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The Effect of Preferred Music on the Grip Strength of Musicians versus Nonmusicians: a Cross-sectional Analysis

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ABSTRACT

While prior scholarship documents the ergogenic benefits of music in athletic settings, it fails to address how musical training influences physiological and neuromotor responses. This cross-sectional study investigated whether neurological activations caused by preferred music impact maximal grip strength (a surrogate marker for neuromuscular connectivity) differently in musicians compared to nonmusicians. Utilizing a quantitative, pretest-posttest experimental design, 20 participants (10 musicians, 10 nonmusicians) underwent six digital hand dynamometer trials, alternating between listening to a self-selected preferred song and silence. Data was analyzed using a mixed-design ANOVA and exploratory one-tailed paired samples t-tests on each cohort. All tests showed statistically significant improvements in grip strength when listening to preferred music ($p < 0.05$), corroborating current literature. The musician cohort demonstrated a substantially stronger response, with a stronger effect size ($t(9) = -6.34$, $p < .001$, $d = 2.01$), while the nonmusician group yielded a more moderate effect size ($t(9) = -2.45$, $p = .018$, $d = 0.78$). The interaction effect in the main statistical test, however, did not reach statistically significance, although the study may have been underpowered to detect an interaction $F(1, 18) = 30.945$, $p < 0.001$, η^2□ $= .056$. Together, these results suggest that preferred music may increase grip strength in both musicians and nonmusicians and that the magnitude of the improvement may differ by musical training. The exact mechanism is not clear, but it may be due to stronger sensory dissociation from fatigue or more efficient arousal-performance optimization. If replicated in larger experiments with adequate power, these insights offer valuable implications for tailoring noninvasive auditory treatments to combat age-related or neurodegenerative motor declines.

INTRODUCTION

Music plays a central part of the complex human experience. Its ability to evoke powerful emotions and excitement is a result of a complex interplay of melodies, rhythms, and tones. Empirically, music has presented a strong ability to influence the human mind in ways that are not fully understood. The musical stimuli itself is particularly interesting as, unlike other emotional stimuli, it does not have an inherent biological significance (Blood et al., 1999). While other emotional stimuli are biologically necessary (i.e. food, sexual intercourse, fight or flight responses, etc.), music is not necessary for survival. Nevertheless, it presents an unquestionably powerful effect on the brain. Indeed, despite its lack of biological significance, music is able to activate the brain extremely well, eliciting profound psychological responses as a result of the complex brain functions associated with musical processing. It activates multiple brain regions associated with motor skills, cognition, sensory processing, memory, and the emotional response (Zaatar et al., 2023). Medically, due to the widespread activation of neural pathways and the noninvasive nature of such auditory stimuli, music has become a very desirable method in activating the brain as both a therapeutic method and for overall wellbeing. Beyond a psychological sense, music has demonstrated an ability to improve physical strength output in settings such as exercise. In a longitudinal study by Toma et al. (2023), it was observed that music can also be used as a rehabilitative stimulus for elderly patients with neuromuscular deficits, demonstrating permanent strength improvements in their participants due to tailored musical stimuli. Ultimately, music is a topic of intense interest, where its noninvasive ability to improve strength output is medically valuable and interesting in the mechanics of how it improves grip strength.

1. PSYCHOLOGICAL IMPACTS

The psychological impacts of music have been well-documented. It has been demonstrated that music has a powerful ability to "elicit profound emotional and cognitive responses" (Zaatar et al., 2023) through its auditory stimuli. Multiple studies have associated musical stimuli with the activation of various sectors of the brain including the neocortical and paralimbic regions of the brain, responsible for both emotional and high-level cognitive functions (Blood et al., 1999); the amygdala, responsible for processing emotions (Koelsch, 2014; Kraus and Canlon, 2012); Ventral striatum, including the nucleus accumbens, responsible for mediating the reward system and emotion (Blood & Zatorre, 2001); and the hippocampus, responsible for memory (Blood & Zatorre, 2001; Koelsch et al., 2005). Interestingly, the music-associated hippocampus activations are unique compared to that of other biologic necessities like food or erotic rewards. While music lights up the hippocampus, the latter stimuli do not (Koelsch, 2014). These observations have been corroborated across varied studies leveraging different techniques and procedures to provide further insight, using experimental procedures utilizing magnetic resonance imaging [MRI] and positron emission tomography [PET] (Koelsch, 2014; Schaefer, 2017). More generally, multiple studies have observed a significant relationship between listening to music and the reduction of stress and tension (Adiasto et al., 2022; Thoma et al., 2013). Though the underlying mechanisms for the way music imparts neural effects are largely inconclusive, the general hypothesis is that the complex components of music initiate expectations in the brain that cause cascading neurologic effects that ricochet downstream. Additionally, cognitive studies examining the effects of music have highlighted improvements in the processing capacity of subjects listening to select musical compositions. One study found that Mozart's K. 448 Sonata for two pianos significantly enhanced the participants' spatial intellectual quotient (IQ), appropriately dubbed the "Mozart effect" (Rauscher & Shaw, 1993).

The psychological effects of music have contributed to its ability to rewire the brain by activating lesser used pathways in a process called neural plasticity. Hearing-impaired patients, like the elderly and individuals with pre-existing neurologic deficiencies, are particularly receptive to these effects of music to improve their auditory perception and recognition (Liang et al., 2016). Studies have observed long-term improvements in neuromotor ability in elderly/neurodegenerative populations as a direct result of musical therapy (Toma et al., 2023). Therefore, studies examining the impacts of musical conditioning and musical stimuli could prove highly valuable in fostering new symptomatic treatment methods to address the natural deterioration of the senses due to age.

2. PHYSIOLOGICAL IMPACTS

Physiological benefits as a result of musical stimulation have been reported in multiple studies. Table 1 from Ballmann (2021) highlights the impacts of music as an ergogenic stimuli (stimuli for exercise and muscle output) and improved strength. The emotional effects described earlier may be related to these observations. Decreased tension, depression, and anger have been associated with more successful athletic performance (Beedie et al., 2000). While physiological improvements have been shown in studies, the exact mechanisms by which music contributes to performance enhancement are difficult to isolate. This is due to pleiotropic differences in music responses and the systemic changes in the body due to exercise. Current literature suggests that the music influences physiological changes in two ways: “(1) neural activation [i.e., brain activity, autonomic responses, etc.], (2) metabolic responses [i.e., VO2/energy expenditure, lactate clearance, hypothalamic pituitary axis control, etc.]” (Ballmann 2021).

Musical stimuli with endurance exercises have been most widely investigated between all modes of exercise. For example, Ballman et al. (2021) found that listening to preferred music genres (compared to no music) during endurance training (maximum bench press reps to failure) increased motivation and maximum reps to failure. However, these results are not limited to this mode of exercise, as maximum exertion of strength in resistance exercises has also been observed to be improved as a result of music. Silva et al. (2021) found that when listening to their preferred music genre (compared to no music/nonpreferred music), participants exhibited improvements in grip strength metrics. These findings are particularly interesting in the context of hand grip strength as a surrogate marker of an individual's physical and mental health. In fact, Vaishya et al. (2024) noted that lower handgrip strength was associated with a multitude of chronic diseases like “type 2 diabetes, metabolic syndrome, and cardiovascular diseases” as well as cognitive impairment (Vaishya et al., 2024). With the consideration that musical strength impacts physical strength through metabolic/neurologic processes (Ballmann, 2021), the improvements in grip strength found by Silva et al. (2021) imply that grip strength could potentially be a surrogate marker for neuromuscular connection. Ward et al. (2025) clarified this relationship, determining that brain connectivity was directly linked to grip strength. Furthermore, grip strength has been associated with neurologic and cognitive function (Shaughnessy et al., 2020; Vaishya et al., 2024). Thus, grip strength is a particularly interesting biometric indicator, being tied to neuromotor connectivity and cognitive function. Overarchingly, it is biologically plausible that the physiological effects of musical stimulation are deeply related to the psychologic response described previously.

Table 1. This table highlights studies on music preference and resulting exercise measures. It notes the conditions tested and the primary findings from each study. “↑ indicates an increase, ↓ a decrease, ↔ no

change in the outcome. RPE = rate of perceived exertion, HRV = heart rate variability RTF = repetitions to failure, HR = heart rate, [La-] = lactate concentration." (Ballmann, 2021)

Study	**Conditions**	**Primary Findings**
Dyrlund et al., (2008)	No music, Preferred, nonpreferred	↑ enjoyment; ↔ RPE (trend towards sig.)
Nakamura et al., (2010)	No music, Preferred, nonpreferred	↑ cycling distance; ↓ RPE; ↔ HR
Cole et al., (2015)	No music, Preferred, nonpreferred	↑ distance run (females); ↔ distance run (males)
Archana et al., (2016)	No music, Preferred	↓ low frequency/high frequency components of HRV
Ballmann et al., (2021)	Preferred, nonpreferred	↑ barbell velocity; ↑ power; ↑ RTF; ↑ motivation
de Abreu Araújo et al., (2018)	No music, Preferred	↑ repetitions to failure
Ballmann et al., (2019)	Preferred, nonpreferred	↔ performance; ↓ RPE; ↑ motivation
Karow et al., (2020)	No music, Preferred, nonpreferred	↑ power output; ↓ time; ↑ motivation; ↔ RPE
Jebabli et al., (2020)	No music, Preferred	↑ running speed; ↑ distance covered; ↓ Blood [La−]; ↔ RPE
Rasteiro et al., (2020)	No music, Preferred	↑ HR (females); ↑ RPE (females); ↑ time (females); ↔ outcomes (males)
Silva et al., (2021)	No music, Preferred genre, nonpreferred genre	↑ RTF; ↑ grip strength; ↓ RPE
Ballmann et al., (2021)	No music, Preferred	↑ barbell velocity and power; ↑ RTF; ↑ motivation
Ballmann et al., (2020)	Preferred, nonpreferred	↑ RTF; ↔ barbell velocity; ↑

		motivation; ↔ RPE

3. MUSICAL PREFERENCE

One of the most important factors when observing the improvement in physiological and psychological factors is the personalization of musical stimuli. For this study, preferred music was defined according to the review by Ballmann (2021): “preferred music is any song, genre, rhythm, etc., which individuals deem most favorable when presented with an array of music choices". Personalization of music is highly important when attempting to observe improvements of muscular strength output. Observed improvements compared between nonmusic, nonpreferred music, and preferred music conditions are (by large) only significant when listening to preferred music. The review and meta-analysis by Ballmann (2021) highlighted a multitude of studies (Table 1) that observed findings coherent with these ideas which highlight strength improvements across a variety of studies under preferred music conditions. The majority of the results taken from these studies demonstrate that preferred music conditions, compared to nonpreferred or no music, yielded either improvements in the testing criteria or no change at all. The evidence, thus, showed that preferred music is the ideal testing criteria.

There are also key compositional differences in the music that are relevant and influential. Most notable of the compositional features of the musical stimuli are tempo (music speed) and dynamics (loudness). Indeed, for music to be used as an ergogenic stimuli, tempos above 120 BPM are “stimulative” and result in higher heart rate and performance (Edworthy & Waring, 2006). In conjunction with loud dynamics, exercise “performance [is] significantly better in the fast, loud condition in comparison to the slow, quiet condition” (Edworthy & Waring, 2006).

4. MUSICIANSHIP

In addition to the music-sided components of tempo and dynamics, the listener plays an important role in the response to musical stimuli. Responses to music are disparately affected by levels of training and lifetime exposure. The scholarly discussion covering the differences between musicians’ and nonmusicians' ability to process musical stimuli present key differences in the psychologic reception of the musical stimuli. In a study measuring the capability of musicians versus nonmusicians to detect frequency changes, musicians outperformed nonmusicians in all conditions (Liang et al., 2016). Liang et al. (2016) highlighted that musicians were significantly better at discerning frequency changes in the auditory stimuli. In the context of music, this implies that musicians may be more sensitive to varying compositional choices of music (i.e, tempo and dynamics). Agres et al. (2022) also observed similar results with auditory stimuli where musicians were far better at predicting and recognizing structural patterns and overall more effectively responding to musical stimuli specifically.

5. SCIENTIFIC GAPS

The current literature primarily has only focused on the psychologic reception and mental analysis of musical stimuli. There remains a gap in the literature comparing the response of musicians to musical stimuli compared to nonmusicians in both the psychologic and physiologic sense. To address this gap, my study seeks to rectify this by comparing the grip strength of musicians versus nonmusicians in a neuromuscular metric of grip strength with and without preferred music conditions. Specifically, it will address the existing gap in both the physiological and neuromotor response to music as well as determine whether the musical training modifies neuromotor response to preferred music. It seeks to answer the question: Does preferred music impact the grip strength (as a surrogate for neurological activations) in trained musicians and nonmusicians, and (secondarily) does musicianship modulate the strength of the response?

METHODOLOGY

1. PARTICIPANTS

Twenty individuals participated in this study, half of which were musicians and the other half were nonmusicians. Similar to the study conducted by Gaser & Schlaug (2003), musicians were defined as individuals who regularly practice an instrument and had formal training concerning their instrument. Nonmusicians were defined as individuals who had never played an instrument before. One participant was excluded based on exclusion criteria including diagnosed muscular injury in the previous 5 months, impaired hearing, or health issues that directly impact the collection of data or results of tests. All participants and their parents (for participants younger than 18 years) received and signed an informed consent form. The study criteria was also approved by the Institutional Review Board (IRB), given that informed consent was given.

Regarding the characteristics of participants themselves, the gender split was predominately male (9/10 males in both cohorts), and were all right-hand dominant. Concerning the age within the musician and nonmusician cohorts, the average ages were 17.8 and 20.3 years respectively. Within the musicians cohort, individuals had played an instrument for an average of 10.7 years. Instrument type largely consisted of orchestral/band instruments (trumpet, violin, cello, etc.), with multiple individuals also having played the piano.

2. RESEARCH DESIGN

I used a cross-sectional design with a quantitative pretest-posttest to assess the effect of preferred music in two cohorts (musicians and nonmusicians). As discussed earlier, leveraging the findings of Ward et al. (2025), Silva et al. (2021), and Vaishya et al. (2024), grip strength could be used as a surrogate marker for neuromuscular connectivity, particularly when considering musical stimuli. Each participant underwent a pretest and posttest, where their respective grip strength outputs with and without musical stimuli was compared. Statistical analyses were used to determine if the effect of the stimuli was statistically significant. The statistical analyses from the musician and nonmusician cohorts were compared to determine if musicians demonstrated a stronger response. By examining the influence of the musical stimulus in such a manner, it is possible to determine whether or not music plays a significant role in improving neuromotor performance and if musicians display a more powerful response compared to nonmusicians.

3. PROTOCOL

For each participant, data collection was conducted in multiple steps. Prior to the actual data collection, the participants were sent a form that included consent forms and a questionnaire was designed to collect the following data:

Question 1. Musician or nonmusician, and if so how many years of practice? The recording of musicianship is important so the two cohorts can be distinguished for comparison.
Question 2. Age was recorded to account for potential variances in physical capacity.
Question 3. Gender was recorded to account for potential differences in physical output.
Question 4. A song chosen by the individual to use while testing.

Question 4 (preferred music) was designed to account for the musical preference of the individual. Preference is highly important, as previous studies have shown that there is little difference between the nonpreferred musical and nonmusical stimuli, but there exists a significant difference between those groups and with preferential music selections (Ballmann, 2021; Karow et al., 2020; Nakamura et al., 2010). This question was designed to factor in preference to ensure the proper consideration of preference when listening to music.

Music selection was based on this survey, where the piece that participants chose was the one used during testing as preferred musical stimuli. For the data collection, neuromuscular connectivity was measured through maximum grip strength, validated by the findings of Ward et al. (2025), Silva et al. (2021), and Ballmann (2021) mentioned earlier. This measurement used a handgrip dynamometer (Handexer Grip Strength Tester 265lb/120kg, Digital Hand Dynamometer FDA Registered with Backlit LCD for Grip Strength Testing and Training). Similar to the study by Silva et al. (2021), data collection used the protocol established by the American Society of Hand Therapists where participants were told to grip the dynamometer with their arm next to their torso and elbows flexed to 90 degrees (MacDermid, Solomon & Valdes, 2015). Data collection was done using the dominant hand for all participants. Using this procedure, each participant repeated trials a total of 6 times, 3 with the music condition, and 3 without the music condition. Between the trials with and without the stimuli, participants were allowed a minute of rest for complete muscle recovery, as outlined by the findings of Taga et al. (2015). The trials alternated between the presence of the music condition and the lack thereof, largely to mitigate skewed data as a result of fatigue or other factors.

4. STATISTICAL ANALYSIS

I used the arithmetic mean of the three obtained values of each test as the maximum reading for each test under each music condition. To address the primary research question (*do musicians and nonmusicians have a difference in grip strength when listening to preferred music?)*, a 2x2 Mixed-Design Analysis of Variance (ANOVA) was performed, using the main-effect as the metric for significance. The within-subjects factor was Music (With Music vs. Without Music), the between-subjects factor was Musician Status (Musician vs. Nonmusician), and the independent variable was Grip Strength. Type II sums of squares were utilized and the statistical significance threshold was set at $\alpha = .05$.

To further explore the differences in the trends between the two cohorts, I performed two secondary exploratory paired samples t-tests in conjunction with the interaction effect of the ANOVA. Using the presence of the music condition as the independent variable, t-tests were conducted across each cohort (musician/nonmusician) where the effect size (Cohen's d) and significance values (p-values) were recorded. As previously outlined, in the multiple past investigations shown in Table 1, the resulting performance markers only demonstrated increases or no changes at all (Ballmann, 2021). Based on the hypothesis that musical stimulus will demonstrate increases in grip strength or no increase at all. Therefore a one-tailed repeated measures t-test was registered before collecting data. All statistical analyses were performed using R (version 4.5.1).

RESULTS

Data was collected over the course of a 3 week period (late January 2026 and ending mid-February 2026). Twenty participants (10 musicians, 10 nonmusicians) participated in the data collection process and trials. Each participant had 3 trials conducted for each musical condition. The maximum grip strength value was the average of the three trials in each condition.

The results of the 2x2 mixed-design analysis of variance found that the between-subjects main effect of musician status was not statistically significant, $F(1,18) = 0.035$, $p = .854$, η^2□ = .002. This indicates that the overall baseline grip strength without the music condition, did not differ inherently between the two cohorts.

Conversely, a highly significant within-subjects main effect for the musical stimulus was observed, $F(1, 18) = 30.945$, $p < 0.001$, η^2□ = .056. These results show that participant grip strength increased significantly when listening to music across both cohorts.

The interaction effect between musician status and the musical stimulus did not reach statistical significance at the traditional alpha level, $F(1, 18) = 2.159$, $p = .159$, η^2□ = .004. This suggests that while numeric differences in strength improvement rates were observed, with musicians showing a larger increase on average, the upward trajectory in grip strength following the musical stimulus cannot be considered statistically different between musicians and nonmusicians at this sample size.

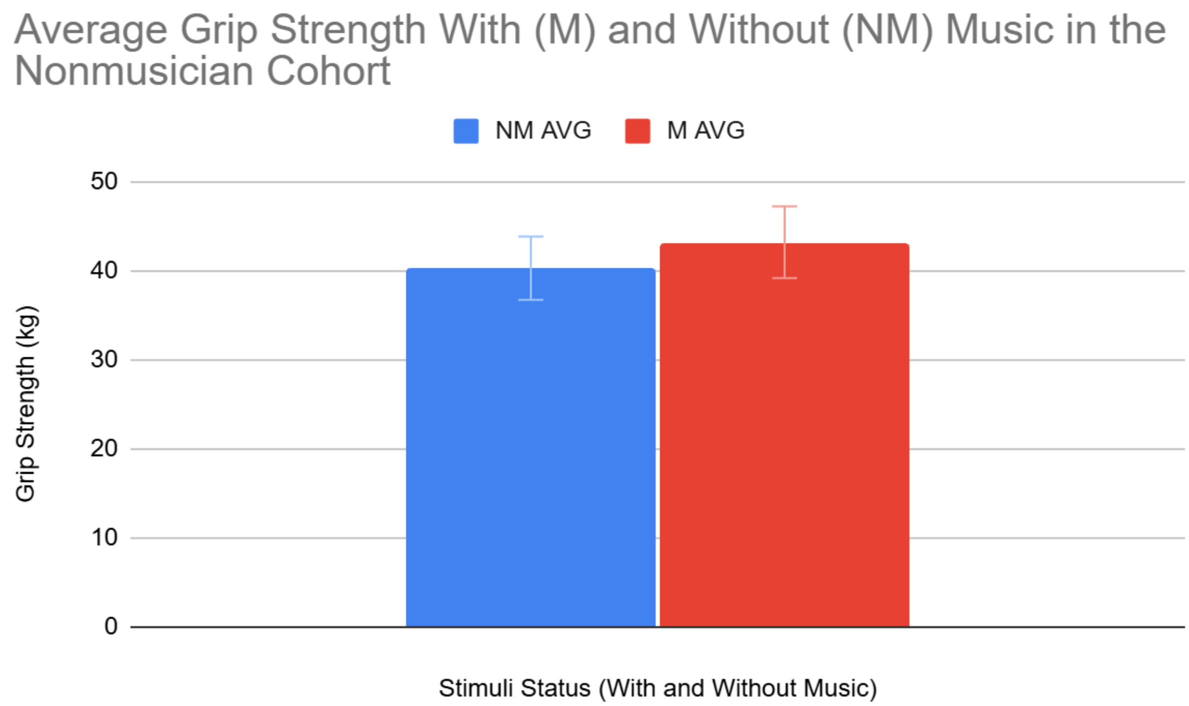

Figure 1a: The average strength output of the nonmusician cohort with (M, red) and without (NM, blue) the music condition [$t(9) = -2.45$, $p = .018$, Cohen's $d = 0.78$]

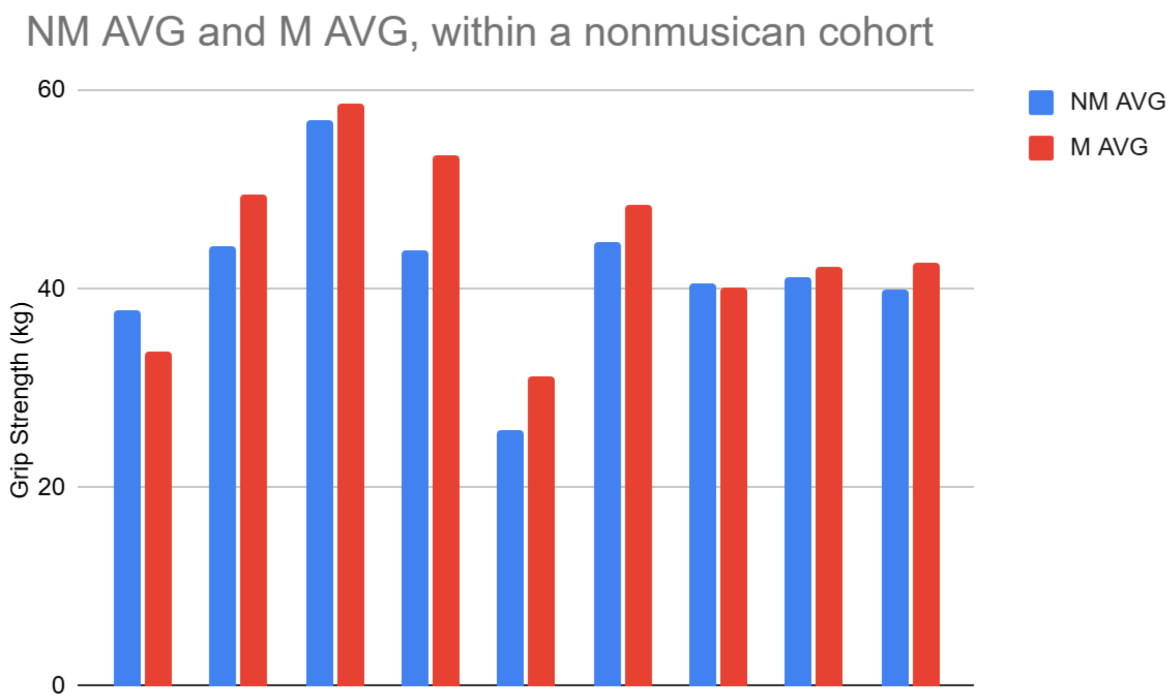

Figure 1b: Bar chart representing individual measurements in the nonmusician cohort with (M, red) and without (NM, blue) the music condition. [$t(9) = -2.45$, $p = .018$, Cohen's $d = 0.78$]

Results of the exploratory one-tailed paired samples t-test conducted on the nonmusician cohort (Figure 1) revealed that the results were statistically significant ($t(9) = -2.45$, $p = .018$, Cohen's $d = 0.78$). Coherent with the mixed-design ANOVA conducted, the results imply that the nonmusician cohort's grip strength increased significantly when under the music condition. Furthermore, the results of this t-test determined an effect size (Cohen's d) of 0.78, which reveals a moderate effect as a result of the presence of the musical stimuli.

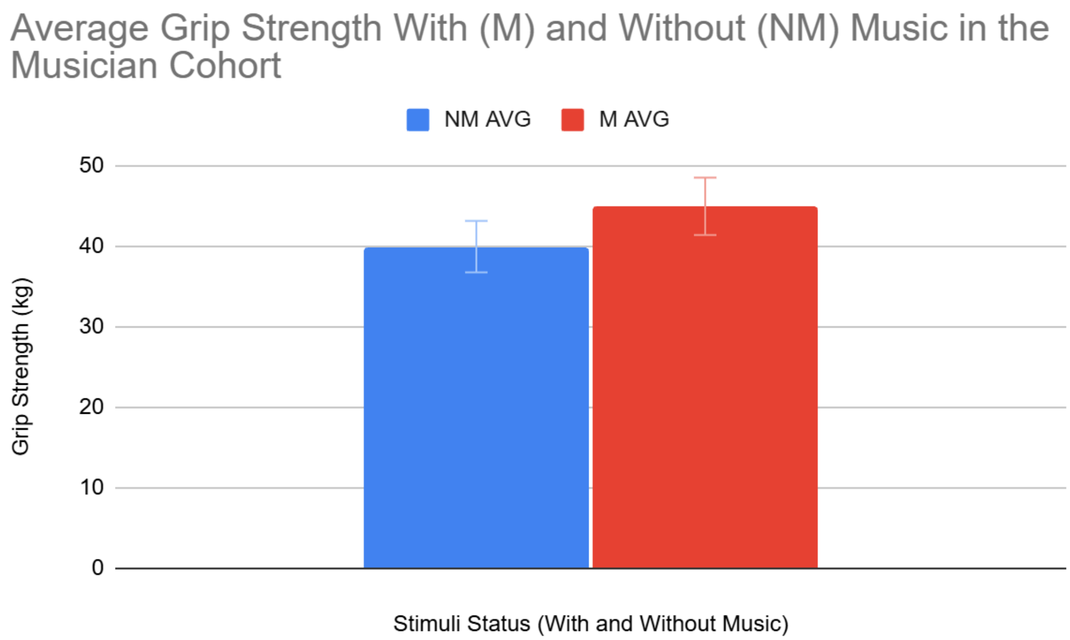

Figure 2a: The average strength output of musicians with (M, red) and without (NM, blue) the music condition. [t(9) = -6.34, p < .001, Cohen's d = 2.01]

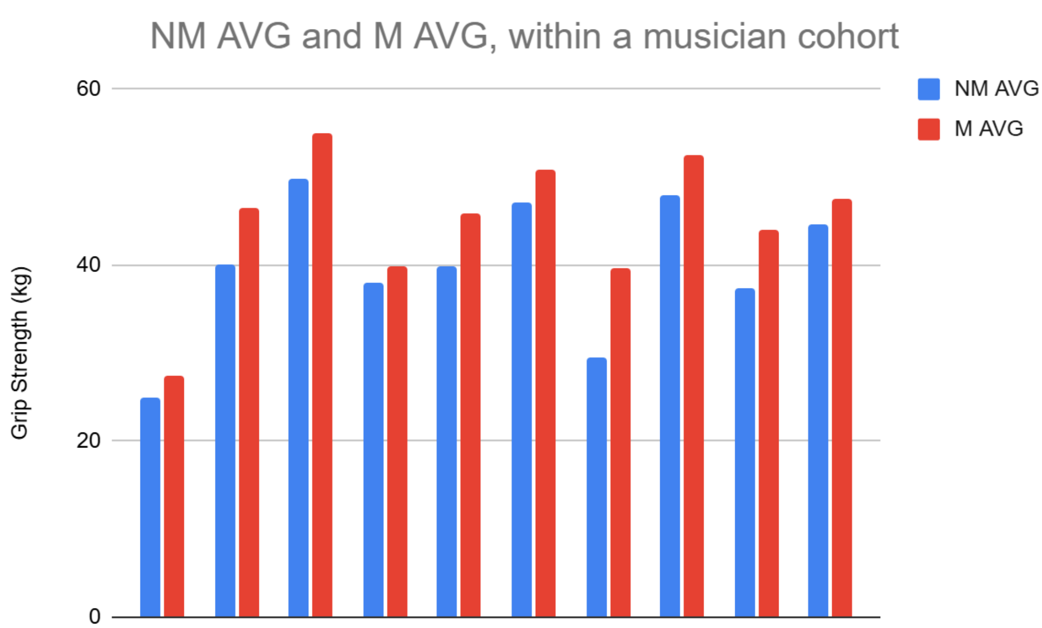

Figure 2b: The individual strength output of musicians with (M, red) and without (NM, blue) the musical condition. [t(9) = -6.34, p < .001, Cohen's d = 2.01]

The results of the exploratory one-tailed paired samples t-test conducted on the musician cohort (Figure 2) revealed that the differences between the grip strength with and without the musical condition were statistically significant ($t(9) = -6.34$, $p < .001$, Cohen's $d = 2.01$). These results, as expected, indicate that the musical condition improved the grip strength of the musician cohort significantly. The t-test also determined an effect size of 2.01, which reveals a substantial effect as a result of the presence of musical stimuli.

The ANOVA and both t-tests, though exploratory, determined statistically significant results with p-values <0.05 regarding the main effect for the musical stimulus. Thus, this confirms the alternative hypothesis (for the main effect of the musical stimulus) and corroborates the current scholarly consensus: individuals present improved grip strength as a result of preferred musical stimuli. However, regarding the primary research question entailing whether or not musicians are more physiologically responsive to musical stimulus compared to nonmusicians, the primary mixed-design ANOVA did not reach the statistical significance ($p = .159$) at the traditional alpha level. The lack of observed statistical significant interaction could be contributed to the study's sample size and may be underpowered to detect an interaction. However, exploratory analyses highlighted a divergence in standardized effect sizes between the two cohorts (0.78 vs. 2.01). Nonetheless, since the main statistical analysis is not statistically significant, this study cannot reject the null hypothesis and confirm that musicians are more physiologically responsive to music than nonmusicians.

DISCUSSION

In my experiment, the results showed that preferred music significantly increased grip strength across both musician and nonmusician cohorts. The findings corroborate previous research demonstrating the physical effects of preferred music during exercise. Although no statistically significant interaction effect between musicianship and music condition was observed, exploratory analyses revealed substantially larger effect sizes among musicians than nonmusicians. These findings suggest that while preferred music benefits individuals regardless of musical training, the magnitude of that response may differ according to musical experience and warrants further investigation in larger, adequately powered studies.

This study aimed to analyze if the differences in analytical ability of music (in the musician vs nonmusician cohorts) yielded significant differences in the neuromotor response to music. The findings from this study answered this by demonstrating a significant main effect for the musical stimulus ($p < .001$), indicating that the presence of music increases physical output regardless of musicality. Although the interaction effect did not reach statistical significance, exploratory analyses showed notable differences in the magnitude of the improvement in grip strength between the two cohorts. Specifically, in terms of effect size, musicians' grip strength was substantially larger than nonmusicans' (2.01 vs. 0.78). This finding is exploratory and should be interpreted judiciously. Nevertheless, a Cohen's d greater than 2.0 is remarkably rare in behavioral physics; it indicates that the average musician's grip strength shifted upward by two full standard deviations under the musical stimulus. If confirmed in larger studies, this difference in effect sizes suggests that while music may benefit nonmusicians, the magnitude of effect in performance improvement is substantially increased in individuals with formal musical training.

Although the interaction was not statistically significant, the exploratory analyses pointed to several plausible hypotheses that may explain the observed differences between musicians and nonmusicians. As speculated by Ballman et al., two possible mechanisms that music could use to improve performance, being dissociation and performance-arousal optimization (Ballmann et al., 2021). Because my study did not directly measure perceived exertion, neural activity, or physiological arousal, the mechanisms below are discussed in the context of possible explanation and should be interpreted as such.

1. **DISSOCIATION**

One of the possible mechanisms by which grip strength could improve when listening to preferred music is through dissociation or distraction during exercise. A multitude of studies have presented data that corroborates lower perceived exertion (RPE) or improved emotional perception of exercise (Ballmann et al., 2019; Ballmann et al., 2021; Ballmann et al., 2020; Drylund et al., 2008; Karow et al., 2020; Nakamura et al., 2010; Silva et al., 2021). The lower perceived exertion and improved emotional feelings during physical activity may indicate the “bottleneck hypothesis of sensory input whereby only a finite amount of sensory information can reach the central nervous system at one point in time” (Ballmann, 2021). Music is also an exceptional psychological stimulant, achieving significant widespread activations of the brain (Zaatar et al., 2023). As a result, music may fill up this finite amount of sensory input and distract the brain from the physically demanding task.

My study’s findings corroborate this, showing the improvements in grip strength across each cohort in both the main effect of the ANOVA and the individual exploratory t-tests. These results may be related to the dissociation from fatigue, resulting in better performance. The different effect sizes in the t-tests between musicians and nonmusicians may be due to heightened sensitivity of musicians to changes in music compared to nonmusicians (Agres et al., 2022; Liang et al., 2016). Musicians are trained to listen critically to multiple layers of music at once (e.g., tracking melody, harmony, and rhythm simultaneously), their auditory processing workload is naturally much higher than a nonmusician's. Musical training may cause their sensory bandwidth to be more quickly and fully overloaded by musical stimuli because of the increased neural input taken by the more auditorily sensitive musicians. Following the bottleneck hypothesis, musicians could experience larger dissociation or distractions from fatigue/discomfort. Consequently, musicians may experience greater dissociation from fatigue than nonmusicians, potentially contributing to the larger observed effect size observed in the exploratory analyses. Future studies could be designed to investigate this mechanism specifically as it is beyond the scope of my study.

2. OPTIMIZATION OF AROUSAL AND PERFORMANCE

A second possible explanation is optimization of arousal during physically intensive tasks. As proposed by Stennett (1957), performance and neural arousal have an inverted U-shaped bell curve, where either too much arousal or too little arousal could cause declines in performance. Stennett posited that there may exist some point of arousal where performance is optimized. Coupling this with evidence supporting the arousing properties of music and improving performance, the neural response to preferential music may be able to target this point of peak performance (Ballmann, 2021; Silva et al., 2021; Zaatar et al., 2023). Preferred music may also be one of the reasons by which it can more accurately focus on this point of optimal performance, as the addition of preference plays a key role in the response to music (Karow et al., 2020; Silva et al. 2021). Through subjective selection of the musical stimuli, individuals may be able to target this point of performance.

The differences in the musician vs. nonmusician cohorts could support this point. As previously established, musicians have demonstrated a more acute analytical ability when listening to music (Agres et al. 2022; Liang et al., 2016). One possible explanation is that the musicians' enhanced auditory processing associated with musical training may interact with motor performance (e.g., grip strength). As such, the differences between the musician and nonmusician cohorts shown by the exploratory tests are feasible. The greater neuromuscular connectivity could work in conjunction with the optimization of arousal and performance, where the peak of the optimization curve may be raised due to improved neuromotor connection by virtue of musical experience. As a result, the optimization of performance may yield even greater results for musicians compared to nonmusicians, as shown in my study. Although this mechanism is plausible and consistent with current theories of music and performance, physiological metrics (e.g., heart rate or neural activity) were not measured in my study. As a result, arousal optimization should be regarded as a hypothesized mechanism to explain the observed results.

3. IMPLICATIONS

While the proposed mechanisms are largely speculative, the research question of this experiment addresses a current gap in the literature. Findings from my study further contribute to the body of literature investigating whether music could be used as a non-invasive intervention or approach capable of improving physical performance. If my study's findings are replicated in future studies with sufficient power, they may have implications for tailored music-based interventions in various environments or populations like rehabilitation settings or advancing healthy aging for the elderly. Other extended implications, if mechanisms are elucidated, could be in the clinical setting whereby medical practitioners who could potentially prescribe music-centric treatments for neural degeneration found with natural aging, dementia, stroke, and Parkinson's disease. Already, pilot studies like Toma et al. (2025) have demonstrated the ability of tailored musical treatment methods like Pattern Sensory Enhancement (PSE) techniques in combating neuromotor decline through grip strength improvement.

LIMITATIONS, CONCLUSIONS, AND FUTURE RESEARCH

Current scholarship has suggested that musicians are more sensitive to musical stimuli, but hasn't examined whether or not they demonstrate differences in physiologic response to music. My research demonstrates that preferred music improves grip strengths across musician and nonmusician cohorts. Although exploratory analyses suggested grip improvements were stronger in musicians than nonmusicians, the primary analyses showed that the difference was not statistically significant.

The interpretation of this study, however, should be considered within the context of the study's limitations. The study's findings are limited to high schoolers and amateur musicians and cannot be generalized to other populations (e.g., adults or professional musicians). Moreover, while it is unlikely that there is a gender difference, the study's participants were mainly male. The participants' musical experience was relatively limited (average of 10.7 years). The observed effect size may be weakened due to their lower experience with music, as more experienced musicians demonstrate a higher sensitivity to auditory stimuli (Agres et al., 2022). Accordingly, professional musicians with extensive musical training and consistent involvement may respond even more powerfully to musical stimulus. Thus, the findings of this study may not be fully indicative of the scope to which musicianship could impact the physiological response to music. Future investigations should use a cohort of musicians with greater experience and involvement in music.

Furthermore, past research has shown that the impacts of music as an ergogenic stimuli can be linked to the gender of the individuals listening to the stimuli. Cole & Maeda (2015) determined that females (opposed to males) experienced a greater impact as a result of the musical stimuli in terms of running distance. Similarly, Rasteiro et al. (2020) conducted another study using variable running distances and observed results where females experienced a more pronounced improvement in heart rate, RPE, and time before exhaustion as a result of preferred music stimuli. Likewise, other studies have demonstrated that females exhibit a greater neural response to music compared to males (Carlson et al., 2015). My study's participants are predominantly male (90% male), and did not consider these gender differences. Therefore, the impacts of the musical stimuli on both cohorts may be underrepresented, as females have been shown to exhibit a more powerful response to music. Future research should investigate how sex may influence the impact of music on the strength of the neuromotor response to music.

This study did not investigate the effect of nonpreferred music. Previous research has observed no statistical difference between nonpreferred music stimuli and no music. noting that preferred musical stimuli shifts focus to external information, causing distraction from fatigue, while nonpreferred music does not (Archana et al., 2016; Ballmann et al., 2021; Cole et al., 2015; Dyrlund et al., 2008; Gfeller, 1988; Hayakawa et al., 2000; Karow et al., 2020; Nakamura et al., 2010). The lack of review concerning preference may limit the findings of this study by excluding nonpreferred auditory stimuli. While possibly not to the scale of preferred music, nonpreferred musical stimuli could still have a significant effect, and is worth considering for future study.

Moreover, this study did not measure the RPE, emotional perceptions (like motivation), or physiologic metrics (e.g., heart rate or neural activity) of each individual performing the tasks. As such, it is difficult to establish evidence supporting the mechanistic reasons behind the observed results. Motivation and RPE are also key variables to consider, as studies like Ballmann et al. (2021) have noted that “motivation from music may be a key mechanism” for improved performance. Future research should consider conducting trials with nonpreferred musical stimuli and record the RPE, emotional variables, and physiologic metrics of individuals within each trial to see how differences in these factors impact performance.

The study is limited by small sample size. Although the difference in the cohorts’ strength improvements were notable, the sample size (N= 10) may have limited the primary omnibus ANOVA from reaching statistically significant for interaction even if one exists. The decoupled effect sizes (0.78 vs. 2.01), nevertheless, still point towards a compelling trend: musical experience may have the capability to modulate the response to music, a phenomenon that warrants further investigation with a larger sample size. Power calculations indicate that expanding the sample size to at least 20 participants per group would provide statistical power to test for the interaction effect.

In summary, this study confirmed that preferred music improves grip strength, consistent with existing evidence of the physical benefit associated with music. While the results showed improved grip strength for both musicians and nonmusicians, the stronger effect size observed, while insignificant, for musicians is suggestive and warrants further investigations. Moreover, it is biologically plausible that musical training may influence stronger responsiveness to preferred music through several mechanisms such as sensory dissociation or arousal optimization. Future studies with larger sample size and direct measurement of neural activity may yield more conclusive findings.

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Appendix A

Questionnaire prior to actual data collection:

Do you identify as a musician (someone who recieves formal training for an instrument and regularly practices said insttrument). *

- Yes, I am a musician
- No, I am not a musician

What is your Gender (Optional)

- Male
- Female
- Other:

How old are you? (Optional)

Short answer text

Please name an exericise song (high energy song) you really enjoy and would like to listen to while you perform the grip strength testing. This song will be used while you perform the grip strength testing. *

Short answer text

What would you rate your enjoyment of this song on a scale of 1-10 *

1 2 3 4 5 6 7 8 9 10

Appendix B

Consent form:

Consent to Participate in an AP Research Study

Title of Study: The presence of music and its effect on neuromuscular performance.

Student Investigator: Student X **Cell:** 240-665-2100

Name:

Introduction

- You are being asked to participate in an AP Research study on the effects of music on neuromuscular performance measured in grip strength
- You were selected as a possible participant because you are either a musically active individual or a nonmusically active individual that is comparable to a musically active group.
- Please read this form and ask any questions that you may have before you participate in this study.

Purpose of Study

- The purpose of this study is to determine whether music has a quantifiable effect on neuromuscular performance (measured in a metric of grip strength).
- The key research question is: To what extent do neurological activations caused by classical music impact the neuromuscular performance in a metric of grip strength [using a grip strength dynamometer] of normal individuals versus musically trained individuals.
- Value/Significance of the study is to address the gap in scholarly research concerning the physical effects of music. While studies like those conducted by Toma et al. have taken some measures to address this in individuals with neuromotor deficient conditions, the results have not been generalizable to other populations. Our findings could potentially help patients in developing different less intrusive means of aiding patients recovering from muscular atrophy or other muscular deficiencies (not in relation neurologically).
- By looking into the different factors, we will be able to understand the potential benefits that music can have beyond vulnerable populations.

Description of the Study Procedures

- If you decide to participate in this study, you will be asked to do the following:
  - Take a survey that will identify themselves as musicians or nonmusicians as well as a few physical characteristics.
  - Possibly participate in a focus group to test grip strength with and without the presence of music.

Risks/Discomforts of Being in this Study

- There are no evident risks/discomforts related to participating in this study. However, if at any point in the research the participants feel as if their privacy is being violated they can stop the study immediately.

Benefits of Being in the Study

- There are no expected benefits to participants.

Confidentiality

- The records of this study will be kept strictly confidential. Research records/electronic information will be secured using a password protected file. I will not include any information in any report I may publish that would make it possible to identify you
- The Google form will not ask the participant for any identifying/potentially harmful information, including their name or school ID number. The only personal information asked by the form (and is not required) is their status as a musician, age, and gender
- Once the study is complete, survey responses will be deleted. Consent forms will be shredded.

Payments/Benefits

- Participants will receive no payment.

Right to Refuse or Withdraw

- The decision to participate in this study is entirely up to you. You are welcome to observe/view the interview/survey if you wish. You may refuse to take part in the study *at any time* without affecting your relationship with the investigators of this study or Highschool X or losing benefits to which you are otherwise entitled. You have the right not to answer any single question, as well as to withdraw completely from the interview/survey at any point during the process; additionally, you have the right to request the interview/survey material not be used in the study.

Right to Ask Questions and Report Concerns

- You have the right to ask questions about this research study and to have those questions answered by me before, during or after the research. If you have any further questions about the study, at any time feel free to contact me, student X, at …@gmail.com. If you like, a summary of the results of the study will be sent to you. If you have any other concerns about your rights as a research participant that have not been answered by the investigators, you may contact Michelle Hanson, AP Research Instructor and Coordinator of the Humanities & Arts Signature Program at Michelle_A_Hanson@mcpsmd.org.
- If you have any problems or concerns that occur as a result of your participation, you can report them to Michelle Hanson at the email above.

Consent

Your signature below indicates that you have decided to participate as a research subject for this study, and that you have read and understood the information provided above.

Parent/Guardian Phone Number: ________________________

Signature of Investigator:____________________________________ Date: _______