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Investigating music-based cognitive rehabilitation for individuals with moderate to severe chronic acquired brain injury: A feasibility experiment

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Abstract.
BACKGROUND: Acquired brain injuries often cause cognitive impairment, significantly impacting participation in rehabilitation and activities of daily living. Music can influence brain function, and thus may serve as a uniquely powerful cognitive rehabilitation intervention.
OBJECTIVE: This feasibility study investigated the potential effectiveness of music-based cognitive rehabilitation for adults with chronic acquired brain injury.
METHODS: The control group participated in three Attention Process Training (APT) sessions, while the experimental group participated in three Music Attention Control Training (MACT) sessions. Pre-and post- testing used the Trail Making A & B, Digit Symbol, and Brown-Peterson Task as neuropsychological tests.
RESULTS: ANOVA analyses showed no significant difference between groups for Trail A Test, Digit Symbol, and Brown-Peterson Task. Trail B showed significant differences at post-test favouring MACT over APT. The mean difference time between pre-and post-tests for the Trail B Test was also significantly different between APT and MACT in favour of MACT using a two-sample *t*-test as well as a follow-up nonparametric Mann Whitney U-test.
CONCLUSIONS: The group differences found in the Trail B tests provided preliminary evidence for the efficacy of MACT to arouse and engage attention in adults with acquired brain injury.

Keywords: Neurologic Music Therapy (NMT), music, music therapy, intervention, efficacy, acquired brain injury (ABI), Traumatic Brain Injury (TBI), Music Attention Control Training (MACT), Attention Process Training (APT), neurological rehabilitation, cognitive impairment, executive functioning, attention, working memory, randomized controlled trial, Trail Making Test, Brown-Peterson Task, Auditory Consonant Trigram, Digit Symbol Test, humans, female, male

1. Introduction

The most common sequelae following an acquired brain injury (ABI) is cognitive impairment (Haskins, 2012; Lesniak et al., 2019; Michel & Mateer,

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2006; Ponsford, 2008). Cognitive impairment can significantly impact an individual's ability to participate in rehabilitation therapies, to complete activities of daily living (ADLs), and to return to pre-injury school or work. It affects functional independence and quality of life. Cognitive impairment can negatively affect social interactions and, together with the related behavioural outcomes, is reported as greatest source of stress for caregivers (Ponsford et al., 2003; Verhaeghe et al., 2005). An individual with cognitive impairment may experience difficulties remaining on task, shifting between tasks, sequencing components of a task, suppressing distraction, following directions, remembering, or initiating.

An ABI that causes cognitive impairment may be traumatic or non-traumatic. A traumatic ABI is the result of a blow or force to the head. Examples include motor vehicle accident, fall, or assault. A non-traumatic ABI is a result of a lack of blood or oxygen to the brain. Examples include stroke, suffocation, or near-drowning. It is estimated that annually 150–200 million individuals worldwide experience a traumatic ABI that results in severe disability (Whyte et al. 2011). Approximately 32%–52% of stroke survivors experience cognitive impairment (Whyte et al.). Due to the prevalence of ABI and the scope of impact of cognitive impairment on the lives of the individuals and their caregivers, it is imperative to have on-going investigations into cognitive rehabilitation techniques and the development of effective interventions.

Although attention, memory, and executive functioning are functionally interconnected, attention is foundational to other cognitive functioning (Ceravolo, 2006; Haskins, 2012; Jonides et al., 2002; Michel & Mateer, 2006; Sohlberg et al., 2000). Therefore, attention training should be a primary goal of cognitive rehabilitation. Because attention is a multidimensional construct, there are several definitions of attention in the literature (Cohen, 1993; Mesulam, 2010; Tallon-Baudry, 2012). The various definitions of attention include the components of limited attentional resources, the process of directing attention to the target stimulus while suppressing distraction, and vigilance. These components of attention are also reflected in attentional processing theories. Mesulam's attentional matrix includes concentration span, vigilance, and suppression of distraction. Peterson and Posner's (2012) theory of attention describes three networks: alerting, involved in vigilance and lateralized to the right hemisphere; orienting, prioritizing sensory input and involving parietal, frontal, and posterior areas; and executive, involved in the moment of target detection, with widely distributed connections from midline cortex and the anterior cingulate cortex (ACC). The executive network is engaged during top-down control signals to other brain areas. Dosenbach et al. (2008) propose that this executive control is based on two separate networks: cingulo-opercular, engaged in task maintenance, and the frontoparietal system, engaged during initiation and task switching.

Based on theories of attention, cognitive rehabilitation interventions targeting the remediation of attention should include tasks that place demands on the attentional components of concentration span, suppression of distraction, and task switching. Sohlberg and Mateer (2001) have identified these forms of attention as: sustained attention, selective attention, and alternating attention. Because the mechanisms for attention and working memory overlap functionally (Corbetta & Shulman, 2002), cognitive rehabilitation interventions should also include tasks that place demands on working memory. Baddeley (2012) describes working memory as a limited capacity temporary storage of information.

In addition, cognitive rehabilitation interventions should target increased attentional control. Attentional control enables an individual to overcome automatic responses, suppress distraction, and to remain on task (Miller, 2000). A lack of attentional control and drifting from a task is a common difficulty following ABI (Dockree et al., 2004). In order to increase attentional control, interventions must require effortful processing and therefore should be varied and follow a hierarchy of difficulty and complexity. This will also help to ensure that gains are not task-specific, but rather are gains from improved attentional processing. Thus, in this study, the interventions of both Attention Process Training (APT) and Music Attention Control Training (MACT) targeted the specific components of attention mentioned above - sustained, selective, and alternating - and required effortful processing. They also included a small memory component. APT is one of the most common interventions to address attention deficits in the chronic ABI population (Cicerone et al., 2019; Nowell et al., 2020). APT uses a direct attention training approach based on the principles of neuroplasticity. In APT, structured drills are designed to target aspects of attention with the goal of activating and stimulating attention processes and strengthening underlying neural circuitry (Sohlberg & Mateer). APT uses computer-based tasks to address attention in a hierarchical manner, from focussed, to sustained, to selective, to alternating, to divided attention (Sohlberg & Mateer). MACT is a standardized treatment within Neurologic Music Therapy (Thaut & Gardiner, 2014). MA CT provides structured music based auditory training exercises in which musical elements cue different musical responses by the participant to practice attention functions. MACT does not have any requirements regarding patients' musical expertise. This study chose to investigate MACT as a unique and potentially effective cognitive rehabilitation intervention for this population due to the wide neurological distribution of music processing (Peretz & Zatorre, 2005, 2009; Sarkamo et al., 2013), the potential role of rhythm in attention (Thaut, 2005), and literature demonstrating enhanced cognitive abilities of musicians such as increased cognitive control (Barret et al., 2013; Pallesen et al., 2010) and executive functioning abilities (Moreno et al., 2011; Strait & Kraus, 2011; Strait et al., 2010; Bialystok, & DePape, 2009; Hannon & Trainor, 2007).

Both APT and MACT are designed to remediate attention in persons with chronic ABI. A remedial approach to cognitive rehabilitation seeks to address the underlying mechanisms of cognitive impairment and to improve attentional processing. This contrasts with a compensatory approach to cognitive rehabilitation in which environmental supports or cues are established to compensate for cognitive deficits.

The objective of this study was to investigate the potential effectiveness of music-based cognitive rehabilitation interventions to remediate cognitive impairment following an acquired brain injury. We hypothesized that the participants in the MACT group will demonstrate improvement on neuropsychological tests measuring attention and executive functioning compared to the APT group.

2. Methodology

2.1. Participants

Participants were recruited through an adult ABI day program, in a major Canadian city. Study participants met the following inclusion criteria: adult (age 18+); ABI rated as moderate or severe according to Glasgow Coma Scale, NIH scale, or physician's report; identified as having a cognitive impairment with no known pre-existing (pre-injury) cognitive deficits; be able to complete the pre- and post- tests independently. Exclusion criteria included: hearing impairment or central auditory processing disorder; clinical diagnosis of depression; motor impairment to preclude execution of treatment exercises. None of the participants were receiving other therapies prior to and during the study. Twenty-one participants met the inclusion/exclusion criteria and gave informed consent to enter the study. Three participants did not commence the study because they had forgotten, two were withdrawn at the discretion of the recruitment site due to potential behavioural problems that could result from possible frustration with the cognitive tasks involved in the study, and one did not attend the post-test session for medical reasons. The number of participants in this study was impacted by the outcomes of the cognitive impairment being experienced by these individuals. This dropout rate is comparable to other clinical studies with ABI patients (Magee et al., 2017). Participants were randomly assigned to either the control (APT) group or the experimental (MACT) group. Randomization was achieved through an unpredictable allocation sequence with names of participants contained in sealed, opaque envelopes to maintain concealed allocation. The randomization process was completed by two individuals blinded to the study. One individual placed each name in an individual opaque envelope and sealed it. The second individual randomized the envelopes into the two treatment groups. The study was completed by fifteen participants: eight in the control (seven male) and seven in the experimental *c*ondition (six male). See Fig. 1 for randomization flowchart. Participants did not know which group they had been assigned to until immediately after the pre-testing. Therefore, group assignment did not influence attending the pre-testing or involvement in the study. Because of the relatively small group sizes, profiles on the groups were compiled after the study to assess whether they were equivalent on important factors. Although the ABI clinical population in inherently heterogenic, the experimental group and the control group in this study were reasonably equal (Table 1). A *t*-test found no significant differences between the MACT and APT groups in participants' mean age ($t = 0.63$; $p = 0.54$), and mean years post-incident ($t = 0.71$; $p = 0.49$).

2.2. Study design and training materials

Participants in the two treatment conditions received a one-on-one 45-minute treatment session per week, for three consecutive weeks, totaling three sessions each. Pre- and post-test sessions were held in week one and week three prior to and after treatment,

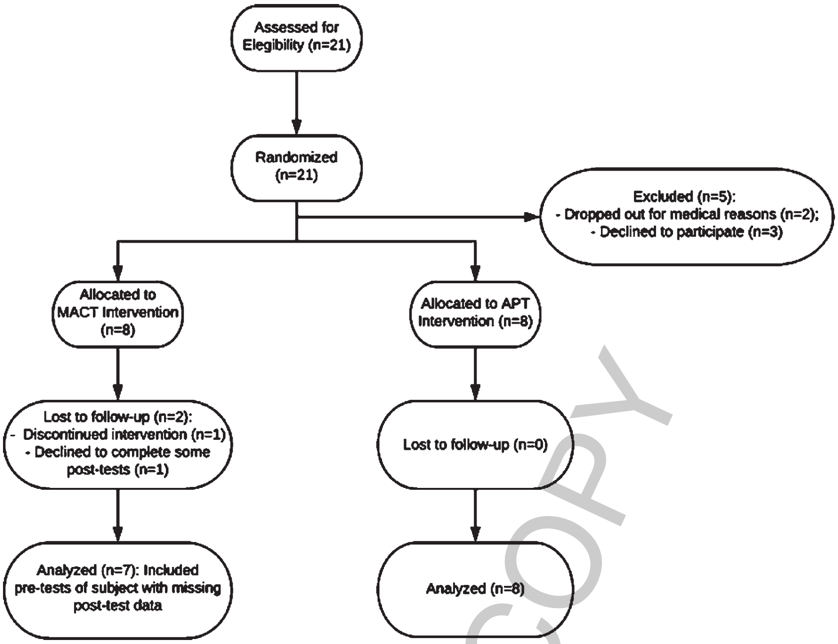

Fig. 1. Randomization flowchart.

Table 1
Demographic information

Variables	MACT group ($n = 8$)	APT group ($n = 7$)
	Mean (standard deviation)	Mean (standard deviation)
Age	51.9 +/–11.02	55.4 +/–10.54
Years post-incident	9 +/– 7.48	11.5 +/–6.21
	n (%)	n (%)
Sex		
Male	7 (87.5)	6 (85.7)
Female	1 (12.5)	1 (14.3)
Level of education		
High school	4 (50)	3 (42.9)
College/University	4 (50)	4 (57.1)
Primary language		
English	6 (75)	6 (85.7)
Other	2 (25)	1 (14.3)
Injury type		
Stroke	4 (50)	1 (14.3)
Brain tumour	1 (12.5)	0 (0)
TBI	3 (37.5)	6 (85.7)

respectively. The purpose of a short intervention period for the study was to start with a smaller dosage which would help to identify the point of earliest possible treatment effect. This in turn could provide the logical basis for stepwise lengthening of treatment in future research until positive responses are found. A second reason for a short data collection was to reduce participant dropout from the study which is a concern in this population.

2.2.1. Attention Process Training (APT)

Each participant in the control group participated by completing the computerized-version (APT-3) of the APT program developed by Sohlberg and Mateer (2001). Tasks focusing on sustained & selective attention, and cognitive control (executive function and mental flexibility) were given to all participants with graded increases in difficulty across the three weeks. Instructions were given by a trainer on the computer screen. However, the researcher sat beside the participant to help clarify instructions quickly if necessary and to assure that computer mouse was functioning properly.

2.2.2. Music Attention Control Training (MACT)

MACT exercises were modeled closely to the APT tasks in task structure, duration, and number of exercise targets; however, these were translated on to live musical instruments (pitched and non-pitched percussion instruments). For example: in sustained MACT exercises the participants attended to the changes in musical patterns (e.g., changes in pitch register, tempo, loudness, etc.) played by the researcher, and continuously imitated these changes on their own instruments; in selective attention participants played freely and only responded on their instruments (stop playing, resume playing) when they heard (in the music improvised by the researcher) a pre-determined musical target sound, ignoring other musical events; in cognitive control participants had to follow musical cues to initiate or inhibit responding, to predict changes in musical patterns, and to track and respond to alternating sound cue sources in space. The researcher's instructions were given verbally following a pre-set script and no further prompting, coaching, or feedback was given during the exercises.

Both groups went through eight exercises per session, three minutes per exercise. Following each session participants were asked to rate their level of effort and their level of motivation on two separate Likert scales of 0–10. Since the two treatment conditions used very different exercise modalities the scales were intended to measure if participants in both groups gave equal commitment to their assigned tasks and different effort or motivation did not influence task outcomes.

2.3. Testing

Pre- and post-tests measures used three standardized neuropsychological tests (Trail Making A and B; Digit Symbol; Brown-Peterson). All tests were administered by a research assistant trained in the test administration and blinded to the participant's group assignment. Tests were administered prior to the first training session and after the last session. The results of these tests were scored by a blinded assessor for statistical analysis.

The Trail Making Test (TMT), comprised of the Trail A and B tests, is a measure of attention, speed, and cognitive flexibility. Correlating moderately well (r = 0.31–6), Trail A and B measure slightly different functions (Heilbronner et al., 1991; Pineda & Merchan, 2003). Trail A is sensitive to attention maintenance whereas Trail B places greater cognitive demands on visual search, reasoning, cognitive flexibility, and motor speed (Strauss et al., 2006). The TMT is a standardized neuropsychological test (Barr, 2003, Lucas et al., 2005; Mitrushina et al., 2005; Steinberg et al., 2005; Tombaugh, 2004) that ranks as the top instrument to measure attention and fourth in use for measuring executive functioning (Rabin et al., 2005).

The Digit Symbol Test is a subtest of the Symbol Digit Modalities Test (Smith, 1991) and has been used to test divided attention (Bowler et al., 1992; Emmerson et al., 1990; Gilmore et al., 1983; Joy et al., 2004, Hinton-Bayre & Geffen, 2005; Yeudall et al., 1986). It also requires visual scanning, perceptual speed, motor speed and memory (Laux & Lane, 1985; Lezak, 1995). The version of the Digit Symbol Test used in this study included measurement of incidental learning (Uchiyama et al., 1994).

The Brown-Peterson Task (Peterson & Peterson, 1959) measures working memory, the ability to maintain information no longer available through sensory input and to maintain it during distraction (Bherer et al., 2001; Boone al., 2000; Kopelman & Stanhope, 1997; Stuss et al., 1987). Lower performance is seen with individuals with memory, attention, or executive function deficits (Strauss et al., 2006). The version used in this study was Auditory Consonant Trigrams (Stuss et al., 1987, 1988, 1989).

2.4. Statistical analysis

Two-way mixed model ANOVAs were performed in R (R Core Team, 2017), to analyze pre- vs post-test differences between the two treatment conditions. Change scores for time differences between pre- and post-test were analyzed used two-sample *t*-tests. Due to the small sample size, in case of statistical significance, Mann-Whitney nonparametric tests were applied for pre- vs post-test mean time differences to confirm results.

3. Results

3.1. Trail Making Tests A and B

The mean and standard deviation time in seconds was determined for the Trail A and Trail B Tests (Table 2). A mixed ANOVA provided insufficient evidence for the presence of any interaction between test (pre & post) and group (APT & MACT), [$F(1, 12) = 0.39$, $p = 0.54$], or main effects of test, [$F(1, 12) = 1.72$, $p = 0.21$] or group, [$F(1, 12) = 0.45$, $p = 0.51$] for the Trail A test. Results for Trail B test provided evidence for significant interaction between Test (pre vs post) and Group (APA vs MACT), [$F(1, 12) = 5.423$, $p = 0.037$]. *Post hoc* comparison located the difference in the post-test performance of the MACT group, in that the MACT scores were more improved than the APT scores. Main effects were not significant.

A two-sample *t*-test was used to compare change scores, calculated as the difference between pre- and post-test means, between the APT group and the

Table 2
Group times in seconds for the Trail A and B tests

	APT group	MACT group
	Mean (standard deviation)	Mean (standard deviation)
Test A		
Pre-test	73.88 (78.38)	52.86 (26.84)
Post-test	55.25 (31.69)	46.29 (20.85)
Test B		
Pre-test	140.00 (100.07)	157.33 (75.33)
Post-test	160.00 (91.34)	137.17 (78.03)

Table 3
Trail A/B: Difference (seconds) between pre- and post-tests

	APT group	MACT group
	Mean (standard deviation)	Mean (standard deviation)
Trail A	–18.62 (49.86)	–6.57 (9.07)
Trail B	20.00 (42.25)	–20.17 (18.30)

MACT group (See Table 3 for mean change scores). Levine's test for equality of variance was non-significant, therefore the *t*-tests used the assumption of equal variance. There was no evidence for a difference in change scores for the Trail A test ($p = .50$), but there was evidence of a significant difference between APT and MACT groups in the change scores for the Trail B Test ($p = 0.03$).

Results were confirmed by non-parametric testing using the Mann-Whitney U-test, indicating strong evidence for the change score difference between pre- and post-test for APT and MACT groups. Change score was significantly higher in the MACT intervention ($p = .029$) using an exact sampling distribution for U (Dineen & Blakesley, 1973).

Individual participant data. Inspection of individual participant data scores for pre- versus post-test showed a higher consistency in post-test improvements for MACT. After MACT, five participants improved while one decreased performance. In the APT a much higher degree of variability was present. One participant improved, two stayed the same, and five decreased to various degrees.

3.2. *Digit Symbol Test*

The four subtests for the Digit Symbol Test were also analyzed using a two-way mixed ANOVA. The incidental learning subtest showed insufficient evidence for the presence of an interaction between the intervention and time on the test scores, [$F(1, 12) = .461$, $p = 0.510$] no evidence for a main effect of time [$F(1, 12) = 0.984$, $p = 0.341$] or of treatment [$F(1, 12) = 0.229$, $p = 0.641$]. Similar results were obtained for the free recall subtest [interaction intervention × time $F(1, 10) = 0.137$, $p = 0.719$, main effects time, $F(1, 10) = 2.298$, $p = 0.161$, treatment $F(1, 10) = 0.289$, $p = 0.289$], the subtest for time [interaction effect treatment × time on test scores, $F(1, 12) = 0.003$, $p = 0.955$, main effects time, $F(1, 12) = 0.025$, $p = 0.877$, treatment, $F(1, 12) = 0.854$, $p = 0.374$] and the subtest time at 2 minutes delay [interaction treatment × time on test scores, $F(1, 12) = 0.059$, $p = 0.812$, main effects time, $F(1, 12) = 0.486$, $p = 0.499$, treatment, $F(1, 12) = 0.448$, $p = 0.516$.

3.3. *Brown-Peterson Task (Auditory Consonant Trigram)*

Similarly the pre- and post-test scores for the Auditory Consonant Trigrams were analyzed using a two-way mixed ANOVA. Results were nonsignificant [interaction $F(1, 12) = 0.456$, $p = 0.512$, main effects time (pre/post), $F(1, 12) = 2.207$, $p = 0.163$, treatment, $F(1, 12) = 0.000293$, $p = 0.987$.

3.4. *Likert scales of effort and motivation*

The self-reported levels of effort and motivation between the APT and MACT groups were not significantly different.

4. Discussion

4.1. *Explication of results*

Results of the Trail B Test showed that the MACT group improved in score relative to the APT group from pre- to post-test, but no significant differences between the APT and MACT treatments were found in the test scores for the Trail A Test, Brown-Peterson, or Digit Symbol Test. It seems likely that the Trail B Test was sensitive to changes in attention because it measured improvements in attention skills that underlie executive functioning without interference from additional task demands such as memory and divided attention. The differences in scores from pre- to post-test between the APT and MACT groups highlight how MACT may have more efficiently and effectively been able to address underlying attention skills. Because the music tasks included targets of rhythm, melody, and harmony, the MACT group likely experienced an increased attentional engagement during treatment relative to the APT group. Each of these musical components engage different brain sites: melody (memory of) engages the left inferior temporal and frontal areas, rhythm engages the left temporal lobe and the basal ganglia, and harmony engages the inferior frontal areas (frontal operculum) bilaterally. As a result, the MACT group may have received a more distributed attentional stimulus. This may have aroused and engaged attentional processing to a degree that the MACT group was able to sustain their attention and process the Trail B task more effectively and efficiently.

One might question why Trail A test results did not also reveal a stronger difference between APT and MACT post-test times, since it is related to the Trail B test. Upon further examination of the data, an outlier was noted in the APT group. One participant in the APT group had a marked decrease in time (pre-test: 227 seconds, post-test: 111 seconds). This large decrease in time may have skewed the data results for the APT group. As well, both groups had a lower post-test time suggesting the benefit of both APT and MACT treatments. However, on Trail B test, with the inclusion of executive functioning and cognitive flexibility demands, the distinction of the benefit of MACT on attentional processing may have become more observable.

Null findings for the Brown-Peterson and Digit Span tasks may be because both assessments involved significant memory and divided attention components, which were more challenging for participants. Working memory tasks were only used for a small percentage of time (12%) in both the APT and MACT treatments, and this may have contributed to the lack of significant results in these measures. During the Brown-Peterson task, participants are also required to audibly do mental math calculations during the delay interval, providing a divided attention element to the test. The cognitive demands of the mental math calculations during testing may have resulted in an increased cognitive load in comparison to the treatment tasks, resulting in no overall improvements in either groups post-test. Similarly, the Digit Symbol Test has been used as a test of divided attention (Ponsford & Kinsella, 1988). Comparison between test times of study participants and norm test times revealed that the study participants required four times more length of time to complete the Digit Symbol Test. Indeed, feedback from several participants in both the APT Group and the MACT Group following treatment tasks targeting divided attention indicated that this area of attention was particularly challenging. With the moderate to severe level of cognitive impairment seen in study participants, a longer treatment period might be needed in order to see in change in post-test results for the Brown-Peterson and Digit Span tasks (Couillet et al., 2010; Tucker et al., 2010; Thaut et al., 2009; Vallet-Azouvi et al. 2009). Interestingly though, in comparing pre- and post- tests, the MACT group had a higher total recall of correct letters (mean of four more letters) in the post-test than the APT group (mean of one more letter).

Although three of the four standardized neuropsychological tests did not reveal significant improvements in the group, individuals in both the APT and MACT group demonstrated improvement on different tasks within treatment. For example, in session one Participant No. 11 (MACT) could not complete the alternating attention task and ended the task prematurely. In the second session, he was able to complete one of the two alternating attention tasks. He did not attempt the second alternating attention task due to difficulty. However, in the third session, he successfully completed both alternating attention tasks and stated, "it is getting easier." In session one, Participant No. 15 (MACT) did not complete either the alternating attention tasks, withdrawing after a few moments for the first task. In session two he stopped at two minutes, stating "this is not relating" and did not attempt the second task. However, in session three he successfully completed both alternating attention tasks with a good performance on each. Any possible improvement of Participant 15's performance could not be captured in post-testing as he refused to complete post-tests shortly after post-testing began. Although the tasks varied slightly, and gradually increased in level of difficulty over the three treatment sessions, Participant No. 10, 11, 13, 14 (MACT) all spontaneously stated during session three that "it is getting easier." Participants in the APT group also demonstrated improvement on some tasks during the course of treatment. Because these observations were not part of a formal assessment, for both groups, it might be challenging to differentiate between improvement in cognitive functioning and improvement in self-confidence. The tasks varied and slightly increased in difficulty over the three treatment sessions, therefore, it is reasonable to expect that the improvements observed were not only task specific improvements due to practice. Although these observations do not affect the results of this study, they do suggest that future studies with a longer data collection period may show an accumulative benefit of treatment and stronger study results.

4.2. Discussion of findings

The results of this investigation provide new evidence in support of literature on the strong benefits of music on the development and remediation of cognitive skills such as attention. In fact, the current study is the first of its kind providing evidence that neurologic music therapy treatment has a positive impact on the rehabilitation of attention skills in chronic ABI patients with a moderate to severe injury. Outside of the clinical literature, there is strong evidence in support of music's influence on general attention processes (Janata et al., 2002; Koelsch, 2009, Moreno & Bidelman, 2014; Pallesen et al., 2010). Music stimuli may provide a more effective recruitment of attentional processes than spoken or play stimuli (Wolfe & Noguchi, 2009). Moreno et al. (2011) observed improved verbal scores in children aged four to six following 20 days of music training and attributed these gains to improved attention and memory rather than verbal ability.

The literature regarding music-based cognitive rehabilitation is still emerging (Magee et al., 2017), however, recent studies involving music tasks have revealed the positive influence of music on attention and memory. Using a crossover randomized controlled trial, Siponkoski et al. (2020) used neuropsychological testing, motor testing, and fMRI to investigate the influence of three months of music-based cognitive training on executive functioning and prefrontal neuroplasticity. Their results indicated a significant increase in gray matter volume in the right inferior gyrus during treatment, correlated with cognitive improvement in executive functioning. A study by Vik et al. (2018) revealed improved attention and memory following eight weeks of music training for individuals with mild cognitive impairment following an ABI. Using fMRI results, Vik et al.'s results indicated training-related neuroplasticity in the orbitofrontal cortex and cognitive gains were demonstrated on improvement in post-tests on three standardized neuropsychological tests. These results were also reflected in Jones' (2020) case study in which the participant, with a TBI rated as catastrophic, demonstrated large gains on three standardized neuropsychological tests of attention and executive functioning following 12 months of music training. Sarkamo et al.'s (2008) study results indicated improved focused attention and verbal memory following music listening tasks in persons in the acute state after cerebral artery stroke. Thaut et al. (2009) observed significant improvement in executive function following a single 30-minute music-based treatment, and proposed that the inherent temporal structure of music in the tasks during treatment provided a strong self-regulatory constraint which supported elements of executive function. Indeed, the influence of temporal and rhythmic components of music on attention and memory processes has also been explored in other studies (Drake et al., 2000; Jakobson et al., 2002) and suggest the unique properties of musical stimuli on attentional processes. The potential effectiveness of NMT to address cognitive rehabilitation goals has been discussed in the literature (Hegde, 2014, 2019; Thaut & Gardiner, 2014). In addition, because of the emerging evidence of the influence of music on attentional processing, two studies have developed and proposed music-based attention assessments (Eslava-Mejia, 2017; Jeong & Lesiuk, 2011).

Lesniak et al.'s (2019) study investigated the potential of treatment, using non-music tasks, to improve attention and memory for individuals with ABI. Like the current study, Lesniak and al.'s study participants were in the post-acute stage and had injury ratings of moderate-severe. The sample size was 15 participants, and the data collection period was three weeks. A crucial difference between Lesniak et al.'s study and the current study is that Lesniak et al. participants received both a 45-minute group and a 45-minute individual treatment daily for three weeks. In their study, the group session focused on teaching memory strategies while the individual sessions were focused on attention tasks. Results indicated improvement on two of five standardized measures of attention and memory. In contrast, the participants in the current MACT-APT study received one 45-minute individual session per week for three weeks and post-tests revealed improvements on one of three standardized neuropsychological tests. The lower number of treatments, yet with positive outcomes on the Trail B test in the current study, may suggest greater effectiveness of music-based cognitive interventions. Thus, the current study supports the results of previous research, and contributes to the literature regarding the benefit of music-based cognitive rehabilitation interventions to remediate cognitive impairment following an ABI.

4.3. Limitations and recommendations

There are several limitations to this study that should be noted. First, this study had a very small sample size, limiting generalizability of results. A larger sample size would be needed for future studies

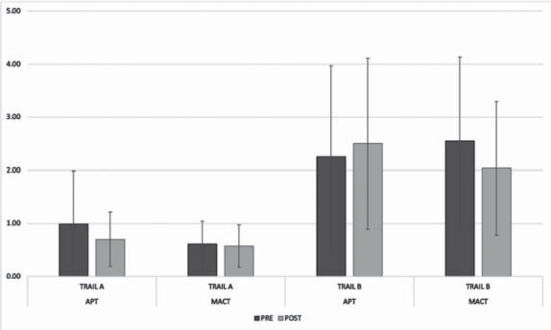

Fig. 2. Trail A and B timing results for APT and MACT, pre- versus post-tests (in minutes).

in order to increase statistical power and to provide a more precise estimate of the benefit of music-based cognitive rehabilitation interventions. Second, the study collected data through pre- and post-testing over a short period of time. The research utilized a three-week timeframe in order to investigate the effect of repeated treatment over a short period. This allowed for identification of a time point of earliest possible efficacy of treatment, providing the logical basis for stepwise lengthening of treatment until positive responses are found. In addition, a three-week separation of the pre- and post-tests was intended to reduce a practice effect on post-tests and also helped to reduce participant drop-out as longer study periods often lead to severe attrition of subjects in clinical studies. Although this study's design used a three-week data collection period for the reasons outlined above, this time period may have been too short to gain significant results due to the severity of brain injury and cognitive impairment of the participants. A longer data collection period in future research could allow for observation of an accumulative effect of APT or MACT treatment on attentional arousal and engagement and may provide different results. A third limitation is that the inclusion criteria for the study participants included having a cognitive impairment following an ABI rated as moderate or severe. However, specific forms of attention deficit were not identified in the inclusion criteria. The individuality of the attention deficits and the degree of deficit in the various attention types of the participants may have impacted the results. Future studies might investigate the influence of the individual musical components of MACT on a single attention type. Finally, most participants commented on the effort required to complete the MACT and APT tasks. This is to be expected due to the identified cognitive impairment. However, cognitive fatigue was not factored into results.

In terms of other considerations for the future, forthcoming research might also investigate and compare the influence of single music components, melody, rhythm, and harmony, on attention. It would also be interesting to investigate the influence of single music components with participants included in the study based on lesion site to see if the injured brain responds to the stimuli as music cognition literature might predict according to the lesioned brain area. This may lead to an exploration of a neuroplastic response developed through the treatment of music-based cognitive rehabilitation.

Because executive functioning engages several aspects of attention, a future study may use executive function measures as pre-and post- treatment assessment of attention and overall cognitive gains following music-based cognitive rehabilitation. The executive function measures should be standardized neuropsychological measures. However, it would be interesting to also measure any executive functioning gains in a functional, real-life setting.

As literature support for the effectiveness of music-based attention tasks continues to grow, future studies should include brain imaging data to indicate the degree of engagement and the brain networks involved and to inform the clinical application of interventions.

It is recommended that future studies also include a participant feedback survey. This feedback can provide insights when interpreting data results and provide opportunity to gain information not specifically set out in data collection goals. Although quantifiable results are important to studies, other valuable information may be captured in a participant survey or through documentation of participant feedback or comments. In particular because of the number of participants in this study who expressed concern about, or apologized for, their attention deficit, it may be interesting for a future study to include a participant survey regarding self-confidence and how this might be affected during the course of treatment. A second question could be "how might self-confidence affect test results?"

Finally, it is also important to consider the connection between MACT tasks and pre-frontal cortex (PFC) functioning, given the results of the Trail B Test. MACT tasks are goal directed and stimulus driven, engaging attention as described by Corbetta and Shulman (2002), providing a clear perceptual input and placing demands on attentional resources over a period of time and to respond to the target with a specific behavior. The goal-directed nature of MACT tasks engages the PFC and drive top-down processing which can serve to increase cognitive control, a significant contributor to improved attention and cognitive functioning. Further examination of the data revealed that three of the four most improved MACT results on Trail B were from participants who had experienced a PFC injury. The fourth MACT participant with a PFC injury also improved, but to a lesser degree. The improvement of MACT participants who had experienced PFC injury is significant as a primary goal of cognitive rehabilitation is to use interventions that will engage the PFC, increasing cognitive control and improving attention (Chen et al., 2006). This study did not include lesion site in inclusion criteria. Future studies might investigate the influence of music on attention with participants with a specific lesion site, in particular the prefrontal cortex.

In terms of the clinical implications of this research, our results provided preliminary evidence for the efficacy of MACT to arouse and engage attention. Successful attentional engagement was shown on measures that included executive functioning without added divided-attention or memory components (Trail B). In all other measures both APT and MACT produced similar results in attention training. There is a need for further research evidence, however, the current study provides preliminary clinical evidence that MACT is a valid and effective treatment tool for targeting attention deficit in those with TBI.

5. Conclusion

The current study used a randomized design to investigate an evidence-based neurologic music therapy intervention (MACT), in comparison with a non-musical standard intervention (APT). Findings revealed that the group who received the music intervention (MACT) improved significantly more on the Trail B test than the group who received APT training. This study adds new, robust evidence to the literature supporting the benefits of music-based cognitive rehabilitation for individuals with moderate to severe ABI.

Conflict of interest

The authors declare they have no conflicts of interest.

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