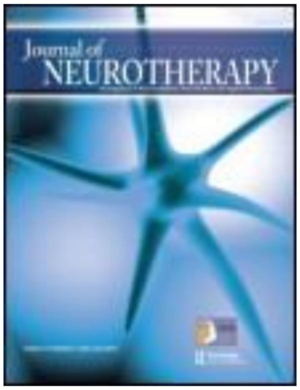

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Operational Study to Evaluate Music-Based Neurotraining at Improving Sleep Quality, Mood, and Daytime Function in a First Responder Population

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OPERATIONAL STUDY TO EVALUATE MUSIC-BASED NEUROTRAINING AT IMPROVING SLEEP QUALITY, MOOD, AND DAYTIME FUNCTION IN A FIRST RESPONDER POPULATION

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The objective of this study was to determine if a music-based intervention could be successfully used by a group of law enforcement officers and firefighters to improve measures of sleep quality, mood, and daytime function. The Wellness Program Study included 41 male and female first responders who volunteered to participate in the 8-week study investigating the use of a music-based neurofeedback therapy known as Brain Music (BM). Creating the individualized BM recordings required 5 min of brain wave activity from 4 sensors located at F3, F4, C3 and C4 sites. The music consisted of two MP3 files, one for activating and the other for relaxing, where the ratios of peak frequencies in the delta (1–4 Hz) through beta (up to 30 Hz) EEG bands were used to select the notes used and their characteristics (e.g., duration, pitch, amplitude, and symmetry) as a means to individualize the compositions for each subject. Results of the study indicated statistically significant improvements in 4 behavioral measures: sleep quality (94%), insomnia (89%), mood (74%), and daytime function (82%). These results extend earlier insomnia research of music therapy applications from the clinic into an operational setting and lay the groundwork to address many questions concerning neurofeedback interventions targeting stress management and improved job performance. The implication of this study goes beyond the utility of BM in the first responder setting to a broader audience because many persons suffer from sleep problems that negatively impact daytime function and work performance.

INTRODUCTION

One of the most basic features of wellness and critical to optimum brain function, sleep has taken a backseat to the increasing demands of life and advancing careers. In particular, the lack of sleep brings about reductions in mental performance and negatively impacts general well-being. The association between sleep and performance is well known, and this knowledge has led to the development of numerous tools and treatments aimed at optimizing cognitive function (Miyata et al., 2010; Reimann, Manz, Prieur, Reichmann, & Ziemssen, 2009). Although advancements in pharmacology have produced great benefits to some who suffer from limited sleep, the effect on sleep quality of such medicines is

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quite variable (Curran et al., 2003). In addition, sleep medications must be used with caution, as they come with side effects that negatively impact cognitive performance and might lead to dependency (Dündar et al., 2004; Nau, McCrae, Cook, & Lichstein, 2005). To investigate an alternative intervention for improving sleep and enhancing cognitive performance, this article describes the results of an 8-week crossover controlled investigation of Brain Music (BM), a form of auditory neurofeedback training derived from each subject's EEG. Behavioral changes were investigated in 41 law enforcement officers and firefighters before and after use of the BM recordings during their on and off work periods for 4 weeks. Results of the study indicated statistically significant improvements in four of six behavioral measures tracked, including sleep quality, insomnia, depression, and daytime function. These results extend earlier clinical insomnia research from the lab into an operational setting and begin to address some of the questions concerning the application of music-based interventions targeting improvements in sleep, stress, and job performance.

Nonpharmacological approaches to sleep improvement have been investigated for years, with quite a few products now available in the commercial sleep marketplace (Bendz & Scates, 2010; Burkhart & Phelps, 2009). Treatment approaches for apnea, for instance, require a sleep study in a clinic prior to use. There are sleep products available for home use that monitor body position and movement during sleep, but they require the sleeper to be wired up to a monitoring device. What's missing is a product that does not require cumbersome measures during sleep, is easy to use, and is available anywhere, anytime.

From recent technological achievements in device size and capability, simple physiology-based sleep improvement products are being produced for university and private sleep labs across the country. The goal has been to develop products able to individualize the treatment of sleep disorders, like apnea or insomnia (Cooke et al., 2009), and to better understand the implications of such disorders on individual wellness (Pilcher & Huffcutt, 1996; Veasey, 2001). One of the most promising of the products available for ameliorating insomnia-related sleep problems is an intervention known as BM.

BM is a neurotraining module that uses individualized music compositions derived from one's own brain wave patterns to improve sleep duration and quality, ultimately leading to measurable improvements in both, performance and mood. The use of BM was first investigated by I. I. Levine in 1991 (Levine, Gavrilov, Goldstein, & Dallakian, 1991), and a follow-up study by G. Mindlin was published on the use of BM among in-patient insomniacs (Mindlin & Evans, 2009). In the latter, Mindlin reported significantly improved measures of *sleep quality* and *emotional regulation,* two vital mental health components underlying optimum cognitive function, mood, and overall wellness. Related to sleep quality, the author reported a statistically significant improvement in symptoms of insomnia in more than 80% of the subjects after the music-based intervention, as well as significant improvements in emotional regulation, particularly in regard to anxiety disorders.

The aforementioned studies have established the success of BM among clinical patient populations but provided little detail of how such music-based neurotraining might work in a healthy population of at-work individuals. Thus, new research was required to understand if BM could be transitioned from the sleep lab out into the real world to improve sleep quality, reduce insomnia symptoms, and bolster emotional wellness. Here we report the results from a new BM study to extend prior investigations under clinical settings into an operational environment. As part of this investigation, volunteers used the personalized BM compositions for 4 weeks while continuing to perform their routine work and home schedules (DuRousseau, 2009). The two BM compositions, one for activating and the other for relaxing, were created from a 5-min sample of each volunteer's brainwaves and stored on a digital MP3 player for use anywhere and anytime as needed. This BM investigation was part of the broader Wellness Program Study sponsored by the Department of Homeland Security, which evaluated the use of nutrition education and music-based neurotraining by first responders working in operational settings.

METHODS

A series of 16-channel EEG studies were performed using a linked-ear reference and AFz ground to develop the BM algorithm and down select the four sites used at F3, F4, C3, and C4 for general application of the method. The BM algorithm carries out spectral analyses using the Fast Fourier Transformation after automatic removal and manual review of artifacts in the EEG. With these data, a numerical expression of percentage power for the main frequency ranges Δ, Θ, α, β_1, and β_2 are computed and each peak frequency identified for all four leads. At this point, ratios of the peak band powers within each lead are used to transform the EEG into musical notes assigned from a three-octave piano keyboard. There are presently 18 different transformation algorithms that have been evaluated at controlling the particular characteristics of the notes selected from the ratios of EEG power. Based on the frequency ratios of the EEG in all four leads, the algorithm adjusts the selection of octaves, musical tempo, variations in the volume of the two audio channels, and transposition of the sounds from one audio channel to the other (fade), and it changes musical parameters like legato–staccato and the use of major and minor chords. The result is the creation of a ''musical map'' to correlate brain activity ratios associated with two primary functional resting states—active and relaxed. The two musical scores are created for each person, one for activating and the other for relaxing their brain activity. The use of these two scores is referred to as Brain Music Therapy.

To test the practicality of using BM in an operational environment, researchers recruited 47 first responders (an occupation that demands a high level of performance and often chronically interferes with sleep patterns) from state and federal agencies located in the metro-Washington, DC, region. Institutional Review Board review and approval for the study was achieved, and all subjects signed informed consent forms. The study design provided for three independent behavioral assessments to test before versus after intervention results: (a) an initial baseline test (Bl) made 4 weeks before using BM, (b) a pre-BM test (Pre) made when BM was started, and (c) a post-BM test (Post) taken immediately after 4 weeks of use. To evaluate changes in the behavioral results across test periods, difference results were computed for the Post–Pre, Post–Bl, and Post–Average (e.g., Bl +Pre/2) results. The entire study provided for three assessments from each subject and lasted for 8 weeks.

Forty-one of the 47 participants completed the 8-week study in its entirety (4-week waiting period and 4 weeks of use). These volunteers included 28 men and 13 women, ranging from 24 to 58 years of age. Subjects were divided into two experimental groups by job classification: operations (ops) support (15) and first responder (20). A crossover control group (6) was randomly assigned after the Bl assessment from a pool of 28 first responders (two other control subjects were not able to complete the study). All subjects chosen as a control had a Beck Depression Index score of less than 7 (30-point scale) and age within 5 years of the sample mean for all participants. The control subjects each received BM compositions that were generated from a subject other than themselves. All subjects were divided equally among experimental and control groups with respect to race, gender, and age.

Researchers evaluated before versus after intervention scores from each participant using a 128-question self-report instrument that provided separate assessments of insomnia, sleep quality, depression, life satisfaction, and daytime function positive and negative attributes. The individual assessments used were the Pittsburgh Insomnia Rating Scale, Subjective Sleep Questionnaire, Beck Depression Inventory, Life Satisfaction Scale, and the Daytime Functioning Scale. During their first visit, participants

TABLE 1. Type and Distribution of the 128-Question Behavioral Self-Assessment Instrument Comprising Six Targeted Behavioral Assessments Providing Details About Mood, Sleep Quality, Insomnia Level, Job Performance, and Life Satisfaction

Anova: single factor – alpha = 0.002	P-Value	F Critical	*Significant*
Grand Mean – Raw	1.S3E-17	2.0038	Yes
Sleep Quality – Raw	1.18E-07	1.9806	Yes
Insomnia – Raw	5.24E-16	2.0038	Yes
Mood Scale – Raw	4.16E-18	2.0038	Yes
Daytime Function Positive – Raw	3.21E-13	2.0038	Yes
Daytime Function Negative – Raw	5.40E-22	2.0038	Yes
Life Satisfaction – Raw	1.38E-50	2.0038	Yes
Grand Mean – Difference	2.17E-26	2.1271	Yes
Sleep Quality – Difference	2.S7E-34	2.1271	Yes
Insomnia – Difference	1.74E-27	2.1271	Yes
Mood Scale – Difference	2.11E-25	2.1271	Yes
Daytime Function Positive – Difference	6.37E-46	2.1271	Yes
Daytime Function Negative – Difference	4.55E-24	2.1271	Yes
Life Satisfaction – Difference	1.59E-23	2.1271	Yes
t-Test: Paired Two Sample for Means (Alpha = 0.02)	P(T< = f) two-tail	t Critical two-tail	*Significant*
All 41 – Grand Mean (Post vs. Pre)	6.91E-06	2.42326	Yes
All 41 – Grand Mean (Post vs. Bl)	4.31E-06	2.42326	Yes
All 41 – Grand Mean (Post vs. Avg)	1.48E-06	2.42326	Yes

Note. The self-report instruments were filled out on three separate occasions by each subject; at the initial meeting (baseline [Bl]), 4 weeks later when they picked up their Brain Music (Pre), and after using the Brain Music compositions for 4 weeks (Post).

completed the Bl behavioral assessment and their EEG at F3, F4, C3, and C4 was recorded to produce the individualized activating and relaxing BM compositions. On a second visit 4 weeks later, participants again filled in self-reports and received their own BM compact disc along with a prescription for using the compositions during the test period. The six members of the crossover control group did not receive their own compositions; instead, they received music made from the brainwaves of one of the other control subjects, matched by gender. The control subjects received their own BM at the end of the study. A final assessment was filled out by all subjects and mailed to the investigators immediately after completion of the 4-week BM test period. This final assessment provided the after results used to evaluate the effectiveness of the intervention over the Bl to Post and Pre to Post periods. An assessment of the average of the Bl and Pre periods (e.g., the entire 8-week pre–post) was also included in the study (Avg to Post).

To analyze the behavioral assessment data, we compared the before versus after intervention differences by subtracting the Pre from the Post (Δ^1) and Bl from the Post (Δ^2) scores. In addition, to increase the sample size, researchers looked at the average difference between the Bl and Pre results (Δ^3) by subtracting the average of the Bl and Pre scores from Post scores for each subject. The raw and difference scores from all three test periods were analyzed statistically with respect to the combined assessment and six individual assessments contained in the behavioral questionnaire (Table 1).

RESULTS

Behavioral Measures

In all cases, the terms Bl and Pre represent the beginning and end of the 4-week waiting period immediately preceding the use of BM. The Post period represents the condition of BM use, reported at the end of the 4-week test. The between-condition results from the behavioral assessments are $\Delta^1 =$ Post minus Pre (change in response since the end of the waiting period), $\Delta^2 =$ Post minus Bl (change in response since the beginning of the waiting period), and $\Delta^3 =$ Post minus Avg (change in response over the entire test period). The group data summed over the six assessments were reported in Table 2, showing the analysis

TABLE 2. Group Analysis of Variance and Paired *t*-Test Results of the Raw Samples and Difference Data Sets from the 128-Question Behavioral Assessment for all 41 Subjects: Operations Support (15), First Responder (20), and Crossover Control (6)

t-Test: Two-sample assuming unequal variances (alpha = 0.05)	P (T ≤ t) Two-tail	t Critical two-tail	*Significant*	*Gains*
Sleep Quality (Post vs. Pre)	2.20E-08	1.9917	Yes	90.0%
Sleep Quality (Post vs. Bl)	8.90E-11	1.9917	Yes	95.0%
Sleep Quality (Post vs. Avg)	8.11E-10	1.9925	Yes	97.5%
Insomnia (Post vs. Pre)	2.95E-05	1.9944	Yes	90.0%
Insomnia (Post vs. Bl)	1.26E-05	1.9966	Yes	90.0%
Insomnia (Post vs. Avg)	9.64E-06	1.9944	Yes	87.5%
Mood Scale (Post vs. Pre)	0.0008	1.9949	Yes	70.0%
Mood Scale (Post vs. Bl)	0.0012	1.9930	Yes	67.5%
Mood Scale (Post vs. Avg)	0.0006	1.9925	Yes	85.0%
Daytime Function Positive (Post vs. Pre)	0.2821	1.9908	No	67.5%
Daytime Function Positive (Post vs. Bl)	0.3388	1.9901	No	62.5%
Daytime Function Positive (Post vs. Avg)	0.3005	1.9905	No	72.5%
Daytime Function Negative (Post vs. Pre)	0.0028	1.9908	Yes	82.5%
Daytime Function Negative (Post vs. Bl)	0.0037	1.9913	Yes	80.0%
Daytime Function Negative (Post vs. Avg)	0.0023	1.9905	Yes	85.0%
Life Satisfaction (Post vs. Pre)	0.2330	1.9905	No	67.5%
Life Satisfaction (Post vs. Bl)	0.4337	1.9901	No	60.0%
|Life Satisfaction (Post vs. Avg)	0.3148	1.9901	No	65.0%

Note. Bl = baseline.

TABLE 3. Paired *t*-Test Results of Group Differences from Six Behavioral Assessment Over Three Test Periods Δ1, Δ2, and Δ3

Effect size	Sleep quality	Gains	Insomnia	Gains	Mood	Gains	Daytime function (−)	Gains
Ops Support	7.0	4 of 15	37.2	5 of 15	5.0	6 of 15	10.8	4 of 15
First Responder	5.7	5 of 20	40.9	7 of 20	5.9	5 of 20	10.7	5 of 20
Control	3.5	1 of 6	31.1	1 of 6	3.1	1 of 6	8.5	0 of 6

Note. Average gains reported for the significant assessments: sleep quality (94.2%, P < .001), insomnia (89.2%, P < .001), mood (74.2%, P < .001), and daytime function negatives (82.5%, P < .004). Ops = operations.

of variance (ANOVA) and paired *t* test for means analyses for all 41 subjects. These data were subjected to the single-factor ANOVA at an alpha level of .002 (99.8%), where the analysis of the grand mean Δ^1 difference indicated the responses were normally distributed (P-Value = 2.17E-26; *F* Critical = 2.127, *N* = 41). As an alternative to the ANOVA, Table 2 (bottom) lists the results of the paired two sample *t* test for means, which evaluated the distribution of the reported changes over the three test periods. For sleep quality, the resulting change in the Δ^1 sample was significant at P $(T \leq t)$ two-tailed = 6.91E-06; *t* Critical = 2.423, *N* = 41. The six assessments were individually evaluated with the *t* test summed for means with unequal variance on a pairwise basis at $\alpha = .05$ (Table 3). These *t*-test results demonstrated significant levels of change in four of the six behavioral assessments.

Researchers evaluated the before versus after behavioral changes using the *t* test of means with unequal variance because of a large expected pre versus post difference from the BM intervention. Table 3 shows the results for Δ^1, Δ^2, and Δ^3 data sets from all six assessments used in the Wellness Program Study in which only the Daytime Function positive aspects and Life Satisfaction survey were not significant (P > .05). Overall, four of six assessments demonstrated significant levels of change over all three test periods in before versus after sleep quality, insomnia, mood, and daytime function negative aspects.[1] Whereas, the daytime function positives[2] and life satisfaction assessments

[1](Weaknesses) fatigue, irritability, emotional vulnerability, headache, muscle tension, and startle response.

[2](Strengths) concentration, energy level, work productivity, home task completion, interest in sex, and social activities.

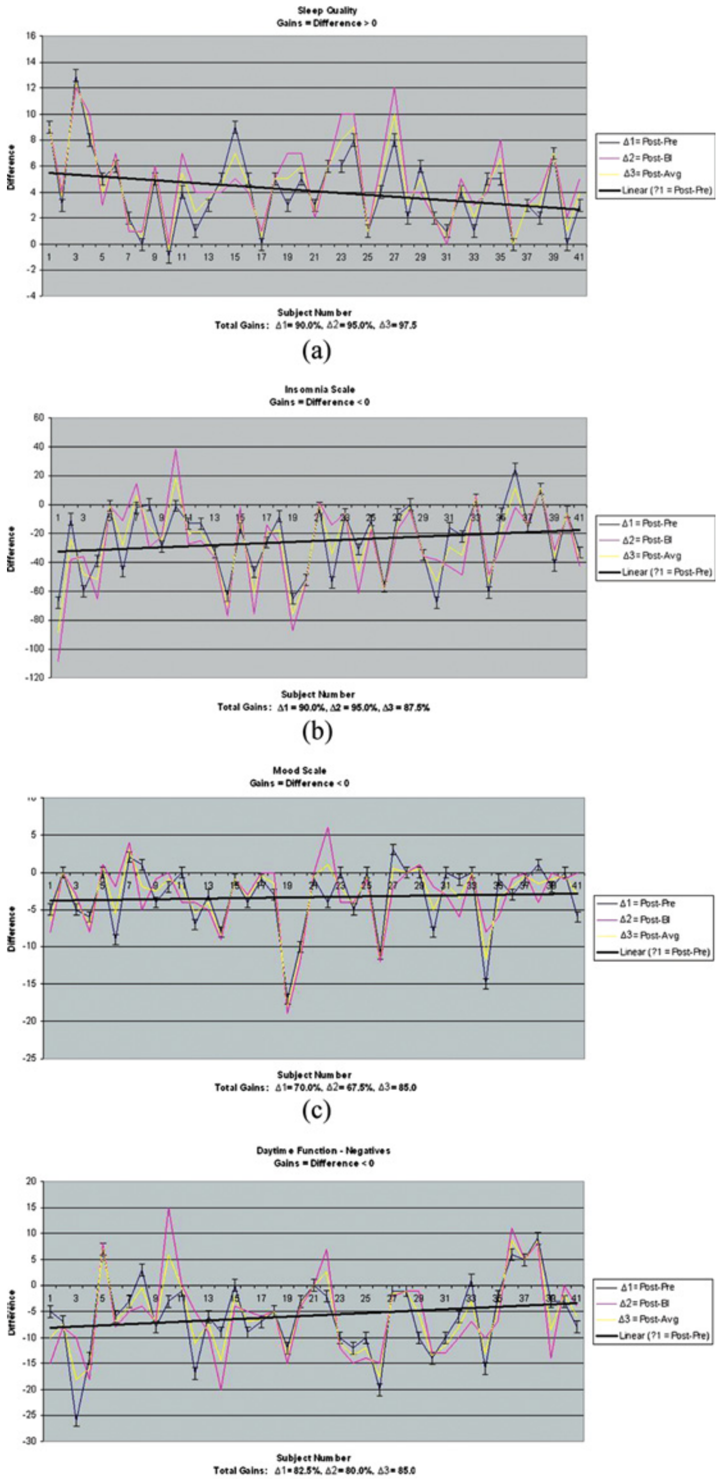

FIGURE 1. Changes in (a) sleep quality, (b) insomnia, (c) mood, and (d) daytime function negatives from three test periods (trend and standard deviations for post-pre only). *Note.* Blue line: post – pre, pink line: post – Bl, and yellow line: post – avg. ops support (1–15) shown on the left, first responder in the middle (16–35), and control on the right (36–41). (Color figure available online.)

did not show significant changes in any comparisons after 4 weeks use of the BM.

Figures 1a through 1d graph the difference scores from the sleep quality, insomnia, mood, and daytime function negative aspect assessments. The three lines in the graphs are from the computed differences $\Delta^1 = $(Post minus Pre), $\Delta^2 = $(Post minus Bl), and $\Delta^3 = $(Post minus Avg (Bl + Pre/2)). Δ^1 scores are shown in blue, Δ^2 in pink, and Δ^3 in yellow. All four figures show a high level of individual test–retest reliability across the assessments. In each figure, the graphs indicate positive and negative changes from all subjects after 4 weeks use of the individualized music compositions (only positive results reported). The graphs also indicate the linear trend line and standard error bars for the Δ^1 results only. The graphs are ordered from left to right according to experimental group assignment, where numbers 1 to 15 are ops support, numbers 16 to 35 are first responder, and numbers 36 to 41 are the crossover control group.

In Figure 1a, the before versus after BM intervention results (Δ^1, Δ^2, and Δ^3) are shown for the sleep quality assessment. For the Δ^1 period, 90.0% of subjects showed improvement ($N = 41$, $\alpha = .05$, $P(T \leq t)$ two-tailed = 2.20E-08, t Critical two-tailed = 1.99167). Figures 1b through d show the differences from the insomnia, mood, and daytime function negative aspect assessments.

Effect sizes ranged between 3.5 and 7.0 for sleep quality, 31.1 to 40.9 for insomnia, 3.1 to 5.9 for mood, and 8.5 to 10.8 for daytime function negatives over the experimental and crossover control groups (Table 4). The calculation of effect size is used to investigate the significance of the within-group differences reported by subjects. Effect size is determined by dividing the standard deviation of the within-group test samples for each assessment by the smallest measurable difference ($d = \frac{1}{2}$ point for all assessments). For the sleep quality assessment (Figure 1) the effect sizes are as follows: ops support = 7.0, first responder = 5.7, and control = 3.5. Once the effect size is determined for a group, the difference score from each subject in the group can be compared to the average group effect size, where an individual's score found outside the average is considered a significant change for that subject, either positive or negative.

By examining the first 15 entries in Figure 1a (ops support), we see that four of the 15 subjects have scores over 7.0. Thus, 26.7% of the ops support group demonstrated a significant improvement in sleep quality. In addition, for the sleep quality assessment, 25% of the first responders (five of 20) and 16.7% of the crossover controls (one of six) experienced a significant positive change after BM. Table 5 shows the percentage of subjects by group who experienced a significant level of improvement across the four assessments.

TABLE 4. Effect Sizes and Number of Subjects with Scores Greater Than the Effect Size for the Four Behavioral Assessments: Sleep Quality, Insomnia, Mood, and Daytime Function Negative Aspects

Major changes	Sleep quality	Insomnia	Mood	Daytime function
Ops Support First	26.7%	33.3%	40%	13.3%
Responder	25%	35%	25%	25%
Control	16.7%	16.7%	16.7%	0%

Note. Ops = operations.

TABLE 5. Percentage of Subjects by Group Showing Significant Improvement in Before versus After Scores for the Four Significant Behavioral Assessments

Number of questions by test type		
1	Mood Scale	20
2	Sleep Quality Scale	6
3	Insomnia Scale	65
4	Daytime Function	
a	Negative Symptoms	6
b	Functional Measures	6
5	Life Satisfaction	25
Total	Bebavioral Questions	128

DISCUSSION

A 4-week-long test of two individualized BM activating and relaxing compositions was carried out by 41 male and female volunteers, while at home and work, to investigate pre- versus postchanges recorded with six targeted behavioral assessment questionnaires. The assessments were made on three occasions (two before and one after use of BM), and differences were determined individually and summed for group analyses. ANOVA and *t* test for means with unequal variance were applied to the raw and pre versus post difference data sets of which four of the six assessments indicated a significant level of change. Of the significant assessments, the average gains over the three test periods were sleep quality (94.2%, $P < .001$), insomnia (89.2%, $P < .001$), mood (74.2%, $P < .001$), and daytime function negatives (82.5%, $P < .004$).

These data indicated that most subjects experienced some amount of positive change in measures of sleep quality, insomnia, mood and performance, where benefits were reported at the end of four weeks use of the music compositions. What we really wanted to know, however, was how many participants experienced an individually significant positive change. To determine this, we evaluated the individual versus group effect size differences and identified those subjects with difference scores larger than their group effect size. Volunteers classified as operations support showed the largest gains in sleep quality and mood scales, whereas the first responder group showed the largest gains in insomnia and daytime function scores. The crossover control group did show improvements on the assessments, but they were always lower than those of the experimental groups. The fact that one of six members (16.7%) of the control group did show a positive change indicates that BM may have a minimal effect even when using someone else's compositions.

Although most of the assessments demonstrated a high degree of positive outcome with little variation across test conditions, the Daytime Function Positive and Life Satisfaction assessments were not significant at either the group or individual levels. The reason that these assessments were not significant is likely due to the increased range of both the positive and negative values reported in the two assessments. In addition, the measures of daytime function positives and life satisfaction tended to focus on more complex life issues as compared to the sleep and depression-related questionnaires. For instance, one subject noted at the end of the third assessment,

> I don't really understand the questions regarding romantic relationship. My wife hates it because I'm more of a realist not a romantic. I did, however buy my wife flowers last week for the 1st time in 6 months. I do notice that I fall asleep better after listening to the music, however this takes away from ''Pillow Talk'' which annoys my wife since I fall asleep right away and she wants us to talk about our day.

Clearly, identifying changes in sleep is much easier than measures that include complex relationship dynamics. Even as subjective indicators of complex behaviors, these results do show a broad range of improvement across the experimental and control groups, even in the assessments that were not found to be significant.

The Wellness Program Study utilized a pairwise analytical approach without evaluating the individual responses on the self-report instruments. Considerable useful information could still be gleaned from these data using meta-analysis approaches to investigate correlations among the assessments and the behavioral outcomes. A multiple analysis of variance and cross-correlation methods may be able to identify predictors of positive or negative effects from BM. If so, then future screening tools might be developed to identify those persons most likely to benefit from the neurofeedback training intervention.

The 21st century will be an exciting time in brain research where neurotechnologies will emerge as a valuable weapon in the fight against mental illness and a plowshare for cutting new paths toward mental and physical well-being. The technology advances made over the last 10 years have opened the door for treatments like BM that have broad implication to improving mental health in revolutionary new ways. With easy to make and use tools like BM, we now have improved capabilities at hand for treating sleep disruptions and improving one's overall state of wellness. Prior research has demonstrated its clinical effectiveness against insomnia, and the Wellness Program Study has demonstrated the ability of BM to improve sleep quality, insomnia, mood, and job function within a population of first responders under real-world conditions. Thus, the link between neurotechnology and human behavioral performance has been made in both the clinical and operational settings. We now face the task of broader testing to better understand the effects on the nervous system and to quantify the accuracy and specificity of neurofeedback training interventions. There is growing evidence-based science in support of brain wave feedback as a mechanism to modulate resting state brain network activity for benefit in psychiatric conditions like depression and attention-related conditions (Buzsáki, 2006; Gevensleben et al., 2009; Paquette, Beauregard, & Beaulieu-Prévost, 2009). Thus, the use of neurotraining technologies is not merely speculation but rather another viable method, which needs more limelight and investigation to understand if such interventions can provide a capable tool for improving on the job performance and mental health in general.

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