An Investigation of Computer-based Brain Training on the Cognitive and EEG Performance of Employees

Conference Paper *in* Conference proceedings: ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Conference · July 2019

DOI: 10.1109/EMBC.2019.8856758

An Investigation of Computer-based Brain Training on the Cognitive and EEG Performance of Employees *

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***Abstract*—Neurocognitive skills (e.g., processing speed, attention and memory) were hypothesized to be critical for workplace performance and by extension for the work-life balance of employees. Twenty-one employee volunteers underwent a neurocognitive training program – which consisted of an initial pre-test assessment, a six week "boost" or intervention period, and then a re-assessment to track the progress of each participant. A median split of the group created two training groups: a long-training group that averaged 30 hours of total training during the boost period; and a short-training group that averaged 7 hours of training. On pre-training measures of neurocognitive performance, group differences in performance did not reach statistical significance. Following training participants experienced a positive impact from the program as measured in three ways: standardized higher behavioral metrics, improved cognitive state metrics using EEG and positive self-reported data. From a quantitative perspective, participants' cognitive efficiency increased by 12% for the high-training group and 5% for the low-training group (cognitive efficiency refers to a behavioral measure which combines accuracy and speed). Qualitatively, study participants reported improvements in their productivity and mental performance post-study.**

I. Introduction

Measures of cognitive ability and overall brain health are significant predictors of employment status, future cognitive decline and brain disease [1]. In older adult populations brain training programs have demonstrated positive benefits immediately following brain training as well as longitudinally including at 10-year follow-ups [2]. While results for slowing cognitive decline in the aged are gaining acceptance among many in the scientific community, few studies have extended brain training approaches to improving workplace performance or employee cognition [3].

The present study was implemented to establish the utility of a neuroscience-based approach for measuring, positively impacting and tracking work performance – or work-style transformation in corporate employees. The goal of the project was to see if neurocognitive data and brain training performance could benefit employees as well as provide insights into the measurement of neurocognitive performance in the workplace. To support the project, a large multinational information technology equipment and services company agreed to participate in the study. At the corporate level senior executives were searching for methods to improve work satisfaction and have been active in promoting work-transformation with the goals of decreasing worker stress, extending career longevity and increasing overall happiness. The corporation, through their own research, had become convinced that neuroscience will play a large role in the future of work and the implementation of artificial intelligence and other human-machine systems. The efforts described in the following paper were subsequently designed in full collaboration with the corporation and the corporation waived any rights to see individual performance data.

II. Data Collection and Processing

A. Research Design

This study used a two group, quasi-experimental, pre- and post-test intervention design. Subjects were administered a pre-test evaluation to establish a baseline and assigned to a brain training program prior to group assignment. Following 6 weeks of training the subjects were re-evaluated (post-test). A median split created two groups, based on the number of training hours completed to compare the impact of brain training on the independent measures of cognitive test performance. Analysis of the pre- and post-test electrophysiological and behavioral test scores was performed using multivariate analysis of variances procedures.

B. Brain Training and Assessments

Subjects: Twenty-two employee volunteers were recruited[1] for the study (11 males; 11 females; average age 42.3 years). Subjects were between the ages of 18 and 65 years and did not present co-occurring neurological disorders. The goal of the study was to demonstrate the capability for the deployment of online brain training to build employee cognitive capacity.

Brain Training Program: Subjects were given the goal of completing twenty 30-minute training sessions over a 6-week period; for a total goal of 10 training hours. Brain training was available on-line via computer, cellphone, etc. using a BrainHQ.com account set up for the study. Data tracking and program compliance updates were done weekly. The following training areas were targeted for training using BrainHQ: brain speed, attention, people skills and intelligence (memory and navigation were not selected for training). Following the completion of brain training, a median split of the group, based on the total brain training hours, was performed to compare the impact of brain training on a battery of independent measures of cognitive performance.

Assessments: Following informed consent, prior to and

*Research supported by Fujitsu Laboratories of America, Inc. and The Platypus Institute.

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following brain training, subjects performed the following assessments with behavioral and electrophysiological data recording: Baseline Task of Eyes Open/Eyes Closed, the Eriksen flanker task, the DANA Standard Assessment, and surveys on sleep, stress and emotional resilience. The DANA Standard battery tasks were chosen because they are FDA cleared, and easy to administer via a tablet; in addition, it is well-normed for comparison with other groups. The present discussion will focus on the data from the DANA tasks listed in Table 1. For DANA tasks, a cognitive efficiency measure is calculated which is a normalized metric (combining speed and accuracy) of the number of correct responses per minute, see [4] and [5]. Cognitive efficiency is used to quantify an individual's capacity to make correct responses per minute. Higher scores indicate better performance.

TABLE 1: DANA STANDARD TASKS – Cognitive and psychological tasks designed to provide a standardized measure of cognitive efficiency across repeated measures. Cognitive efficiency refers to a behavioral measure which combines accuracy and speed; see [4] and [5].

Test Name	Task Description
Simple Reaction Time (SRT1)	Recognize the presence of an object and tap the object.
Procedural Reaction Time (PRT)	Recognize 1 of 4 numbers and tap 1 of 2 buttons.
Go/No-Go Task (GNG)	Recognize a green or gray object and only tap in response to gray.
Code Substitution Learning (CSL)	Recognize whether a symbol-digit pair matches the key code shown and tap "Yes" or "No".
Spatial Processing (SP)	Recognize rotation of a visual object and tap "same" or "different".
Matching to Sample (MTS)	Recall a 4x4 checkboard pattern after it disappears for 5 seconds and two options appear.
Memory Search (MS)	Recognize letters that have been previously memorized.
Simple Reaction Time (SRT2)	Recognize the presence of an object and tap the object (after ~15 minutes of cognitive exertion).

a. For more information see Anthrotronix.com

C. EEG Data Collection

EEG data was collected with Cognionics Quick-20 headsets (Cognionics, San Diego, CA); consisting of 20 dry electrodes with a sampling rate of 500 Hz. As shown in Fig. 1, EEG processing included the rejection of bad channels, artifacts such as eye blinks, and separate low and high frequency bandpass filters using NeuroPype software (Intheon, San Diego, CA); see [6] for a representative publication explaining the processing stages for EEG.

Power spectrum density (PSD) estimation was performed with the Welch method and 1/f normalized. For each trial, band power was calculated for various frequency bands and workload was calculated using the following formula from [7]: beta / (theta + alpha). A robust winsorized mean was used to average across trials.

EEG was recorded during all assessments except the surveys. Assessments took approximately 90 minutes.

For space purposes, we report the behavioral data for all eight of the DANA Standard Battery tasks and the electrophysiological data for two of the eight DANA tasks: Simple Reaction Time (SRT1) and Go/No-Go task (GNG).

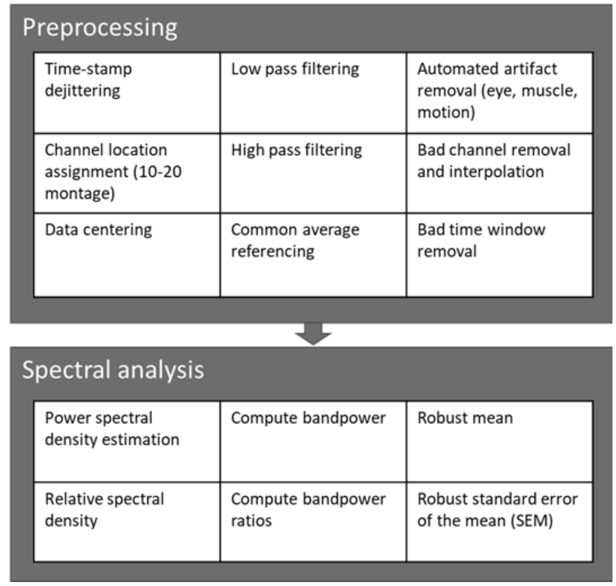

FIGURE 1: EEG PROCESSING STEPS - Major steps in processing the electrophysiological data. Preprocessing removes noise, artifacts, etc.; spectral analysis finds signals of interest such as bandpower and ratios thereof.

III. RESULTS

A. Brain Training Performance

Participants received access to a BrainHQ account immediately following the assessment and were instructed to complete the specified programs at least 3 times per week. The Longer Training group had 10 participants (6 females, 4 males) in the study with an average age of 43.8 years and an average of 30 hours trained. The Shorter Training Group had 11 subjects (5 females, 6 males) with an average age of 40.9 years and an average of 7 hours trained. During training, the Long Training Group completed 824 levels of training progression (i.e., higher task difficulty) compared to 201 levels completed by the Short Training Group

B. Cognitive Efficiency Results (Pre- and Post-training)

Table 2 shows the means and standard errors for the individual behavioral tasks for each group (Long Training Group and Short Training Group) and Time (Time 1 or before brain training and Time 2 or after brain training). Analyses of these pre-brain training data (Table 2, Time 1 Means) did not reach statistical significance for any of the individual tasks. In addition, the sum of the cognitive efficiency scores across all the tasks for the Long and Short Training Groups was 716.2 and 715.9, respectively. Again, these differences prior to brain training did not reach statistical significance.

After brain training, both groups showed significant improvements on the measures of cognitive efficiency for several DANA Standard assessments, see Table 2. The sum across the tasks reflected an overall cognitive efficiency score of 801.3 and 752.6 for the Long and Short Training Groups, respectively. Higher cognitive efficiency scores reflect faster, more accurate task performance. In this study we observed a 12% improvement in brain speed for the Long Training Group and a 5% increase for the Short Training Group. Differences across the groups are significantly larger for the Longer training group on the Procedural Reaction Time (PRT) task and the Go/No-Go (GNG) task. Both tasks, PRT and GNG require more than a fast response, as measured by the Simple Reaction Time tasks (SRT1 and SRT2) and include an additional cognitive control component to rapid response selection.

TABLE 2: GROUP, TASK AND TIME PERFORMANCE ON THE DANA STANDARD TASKS - Significant Time effects for the specified Task ($p<.05$) are marked with "#"; significant Group by Time effects for the specified Task ($p<.05$) are marked with "*".

Task	Group	Time	Mean	S.E.M.
SRT1 #	Long Training Group	1	154.823	7.398
		2	171.665	5.951
	Short Training Group	1	152.527	6.940
		2	164.847	5.582
CS #	Long Training Group	1	42.548	3.237
		2	51.277	3.234
	Short Training Group	1	44.245	3.036
		2	49.963	3.034
PRT #, *	Long Training Group	1	102.120	4.225
		2	114.085	3.855
	Short Training Group	1	104.855	3.964
		2	108.720	3.616
SP #	Long Training Group	1	32.883	2.835
		2	39.220	3.010
	Short Training Group	1	32.683	2.660
		2	36.239	2.824
GNG #, *	Long Training Group	1	128.512	6.907
		2	140.725	4.239
	Short Training Group	1	127.235	6.480
		2	127.254	3.976
MTS	Long Training Group	1	39.623	3.969
		2	38.648	3.423
	Short Training Group	1	39.684	3.723
		2	39.448	3.211
MS #	Long Training Group	1	54.973	4.286
		2	76.083	5.346
	Short Training Group	1	54.838	4.021
		2	65.805	5.015
SRT2	Long Training Group	1	160.709	6.065
		2	169.560	6.491
	Short Training Group	1	159.848	5.690
		2	160.329	6.089

C. EEG Data Analyses

Due to the behavioral differences the EEG measure of workload is limited in the current discussion to the tasks of SRT1 and GNG. Like the behavioral measurements, before brain training (pre-testing), subjects from both the Long Training group and the Short Training group were undifferentiated in the workload EEG measure for both the SRT1 and GNG tasks (see Fig. 2). Both groups showed moderate bilateral parietal activation and low central and posterior activation at pre-testing.

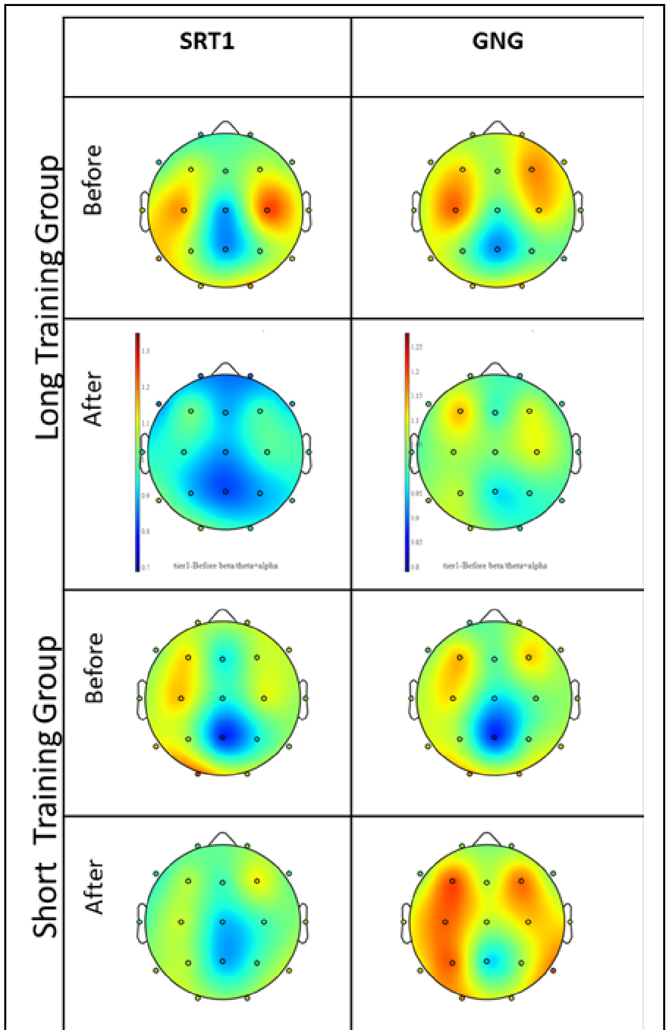

FIGURE 2: WORKLOAD EEG MEASUREMENTS FOR THE SIMPLE REACTION TIME TASK (SRT1) AND THE GO/NO-GO TASK (GNG) -Tasks as a function of training and group.

After training (post-testing) for SRT1, both groups show smaller workload measurements across the head, although the decrease is larger for the Long Training Group. For example, both groups show less bilateral parietal activation. This parallels the behavioral—both groups performed the SRT1 task with greater efficiency. For the GNG task, however, the changes for each group were different. After training the Long Training Group showed decreases in the frontal regions while the Short Training Group showed increases in the same region, especially on the left side. Both groups did however show an increase in central and posterior activation. It appears that the Long Training Group was able to handle the task with less workload. The behavioral data showed that the Long Training Group performed the task better after training while the opposite for the Short Training Group. Thus, changes in behavioral data had corresponding changes in neural data.

III. Conclusion

Executive functions (e.g., information processing, sequencing, decision making, planning, etc.) are associated with optimal cognitive performance and are also known to contribute to corporate work tasks [1]. In the present discussion we have demonstrated that independent computer-based brain assessment (DANA) and training (BrainHQ) could provide a scalable solution to evaluate and develop executive functions, functions that are malleable throughout the life-span. BrainHQ training increased brain processing speed as measured by the DANA Standard battery on a variety of neurobehavioral tasks. Further, the independently developed DANA Standard battery [5] and BrainHQ training program [8] cross-validate their respective evaluation and training of brain speed. The further elaboration of the neuroplastic mechanisms that may underly these behavioral changes appear to be clarified by an electrophysiological measure of workload. The next stage of research in this area will include greater rigor along several dimensions such as: more subjects, randomized assignment to groups with an active control group, detailed statistical analysis of EEG data, parameterization of where the workload EEG measure is appropriate (as well as other measures such as attention or memory), and so on. This information will further optimize and personalize brain training.

Overall, the corporate study demonstrated positive benefits for the group of participants in several areas of neurocognitive performance. Further, significantly higher gains were recorded in the highest training group with moderate gains in the lower training group. With additional EEG-based analysis, we will be able to refine our understanding into the mechanisms of neuroplasticity that occurred as a direct result of our program. More importantly, with this study, we demonstrate that a cognitive state (e.g., workload performance) could support the further extension of real-time brain performance evaluations in the corporate environment. The loop of "measure-boost-track" was shown to be effective both qualitatively and quantitatively – and worthwhile results were seen with modest training, gains in attention, executive control and decision-making systems were present. Finally, while the study was not designed to elucidate the "dose response" of cognitive training – there does appear to be some value in extending further research in determining the dose-response curve for brain training benefits as well as the extension of the nature of the benefits to specific corporate tasks (e.g., bookkeeping, digital correspondence).

Appendix

EEG bands were defined as follows: delta [1, 3], theta [4, 7], alpha [8, 15], beta [16, 31], gamma [32, 40]; all intervals are closed on both ends.

Acknowledgment

We would like to recognize the efforts of Fujitsu Laboratories of America, Inc. for sponsoring the study. In addition, we would like to thank the executive team at Intheon.io for assistance in the analysis of the electrophysiological data and executives at Anthrotronix and Posit Science for in-depth guidance and support on the use of their respective products to support the study.

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Notes: [1] Subjects were recruited for the study after attending a research briefing by two members of the Platypus Institute research team. The participating organizations provided written assurances that all reasonable efforts would be made to keep their individual performance and EEG data anonymous. Subjects provided informed consent prior to the start of the study and could terminate their participation without consequence. Subjects received modest compensation for their participation.