Neuroscience Letters 683 (2018) 27–32

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

Research article

The influence of moving with music on motor cortical activity

Elizabeth L. Stegemöller[a,*], Patricia Izbicki[a], Paul Hibbing[a,b]

[a] Department of Kinesiology, Iowa State University, Ames, IA, 50011, United States
[b] Department of Kinesiology, Recreation, and Sports Studies, University of Tennessee, Knoxville, TN, 37996, United States

ARTICLE INFO

Keywords:
Beta band
Music style
Music experience

ABSTRACT

Although there is a growing interest in using music to improve movement performance in various populations, there remains a need to better understand how music influences motor cortical activity. *Listening* to music is tightly linked to neural processes within the motor cortex and can modulate motor cortical activity in healthy young adult (HYAs). There is limited evidence regarding how *moving* to music modulates motor cortical activity. Thus, the purpose of this study was to explore the influence of moving to music on motor cortical activity in HYAs. Electroencephalography was collected while 32 HYAs tapped their index finger in time with a tone and with two contrasting music styles. Two movement rates were presented for each condition. Power spectra were obtained from data collected over the primary sensorimotor region and supplemental motor area and were compared between conditions. Results revealed a significant difference between both music conditions and the tone only condition for both the regions. For both music styles, power was increased in the beta band for low movement rates and increased in the alpha band for high movement rates. A secondary analysis determining the effect of music experience on motor cortical activity revealed a significant difference between musicians and non-musicians. Power in the beta band was increased across all conditions. The results of this study provide the initial step towards a more complete understanding of the neurophysiological underpinnings of music on movement performance which may inform future studies and therapeutic strategies.

1. Introduction

There has been growing interest in using music to improve movement in persons with neurological disease, including Parkinson's disease (PD). Learning and performing various styles of dance steps improved functional mobility, gait, and postural instability in persons with PD [1–4]. However, understanding how music impacts motor cortical activity remains limited. Current drug and surgical treatments undergo substantial investigation and much is known about how these treatments affect brain activity before they are considered safe. To establish music as an effective alternative treatment, it should be investigated in the same way, and to the same degree, as current standards of care. A basic understanding of how music modulates motor cortical activity in healthy young adults (HYAs) will provide the foundation for further examination of the effect of music in neurological diseases.

Listening to music is tightly linked to neural processes within the motor cortex and can modulate motor cortical activity in HYAs [5,6]. Moreover, the perception of auditory rhythms evokes activity in motor regions [7,8]. Less is known about how *moving* with music modulates motor cotrical activity in HYAs. Research has shown, though, that style of music affects the urge to move. Music with faster tempos, moderate syncopation, and a repetitive rhythm elicited a greater urge to move compared to music with slower tempo, excessive syncopation, and non-repetitive rhythms [9]. Moreover, Leman and colleagues showed that in HYAs, stride length increased when walking with activating music compared to relaxing music [10]. This suggests that style of music may play a role in how music modulates motor cortical activity.

Movement rate may also influence how music modulates motor cortical activity. Previous research has demonstrated that the rate of the intended movement influences movement performance in HYAs [11]. Movement performance on various repetitive finger tapping tasks changes around a rate of 120 beats per minute (BPM), which was associated with changes in motor cortical activity [12–14]. Thus, consideration of movement rate, specifically above and below 120 BPM, should be taken into account when exploring the effects of music on motor cortical activity during movement performance.

Previous music experience also impacts motor cortical activity. When listening to music, HYAs musicians demonstrated greater motor cortical activity than non-musicians [15]. Similarly, musicians demonstrated greater corticospinal excitability while listening to high-groove (i.e. tendency to make one move) music compared to low-

* Corresponding author at: 534 Wallace Road, Iowa State University, Ames, IA, 50011, United States.
E-mail address: esteg@iastate.edu (E.L. Stegemöller).

https://doi.org/10.1016/j.neulet.2018.06.030
Received 8 May 2018; Received in revised form 8 June 2018; Accepted 16 June 2018
Available online 19 June 2018

groove music [6]. However, there is limited research comparing motor cortical activity in musicians and non-musicians when *moving* with music.

The primary purpose of this study was to explore the influence of music on motor cortical activity in HYAs. Participants performed a repetitive finger movement task in time with a tone only, and two differing styles of music at two movement rates (70 and 140 BPM). Electroencephology (EEG) was recorded from electrodes over motor cortical regions, and power spectra were compared between the tone only condition and each music style condition at both movement rates. The secondary aim of this study was to explore motor cortical activity when musicians and non-musicians move with different styles of music at different movement rates. Thus, power spectra were also compared between musicians and non-musicians for each music style at both movement rates. Our primary hypotheses are that motor cortical activity would differ when moving to music compared to only a tone and that the difference between music and the tone would be modulated by the style of music and movement rate. Our secondary hypothesis is that music experience would influence motor cortical activity.

2. Methods

2.1. Participants

Thirty-two HYAs (17 men, 31 right hand dominant, mean age ± standard deviation age = 23 ± 2.9 years) with no history of neurological disorder completed the study. Handedness was self-reported. See Table 1 for detailed demographic information. All procedures were approved by the University Institutional Review Board, and all participants provided informed consent prior to data collection. This study has been performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments.

2.2. Experimental design

2.2.1. Music experience and music preference

Prior to EEG data collection, all participants provided information about their previous music experience. Participants were classified as musicians (≥5 years experience, n = 12, mean ± standard deviation = 8 ± 1.1 years) or non-musicians (< 5 years experience, n = 20, mean ± standard deviation = 1.5 ± 1.5 years). Music experience was defined as private lessons on an instrument or voice. See Table 1 for detailed information on music experience.

Participants listened to two recordings of original musical instrumental digital interface (MIDI)-generated pieces that were used later during the EEG data collection. Original pieces were composed to control for previous experience/familiarity with music. One piece featured an “activating” style (Style 1) while the other featured a “relaxing” style (Style 2). For Style 1, buoyant rhythmic patterns and major tonalities were intended to evoke an “active” feeling. The initial tempo for this piece was set at 140 BPM. For Style 2, the rhythm was slower and major seventh tonalities were intended to evoke a “relaxing” feeling. The initial tempo for this piece was set at 70 BPM. After listening to each excerpt, participants immediately rated how much they liked each piece using a ten-point Likert scale in which a score of ten designated the best music ever heard and one designated the worst music ever heard.

2.2.2. Finger tapping task

A speaker was used to present the auditory stimuli at each participant’s preferred loudness level. The dominant forearm and hand were secured in a partial brace in the pronated position. Participants were instructed to “tap your index finger along with the beat” using their dominant hand. The index finger flexion and extension movement was unconstrained (i.e. no tactile feedback). Data were obtained for the following six conditions; 1) Style 1 at 140 BPM, 2) Style 1 at 70 BPM, 3)

Table 1
Participant Demographics and Music Experience.

Participant	Gender	Age (years)	Ethnicity	Handedness	Music Training (years)	Instrument
1	M	33	Hispanic	R	1	Trumpet
2	F	23	African American	R	0	NA
3	M	24	Caucasian	R	2	Trumpet
4	F	24	Other	R	0	NA
5	M	22	Caucasian	R	2	Trumpet
6	M	24	Asian	R	0	NA
7	M	24	Caucasian	R	2	Trumpet
8	F	22	Caucasian	L	2	Voice
9	M	21	Caucasian	R	4	Trumpet
10	F	20	Caucasian	R	0	NA
11	M	25	Caucasian	R	0	NA
12	M	29	Caucasian	R	2	Violin
13	M	21	Other	R	3	Trumpet
14	M	25	Caucasian	R	0	NA
15	F	22	Caucasian	R	4	Flute
16	M	23	Caucasian	R	4	Voice
17	F	21	Caucasian	R	3	Flute
18	F	21	Caucasian	R	1	Flute
19	M	23	Caucasian	R	0	NA
20	M	21	Caucasian	R	0	NA
21	F	20	Caucasian	R	7	Saxophone
22	M	21	Caucasian	R	9	Euphonium
23	F	27	Caucasian	R	8	Guitar
24	F	20	Caucasian	R	8	Tenor Saxophone
25	M	26	Caucasian	R	6	Piano
26	M	24	Caucasian	R	7	Guitar
27	F	28	Caucasian	R	7	Piano
28	F	21	Caucasian	R	8	Flute
29	F	21	Caucasian	R	9	Piano
30	F	22	Caucasian	R	8	Flute
31	F	21	Caucasian	R	9	French Horn
32	M	22	Caucasian	R	10	Trombone

M = male; F = female; R = right; L = left; NA = not applicable.

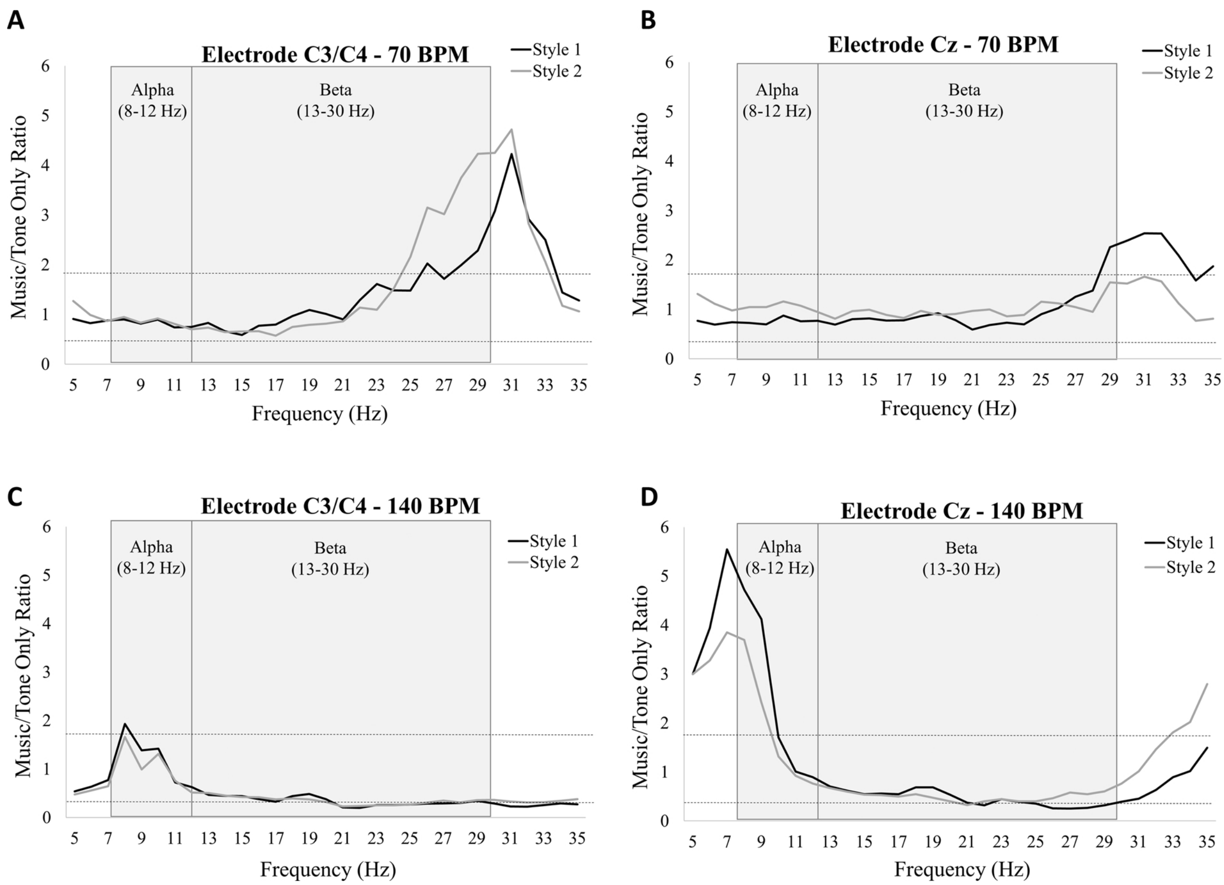

Fig. 1. Power Spectrum Ratios for Comparisons between Music and Tone Only Conditions.
Ratio between Style 1 (activating music) and Tone only and Style 2 (relaxing music) and Tone only conditions are shown for the frequency range from 5 to 35 Hertz (Hz). Data from electrodes A) C3/C4 at 70 beats per minute, B) Cz at 70 beats per minute, C) C3/C4 at 140 beats per minute, and D) Cz at 140 beats per minute are shown. Dashed horizontal lines represent the 95th confidence intervals. Any value above or below these lines indicated a significant difference between power spectrum.

Style 2 at 140 BPM, 4) Style 2 at 70 BPM, 5) Tone Only at 140 BPM, and 6) Tone Only at 70 BPM. Metronome clicks were inserted in the music conditions to ensure that participants were tapping in time to the same beat as the tone only condition. Four trials, approximately 10 s in duration, of each condition were completed before completing the next condition. Each condition was presented in a random order. Trials for the music conditions included random portions of the music selections. Movement performance results are reported elsewhere [16].

2.2.3. Data collection

A 2 mm electromagnetic position sensor (Ascension trakStar, Shelburne, Vermont) was placed on the dorsum of the index finger and electromyography (EMG) sensors were placed on the first dorsal interosseous (FDI) and the extensor digitorum communis (EDC) (Delsys, Natick, Massachusetts). EMG signals were recorded at a sampling rate of 2048 Hz, bandpass filtered in a range from 20 to 500 Hz, and notch filtered at 60 Hz (The Motion Monitor, Chicago, Illinois). Both the position and EMG data were used to determine movement onset. EEG was also recorded at a sampling rate of 2000 Hz using a 64-channel unit conforming to the international 10–20 system (Biosemi, Amsterdam, Netherlands).

2.2.4. Data analysis

Analysis was focused on regions that are primarily involved with motor cortical activity, and signals from electrodes overlying the region of the primary sensorimotor region (S1/M1) (electrode C3: right-handed participants or C4: left-handed participant) and the SMA (electrode Cz) were obtained. EEG data was epoched −500 to 500 miliseconds relative to movement onset. Epoched data was low-pass filtered (62.5 Hz) and down-sampled by a factor of 4. A 2nd order dual-pass Butterworth high-pass filter (1 Hz) to remove DC bias and drift and a Laplacian spatial filter using 8 neighboring electrodes to reduce the common activity from surrounding electrodes were subsequently applied. Epoched data were manually inspected, and any epochs with eye blinks or extraneous noise greater than 50 μV were rejected. Epochs were then averaged across each of the six conditions, and a Fast Fourier Transform was applied to obtain the power spectrum. Each power spectrum was then normalized so that the total power in the spectrum was equal to one and then summed across participants. This resulted in a chi-square distribution for each condition.

2.3. Statistical analysis

Because the power spectra fit a chi-square distribution, one spectrum was divided by another spectrum (i.e. ratio between two spectrums) resulting in an *F* distribution for comparison. From the *F* table, 95th percentile confidence intervals were obtained using the total number of epochs in each group as the degrees of freedom. Any value below or above these limits was designated a significant difference ($\alpha = 0.05$) between power spectrums [17,18]. To address the primary hypotheses of this study, power spectra ratio were determined and compared between Style 1 and Tone only conditions at both 70 BPM and 140 BPM and Style 2 and Tone only conditions at both 70 BPM and 140 BPM. The mean power spectra of the music condition was divided by the tone only condition to obtain the ratios between the conditions. To address the secondary hypothesis, the same procedure was completed to compare power spectra ratios between musicians and non-musicians. The mean power spectra from the musicians were divided by mean power spectra from the non-musicians for Style 1 at 70 BPM and 140 BPM and Style 2 at 70 BPM and 140 BPM. The power spectra for each comparison were obtained from electrodes C3/C4 and Cz.

3. Results

3.1. Music preference

Participant ratings were similar for Style 1 and Style 2 (mean ± standard deviation, range: Style 1 = 5.05 ± 2.10, 1–9; Style 2 = 5.97 ± 2.04, 2–9). However ratings for Style 2 were larger among both musicians and non-musicians (Musicians: Style 1 = 5.58 ± 2.23, 1–9; Style 2 = 6.75 ± 1.29, 4–9; Non-musicians: Style 1 = 4.73 ± 1.20, 2–9; Style 2 = 5.50 ± 2.83, 2–9). Moreover, preferences for both styles of music were higher among musicians compared to non-musicians.

3.2. Style and rate of music

Given that power in the beta band (13–30 Hz) and alpha band (8–12 Hz) have been shown to be associated with repetitive finger movement performance [12,18,19], reporting of results are focused on these two frequency bands. Fig. 1 shows the results for comparisons of power spectrum between each music style and a tone only. A value above the 95th confidence interval indicates that power in the numerator position (i.e. music style) is greater than power in the denominator position (i.e. tone only). Results, in general, did not reveal values below the 95th confidence interval.

For movements performed at 70 BPM, results revealed significantly more power for Style 1 (activating music) in the high beta band for both electrodes C3/C4 and Cz (Fig. 1A and B – black line). For Style 2 (relaxing music), results revealed significantly more power in the high beta bands for electrode C3/C4 only, but no significant differences were revealed for Style 2 for electrode Cz (Fig. 1A and B – grey line).

For movements performed at 140 BPM, results revealed results revealed significantly more power for Style 1 in the in the alpha band for electrode C3/C4 and low alpha band for electrode Cz (Fig. 1C and D – black line). For Style 2, results revealed significantly more power in the low alpha band for electrode Cz only, but no significant differences were revealed for Style 2 for electrode C3/C4 (Fig. 1C and D - grey line).

3.3. Musicians and non-musicians

Fig. 2 shows the results for comparisons between power spectra for musicians and non-musicians. A value above the 95th percentile confidence interval indicates that power in the numerator position (i.e. musician) is greater than power in the denominator position (i.e. non-musician). Results, in general, did not reveal values below the 95th percentile confidence interval.

For movements performed at 70 BPM, results differed between style of music and electrode. For Style 1, no significant differences were revealed for electrode C3/C4, but results revealed significantly higher power for musicians in the beta band for electrode Cz (Fig. 2A and B – black line). In contrast, for Style 2, results revealed significantly higher power for musicians within the beta band for electrode C3/C4 only, but no significant differences were revealed for electrode Cz (Fig. 2A and B – grey line).

Similarly for movements performed at 140 BPM, results also differed between style of music and electrode. For Style 1, results revealed significantly higher power for musicians in the beta band for both electrodes C3/C4 and Cz (Fig. 2C and D – black line). For Style 2, results revealed significantly higher power for musicians in the beta band for electrode C3/C4 only, but no significant differences were revealed for electrode Cz (Fig. 2C and D – grey line).

4. Discussion

The primary purpose of this study was to determine the influence of music on motor cortical activity while moving, including the effects of music style and movement rate. The secondary purpose was to determine the influence of music experience on motor cortical activity while moving. The findings support our hypotheses revealing that there was significantly more power in the alpha and beta bands for the music conditions. However, movement rate had the largest influences on differences in power spectra. Results also revealed significantly more power in the beta band for musicians that was influenced by music style and movement rate. To our knowledge, these results are the first to demonstrate the influences of music and music experience on motor cortical activity while moving.

An interesting findings is that the pattern of differences between music conditions and the tone only condition was similar across music style, though differences did not always reach significance for Style 2. Moreover, the similarity in the pattern of differences extended to both motor regions of interest. It was suspected that since S1/M1 is primarily involved with movement execution and the SMA is primarily involved with movement planning [20], that moving with music may have modulated activity over the S1/M1 differently than activity over the SMA. However, the results of this study revealed significant differences in the same frequency bands for both regions of interest. This suggests that music, compared to a tone only cue, may change larger frequency networks involved with movement performance or those involved in auditory-motor coupling [21]. However, the magnitude of the differences was also mediated by movement rate, suggesting that movement rate may also influence the activity of larger frequency networks involved in moving with music.

Results revealed that the power spectra differed with movement rate. Differences in the beta band emerged at low movement rates, while differences in the alpha band emerged at higher movement rates. This supports previous findings that indicate that motor cortical activity differs between low and high rate movement [12–14]. Specifically, power in the beta band is reduced for high rate movements compared to low rate movements [12,18]. Thus, the lack of difference in power spectra in the beta band at the high pacing rate may due to a general reduction in power. Previous studies have also demonstrated that power in the alpha band is reduced during high rate movements [12,18]. The results of this study revealed an increase in power in the alpha band during the music conditions at the high rate. This conflict may be attributed to differences in methodology. EEG analysis methods used in this study only demonstrate general differences in power and not changes in power over the time course of a movement like in previous studies. Thus, more general processes, such as the role of the alpha band in attention processes, may contribute to differences in findings [22]. Moving with music at high pacing rates may demand greater attentional resources to maintain adequate auditory-motor coupling. Further exploration of this data set using different EEG methodology, such as time-frequency analysis or independent component analysis, may provide more insight on the influence of music and movement rate on both time-dependent and network changes in motor cortical activity. Nonetheless, the results of this study demonstrated that music influences global motor cortical activity similarly across music styles, but differentially across movement rates.

Research has shown that music experience has wide ranging effects on brain activity [21,23–25]. However, research examining music experience on motor cortical activity during movement is sparse. There is some evidence that musicians demonstrate greater motor cortical activity and corticospinal excitability than non-musicians when listening to music [6,15]. Our results revealed significant differences in power spectra that varied across music style and movement rate. In general,

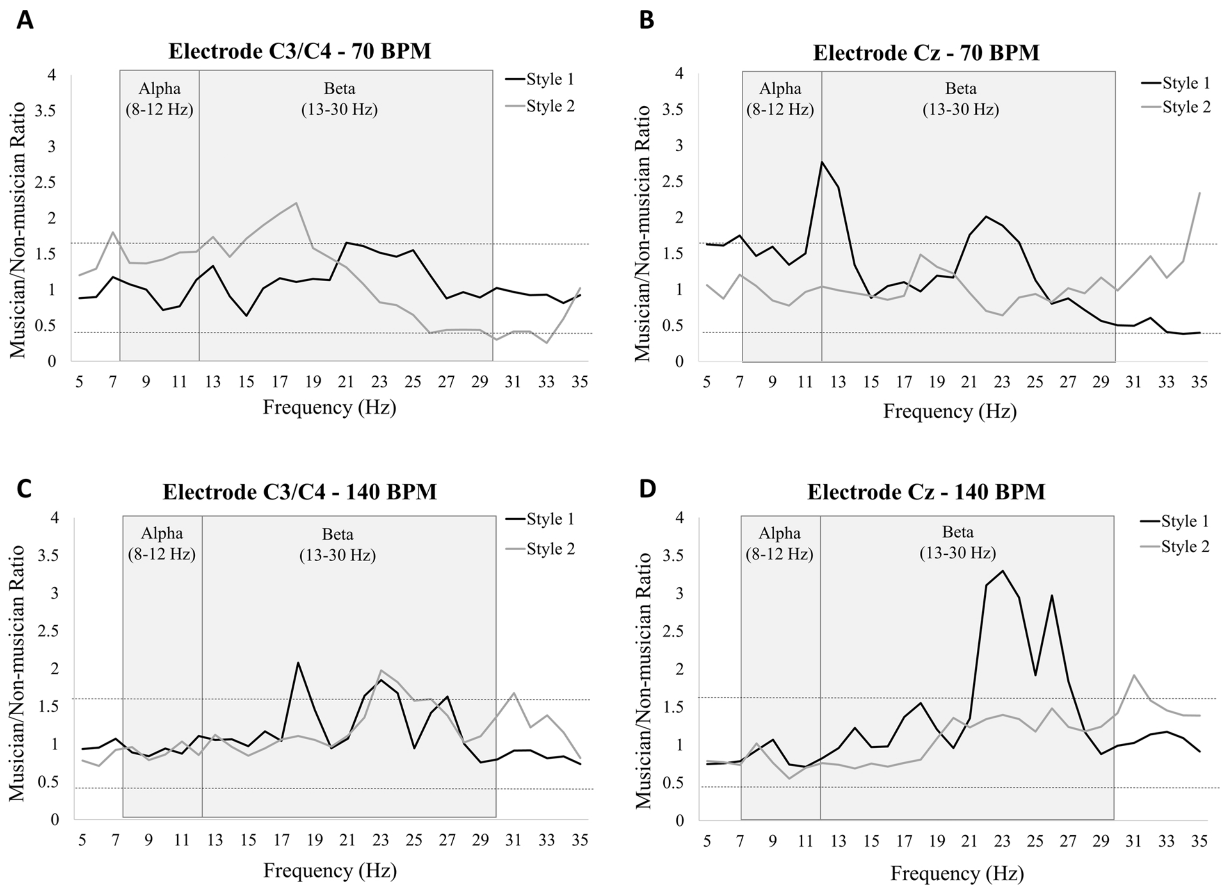

Fig. 2. Power Spectrum Ratios for Comparisons between Musicians and Non-Musicians.
Ratio between musicians and non-musicians for Style 1 (activating music) and Style 2 (relaxing music) are shown for the frequency range from 5 to 35 Hertz (Hz). Data from electrodes A) C3/C4 at 70 beats per minute, B) Cz at 70 beats per minute, C) C3/C4 at 140 beats per minute, and D) Cz at 140 beats per minute are shown. Dashed horizontal lines represent the 95th confidence intervals. Any value above or below these lines indicated a significant difference between power spectrum.

musicians demonstrated more power within the beta band than non-musicians across both regions of interest. However, there was no specific pattern of similarity between regions of interest, music style, or movement rate limiting interpretation of the data. Musicians are often considered a unified group, but there are many individual differences that should be considered. Previous research has suggest that individual music preferences, such as instrument, genre, and practice style, diversify the group [26]. Moreover, these variances are likely to have differential effects on underlying motor cortical activity. Indeed, individual differences in music experience (Table 1) were evident in the musician group in this study, and may have contributed to the lack of consistency in the results. Moreover, musicians and non-musicians had different preferences for the two music styles used in this study which may have also contributed to the variability in the results. Continued research to better understand the effect of previous music experience on movement performance and associated motor cortical activity is needed.

Abnormalities in beta band oscillations have been previously shown in persons with PD [18,19,27]. Recordings from the subthalamic nucleus revealed increased power in the beta band that has been associated with movement impairment [27]. This would suggest that greater power in the beta band as revealed in this study may not be beneficial for persons with PD. However, changes in oscillation patterns within the basal ganglia may not directly translate to motor cortical areas. Indeed, more recent research examining EEG recordings over S1/M1 has revealed an abnormal decrease in power in beta band oscillations that is associated with impairments in repetitive finger movement in persons with PD [18,19]. Thus, the results of this study suggest that an increase in beta band power when tapping with music may be beneficial in improving repetitive finger movements and associated motor cortical activity in persons with PD.

In conclusion, this study lays the ground work for future research exploring the effects of music on motor cortical activity and informs the therapeutic application of music in neurological populations. When using music to improve movement performance in persons with PD, the results of this study suggest that both movement rate and previous music experience should be considered. Yet, there is still a considerable gap in knowledge, and there remains a need to better understand how music impacts brain function in HYAs before extending to neurological populations. This study provides the initial step towards a more complete understanding of the neurophysiological underpinnings of alternative therapies, such as music therapy, on movement performance.

4.1. Limitations and future directions

Limitations should be considered when interpreting the results of this study. The two styles of music are described as activating and relaxing, but no rating of whether participants perceived the pieces of music as activating or relaxing was recorded. Interpretation should be limited to comparing two contrasting styles of music only. When comparing results to previous studies that carefully describe activating/groovy music, this consideration should be taken into account. Moreover, ratings of preference do not always correlate to ratings of “groove”. Though there were differences in preferences between musicians and non-musicians, this does not indicate that musicians felt more of an urge to move than non-musicians. Continued research is needed to more fully account for music preference in understanding how motor cortical activity changes when moving with music. When comparing musicians to non-musicians, sample size was limited and instrument type (i.e. brass, wind, string, percussion, voice) was not evenly distributed limiting the extension of these results to all musicians. Future research is needed to determine if instrument type and voice have differential effects on motor cortical activity. Finally,

Declaration of interest

None

Acknowledgement

This work was funded by the Research Enhancement Grant from the College of Human Sciences, Iowa State University.

References

[1] M.E. Hackney, G.M. Earhart, Effects of dance on gait and balance in Parkinson's disease: a comparison of partnered and nonpartnered dance movement, Neurorehabil. Neural Repair 24 (2010) 384–392.
[2] E.R. Foster, L. Golden, R.P. Duncan, G.M. Earhart, Community-based Argentine tango dance program is associated with increased activity participation among individuals with Parkinson's disease, Arch. Phys. Med. Rehabil. 94 (2013) 240–249.
[3] S. Houston, A. McGill, A mixed-methods study into ballet for people living with Parkinson's, Arts Health 5 (2013) 103–119.
[4] D. Volpe, M. Signorini, A. Marchetto, T. Lynch, M.E. Morris, A comparison of Irish set dancing and exercises for people with Parkinson's disease: a phase II feasibility study, BMC Geriatr. 13 (2013) 54.
[5] E.M. Wilson, N.J. Davey, Musical beat influences corticospinal drive to ankle flexor and extensor muscles in man, Int. J. Psychophysiol. 44 (2002) 177–184.
[6] J. Stupacher, M.J. Hove, G. Novembre, S. Schütz-Bosbach, P.E. Keller, Musical groove modulates motor cortex excitability: a TMS investigation, Brain Cogn. 82 (2013) 127–136.
[7] R.J. Zatorre, J.L. Chen, V.B. Penhune, When the brain plays music: auditory-motor interactions in music perception and production, Nat. Rev. Neurosci. 8 (2007) 547–558.
[8] S.L. Bengtsson, F. Ullén, H.H. Ehrsson, T. Hashimoto, T. Kito, E. Naito, H. Forssberg, N. Sadato, Listening to rhythms activates motor and premotor cortices, Cortex 54 (2009) 62–71.
[9] P. Janata, S.T. Tomic, J.M. Haberman, Sensorimotor coupling in music and the psychology of the groove, J. Exp. Psychol. Gen. 141 (2012) 54–75.
[10] M. Leman, D. Moelants, M. Varewyck, F. Styns, L. van Noorden, J.P. Martens, Activating and relaxing music entrains the speed of beat synchronized walking, PLoS One 8 (2013) e67932.
[11] B.H. Repp, Sensorimotor synchronization: a review of the tapping literature, Psychon. Bull. Rev. 12 (2005) 969–992.
[12] K. Toma, T. Mima, T. Matsuoka, C. Gerloff, T. Ohnishi, B. Koshy, F. Andres, M. Hallett, Movement rate effect on activation and functional coupling of motor cortical areas, J. Neurophysiol. 88 (2002) 3377–3385.
[13] J.M. Mayville, K.J. Jantzen, A. Fuchs, F.L. Steinberg, J.A.S. Kelso, Cortical and subcortical networks underlying syncopated and synchronized coordination revealed using fMRI. Functional magnetic resonance imaging, Hum. Brain Mapp. 17 (2002) 214–229.
[14] K.J. Jantzen, F.L. Steinberg, J.A.S. Kelso, Coordination dynamics of large-scale neural circuitry underlying sensorimotor behavior, J. Cogn. Neurosci. 21 (2009) 2420–2433.
[15] J. Haueisen, T.R. Knösche, Involuntary motor activity in pianists evoked by music perception, J. Cogn. Neurosci. 13 (2001) 786–792.
[16] E.L. Stegemöller, J.R. Tatz, A. Warnecke, P. Hibbing, B. Bates, A. Zaman, Influence of music style and rate on repetitive finger tapping, Mot. Control 9 (2018) 1–14 In Press.
[17] P.J. Diggle, A point process moedeling approach to raised incidence of a rare phenomenon in the vicinity of pre-specified point, J. R. Stat. Soc. 160 (1990) 491–505.
[18] E.L. Stegemöller, D.P. Allen, T. Simuni, C.D. MacKinnon, Motor cortical oscillations are abnormally suppressed during repetitive movement in persons with Parkinson's disease, Clin. Neurophysiol. 2 (2016) 6.
[19] E.L. Stegemöller, D.P. Allen, T. Simuni, C.D. MacKinnon, Altered premotor cortical oscillations during repetitive movement in persons with Parkinson's disease, Behav. Brain Res. 317 (2017) 141–146.
[20] J. Tanji, K. Shima, Contrast of neuronal activity between the supplemental motor area and other cortical motor areas, Adv. Neurol. 70 (1996) 95–103.
[21] G. Schlaug, Musicians and music making as a model for the study of brain plasticity, Prog. Brain Res. 217 (2015) 37–55.
[22] J.N. Frey, P. Ruhnau, N. Weisz, Not so different after all: the same oscillatory processes support different types of attention, Brain Res. 1626 (2015) 183–197.
[23] R.J. Zatorre, Musical pleasure and reward: mechanisms and dysfunction, Ann. N. Y. Acad. Sci. 1337 (2015) 202–211.
[24] S. Benz, R. Sellaro, B. Hommel, L.S. Colzato, Music makes the world go round: the impact of musical training on non-musical cognitive functions – a review, Front. Psychol. 6 (2016) 2023.
[25] N. Kraus, J. Slater, Beyond words: how humans communicate through sound, Annu. Rev. Psychol. 67 (2016) 83–103.
[26] M. Tervaniemi, Musicians – same or different? Ann. N. Y. Acad. Sci. 1169 (2009) 151–156.
[27] P. Brown, Abnormal oscillatory synchronization in the motor system leads to impaired movement, Curr. Opin. Neurobiol. (2007) 656–664.