Neurologic Music Therapy Improves Executive Function and Emotional Adjustment in Traumatic Brain Injury Rehabilitation

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This study examined the immediate effects of neurologic music therapy (NMT) on cognitive functioning and emotional adjustment with brain-injured persons. Four treatment sessions were held, during which participants were given a pre-test, participated in 30 min of NMT that focused on one aspect of rehabilitation (attention, memory, executive function, or emotional adjustment), which was followed by post-testing. Control participants engaged in a pre-test, 30 min of rest, and then a post-test. Treatment participants showed improvement in executive function and overall emotional adjustment, and lessening of depression, sensation seeking, and anxiety. Control participants improved in emotional adjustment and lessening of hostility, but showed decreases in measures of memory, positive affect, and sensation seeking.

Key words: **brain injury; neurologic music therapy; cognitive rehabilitation; attention; memory; executive function; emotional adjustment**

Introduction

Cognitive rehabilitation (CR) has become a viable force to help improve the cognitive functioning of persons with neurologic illnesses and injuries.[1–4] The profession now has evidence-based practice standards, guidelines, and options for CR practitioners to ultimately benefit clients who seek to improve attention, memory, verbal skills, spatial skills, executive function, and psychosocial adjustment.

In parallel to the growth of CR, neurologic music therapy (NMT) has emerged as a discipline defined as the "therapeutic application of music to cognitive, sensory, and motor dysfunctions due to neurologic disease of the human nervous system" (p. 2).[5] In NMT, the therapeutic mechanisms in music are based on an understanding of music as a language of cognition and perception that stimulates physiologically complex cognitive, affective, and sensorimotor processes that are generalizable and transferable to nonmusical brain and behavior function.[6–9] Related research in motor therapies has shown the ability of musical-rhythmic stimuli to regulate motor functions, such as gait and arm control, in patients with stroke and Parkinson's disease.[10–12] Two of the better understood driving mechanisms behind this effect are: (1) arousal and priming of the motor system via auditory stimulation; and (2) timing and entrainment of the motor system (i.e., synchronization and entrainment of motor responses to the temporal structure of the

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sensory cues), leading to increased spatiotemporal optimization patterns in motor coordination. In addition, the music research literature provides strong evidence that music and rhythm not only engage the motor system, but also have critical attributes that can regulate and stimulate cognition and perception.[13,14] There is evidence that music engages attentional networks by streaming and analyzing dynamic perceptual patterns in music.[13–17] A critical role in this process has been assigned to rhythm as a temporal ordering process, producing rhythmic attention control.[18] Translational research investigating possible effects of temporal cues in music and rhythm on cognitive function have produced findings that encourage the application of NMT to CR. For example, the effect of musical mnemonics on verbal learning in healthy subjects showed changes in EEG topography and higher coherence in alpha brain wave rhythms across frontal cortical networks, indicating music-induced neural plasticity.[19] Positive effects of music on memory training in healthy subjects have also been reported by Wallace.[20] Subjects with multiple sclerosis showed increased memory performance using musical mnemonics concomitant with increased EEG coherence in right frontal brain networks.[19] Other studies have shown the positive effect of music on memory in dementia[21–24] and learning disabilities.[25,26] Many clinical reports have emphasized the relative survival of musical memories in neurologic memory disorders. However, studies also suggest that music can be utilized as a mnemonic device to enhance memory for nonmusical events.[27,28] In addition to attentional dimensions in music perception, temporal ordering in relationship to perceptual grouping and chunking has been suggested as one mechanism behind the efficacy of musical mnemonics.[15]

In spite of a fairly impressive understanding of attention mechanisms in music perception, actual clinical research in utilizing musical attention control to help remediate attention deficits in neurologic disorders has been limited thus far.[29–32] Knox, Yokota-Adachi, Kershner *et al.*[31] conducted one of the few studies of the effects of music therapy on brain-injured clients. Using a single-case research design, they demonstrated that attention capacities improved after participation in a 10-week musical attention training program.

In the area of emotional adjustment and response, researchers have examined responses in the brain to musical stimuli[33–35] and have demonstrated that emotional centers in the brain respond favorably to music. In their review of the studies of music and brain injury rehabilitation, Kleinstauber and Gurr[36] reported that music can decrease depression and anxiety, and that music "offers a comfortable, nonthreatening milieu which is an important aspect for the mood of the patient during therapy sessions" (p. 8).

A review of the literature reveals that no studies have been reported to date investigating the effects of therapeutic music training on executive function. Therefore, the purpose of this study was to provide a preliminary investigation of the immediate effectiveness of therapeutic music techniques—within the conceptual framework of NMT—in improving executive function, as well as other areas of cognitive functioning, with persons with acquired brain dysfunction. The study predicted that persons who engage in one session of NMT will improve in ability to concentrate, remember verbal information, think flexibly, and adjust emotionally.

Methods

Research Design, Participants, and Procedures

A pre-test- post-test quasi-experimental design was used to test the hypothesis of this study.[37] Two groups were recruited to participate. Control participants ($n = 23$) were recruited from persons with acquired brain dysfunction, including traumatic brain injury (86.95%), cerebrovascular accident (4.35%), and toxic exposure (8.70%), who were referred for neuropsychological evaluations. Control participants were given one of the assessment measures and then directed to a quiet room to rest for 30 min, after which the same instrument was re-administered.

Treatment participants ($n = 31$) for the study were recruited from persons with traumatic brain injury (77.42%), cerebrovascular accident (12.90%), seizure disorder (6.45%), and brain tumor (3.23%). The treatment group was involved in four separate sessions (attention, memory, executive function, and emotional adjustment), conducted on four different days. The first session focused on emotional adjustment, and executive function was the focus of the session on the following day. Then 2 weeks later the third (attention) and fourth (memory) sessions were conducted on consecutive days. At the beginning of each session, the cognitive measure pertaining to the skill being addressed was administered to each person. Then a 30-min NMT intervention was administered in a group setting by a board-certified music therapist with additional certification in NMT. Each musical session began with an introduction to the intervention and musical (vocal and instrumental) warm-up exercises. After the completion of each experimental session, the appropriate cognitive or emotional post-test was administered.

The study participants were predominantly male (83% in the control group and 89% in the treatment group) and Caucasian (95.65% in the control group and 90.32% in the treatment group), with 4.35% Native American participants in the control group and with 6.45% Native Americans and 3.23% Asian Americans in the treatment group. The average age of the treatment group was 52.65 years, while the control group's age averaged 47.39 ($t = -1.44$; $P = 0.16$). Years of education completed by the treatment and control groups were 13.48 and 14.30, respectively ($t = 1.15$; $P = 0.26$). For the subjects with traumatic brain injury, the severity of injury was noted. Within the treatment group, 28.57% had mild injuries, 17.86% had moderate injuries, and 53.57% had severe injuries. The control group consisted of 70% with mild injuries, 10% with moderate injuries, and 20% with severe injuries. The treatment and control groups were not significantly different in number of years since last injury (15.18 and 14.05, respectively; $t = -0.24$, $P = 0.81$). The reason that the number of years since the last injury was unusually high for both groups is that the subjects were from a rural area where brain rehabilitation services for military veterans have only recently become available. The two groups differed significantly on number of reported brain injuries (treatment = 1.28, control = 2.32; $t = 2.71$, $P = 0.01$). Persons with degenerative brain diseases, such as senile dementia of the Alzheimer's type, were excluded from the study. Procedures for this study were approved by the Institutional Review Board and the Research and Development Committee of the Black Hills Veterans Affairs Health Care System. Each subject gave written informed consent before participating in the study.

Measures

Assessment devices were chosen that were (1) well established in reliability and validity; (2) brief, so that they could be administered quickly as pre- and post-tests during one session; (3) did not demand large amounts of energy from the participants, who needed plenty of stamina for two administrations of the test plus a 30-min session of NMT; (4) able to produce scores that could reflect pre/post changes; and (5) minimal in producing practice effects.[35,39–41]

Attention was measured with the Digit Span subtest of the Wechsler Adult Intelligence Scale-III.[42] Memory was assessed with the Auditory Verbal Learning Test (AVLT).[43] Learning was defined as the total number of words learned over the five trials of the AVLT, and Recall was defined as the number of words remembered from the original list after a distracter was administered. The AVLT pre-test was taken from Rey's[43] original list of words.

On the post-test, Form 4[44] was administered to both control and experimental participants so that the words learned on the pre-test would not contaminate performance on the post-test. Mental flexibility, an aspect of executive function, was assessed with Part B of the Trail Making Test.[38] Emotional adjustment was assessed with two measures: the Global Severity Index from the Brief Symptom Inventory-18 (BSI-18)[45] and the Multiple Affect Adjective Check List (MAACL),[46] which measures depression, anxiety, hostility, sensation seeking, and positive affect. Two additional measures were used to assess the nature of the NMT experience. An adapted Self Efficacy Questionnaire[47] measured the participants' confidence in their cognitive skills and emotional adjustment. Likert rating scales were employed to measure the participants' level of enjoyment with the NMT experience and to rate the helpfulness of the therapist. Measures for this study were administered according to standard protocols by a board-certified neuropsychologist and pre-doctoral psychology interns who were trained and experienced in administering the tests used in the study.

Training Materials

All training exercises were based on interactive musical group improvisations with a highly focused functional content and task structure relative to the clinical rehabilitation goals to be addressed. The musical attention control exercises consisted of rhythmic synchronization exercises in which participants—using percussion instruments—synchronized their rhythm patterns to track "lead" patterns introduced by the therapist and other group members. Percussion patterns were modulated acoustically by tempo, loudness, and rhythmic pattern to entrain sustained and focused attention, following concepts of "paced attention" from Attention Process Training.[48,49] In memory training, lists of 15 unrelated words were taught as chants and songs utilizing music as a mnemonic device in order to create grouping and chunking effects to facilitate learning and recall.[20] As a follow-up, several permutations of reordering words into new mnemonic songs were implemented to strengthen an understanding of musical mnemonics use by the study participants.[26] Musical executive function training focused on individual decision making, problem solving, comprehension, and reasoning in creating group improvisation projects. Specific emphasis was given to switching attention and comprehension in performance to two rapidly alternating musical cues. For emotional adjustment, songs representing strong positive emotions were presented by the therapist vocally and performed in structured group therapeutic singing exercises.

Data Analysis

The results of the cognitive and emotional measures were calculated as pre-test and post-test means for each of the measures utilized in the study. The statistical procedures used were *t*-tests for paired samples, to compare the pre/post means for the treatment group and the control group for each measure. Pre-test and post-test results of the self-efficacy test for the treatment group were compared, also using a *t*-test for paired samples. Rating scale results were calculated using means and standard deviations. The 0.05 level of probability was established as significant.

In addition to probability analyses, effect sizes were calculated, in order to present evidence of the clinical significance of the findings.[50–52] Effect sizes reflect the degree of overlap in scores between two samples, and are considered "more likely to give truth to our reality of brain-behavior relationships"[52] (p. 654).

Results

Attention

The results, presented in Table 1, indicate that neither the control group ($t = 0.00$; $df = 13$; $P = 0.50$) nor the treatment group

TABLE 1. Changes in Cognitive and Emotional Functioning for Treatment and Control Groups

		Mean raw scores				
Measures	Treatment condition	Pre-test	Post-test	*t*	*P*	*d*[b]
ATTENTION						
Digit span	Treatment ($n = 21$)	14.90 (SD 3.77)	14.95 (SD 3.93)	−0.01	0.46	−0.01
	Control ($n = 14$)	15.50 (SD 3.65)	15.50 (SD 3.78)	0.00	0.50	0.00
MEMORY						
AVLT total	Treatment ($n = 18$)	36.50 (SD 11.95)	36.22 (SD 11.99)	0.26	0.40	0.02
	Control ($n = 14$)	43.29 (SD 8.48)	39.86 (SD 10.55)	1.77	0.02[a]	0.36
AVLT recall	Treatment ($n = 18$)	6.89 (SD 4.10)	6.06 (SD 4.44)	1.97	0.03[a]	0.19
	Control ($n = 14$)	9.50 (SD 2.56)	7.50 (SD 3.67)	3.02	0.00[a]	0.64
EXECUTIVE FUNCTION						
Trails B[c]	Treatment ($n = 19$)	107.58 (SD 48.29)	84.05 (SD 40.01)	3.82	0.00	1.21
	Control ($n = 16$)	69.38 (SD 26.83)	61.06 (SD 14.84)	1.63	0.06	0.40
EMOTIONAL ADJUSTMENT						
BSI-18[c]	Treatment ($n = 23$)	18.87 (SD 16.40)	14.57 (SD 13.51)	3.60	0.00	0.29
	Control ($n = 15$)	14.73 (SD 10.20)	12.27 (SD 9.40)	2.64	0.01	0.25
MAACL-Positive Affect	Treatment ($n = 23$)	10.35 (SD 7.20)	10.57 (SD 8.02)	−0.28	0.39	0.03
	Control ($n = 16$)	6.06 (SD 5.69)	4.75 (SD 4.58)	1.91	0.04[a]	−0.26
MAACL-Sensation Seeking	Treatment ($n = 23$)	2.35 (SD 2.31)	3.04 (SD 2.75)	−2.91	0.00	0.27
	Control ($n = 16$) (SD1.58)	1.31	0.88 (SD 1.36)	2.15	0.02[a]	−0.29
MAACL-Anxiety[c]	Treatment ($n = 23$)	1.61 (SD 2.27)	1.09 (SD 1.44)	1.86	0.04	0.28
	Control ($n = 16$)	2.50 (SD 2.68)	2.25 (SD 2.44)	0.55	0.29	0.10
MAACL-Depression[c]	Treatment ($n = 23$)	1.61 (SD 2.57)	0.65 (SD 1.15)	2.14	0.02	0.52
	Control ($n = 16$)	1.31 (SD 1.96)	1.31 (SD 1.99)	0.00	0.50	0.00
MAACL-Hostility[c]	Treatment ($n = 23$)	0.70 (SD 1.46)	0.22 (SD 0.52)	1.59	0.06	0.48
	Control ($n = 16$)	0.88 (SD 1.26)	0.63 (SD 1.09)	2.24	0.02	0.21

[a]Represents a decline in functioning.

[b]Based on Cohen's *d* for effect size, where 0.2 is considered a small effect, 0.5 a medium effect, and 0.8 or greater a large effect.

[c]Lower scores on these measures indicate a higher level of functioning.

($t = -0.01$; $df = 20$; $P = 0.46$) improved in attention functioning. Effect sizes were small for both the treatment ($d = -0.01$) and control ($d = 0.00$) groups.

Memory

Both the control and treatment participants performed lower on the memory post-test than they did on the pre-test. For learning, defined as the number of words learned after five trials, the pre/post difference for the treatment group was not significant ($t = 0.26$; $df = 17$; $P = 0.40$). The control group was significantly lower in learning on the post-test than they were on the pretest ($t = 1.77$; $df = 13$; $P = 0.02$). For recall, defined as the number of words remembered after a short delay, the performances of both the experimental group ($t = 1.97$; $df = 17$; $P = 0.03$) and the control group ($t = 3.02$; $df = 13$; $P < 0.01$) were significantly lower on the post-test than on the pre-test. The effect sizes were small for the treatment group on both learning ($d = 0.02$) and recall ($d = 0.19$) memory. For the control group, the effect size was small for learning ($d = 0.36$), and medium for the decrease in memory recall ($d = 0.64$).

Executive Function

Changes in mental flexibility were not significant in the control group ($t = 1.63$; $df = 15$; $P = 0.06$). The effect size for the control group on executive function ($d = 0.40$) was between small and medium. The treatment group improved significantly in mental flexibility ($t = 3.82$; $df = 18$; $P < 0.01$) and demonstrated a large effect size ($d = 1.21$).

Emotional Adjustment

Overall emotional adjustment, as measured by the BSI-18, showed significant improvement in both the control group ($t = 2.64$; $df = 14$; $P = 0.01$) and in the NMT group ($t = 3.60$; $df = 22$; $P < 0.01$). Effect sizes were small for both the control ($d = 0.25$) and the treatment ($d = 0.29$) groups.

Results of the MAACL measures were mixed. Positive Affect did not change significantly for the treatment group ($t = -0.28$; $df = 22$; $P = 0.39$), and the effect size was small ($d = 0.03$). The control group declined significantly ($t = 1.91$; $df = 15$; $P = 0.04$) on Positive Affect, with a small effect size ($d = -0.26$).

Sensation Seeking measures improved significantly for the treatment group ($t = -2.91$; $df = 22$; $P < 0.01$) with a small effect size ($d = 0.27$), while the control group significantly declined ($t = 2.15$; $df = 15$; $P = 0.02$) in Sensation Seeking, with a small effect size ($d = -0.29$). In the area of Anxiety, the treatment group improved significantly ($t = 1.86$; $df = 22$; $P = 0.04$), with a small effect size ($d = 0.28$). The control group did not change significantly in Anxiety ($t = 0.55$; $df = 15$; $P = 0.29$) and the effect size was also small ($d = 0.10$).

Depression improved significantly for the treatment group ($t = 2.14$; $df = 22$; $P = 0.02$) with a medium effect size ($d = 0.52$). The control group did not change in Depression between the pre-test and the post-test ($t = 0.00$; $df = 15$; $P = 0.50$) and the effect size was small ($d = 0.00$).

In the area of Hostility, the treatment group did not change significantly, ($t = 1.59$; $df = 22$; $P = 0.06$), but had a medium effect size ($d = 0.48$) in a positive direction. The control group improved significantly in the Hostility measure ($t = 2.24$; $df = 15$; $P = 0.02$), while the effect size was small ($d = 0.21$).

Self-Efficacy

After treatment, the participants showed significant improvement in confidence in their executive function ability ($t = -1.86$; $df = 18$; $P = 0.04$), and no significant changes in confidence in attention ($t = -1.50$; $df = 20$; $P = 0.07$), memory ($t = -0.48$; $df = 17$; $P = 0.32$), or emotional adjustment ($t = -0.80$; $df = 22$; $P = 0.22$). Effect sizes in the self-efficacy changes were small to moderate for

TABLE 2. Changes in Confidence in Cognitive Skills and Emotional Adjustment Ratings of the Treatment Experience and the Music Therapist

Areas Measured	Pre-test	Posttest	t	P	d[a]
ATTENTION ($n = 21$)					
Confidence in attention ability[b]	62.38 (SD 18.68)	65.71 (SD 18.59)	−1.50	0.07	0.18
Enjoyment rating, musical experience[c]		3.79 (SD 0.42)			
Helpfulness of music therapist[c]		3.84 (SD 0.37)			
MEMORY ($n = 18$)					
Confidence in memory ability[b]	49.44 (SD 23.63)	51.11 (SD 22.72)	−0.48	0.32	0.07
Enjoyment rating, musical experience[c]		3.31 (SD 0.70)			
Helpfulness of music therapist[c]		3.69 (SD 0.48)			
EXECUTIVE FUNCTION ($n = 19$)					
Confidence in executive function ability[b]	55.26 (SD 20.38)	62.11 (SD 21.75)	−1.86	0.04	0.33
Enjoyment rating, musical experience[c]		3.43 (SD 0.93)			
Helpfulness of music therapist[c]		3.43 (SD 0.93)			
EMOTIONAL ADJUSTMENT ($n = 23$)					
Confidence in emotional stability[b]	64.35 (SD 31.02)	67.39 (SD 26.84)	−0.80	0.22	0.10
Enjoyment rating, musical experience[c]		3.43 (SD 0.79)			
Helpfulness of music therapist[c]		3.65 (SD 0.71)			

[a]Based on Cohen's d for effect size, where 0.2 is considered a small effect, 0.5 a medium effect, and 0.8 or greater a large effect.

[b]Based on a 100-point scale, with 100 indicating the highest level of confidence possible.

[c]Based on a 4-point scale, with 4 indicating the most positive rating possible.

executive function, and small for attention, memory, and emotional adjustment (Table 2).

Patient Satisfaction

Enjoyment ratings of the NMT treatment by the participants, as shown in Table 2, were positive for all groups. They ranged from 3.79 for the attention group to 3.31 for the memory group. Likewise, the group ratings of helpfulness of the music therapist were positive, ranging from 3.84 from the attention group to 3.43 from the executive function group.

Discussion

Executive Function

The results of this preliminary study—investigating the effects of a single, brief, music-based cognitive intervention—are promising in that one 30-min session of NMT produced significantly improved executive function in the form of mental flexibility. Not only were the improvements in the treatment group statistically significant, but they produced a large effect size, suggesting clinical significance as well. In addition, self-efficacy ratings of mental flexibility from the treatment group improved significantly, with a small-to-medium effect size, demonstrating that these subjects improved with respect to both their performance and confidence in their mental flexibility. This combination of improved ability and bolstered confidence may hold promise for therapeutic music interventions to effectively increase a neurologically impaired person's chances for overcoming the executive dysfunction that is particularly common on account of vulnerability to injury in the anterior portion of the brain. Increased flexibility in executive function reflects functionally important gains, in that persons will be able to effectively switch their attention and task management between two important tasks in everyday life.

Very few salient models have been proposed regarding the manner in which musical task training can influence executive function.[53] It is possible that the inherent temporal structure in music and musical tasks provides strong self-regulatory and self-organizational constraints that cue and exercise reasoning, decision making, problem solving, and comprehension processes in real time. Pertinent evidence comes from acoustical arousal studies and alertness training that demonstrate improvements in executive function by adding acoustical stimuli.[54–56] We thus propose a framework for a developing model of musical effects on executive function. As a foundation, music provides an enriched environment for the brain, introducing a variety of sensory stimuli. This rich stimulation promotes dendritic sprouting and enhanced vascularization of the brain.[57] Music embeds functional tasks into the structured auditory arousal process through music's three-dimensional metric–melodic–polyphonic structure,[53] activating both hemispheres of the frontal lobes.[58] Thus, in executive function, music may operate as a sensory prosthetic similar to temporal entrainment by music and rhythm in motor control. However, rather than regulating motor timing, it regulates cognitive timing and mental flexibility mechanisms. The result is a coherent and creative process-to-product matrix that produces increased brain "agility" and eventually, desired cognitive and behavioral outcomes.

Emotional Adjustment

The study's findings in the area of depression were also encouraging. They speak to the potential power of the musical emotional exercises that were designed to articulate and express positive emotions in order to overcome depression. The results support the work of Unkefer and Thaut[59] and are consistent with the findings of Hanser and Thompson,[60] who demonstrated that music therapy can improve a depressed mood.

A second area where the treatment group demonstrated significant improvement, while the control group did not change, was anxiety. However, the NMT effect size was small, indicating that the clinical significance of the anxiety changes in the treatment group may be limited.

The results demonstrated global emotional improvement in both the treatment and control groups. Since both groups changed significantly, with small effect sizes, no conclusions can be drawn about the effects of NMT on global emotional improvement. A second area where both the experimental and control groups changed in a positive direction was hostility, where the control group improved significantly ($P = 0.02$) and the treatment group did not change significantly ($P = 0.06$). The NMT group produced a medium effect size (0.48), while the control group had a small effect size (0.21), allowing no definitive conclusions about the effects of NMT on hostility.

In the area of positive affect, the NMT group did not change significantly, while the control group changed significantly in a negative direction. The effect sizes were small for both groups, indicating limited clinical significance of the findings.

Sensation seeking, which measures a person's tendency to explore new sources of sensory input, showed a significant increase for the treatment group and a significant decrease for the control group. Effect sizes for both groups were small for sensation seeking, limiting the clinical significance.

Memory and Attention

The study showed that neither memory nor attention improved after NMT treatment. While other studies using music in memory training have demonstrated improved memory, most studies examined multiple sessions of memory treatment. It is likely that more than one session is necessary to achieve improvement in memory,[32,61,62] allowing the participants time to incorporate the memory strategies that music provides. Another factor that may have contributed to the lack of improvement in the memory study is fatigue. Many of the study's participants reported being mentally fatigued after learning two (for the control group) or three (for the treatment group) lists of words during a 1-h session. The significant decrease in memory performance by both the treatment and control groups on the post-test may support the conclusion that lack of time to adequately learn the new techniques and/or fatigue were likely important factors in the memory results. Future studies on memory will need to take these factors into account. Attention NMT training with traumatic brain injury may also require a series of intervention dosages in order to produce quantifiable and generalizable results on standardized measures.[63–65]

Conclusions

The focus of this study was short term, with no delayed measurement of the effects of the cognitive skill training, limiting the generalizability of the results to the immediate effects of NMT on cognitive functioning. While a control group was used to compare the findings of the experimental group, participants were not randomly assigned to conditions. Although there was a reasonably close match in subject diagnostics and demographics between the treatment and control groups (not significantly different in age, years of education, or years since the most recent neurologic injury), there were other differences that need to be taken into account. First, although the control group had significantly more neurologic injuries (2.32) than did the treatment group (1.28), the severity of the injuries to the treatment group (53.57% severe, 17.86% moderate, and 28.57% mild) was greater than that of the control group (20.00% severe, 10.00% moderate, and 70.00% mild). Thus, the two groups were not identical enough to provide a strong direct comparison between the two, and the generalizability of these results is limited. This study should be considered a preliminary exploration into the immediate effects of Neurologic Music Therapy on cognitive and emotional functioning, and further investigation is needed.

In conclusion, this exploratory study provided preliminary evidence that music-based CR can provide improvement in the mental flexibility aspect of executive function with brain-injured participants. These findings provide a first basis for additional research and advances in the neuroscience of music cognition, learning, perception, executive functioning, and plasticity in brain rehabilitation.

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Conflicts of Interest

The authors declare no conflicts of interest.

References

1. Cicerone, K.D., C. Dahlberg, K. Kalmar, *et al*. 2000. Evidence-based cognitive rehabilitation: recommendations for clinical practice. *Arch. Phys. Med. Rehabil.* **81:** 1596–1615.
2. Gordon, W.A. & M.R. Hibbard. 1992. Critical issues in cognitive remediation. *Neuropsychology* **6:** 361–370.
3. Gordon, W.A., R. Zafonte, K. Cicerone, *et al*. 2006. Traumatic brain injury rehabilitation: state of the science. *Am. J. Phys. Med. Rehabil.* **85:** 343–382.
4. Rimmele, C.T. & R.K. Hester. 1987. Cognitive rehabilitation after traumatic head injury. *Arch. Clin. Neuropsychol.* **2:** 353–384.
5. Thaut, M.H. 1999. *Training Manual for Neurologic Music Therapy*. Center for Biomedical Research in Music. Fort Collins, CO. Unpublished manuscript.
6. Peretz, I. & R.J. Zatorre. 2005. Brain organization for music processing. *Annu. Rev. Psychol.* **56:** 89–114.
7. Purdie, H. 1997. Music therapy™ in neurorehabilitation: recent developments and new challenges. *Crit. Rev. Phys. Rehabil. Med.* **9:** 205–217.
8. Zatorre, R.J. 2003. Music and the brain. *Ann. N. Y. Acad. Sci.* **999:** 4–14.
9. Zatorre, R.J. 2001. Neural specializations for tonal processing. *Ann. N. Y. Acad. Sci.* **930:** 193–210.
10. Hoemberg, V. 2005. Evidence based medicine in neurological rehabilitation: a critical review. *Acta Neurochirurgica* **93:** 3–14.
11. Hummelsheim, H. 1999. Rationales for improving motor function. *Curr. Opin. Neurol.* **12:** 697–701.
12. Thaut, M.H., G.P. Kenyon, M.L. Schauer & G.C. McIntosh. 1999. The connection between rhythmicity and brain function. *IEEE Eng. Med. Biol. Mag* **18:** 101–108.
13. Reiss Jones, M. & S. Holleran. 1992. *Cognitive Bases of Musical Communication*. American Psychological Association. Washington, DC.
14. Thaut M.H. 2005. Rhythm, human temporality, and brain function. In *Music Communication*. D. Miell, R. MacDonald & D. Hargreaves, Eds.: 171–192. Oxford University Press. Oxford, UK.
15. Deutsch, D. 1982. Organizational processes in music. In *Music, Mind and Brain*. M. Clynes, Ed.: 119–131. Plenum Press. New York, NY.
16. Nayak, S., B.L. Wheeler, S.C. Shiflett & S. Agostinelli. 2000. Effect of music therapy on mood and social interaction among individuals with acute traumatic brain injury and stroke. *Rehabil. Psychol.* **45:** 274–283.
17. Sloboda, J.A. 1985. *The Musical Mind: The Cognitive Psychology of Music*. Oxford University Press. Oxford, UK.
18. Klein, J.M. & M. Reiss Jones. 1996. Effects of attentional set and rhythmic complexity on attending. *Percept. Pychophys.* **58:** 34–46.
19. Thaut, M.H., D.A. Peterson & G.C. McIntosh. 2005. Temporal entrainment of cognitive functions: musical mnemonics induce brain plasticity and oscillatory synchrony in neural networks underlying memory. *Ann. N. Y. Acad. Sci.* **1060:** 243–254.
20. Wallace, W.T. 1994. Memory for music: effect of melody on recall of text. *J. Exp. Psychol.* **20:** 1471–1485.
21. Baur, B., L. Uttner, J. Ilmberger, *et al*. 2000. Music memory provides access to verbal knowledge in a patient with global amnesia. *Neurocase* **6:** 415–421.
22. Cowles, A., W.W. Beatty, S.J. Nixon, *et al*. 2003. Musical skill in dementia: a violinist presumed to have Alzheimer's disease learns to play a new song. *Neurocase* 9: 493–503.
23. Foster, N.A. & E.R. Valentine. 2001. The effect of auditory stimulation on autobiographical recall in dementia. *Exp. Aging Res.* **27:** 215–228.
24. Haslam, C. & M. Cook. 2000. Striking a chord with amnestic patients: evidence that song facilitates memory. *Neurocase* **8:** 453–465.
25. Claussen, D. & M.H. Thaut. 1997. Music as a mnemonic device for children with learning disabilities. *Can. J. Music Ther.* **5:** 55–66.
26. Gfeller, K.E. 1983. Musical mnemonics as an aid to retension with normal and learning disabled students. *J. Music Ther.* **20:** 179–189.
27. Chan, A.S., Y.C. Ho & M.C. Cheung. 1998. Music training improves verbal memory. *Nature* **396:** 128.
28. Ho, Y.C., M.C. Cheung & A.S. Chan. 2003. Music training improves verbal but not visual memory: cross-sectional and longitudinal explorations in children. *Neuropsychology* **17:** 439–450.
29. Gregory, D. 2002. Music listening for maintaining attention of older adults with cognitive impairments. *J. Music Ther.* **39:** 244–264.
30. Knox, R. & J. Jutai. 1996. Music-based rehabilitation of attention following brain injury. *Can. J. Rehabil.* **9:** 169–181.
31. Knox, R., H. Yokota-Adachi, J. Kershner & J. Jutai. 2003. Musical attention training program and alternating attention in brain injury: an initial report. *Music Ther. Perspect.* **21:** 99–104.
32. Morton, L.L., J.R. Kershner & L.S. Siegel. 1990. The potential for therapeutic applications of music on problems related to memory and attention. *J. Music Ther.* **26:** 58–70.
33. Blood, A.J. & R.J. Zatorre. 2001. Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. *Proc. Natl. Acad. Sci. USA* **98:** 11818–11823.

34. Blood, A.J., R.J. Zatorre, P. Bermudez & A.C. Evans. 1999. Emotional responses to pleasant and unpleasant music correlate with activity in paralimbic brain regions. *Nat. Neurosci.* **2:** 382–387.
35. Iwaki, T., M. Hayashi & T. Hori. 1997. Changes in alpha band EEG activity in the frontal area after stimulation with music of different affective content. *Percept. Motor Skills* **84:** 515–526.
36. Kleinstauber, M. & B. Gurr. 2006. Music in brain injury rehabilitation. *J. Cogn. Rehabil.* **24:** 4–14.
37. Campbell, D.T. & J.C. Stanley. 1963. *Experimental and Quasi-Experimental Designs for Research*. Rand McNally. Chicago, IL.
38. Lezak, M.D., D.B. Howieson & D.W. Loring. 2004. *Neuropsychological Assessment*. Oxford University Press. New York.
39. McCaffrey, R.J., A. Ortega & R.F. Haase. 1993. Effects of repeated neuropsychological assessments. *Arch. Clin. Neuropsychol.* **8:** 519–524.
40. McCaffrey, R.J., A. Ortega, S.M. Orsillo, *et al*. 1992. Practice effects in repeated neuropsychological assessments. *Clin. Neuropsychol.* **6:** 32–42.
41. Stuss, D.T., L.L. Stethem & C.A. Poirier. 1987. Comparison of three tests of attention and rapid information processing across six age groups. *Clin. Neuropsychol.* **1:** 139–152.
42. Wechsler, D. 1997. *Wechsler Adult Intelligence Scale-III*. The Psychological Corporation. San Antonio, TX.
43. Rey, A. 1964. *L'Examen Clinique in Psychologie*. Presses Universitaires de France. Paris.
44. Geffen, G.M., P. Butterworth & L.B. Geffen. 1994. Test-retest reliability of a new form of the Auditory Verbal Learning Test (AVLT). *Arch. Clin. Neuropsychol.* **9:** 303–316.
45. Derogatis, L. 2000. *Brief Symptom Inventory-18*. Pearson Assessments. Minneapolis, MN.
46. Zuckerman, M. & B. Lubin. 1965. *Manual for the Multiple Affect Adjective Check List*. Educational and Industrial Testing Service. San Diego, CA.
47. Bickman, L., E. Earl & L. Klindworth. 1991. *Vanderbilt Mental Health Self Efficacy Questionnaire*. Vanderbilt University. Nashville, TN.
48. Ben Yishay, Y., L. Piasetsky & J. Rattock. 1987. A systematic method for ameliorating disorders in basic attention. In *Neuropsychological Rehabilitation*. M. Meier, A. Benton & L. Diller, Eds.: 165–181. Guilford Press. New York.
49. Sohlberg, M.M. & C.A. Mateer. 1989. *Attention Process Training*. Association for Neuropsychological Research and Development. Puyallup, WA.
50. Gold, C. 2004. The use of effect sizes in music therapy research. *Music Ther. Perspect.* **22:** 91–95.
51. Wilkinson, L. & the APA Task Force on Statistical Inference. 1999. Statistical methods in psychology journals: guidelines and explanations. *Am. Psychol.* **54:** 594–604.
52. Zakzanis, K.K. 2001. Statistics to tell the truth, the whole truth, and nothing but the truth: formulae, illustrative numerical examples, and heuristic interpretation of effect size analyses for neuropsychological researchers. *Arch. Clin. Neuropsychol.* **16:** 653–667.
53. Thaut, M.H. 2005. *Rhythm, Music, and the Brain: Scientific Foundations and Clinical Applications*. Routledge. New York.
54. Manly, R., K. Hawkins, J. Evans, *et al*. 2002. Rehabilitation of executive function: facilitation of effective goal management on complex tasks using periodic auditory alerts. *Neuropsychologia* **40:** 271–281.
55. O'Connor, C., T. Manly, I.H. Robertson, *et al*. 2004. An fMRI study of sustained attention with endogenous and exogenous engagement. *Brain Cognit.* **54:** 133–135.
56. Sturm, W., B. Fimm, A. Cantagallo, *et al*. 2002. Computerised training of specific attention deficits in stroke and traumatic brain injured patients: a multicentric efficacy study. In *Applied Neuropsychology of Attention*. M. Leclercq & P. Zimmerman, Eds.: 365–380. Psychology Press. Hove, UK.
57. Goldberg, E. 2001. *The Executive Brain: Frontal Lobes and the Civilized Mind*. Oxford University Press. New York.
58. Levitin, D.J. 2006. *This Is Your Brain on Music: The Science of a Human Obsession*. Penguin Books. New York.
59. Unkefer, R.F. & M.H. Thaut, Eds. 2002. *Music Therapy in the Treatment of Adults with Mental Disorders*. MMB Music, Inc. St. Louis, MO.
60. Hanser, S.B. & L.W. Thompson. 1994. Effects of a music therapy strategy on depressed older adults. *J. Gerontol.* **49:** 265–269.
61. Carruth, E.K. 1997. The effects of singing and the spaced retrieval technique on improving face-name recognition in nursing home residents with memory loss. *J. Music Ther.* **34:** 165–186.
62. Gianutsos, R. & J. Gianutsos. 1979. Rehabilitating the verbal recall of brin-injured patients by mnemonic training: an experimental demonstration using single-case methodology. *J. Clin. Neuropsychol.* **1:** 117–135.
63. Bennett, T., M. Raymond, K. Malia, *et al*. 1998. Rehabilitation of attention and concentration deficits following brain injury. *J. Cogn. Rehabil.* **16:** 8–13.
64. Parenté, R. & D. Herrmann. 1996. *Retraining Cognition: Techniques and Applications*. Aspen. Gaithersburg, MD.
65. Sohlberg, M.M. & C.A. Mateer. 1987. Effectiveness of an attention-training program. *J. Clin. Exp. Neuropsychol.* **9:** 117–130.