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ORIGINAL PAPERS

Binaural Beat Technology in Humans: A Pilot Study to Assess Psychologic and Physiologic Effects

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ABSTRACT

Introduction: Binaural beat technology (BBT) products are sold internationally as personal development and health improvement tools. Producers suggest benefit from regular listening to binaural beats including reduced stress and anxiety, and increased focus, concentration, motivation, confidence, and depth in meditation. Binaural beats are auditory brainstem responses that originate in the superior olivary nucleus as a result of different frequency auditory stimuli provided to each ear. Listeners to binaural beat "hear" a beat at a frequency equal to the difference between the frequencies of the applied tones.

Objectives: The objectives of this pilot study were to gather preliminary data on psychologic and physiologic effects of 60 days daily use of BBT for hypothesis generation and to assess compliance, feasibility, and safety for future studies.

Design: Uncontrolled pilot study.

Subjects: Eight healthy adults participated in the study.

Intervention: Participants listened to a CD with delta (0–4 Hz) binaural beat frequencies daily for 60 days.

Outcome Measures: Psychologic and physiological data were collected before and after a 60-day intervention. *Psychologic:* Depression (Beck Depression Inventory-2), anxiety (State–Trait Anxiety Inventory), mood (Profile of Mood States), absorption (Tellegen Absorption Scale) and quality of Life (World Health Organization-Quality of Life Inventory). *Physiological:* Cortisol, dehydroepiandrosterone, melatonin, insulin-like growth factor-1, serotonin, dopamine, epinephrine, norepinephrine, weight, blood pressure, high sensitivity C-reactive protein.

Results: There was a decrease in trait anxiety ($p = 0.004$), an increase in quality of life ($p = 0.03$), and a decrease in insulin-like growth factor-1 ($p = 0.01$) and dopamine ($p = 0.02$) observed between pre- and postintervention measurements.

Conclusions: Binaural beat technology may exhibit positive effect on self-reported psychologic measures, especially anxiety. Further research is warranted to explore the effects on anxiety using a larger, randomized and controlled trial.

INTRODUCTION

When opposite ears receive two different sound frequencies that are between 90 and 1000 Hz and differ by no more than 35 Hz, binaural beats are perceived by the listener.[1] Normally, differences in sound frequencies between each ear provide directional information about the location of a sound. When the frequencies enter the ear directly with stereo headphones, the listener senses the difference between the two frequencies as another "beat" that appears to be inside the head. The binaural beat perceived is the difference between the two externally presented frequencies. For example, if the right ear receives a pure tone of 400 Hz and the left ear receives a pure tone of 410 Hz simultaneously, a beat of 10 Hz is perceived by the listener. The binaural beats are generated from the me-

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dial superior olivary nucleus, a small mass of gray matter in the ventral part of the pons reticular formation, which is responsible for contralateral integration of the auditory system.[2–4]

The application of binaural beat technology (BBT) relies on its purported ability to entrain brain wave activity. For example, if a person listened to binaural beats at 10 Hz, they should have an increase in brain wave activity at 10 Hz.[3] Studies conducted on BBT suggest many applications (Table 1).[5–23,*] However, many of these studies are poorly reported, contain methodologic flaws such as inappropriate listening devices and unvalidated measures, and are not peer reviewed. The well-designed studies have not been replicated. The simple design and small sample size were chosen to collect preliminary data for a larger, randomized, and controlled trial on a specific health outcome. In order to focus future BBT clinical studies, this study examined the psychologic and physiologic outcomes of suggested benefit with more rigorously conducted and reported methods than previously applied.

*Slocum D. An evaluation of the effects of relaxation training on the subjective experience of chronic fatigue syndrome. Unpublished dissertation, 2002.

MATERIALS AND METHODS

Study design

The study was an uncontrolled pilot of daily BBT use for 60 days. Outcome measures were collected before and after the 8-week intervention.

Subjects

The protocol was approved by the Institutional Review Board at the National College of Natural Medicine (NCNM). Subjects from the general public were recruited in the Portland, Oregon metropolitan area and included men and women, between the ages of 18 and 65, who were naïve to BBT and who consented to participate. Exclusion criteria included pregnancy, history of major neurologic or psychiatric disorder, inability to sit quietly for up to 1 hour a day, and having heard BBT previously. Fifteen interested people were screened within 2 weeks to enroll 8 healthy white subjects (7 women, 1 man; ages 28–68; mean age 42.75).

Schedule

Each volunteer provided consent and was given a home saliva collection kit. The following morning at 6 AM, the

Table 1. Binaural Beat Technology (BBT) Studies

Author	*Study design*	*Participants*	n	*Simple/ complex freq*	*Source freq stated*	*BBT frequency*	*Outcome measures*
Akenhead, undated[5]	UCT	Healthy adults	13	Complex	N	NR	Concentration, relaxation
Atwater, 2001[6]	UCT	Healthy adults	40	Complex	Y	Alpha/delta	EEG
Brady, 2000[7]	UCT	Healthy adults	6	Complex	N	Theta	Hypnotic susceptibility, EEG
Dabu-Bondoc, 2003[8]	RCT	Surgery patients	60	Complex	N	NR	Anesthesia
Foster, 1990[9]	RCT	Healthy adults	60	Complex	N	Alpha	EEG
Guifoyle, 1996[10]	RCT	Developmentally disabled adults	20	Complex	N	Beta	Memory, focus, attention
Hiew, 1995[11]	CT	College students	19	Complex	N	NR	Creativity
Karino, 2004[12]	UCT	Healthy adults	6	Simple	Y	Delta	MEG
Kennerly, undated Dissertation[13]	RCT	College students	50	Complex	N	Beta	Memory
Kliempt, 1999[14]	RCT	Surgery patients	76	Complex	N	NR	Amount anesthesia used
Lane, 1998[15]	COC	Healthy adults	29	Complex	Y	Beta/theta/delta	Mood, vigilance
Le Scouarnec, 2001[16]	UCT	Anxious adults	15	Complex	N	Delta/theta	Anxiety
Louis, 1993[17]	UCT	Sleeping disorders	5	Complex	N	NR	Sleeping quality
Masluk, 1999[18]	UCT	Healthy adults	160	Complex	N	NR	Number of experiences
Morris, 1996[19]	UCT	Developmentally disabled children	20	Complex	N	NR	Behavior
Padmanabhan, 2005[20]	RCT	Surgery patients	108	Simple	N	Delta	Anxiety
Sadigh, undated[21]	OCT	Healthy adults	3	Complex	N	NR	EEG
Schwarz, 2005[4]	UCT	Healthy adults	18	Simple	Y	Gamma	EEG
Slocum, undated dissertation[a]	UCT	Chronic fatigue	90	Simple	N	Delta	Chronic fatigue symptom severity
Stevens, 2003[22]	RCT	College students	27	Complex	Y	Theta	Hypnotic susceptibility, EEG
Sanders, 1997[23]	CT	Alcoholics	9	Complex	N	NR	Depression

[a]See * footnote on this page.

UCT, uncontrolled trial; RCT, randomized controlled trial; CT, controlled trial; COC, crossover controlled trial; OCS, observational case series; NR, not reported; EEG, electroencephalogram.

participant collected a saliva sample and returned to the clinic in the afternoon where he or she returned their saliva sample, completed self-report psychologic questionnaires, had a blood draw, and received additional laboratory kits for home collection. The next day the participant collected saliva at waking, noon, 5 PM, and 10 PM, urine 2–3 hours after waking, and then mailed their collection kits back to the Helfgott Research Institute, NCNM. Participants then began listening to the CD daily for 60 days. After the intervention period, the same collection schedule as baseline ensued. Subjects were called weekly to collect compliance and adverse events data.

Intervention

The auditory stimulus was the Centerpointe Research Institute (Beaverton, Oregon) Holosync Introductory CD consisting of 60 minutes of BBT with an overlay of sound resembling rain and bells. The binaural beat begins in the beta frequency range (10 Hz) and decreases incrementally until reaching the delta frequency range (2.5 Hz), where it remains for 40 minutes. Each participant was instructed to listen with stereo headphones for 30 minutes a day for 14 days and 60 minutes a day for an additional 46 days, sitting upright with eyes closed according to producer instructions.

Psychologic outcome measures

Psychologic outcomes included depression (Beck Depression Inventory-2 [BDI-2]), anxiety (State–Trait Anxiety Inventory),[24] mood (Profile of Mood States), absorption (Tellegen Absorption Scale) and quality of life (World Health Organization–Quality of Life Brief) scales. The Profile of Mood States questionnaire (POMS) contains six subscales: Tension–Anxiety, Depression–Dejection, Fatigue–Inertia, Anger–Hostility, Vigor–Activity, and Confusion–Bewilderment.[25] The Tellegen Absorption Scale (TAS) examines absorption or "the openness to absorbing and self-altering experiences," which is the most studied correlate of hypnotizability.[26] The questionnaires were completed by the participants at baseline and endpoint visits. Subjects also completed a daily listening log for 60 days. Psychologic questionnaires were scored by the lead author.

Physiologic outcome measures

Physiologic outcome measures included cortisol, dehydroepiandrosterone (DHEA), melatonin, insulin-like growth factor 1 (IGF-1), serotonin, dopamine, norepinephrine, epinephrine, high-sensitivity C-reactive protein (hsCRP), weight, and blood pressure. Blood was drawn at the NCNM clinic laboratory for hs-CRP and IGF-1 measurement. Blood was centrifuged, and serum was separated and frozen in a −20°C freezer before shipment to the appropriate processing laboratory. Five saliva samples and one urine sample were collected for each evaluation (Saliva Day 1: 6 AM, Day 2: waking, noon, 5 PM, and 10 PM; Urine Day 2: 2–3 hours after waking). Blood was analyzed for hsCRP at Rhein Consulting Laboratories (Portland, Oregon). Six AM saliva samples were analyzed for melatonin values using enzyme-linked immunoassay by Neuroscience, Inc. (Osceola, Wisconsin). Waking, noon, 5 PM, and 10 PM saliva samples were analyzed to measure cortisol and DHEA using enzyme-linked immunoassay by ZRT Laboratories (Beaverton, Oregon). Dried whole blood via blood spot collection was analyzed to measure IGF-1 by ZRT Laboratories. Urine samples were analyzed to measure serotonin, dopamine, norepinephrine, and epinephrine using enzyme-linked immunoassay by Neuroscience, Inc.

Analyses

All questionnaire scores and laboratory data points were entered into an SPSS 14.0 (Chicago, Illinois) database file where baseline and endpoint measures were compared after testing for normality. Paired *t* tests were conducted to examine significance of relevant changes and correlations were then done for significant values. Linear regressions were performed to test for potential confounding by age, gender, and weight.

RESULTS

Feasibility

The daily compliance for all participants averaged 94%. There was 100% attendance at scheduled visits, and 100% completion of all questionnaires and biologic samples collection and return.

Safety

There were no unusual symptoms reported.

Psychologic and physiologic outcome measures

Four outcomes demonstrated significant changes between pre- and postmeasurements: trait anxiety, quality of life, IGF-1, and dopamine (Table 2). No confounding by age, gender, or weight was observed in these values. Trait anxiety showed a significant decrease ($p = 0.004$) (Fig. 1). The quality-of-life measure also demonstrated significant improvement ($p = 0.03$) (Fig. 2). The POMS showed a decrease in total mood disturbance, a decrease in tension/anxiety, confusion and fatigue subscale, and an increase in the depression and vigor subscales. No clear or significant trends were observed in epinephrine and norepinephrine (Fig. 3 A, B). There was one participant with an abnormally high baseline serotonin value and a large decrease after the intervention (Fig. 3D). Dopamine, an excitatory neurotransmitter, showed a significant reduction from pre- to post-

Table 2. Outcome Measures and Results

Psychologic outcomes	*Baseline mean*	*Endpoint mean*	p *(T ≤ t) two-tail*	*General outcomes*	*Baseline mean*	*Endpoint mean*	p *(T ≤ t) two-tail*
Depression[1]	6.38	5.00	0.32	Weight pounds	169	170	0.43
State Anxiety[2]	32.63	38.88	0.11	Systole mm Hg	116	122	0.23
Trait Anxiety[2]	42.25	33.75	0.004**	Diastole mm Hg	74.13	75.50	0.67
Total Mood Disturb[3]	24.12	16.62	0.20	hsCRP[B] mg/L	1.24	1.05	0.47
Tension/Anxiety[3]	10.63	8.75	0.39	Endocrine outcomes			
Depression[3]	2.38	3.89	0.11	HPA axis cortisol-am[S]	5.64 ng/mL	8.6 ng/mL	0.16
Vigor[3]	12.50	14.50	0.21	Noon[S]	2.24 ng/mL	1.15 ng/mL	0.53
Fatigue[3]	12.00	8.13	0.18	Eve[S]	1.29 ng/mL	0.31 ng/mL	0.11
Confusion[3]	7.25	6.88	0.71	Night[S]	0.28 ng/mL	0.48 ng/mL	0.47
Anger/Hostility[3]	4.38	3.50	0.28	DHEA[S]	11.38 ng/mL	11.22 ng/mL	0.89
Total Absorption[4]	44.50	45.50	0.69	Pineal: melatonin[S]	33.11 pg/mL	29.21 pg/mL	0.47
Response to stimuli[4]	11.38	13.25	0.08	Growth hormone: IGF-1[B]	217.75 ng/mL	178.5 ng/mL	0.01**
Synesthesia[4]	8.50	8.38	0.89	Nervous outcomes	140.11 pg/gCr	92.14 pg/gCr	0.35
Enhanced cognition[4]	9.38	8.88	0.23	Serotonin[U]	163.10 pg/gCr	106.09 pg/gCr	0.02**
Dissociative[4]	9.00	8.00	0.23	Dopamine[U]	40.50 pg/gCr	38.70 pg/gCr	0.71
Vivid reminiscence[4]	3.13	3.38	0.70	Norepinephrine[U]	5.74 pg/gCr	4.28 pg/gCr	0.23
Enhanced awareness[4]	3.13	3.63	0.52	Epinephrine[U]			
Quality of life[5]	84.63	90.75	0.03**				

1, Beck Depression Inventor-2 questionnaire; 2, State–Trait Anxiety Inventory; 3, Profile of Mood States; 4, Tellegen Absorption Scale; 5, World Health Organization–Quality of Life Inventory; B, blood; S, saliva; U, urine. **p 0.05.

DHEA, dehydroepiandrosterone; hsCRP, high-sensitivity C-reactive protein; HPA, hypothalamic–pituitary–adrenal; IGF-1, insulin-like growth-factor 1.

intervention ($p = 0.02$) (Fig. 3C). Melatonin, a hormone released by the pineal gland, showed no change (Fig. 4A). IGF-1 was significantly reduced from pre- to postintervention ($p = 0.01$) (Fig. 4B). Four of 33 measures demonstrated significant changes (12%), greater than expected by chance (5%). Because of the small size, multiple comparison procedures (Bonferroni, Tukey) were not conducted as appropriate for the preliminary nature of the study.

There was a weak correlation between the change in trait anxiety scores and change in dopamine values (Spearman's coefficient = 0.287, $p = 0.490$) and quality of life score (Spearman's coefficient = 0.398, $p = 0.329$). There was also a weak correlation between the change in dopamine values and change in quality-of-life scores (Spearman's coefficient = 0.216, $p = 0.608$) and IGF-1 values (Spearman's coefficient = −0.395, $p = 0.333$). There was a

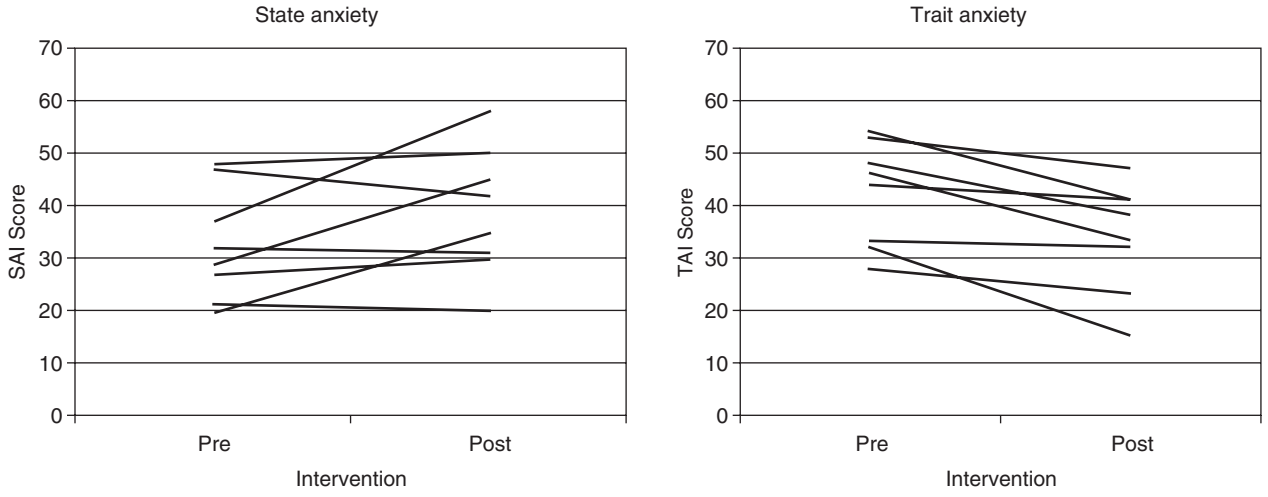

FIG. 1. Trait anxiety significantly decreased. The State–Trait Anxiety Inventory was administered at baseline and after 60 days of intervention and is a 40-item scale completed in 10 minutes or less. It is designed to assess state anxiety, a general anxiety level and trait anxiety, anxiety in a specific situation. Trait anxiety was found to be significantly decreased from baseline to endpoint measures (Baseline mean 42.25 ± 9.98 endpoint mean 33.75 ± 10.48, p = 0.004). State anxiety remained the same for most participants except for three. (Baseline mean 32.63 ± 10.70, endpoint mean 38.88 ± 12.24, $p = 0.11$). SAI Score, State Anxiety Inventory Score; TAI Score, Trait Anxiety Inventory Score.

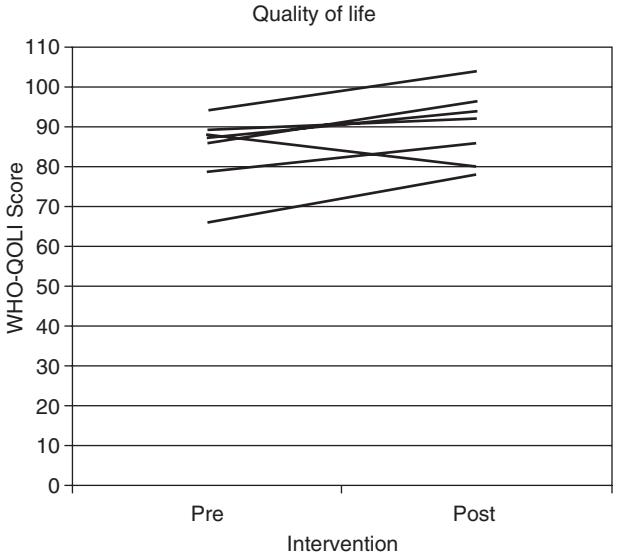

FIG. 2. Quality of life significantly increased. The World Health Organization Quality of Life Inventory (WHO-QOLI), a 26-item self-report questionnaire covering physical, psychologic, social, and environmental aspects of quality of life, was administered at baseline and after 60 days of intervention. A significant increase in quality of life was observed in the participants through paired *t* tests (baseline mean 84.63 ± 8.58, endpoint mean 90.75 ± 8.81, $p = 0.03$).

moderate correlation between change in quality-of-life scores and change in IGF-1 values (Spearman's coefficient = 0.572, $p = 0.138$).

DISCUSSION

Recruitment of this small sample presented no difficulties. High participant compliance was facilitated by weekly phone and e-mail communication. There appear to be no adverse side effects attributed to listening to binaural beats for 60 days according to subject interview, although safety was assessed in an informal way and long-term safety issues have not been addressed.

Psychologic state changes were observed from baseline to endpoint measurements. A decrease in trait anxiety occurred, reflecting an improvement in the participant's perceived reaction and ability to cope with stress and anxiety in general. The state anxiety score did not change and was a reflection of the participant's stress level at the time of completing the questionnaire, which was done in a medical clinic after a blood draw. The finding of reduced anxiety scores is corroborated by results from other studies.[16,20] LeScournaec observed a trend towards reduced anxiety in anxious patients with the use of BBT.[20] Padmanabhan observed a 26.3% reduction in pre-operative anxiety ($p = 0.001$) with surgical patients who listened to BBT prior to surgery.[16] Others have observed increased subjective relaxation in healthy participants with BBT listening as well.[9]

Despite the small sample size, there was also a significant improvement in quality of life scores ($p = 0.03$) and a weak correlation between improvements in quality of life and reduction of trait anxiety (Spearman's coefficient = 0.398, $p = 0.329$). One may argue that relaxation for one hour a day will improve his or her quality of life scores. Appropriate control groups in future protocols can address the relevance of this observation.

IGF-1 was chosen as an outcome measure because of producer's claims that growth hormone levels will rise by listening to BBT in the delta range and thus slow the aging process.[27] Growth hormone is a polypeptide hormone synthesized and secreted by the anterior pituitary gland that stimulates growth and cell reproduction in humans and normally declines with age.[28] IGF-1 is a stable biologic mediator of growth hormone secreted by the liver in response to the average growth hormone level throughout the day.[27] In our study, there was an observed decrease in IGF-1 and thus growth hormone activity from BBT listening, contrary to producer claims. We also found a moderate correlation between IGF-1 values and quality-of-life scores (Spearman's coefficient = 0.572, $p = 0.138$). A majority of other studies also report that growth hormone replacement and IGF-1 correlate well with quality-of-life improvement.[29–33] However, we observed that IGF-1 values significantly decreased while anxiety scores and quality-of-life scores improved. Therefore, the anxiety and quality-of-life changes may be mediated by other mechanisms than growth hormone effects.

Dopamine serves as a precursor to norepinephrine and epinephrine and acts as an excitatory neurotransmitter that modulates neuron voltage potentials to favor glutamate activity and neurotransmitter firing. The reduction in dopamine supports the observation of reduced anxiety, and the two measures had a weak correlation (Spearman's coefficient = 0.287, $p = 0.490$). Other studies have also associated dopamine reduction with anxiety improvements.[34] Even though dopamine had significant reductions, norepinephrine and epinephrine exhibited no effects from the BBT intervention. A 24-hour urine collection and larger sample size may reveal changes in these catecholamines where a spot urine specimen and small sample size did not.

Hypnotic susceptibility and theta brain wave activity has been shown to increase with theta range stimuli in one study.[7] A replication of this study found no such association.[22] Another investigator found that surgery patients who listened to BBT required significantly less fentanyl ($p < 0.001$) than surgery patients who listened to classical music or blank tapes.[14] An additional study explored hypnotic depth in patients undergoing surgery and found no effect.[14] Our finding of no significant changes for either the total or factor scores in pre- to postintervention measurements of TAS hypnotizability sheds no light on these contradictory

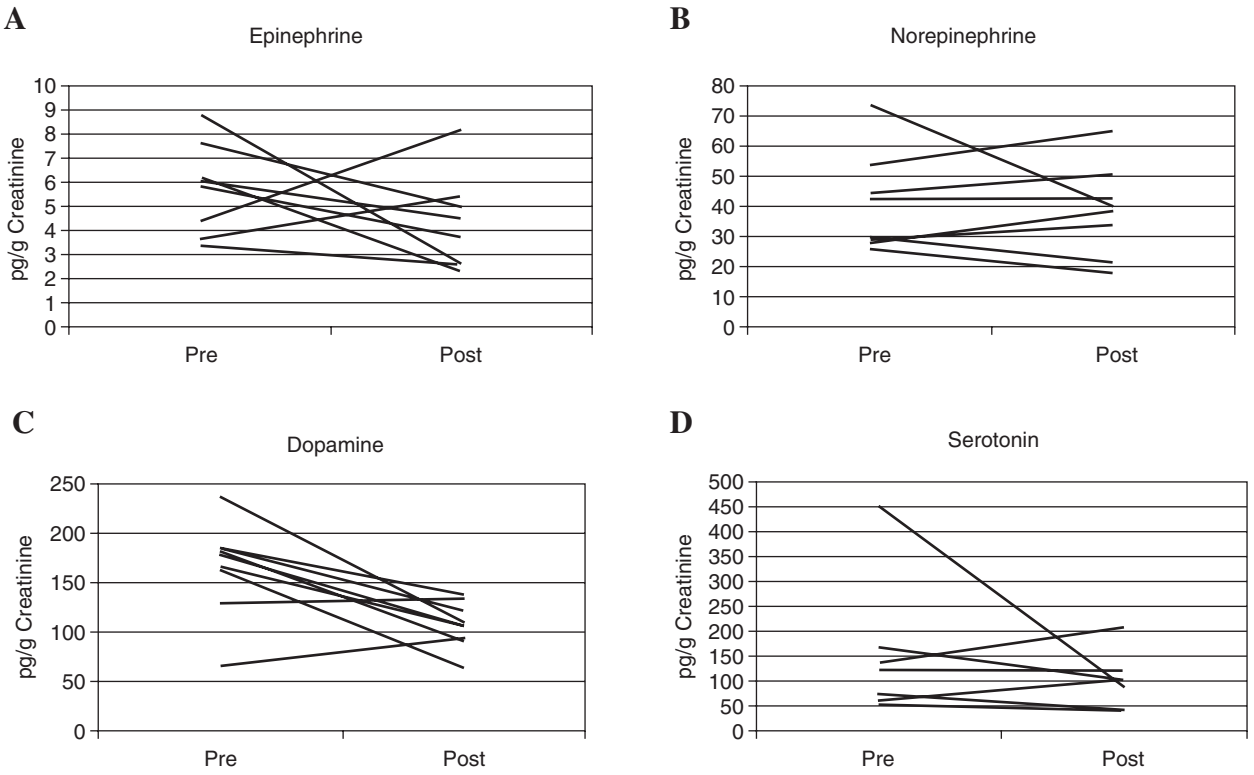

FIG. 3. Neurotransmitter changes. Neurotransmitters were measured at their diurnal peak from a urine sample collected 2–3 hours after waking and measured by enzyme-linked immunoassay standardized to creatinine levels. **A:** Six participants had a decrease in epinephrine, although the changes were not significant (baseline mean 5.74 ± 1.89, endpoint mean 4.28 ± 1.96, $p = 0.23$). **B:** Three participants had a decrease in norepinephrine, although the changes were not significant (baseline mean 40.5 ± 16.65, endpoint mean 38.7 ± 15.27, $p = 0.7$). **C:** Dopamine, an excitatory neurotransmitter, was significantly reduced (baseline mean 163.1 ± 49.73, endpoint mean 106.09 ± 24.25, $p = 0.02$). **D:** Serotonin results were not consistent for any participant (baseline mean 140.11 ± 133.02, endpoint mean 92.14 ± 54.90, $p = 0.35$).

findings. We are uncertain why there was no observed change. It may be that delta frequency BBT does not affect hypnotizability. Other investigators used theta BBT or did not report their stimuli frequencies.

In a double-blind crossover control study, Lane reported an improvement in mood (no p score reported) and increased focus ($p = 0.02$) with beta compared to theta/delta BBT use.[15] Our study also reveals a nonsignificant improvement

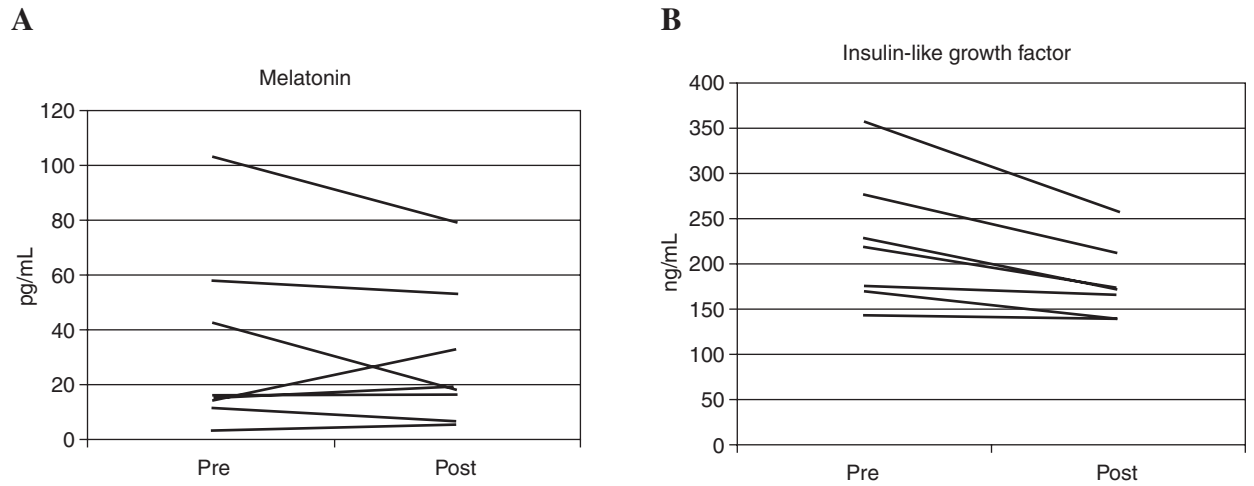

FIG. 4. Endocrine measure demonstrates significant changes. **A:** Melatonin, a pineal hormone associated with sleep cycles, showed no significant change (baseline mean 33.11 ± 33.74, endpoint mean 29.21 ± 25.74, $p = 0.47$). **B:** Insulin-like growth factor-1, a stable marker for growth hormone, showed a significant decrease (baseline mean 217.75 ± 69.46, endpoint mean 178.5 ± 39.64, $p = 0.01$).

in overall mood score ($p = 0.20$). Sanders observed improvements in depressive symptoms ($p = 0.02$) in Native American male alcoholics.[23] In our study, the mean BDI-2 score decreased nonsignificantly from pre- to postintervention ($p = 0.32$) and the POMS mean depression subscale increased nonsignificantly ($p = 0.11$). There is no conclusive evidence from our study that BBT affects depressive symptoms in a healthy population. Although this study is a small exploratory pilot, it provides preliminary data for future studies of BBT on valuable psychologic, endocrine, and nervous system outcome measures.

CONCLUSIONS

In future studies of BBT, scientists must take great care to define the beat frequency used, and implement the appropriate controls. Investigators might consider a control group who sits in a restful state (although blinding would be impossible with such a group) and a control group that listens to the same masking music without binaural beat imbedded within it. This would elucidate the effects of relaxation versus BBT on the psyche. It appears that BBT may exhibit some benefit on self-reported psychologic measures, such as quality of life and anxiety. At this time, BBT warrants larger, randomized, and controlled clinical trials to confirm clinical applicability of treating anxiety.

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