3	I felt my performance was improved
22	I was more aware of how well I was performing
	Action-Awareness Merging
20	I felt like I was more aware of key information
31	I felt my concentration was more reliable and efficient
10	I made correct decisions with less conscious effort
	Transformation of Time
14	The way time passed seemed different
7	Time seemed to be altered differently (either slow down or speed up)
35	At times, it almost seemed like things were happening in slow motion
26	I felt like time stopped when I was performing
	Loss of Self-Consciousness Transformation of Time
34	I was less worried about what others would be thinking of my end performance
25	I was less concerned about my end performance
13	I was less worried about my end performance

Figure 3

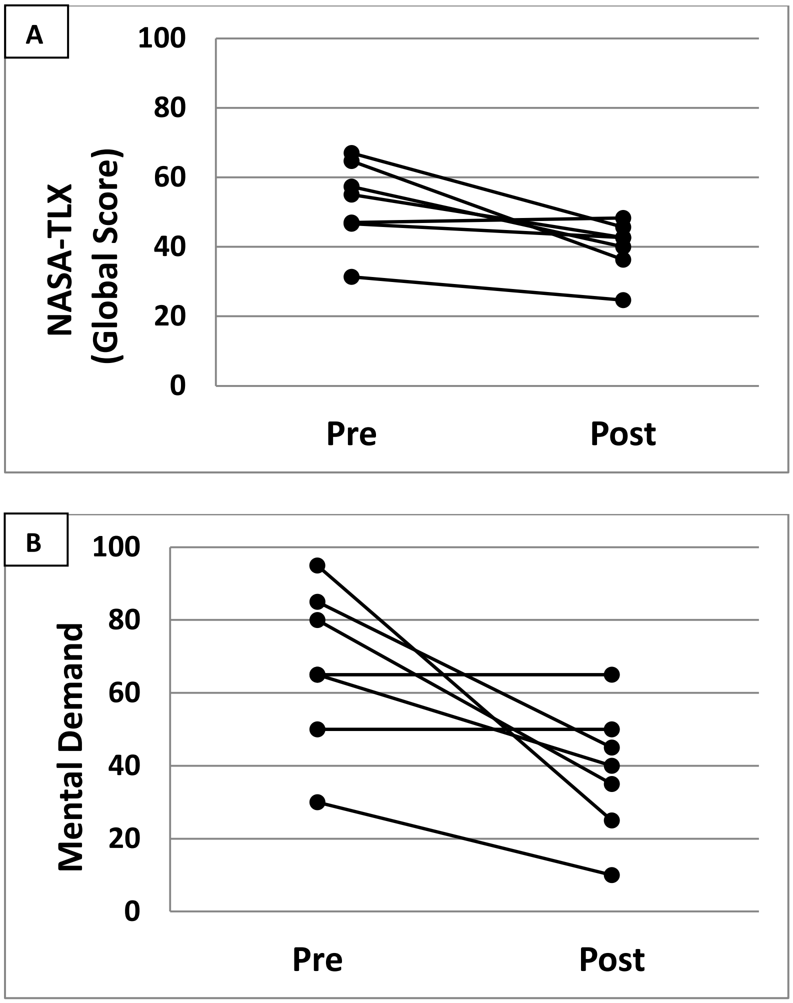
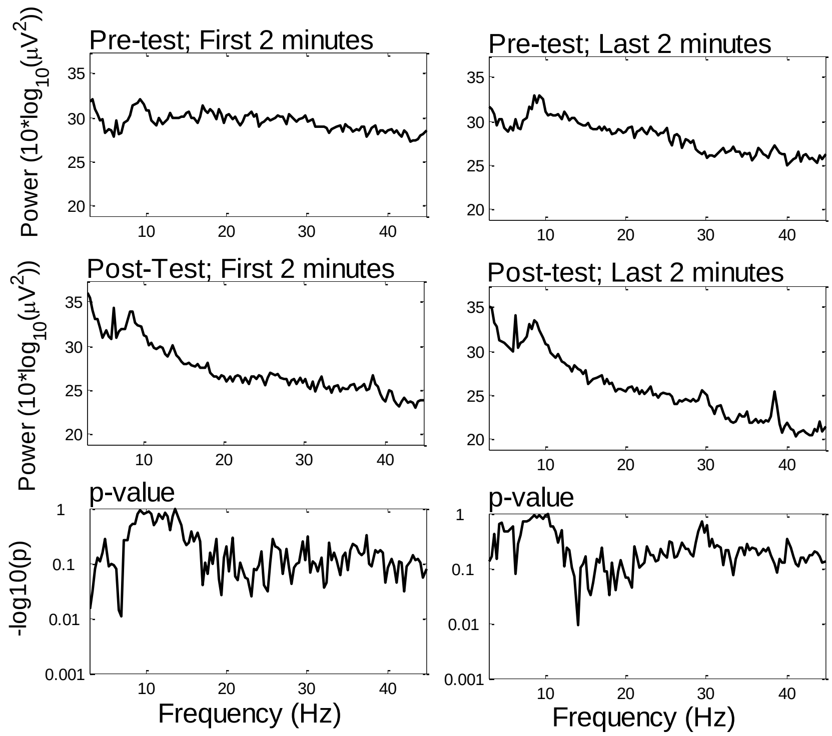

A
100
80
60
40
20
0
NASA-TLX
(Global Score)
Pre
Post
B
100
80
60
40
20
0
Mental Demand
Pre
Post

Figure 4



Pre-test; First 2 minutes
Pre-test; Last 2 minutes
Post-Test; First 2 minutes
Post-test; Last 2 minutes
p-value
p-value
Power ($10*\log_{10}(\mu V^2)$)
Power ($10*\log_{10}(\mu V^2)$)
-log10(p)
35
30
25
20
10
20
30
40
1
0.1
0.01
0.001
Frequency (Hz)
Frequency (Hz)

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