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Behavioural and Neural Differences in Cognitive Abilities Between Musicians and Non-Musicians

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ABSTRACT

Musicians are believed to have enhanced cognitive abilities such as working memory and creativity compared to nonmusicians, due to the skills needed to play music. Research has shown that musicians tend to be more open and extroverted and possess slight differences in brain structure compared to non-musicians. This is not just limited to musicians and nonmusicians, but musicians of different genres have also been seen to have differences. For example, due to its improvisational nature, jazz musicians tend to have a larger working memory capacity compared to classical musicians. These differences can be due to a number of factors: predisposition leading them to choose the specific genre, the genre's teaching style, and the genre's values. Further, benefits of playing music can be implemented into the healthcare system as music therapy. Research has demonstrated positive effects of music as a therapy as an adjunct treatment for individuals suffering from Attention-Deficit Hyperactivity Disorder, Dyslexia, and Autism Spectrum Disorder.

Introduction

Music is prevalent in almost every culture and society around the world.[1] It has the ability to alter one's mood, change perceptions, and inspire change. As of 2023, only 34% of children between the ages of 5-14 received private music lessons.[2] Research has shown numerous benefits that can arise from music lessons: students' English scores have been seen to improve by 22%, 20% in mathematics, self-esteem increase by 81% and many more.[2] There have been numerous research regarding cognitive and neurological benefits that accompany musical training, however, there is little concrete evidence on the specific positive outcomes, differences between genres, and its possible implications in the healthcare system. Evidently, music training contains a multitude of benefits, especially during childhood but also across the lifespan.

This paper aims to be an accessible introduction literature review for those interested in the cognitive neuroscience underlying elements of music cognition. It will address the differences between musicians and nonmusicians, musicians of different genres (classical, jazz, and rock) as well as the implementation of music therapy for individuals with Attention-Deficit Hyperactivity Disorder (ADHD), Dyslexia, and Autism Spectrum Disorder (ASD).

On comparing musicians and nonmusicians, music has been shown to activate the broadest and most diverse networks of the brain.[3] Music can help strengthen certain neural pathways, sometimes even networks,

[1] Peralta, Lia. "Impact of Music on Society - Sociological Effects." *Save the Music Foundation*, Save The Music Foundation, 3 Nov. 2021, www.savethemusic.org/blog/how-does-music-affect-society/.
[2] Lindner, Jannik. "Must-Know Music Education Statistics [Latest Report] • Gitnux." Gitnux.org, 16 Dec. 2023, gitnux.org/music-education-statistics/. Accessed 23 Mar. 2024.
[3] Budson, Andrew. "Why Is Music Good for the Brain?" *Harvard Health Blog*, Harvard Health Publishing, 7 Oct. 2020, www.health.harvard.edu/blog/why-is-music-good-for-the-brain-2020100721062.

that otherwise might be pruned due to lack of use. Neural pruning is "the process in which the brain removes neurons and synapses that it does not need".[4] Preventing neural pruning can be beneficial as it maintains larger neural networks, potentially allowing for more complex pattern and information processing.

This paper also explores differences between musicians of different genres, especially between jazz and classical musicians. Furthermore, it explores the differences in training approaches, and how the style of music can contribute to differences in cognition and personality. For example, jazz music is known to be the genre which requires the most creativity due to its improvisational nature. Additionally, jazz musicians tend to perform for enjoyment more than classical musicians who primarily join in competitions. Moreover, from these stylistic differences, it has been hypothesised that jazz and classical musicians may differ in terms of personality and creativity due to the nature of their genre.

Differences Between Musicians and Nonmusicians

There is a belief that the brains of musicians differ from that of nonmusicians. Whether it be singing or playing an instrument, trained musicians require the culmination of a myriad of skills that nonmusicians might not possess. These skills include acute hearing (the ability of musicians to discriminate properties of sound such as timbre and pitch), a well-developed sense of timing, rhythm and dynamics, and the capability to perform small, precise muscular movements. This topic is well-researched, with the literature in this field being very scattered in terms of subjects, materials, and concentrated sub-topics. Music is believed to have an effect on cognitive skills and general physiological differences in the brain. This review is an attempt to study these domains by discussing behavioural studies underlying cognitive abilities and their neural underpinnings.

Behaviourally, the cognitive domains of creativity, working memory and personality traits have been explored. The realm of music cognition has also been delved into with a focus on music processing, sound processing and pitch discrimination. Neuroscientifically, the grey matter, white matter, corpus callosum, motor cortex, and cerebellum have been explored. Grey matter represents an increase in neuronal cell bodies, dendrites, and synapses. Conversely, white matter is comprised of communication pathways that transmit electrical signals. The corpus callosum is a region of the brain formed from neural pathways across the two hemispheres, which is specific to abilities like music processing which encompasses numerous brain structures instead of one concentrated area. The motor cortex and cerebellum are both activated in the process of playing music. These are not the only regions implicated in music cognition, but these are the most relevant to this literature review. Other regions which are commonly studied in this realm are the amygdala, hippocampus and nucleus accumbens. These brain regions have not been explored in this current review.

Behavioural Studies

Creativity/ Working Memory

Working memory holds limited information to be used within a short amount of time. It is believed that musicians have an enhanced working memory capacity (WMC) due to its repeated usage within musical practices.[5] More specifically, jazz musicians are believed to have better working memory as the practice of jazz requires improvisation. Improvisation is when musicians are given the chords of a piece (often on an instrumental lead sheet) and would have to come up with their own melody and play it immediately on the spot. This tends to lead to enhanced working memory as musicians need to process numerous pieces of information at once: the

[4] Rowden, Adam. "What Is Synaptic Pruning?" *Www.medicalnewstoday.com*, 26 July 2023, www.medicalnewstoday.com/articles/synaptic-pruning. Accessed 23 Mar. 2024.

[5] Nichols, B. E., Wöllner, C., & Halpern, A. R. (2018). Score one for jazz: Working memory in jazz and classical musicians. Psychomusicology: Music, Mind, and Brain, 28(2), 101.

chord changes, the key signature of the chords (which notes fit with the chord), while also coming up with the improvised melody. Therefore, there has been research conducted with regards to whether working memory is truly increased following repeated jazz improvisations, and whether the creativity of the improvisations have a correlation with the musician's practice hours.

In a recent study, the relationship between domain-general cognitive and creative skills was explored in the context of jazz improvisation.[6] This study had a sample size of ten male undergraduate jazz students, of which eight were performance majors and two education majors. The participants were first instructed to improvise using an instrumental lead sheet from 'I Hear a Rhapsody'. This improvisation was recorded and shown to three associate professors of jazz studies to score the participants' improvisational creativity on a 7-point scale. Following this improvisation, the participants were given a 3-minute divergent thinking task to complete measuring verbal creativity, which is believed to be able to predict real-world creative achievements. The task included having the participants generate unusual uses for everyday objects, of which they were scored on a scale of 1 (not at all creative) to 5 (very creative), scoring the novelty, remoteness and cleverness of their answers. Additionally, the participants were given three fluid intelligence (Gf) tests that assessed inductive reasoning. These tasks were given to assist in quantifying the participants' intelligence and creativity. Furthermore, the participants were given two WMC measures: operation span and symmetry span. Both of these tasks were conducted to measure the participants' ability to hold onto information that was to be recalled. Lastly, they were given two questionnaires to assess their musical history and improvisation beliefs.

From these studies, researchers found that there was a strong positive correlation between practice hours and improvisation quality. Moreover, verbal creativity was found to highly correlate with improvisational creativity. On the other hand, Gf tests and WMC were negatively associated with improvisation quality. This finding challenged the assumption that musicians have a larger WMC compared to nonmusicians and indicates that further research must be conducted regarding this topic. To conclude, this study contributed to a deeper understanding of the cognitive underpinnings of musical creativity, emphasising the importance of broader cognitive functions in the improvisational process.

Personality Traits

Personality, and social abilities as a whole, is a less researched avenue when it comes to differences in musicians and nonmusicians. It is believed that due to the performance nature of playing music, musicians are generally more confident and extroverted, as they would have to be more accustomed to being on stage. Furthermore, due to the vast stylistic differences between genres, it can also be assumed that musicians would tend to be more open-minded as it is encouraged in music to experiment with different styles, composers, and occasionally instruments.

In a recent paper, the researchers explored the possible personality differences in musicians and nonmusicians.[7] Similar to prior beliefs, they expected to see differences in openness, extraversion, conscientiousness and neuroticism. Openness describes one's willingness to try new things and their ability to engage in imaginative and intellectual activities. Extraversion refers to one's preference to being outgoing, thriving in social situations compared with preferring to keep to themself. Conscientiousness describes people who are organised, disciplined, and detail-oriented. Finally, neuroticism describes the overall emotional stability of an

[6] Beaty, R. E., Smeekens, B. A., Silvia, P. J., Hodges, D. A., & Kane, M. J. (2013). A first look at the role of domain-general cognitive and creative abilities in jazz improvisation. Psychomusicology: Music, Mind, and Brain, 23(4), 262.

[7] Gjermunds, N., Brechan, I., Johnsen, S. Å. K., Watten, R. G. (2020). Personality traits in musicians. Current Issues in Personality Psychology, 8(2), 100-107. https://doi.org/10.5114/cipp.2020.97314

individual, and their likelihood to interpret an event to be threatening.[8]

From the tests conducted, the authors found that musicians tended to have higher levels of openness and lower levels of conscientiousness. Otherwise, there were no significant differences found in the other personality traits. Openness stands out as the most typical personality trait for musicians. This can be due to the fact that performing and composing music requires key elements of openness such as cognitive engagement and exploration, perceptual integration, creative phantasy, and a refined sense of aesthetics. The lower levels of conscientiousness was unexpected as musicians are typically expected to be disciplined, perceived by the endless hours of practice they go through to perfect their craft. In addition, musicians tend to be detail-oriented, as they are known to carefully focus their attention on technique and phrasing along with emoting differently across different pieces. Therefore, more research should be done on musicians' personality traits compared to nonmusicians as this was the only paper found and offered only one perspective of this topic.

Musical Cognition

Musical cognition refers to the cognitive processes that are undergone when individuals play, write, or listen to music. This includes sound processing, music processing, and pitch discrimination. Alongside this, the short-term and long-term side effects of exposure to music have also been studied.

Sound Processing

Musicians have been seen to possess a highly sophisticated auditory system, exhibiting a more advanced ability to encode and categorise intensity and location of sound information.[9,10] This enhanced ability is likely due to their larger exposure of sound information from practising to simply listening to music. Musicians also displayed better pre-attentive auditory processing (the ability to extract more information out of musically relevant stimuli). These differences are likely due to the musicians' ability to process at higher cognitive levels.[11] This reflects their ability to differentiate acute differences in sound, and notice features such as 'emotion' in music that nonmusicians are less likely to discern. A recent study has found that musicians also exhibited higher responses in the primary auditory cortex which were 102% larger than that of nonmusicians.[12] This links with some neuroscientific studies that will be discussed later in this paper.

Music Processing

A recent study showed that musicians possess strong and efficient associations and interactions between their auditory and motor systems.[13] Musicians tend to be faster than nonmusicians in detecting harmonic, rhythmic

[8] Lim, Annabelle G.Y. "Big Five Personality Traits: The 5-Factor Model of Personality." Simply Psychology, 18 Oct. 2023, www.simplypsychology.org/big-five-personality.html.
[9] Brattico E, Pallesen KJ, Varyagina O, et al: Neural discrimination of nonprototypical chords in music experts and laymen: an MEG study. J Cogn Neurosci 2009;21(11):2230-2244.
[10] Tervaniemi M, Castaneda A, Knoll M, Uther M: Sound processing in amateur musicians and nonmusicians: event-related potential and behavioral indices. NeuroReport 2006;17(11):1225-1228.
[11] Nager W, Kohlmetz C, Altenmüller E, et al: The fate of sounds in conductors' brains: an ERP study. Brain Res Cogn Brain Res 2003; 17(1):83-93.
[12] Münte T, Nager W, Beiss T, et al: Specialization of the specialized: electrophysiological investigations in professional musicians. Ann NY Acad Sci 2003;999:131-139.
[13] Hoppel L, Spruit B: The musical brain: from finger tapping to musical hallucinations. In: Proceedings of April 2008 Cognitive Neuroscience Conference. Leiden, Univ of Leiden, 2008.

and melodic incongruities through the mismatch negativity (MMN) evaluation.[14] MMN is a response to dissonance or mistuned sounds, when the brain has an automatic response that occurs when it detects a deviation or unexpected stimulus amongst a series of repetitive stimuli. This is an expected occurrence, as musicians are believed to have more distinction in terms of pitch to differentiate harmonious and dissonant notes. Additionally, listening to music caused a high degree of electroencephalographic (EEG) phase synchronisation within the gamma frequency range of musicians, distributed across the brain. The brain's electrical activity can be split up into different frequencies, of which gamma band frequencies are associated with higher-level cognitive processes. These processes include attention, memory and perception. Nonmusicians did not demonstrate this same effect, the difference likely due to the musicians' stronger ability in acoustic memory retrieval.[15] Acoustic memory retrieval is the process of recalling or retrieving information from encoded memory that is in the form of sound.

Pitch

Numerous studies have investigated the differences in pitch perception between musicians and nonmusicians. In terms of detecting musical intervals, musicians perform better in tone identification and discrimination as they possess a more acute frequency discrimination threshold. It is believed that these differences are a result of musicians relying on working-memory-based pitch processing compared to nonmusicians.[16] Musicians are faster and more accurate in detecting changes in pitch and the latency for MMN, suggesting that musicians' auditory systems react faster.[17] There have also been pitch function differences in specific brain regions. In a pitch memory task, musicians rely more on the right posterior temporal and supramarginal gyrus, while nonmusicians rely more on the right primary and left secondary auditory cortex.[18] These differences could be because musicians tend to use brain regions specialised in short-term memory and recall.

Exposure to Music and Its Nonmusical Side Effects

Most studies on the differences between musicians and nonmusicians place a focus on playing music and musical training. However, it is believed that even exposure to music has beneficial nonmusical side effects. A recent study explored the short-term and long-term benefits of being exposed to music.[19]

Short-Term Side Effects - The Mozart Effect

The main debate surrounding exposure to music's short term benefits revolve around the Mozart effect. The Mozart effect was named following a recent study, reporting that brief exposure (10 minutes) to a Mozart sonata generates short term increases in spatial-reasoning abilities.[20] This study had three different conditions: the first

[14] Besson M, Faïta F, Requin J: Brain waves associated with musical incongruities differ for musicians and non-musicians. Neurosci Lett 1994;168(1-2):101-105.
[15] Bhattacharya J, Petsche H: Musicians and the gamma band: a secret affair? NeuroReport 2001;12(2):371-374
[16] Koelsch S, Fritz T, Schulze K, et al: Adults and children processing music: an fMRI study. Neuroimage 2005;25(4):1068-1076.
[17] Tervaniemi M, Just V, Koelsch S, et al: Pitch discrimination accuracy in musicians vs. nonmusicians: an event-related potential and behavioral study. Exp Brain Res 2005;161(1):1-10.
[18] Gaab N, Schlaug G: Musicians differ from nonmusicians in brain activation despite performance matching. Ann NY Acad Sci 2003;999: 385-388
[19] Peretz, I., & Zatorre, R. J. (Eds.). (2003). The cognitive neuroscience of music. OUP Oxford.
[20] Nantais, K. M., & Schellenberg, E. G. (1999). The Mozart effect: An artifact of preference. Psychological science, 10(4), 370-373.

condition included listening to a Mozart sonata before completing three tests of spatial abilities. The participants in the other two conditions listened to either a relaxation tape or sat in silence. The researchers found that the group who listened to a Mozart sonata had an intelligence quotient (IQ) score improvement of approximately eight points, with the widely-established conclusion being that 'music makes you smarter'.

Upon closer examination of the findings, the validity of the authors' conclusion has been questioned. The choice of the opposing conditions were problematic as they did not provide a fair comparison between music being the factor that influenced the IQ increase. Sitting in silence or listening to a relaxation tape for 10 minutes is inherently less arousing to the brain compared to listening to Mozart. This is an issue as mood-states are known to influence performance on problem-solving tasks. Therefore, the effect could have arisen due to the arousal induced from listening to Mozart rather than the music itself. Nonetheless, this study can still conclude that listening to music helps with problem solving tasks as it can induce arousal.

Long-Term Side Effects

Several studies have examined whether musical ability, as compared to musical training, has a correlation with other ability domains. A positive association would imply that improving one's musical ability through formal training would be accompanied by nonmusical benefits. Concluding from a number of studies, it was found that musical aptitude was able to predict childrens' ability to interpret and produce symbolic representations of music. Alongside this, improvements in reading abilities, verbal and visual memory abilities, and general intelligence have been found.

Neuroscientific Studies

It is believed that the brain's anatomy and physiology changes after engaging in musical training. This is attributed to the brain's plastic nature, and is more prevalent in individuals who start training young as the brain is more plastic during childhood. A variety of brain structures are studied in the context of music cognition. However, for this literature review; grey matter, white matter, the corpus callosum, the motor cortex, and the cerebellum were studied specifically.

Basic Differences

To determine the precise size and shape differences in the participants' various brain structures, the researchers used voxel-based morphometry (VBM) which is a magnetic resonance imaging (MRI)-based method involving normalising all images into the same anatomical space, extracting the grey matter from the images, and analysing group differences in local concentration of grey matter. In general, the left cerebral hemisphere of nonmusicians tended to be larger than the right, with this asymmetry more significant in nonmusicians. Musicians with as little as 15 months of training displayed a larger right precentral gyrus (the motor hand area), corpus callosum and right Heschl's gyrus (the primary auditory area).[21]

Grey Matter

Grey (cortical) matter in the cerebral and cerebellar hemispheres mainly contain neuron bodies and synapses. Professional musicians showed higher grey matter concentrations compared to nonmusicians in the perirolandic region, the premotor region, the posterior superior parietal region, the posterior mesial perisylvian region bilaterally, and the cerebellum.[22] An example of grey matter differences is in pianists, who have an increased density

[21] Hyde KL, Lerch J, Norton A, et al: The effects of musical training on structural brain development: a longitudinal study. Ann NY Acad Sci 2009;1169:182-186

[22] Peretz, I., & Zatorre, R. J. (Eds.). (2003). The cognitive neuroscience of music. OUP Oxford.

of grey matter in their left primary sensorimotor cortex compared to nonmusicians.[23] A recent study depicted that male orchestral musicians exhibited an increased grey matter density in Broca's area.[24] The musicians demonstrated a positive correlation between their years of musical training and the volume of grey matter in these local areas.

White Matter

White matter, compared to grey matter, contains a few nerve cell bodies and is primarily composed of deep nerve tract fibres, connecting different brain regions. Numerous studies have measured fractional anisotropy (FA) in a variety of brain areas. These studies measured the directional organisation of the brain, greatly influenced by the magnitude and orientation of white matter tracts. It was found that musicians, due to their training, have less FA in the corona radiata and internal capsule bilaterally, and the genu of the corpus callosum and corticospinal tract bilaterally.[25,26] The reduced FA values in the corona radiata suggests greater neural connectivity and less restriction of water diffusion within these pathways. The lower FA values in the genus of the corpus callosum can indicate potential differences in connectivity between the musicians' left and right hemispheres. Lastly, the corticospinal tract is responsible for transmission of motor signals between the brain and the spinal cord. Musicians exhibited lower FA in this region bilaterally, suggesting possible differences in motor-related neural connectivity.

Corpus Callosum

Evidence has shown that the corpus callosum structurally matures during late childhood and early adolescence. From a comparison of 30 professional musicians to their nonmusician control counterparts, it was found that the anterior half of the corpus callosum was significantly larger in musicians, especially in those that started musical education early (<7 years old). This can be seen in figure 1.

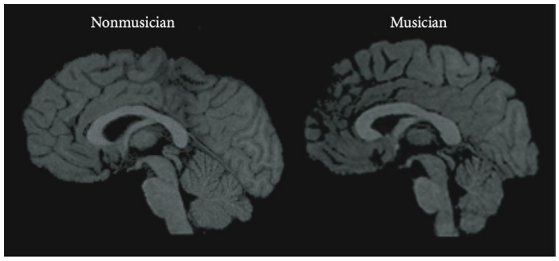

Figure 1. Two MRI scans showing the mid-sagittal area of the corpus callosum in a musician and a nonmusician.[27]

Notably, the corpus callosum is seen to be larger in musicians compared to nonmusicians. The difference in callosal size can be attributed to more fibres crossing through the corpus callosum, larger number of

[23] Han Y, Yang H, Lv YT, et al: Gray matter density and white matter integrity in pianists' brain: a combined structural and diffusion tensor MRI study. Neurosci Lett 2009;459(1):3-6.
[24] Sluming V, Barrick T, Howard M, et al: Voxel-based morphometry reveals increased gray matter density in Broca's area in male symphony orchestra members. Neuroimage 2002;17(3):1613-1622.
[25] Schmithorst VJ, Wilke M: Differences in white matter architecture between musicians and non-musicians: a diffusion tensor imaging study. Neurosci Lett 2002;321(1-2):57-60.
[26] Imfeld A, Oechslin MS, Meyer M, et al: White matter plasticity in the corticospinal tract of musicians: a diffusion tensor imaging study. Neuroimage 2009;46(3):600-607.
[27] Peretz, I., & Zatorre, R. J. (Eds.). (2003). The cognitive neuroscience of music. OUP Oxford.

thicker myelinated fibres with faster interhemispheric transfer, or fibres with thicker axons or more axon collaterals. The anterior region of the corpus callosum mainly contains fibres from frontal motor related regions and prefrontal regions. The anatomical difference in anterior callosal size can be due to the requirement for increased inter-hemispheric communication promoting complex bimanual motor sequences needed in musicians. This structural difference could have been triggered by continuous practice of complicated and independent bimanual finger movements. The benefits associated with these structural differences include enhanced motor skills, improved interhemispheric connectivity, increased neural efficiency, and greater cognitive abilities.

Motor Cortex

A histological analysis of the motor cortex can not be done using the MRI scans. Therefore, a gross anatomical marker of the motor cortex was used: the intra-sulcal length of the posterior bank of the precentral gyrus (ILPG). Results revealed a greater symmetry in the ILPG of the musician group in a dorsal subregion of the motor cortex. In addition to greater symmetry, both the left and right hemisphere of this region was larger in musicians compared to nonmusicians. Additionally, there was also a strong positive correlation found between the age of musical training commencement and the mean ILPG size in both hemispheres.

Cerebellum

Table 1. Absolute brain volume and absolute and relative cerebellar volume in musicians and nonmusicians.[28]

Group	Brain volume (cc)	Rel. cerebellar volume (%)	Abs. cerebellar volume (%)
Musicians (males; n = 30)	1412.0 (84.5)	10.4 (0.7)*	146.2 (9.3)
Nonmusicians (males; n = 30)	1405.2 (120.0)	9.9 (0.7)*	139.9 (14.4)
Musicians (females; n = 26)	1308.4 (92.3)	10.5 (0.6)+	136.7 (9.6)
Nonmusicians (females; n = 26)	1266.6 (76.7)	10.6 (0.7)+	134.8 (11.4)

The cerebellum plays a role in movement coordination and timing of sequential movements, suggesting a correlation between its size and musical training. An analysis of MRI scans done on 56 classically trained professional musicians compared to their matched non-musician counterparts was carried out. To compensate for the high inter-subject variability in cerebellar volume, the relative cerebellar volume (the percentage of it compared to the total brain volume) instead of absolute cerebellar volume was used. Male musicians had a significantly higher mean relative cerebellar volume compared to male non-musicians. In comparison, there was no significant difference in total brain volume in males. On the other hand, there were no significant cerebellar size differences found in females. However, female musicians tended towards a higher absolute brain volume (Table 1.)

The absence of observable difference in the female subgroup's cerebellar size can be due to a few reasons. Firstly, females tend to reach adult cerebellar size much earlier than males do during development. Secondly, the relative cerebellar volume of females is larger than that of males, suggesting that a ceiling effect (when participants' results approach the upper limit of the scale being measured) might have been reached. Thirdly, synaptic up-and-down regulation during the menstrual cycle could have diminished a group difference.

[28] Peretz, I., & Zatorre, R. J. (Eds.). (2003). The cognitive neuroscience of music. OUP Oxford.

Lastly, there was a trend in total brain volume differences in the female subgroups, suggesting that other brain regions apart from the cerebellum might show structural differences. This could indicate gender specific differences in presumed structural plasticity.

Differences Between Musicians of Different Genres (Jazz/Classical/Rock)

Behavioural

Working Memory

A recent study investigated the difference in working memory capacities between jazz and classical musicians.[29] Standardised working memory tests were employed to assess the participants' abilities to retain and manipulate musical information in their minds. Musical stimuli that were representative of both jazz and classical genres were used to evaluate the musicians' responses to genre-specific cognitive demands. The researchers found that there was a significant difference in the working memory capacity between jazz and classical musicians.

Jazz musicians demonstrated a higher level of proficiency in working memory tasks, particularly those related to improvisation and real-time cognitive processing. This suggests that the nature of jazz, which often involves spontaneous improvisation and quick decision-making, may contribute to the development of enhanced working memory skills in jazz musicians. In contrast, classical musicians, while excelling in tasks requiring precision and adherence to pre-established scores, exhibited slightly lower performance in tasks demanding improvisational thinking.

In conclusion, the findings of this study highlighted the influence of musical genre on the development of working memory skills in musicians. Jazz musicians, with their emphasis on improvisation, show superior working memory abilities compared to their classical counterparts. This implies that the cognitive demands inherent in different musical genres can shape and enhance specific cognitive functions. The study underscores the importance of considering genre-specific cognitive skills in understanding the diverse cognitive profiles of musicians. Furthermore, these results contribute to a broader understanding of the cognitive processes involved in musical performance, with potential implications for music education and cognitive neuroscience research.

Personality Traits

In addition to personality trait differences between musicians and non-musicians, research has shown that there are personality variations between musicians of different genres as well. For example, jazz musicians are presumed to be more creative as jazz music requires a high degree of improvisational playing whilst classical musicians are presumed to be more disciplined and strict as their genre focuses more on technique.[30] These differences can be seen in the values they focus on within the genre, the style of music training and simply the genre itself.

Classical musicians tend to receive musical training in a one-on-one, formal education setting, typically practising on their own whereas jazz musicians devote more time to extracurricular activities, typically playing music in groups compared to individually.[31] Furthermore, classical musicians place more importance

[29] Nichols, B. E., Wöllner, C., & Halpern, A. R. (2018). Score one for jazz: Working memory in jazz and classical musicians. Psychomusicology: Music, Mind, and Brain, 28(2), 101.

[30] Barrett, F. J. (1998). Creativity and improvisation in Jazz and organizations: Implications for organizational learning. Organizational Science, 9, 605–622.

[31] Welch, G., Papageorgi, I., Haddon, E., Creech, A., Morton, F., de Bézanac, C., et al. (2008). Musical genre and gender as factors in higher education learning in music. Research Papers in Education, 23, 203–217.

on technique, sight-reading capabilities, notation and quality of tone whilst jazz musicians focus more on improvisation and memorisation.[32] A recent study has found that jazz musicians display higher motivation and pleasure from musical activities compared to classical musicians.[33] This might be due to jazz's more community-based musical setting and emphasis on creativity and experimenting with different ideas compared to classical music's more detail-oriented, perfectionist style of playing.

Not only is the method of music training and genre style different, the music 'culture' for the respective genres vary too. For example, classical musicians tend to participate in more music competitions, produce less music and perform in less music performances compared to jazz musicians.[34] This can contribute to personality differences as classical musicians generally partake in the more competitive side of music. This, alongside classical's emphasis on technique, can result in a more disciplined personality as musicians would have to train to perfect a piece to bring to competitions. This can be why they experience less pleasure from musical activities compared to jazz musicians as their aim for music practice is to compete, not to explore new styles or to experiment with different groups of people. On the other hand, jazz musicians tend to partake in more music performances compared to competitions. Classical musicians tend to view music as an individual, isolated, competitive activity while jazz musicians view it as a more of a communal event. This is proven through previous research depicting how classical musicians focus more on solo achievements, whilst jazz musicians are engaged in more informal methods such as performing in concerts.[35]

In terms of cognition, jazz musicians showed higher divergent creative thinking abilities (the capacity to generate multiple creative ideas and solutions).[36] More specifically, jazz musicians possessed greater ideational creativity - the ability to generate novel and unique ideas. This ability is highly compatible with jazz musicians' ability to creatively improvise. Additionally, jazz musicians were found to partake in more creative endeavours outside of music compared to classical musicians. It was also found that jazz musicians tended to be more open-minded compared to classical musicians.

In conclusion, this means that not only does music training have an effect on one's personality, the specific genre of music they play impacts that too. Jazz is more communal, promoting open-mindedness, creativity and collaboration while classical is more self-centred, drawing emphasis on discipline, competition and self-improvement.

Neuroscientific

Sound Processing

Musical genres differ from each other in various acoustic and musical elements, thus, it is hypothesised that musicians who predominantly play specific genres would develop a specific auditory sound encoding profile that is adapted to the genre's features. This mainly can be seen between jazz and classical musicians wherein

[32] Creech, A., Papageorgi, I., Duffy, C., Morton, F., Haddon, L., Potter, J., et al. (2008). Investigating musical performance: Commonality and diversity among classical and non-classical musicians. Music Education Research, 10, 215–234.

[33] Bézenak, C., & Swindells, R. (2009). No pain, no gain? Motivation and self-regulation in music learning. International Journal of Education & the Arts, 10(16).

[34] Benedek, M., Borovnjak, B., Neubauer, A. C., & Kruse-Weber, S. (2014). Creativity and personality in classical, jazz and folk musicians. Personality and individual differences, 63, 117-121.

[35] Creech, A., Papageorgi, I., Duffy, C., Morton, F., Haddon, L., Potter, J., et al. (2008). Investigating musical performance: Commonality and diversity among classical and non-classical musicians. Music Education Research, 10, 215–234.

[36] Webster, P. (2002). Creative thinking in music: advancing a model. In T. Sullivan & L. Willingham (Eds.), Creativity and music education (pp. 16–33). Edmonton, AB: Canadian Music Educators' Association.

jazz places importance in playing by ear while classical emphasises playing exactly as notated on sheet music.

A recent study tested the impact of low-level and high level changes between jazz, classical and rock musicians.[37] The low level changes include mistuning a note of the melody by half a semitone, deviating timbre (changing the sound from piano to flute for one note of the melody), and timing delay (adding a 100ms silent gap at a random position in the melody). The high level changes include melody modulation (changing the pitch of a tone within the melody), rhythm modulation (exchanging the duration of two adjacent notes), and transposition (shifting a note one semitone up or down). The participants sat in an electroencephalogram (EEG) during these changes, to test any changes in brain activity.

In the case of low-level changes, it was found that mistuned sounds resulted in an enhanced frontal mismatch-negativity (MMN) activation in classically trained musicians when compared to nonmusicians. It was also found that timing delays evoked larger P3a in classical and jazz musicians compared to nonmusicians. The P3a is associated with attention and cognitive processing. This can imply that classical and jazz musicians demonstrate higher attention and cognitive processing towards timing delays compared to non-musicians. Additionally, it was found that timbre deviations evoked larger P3a in jazz musicians compared to rock musicians. This can indicate that jazz musicians possess a higher sensitivity or attentional response to timbre deviations compared to rock musicians.

Furthermore, it was also found that musicians who usually do not play using sheet music were found to exhibit a facilitated MMN response when exposed to melodic stimuli compared to musicians who are reliant on sheet music. As MMN is associated with the brain's ability to process changes in sound, this suggests that musicians who typically play by ear or improvise have an enhanced sensitivity and responsiveness to changes in music compared to musicians who rely on sheet music. Additionally, jazz musicians were found to have larger MMN amplitudes compared to the musicians of other genres, exhibiting the greater sensitivity to musical changes implied from the findings between musicians who do and do not use sheet music.

Self-Taught V.S. Formally Trained Musicians

Apart from genres, musicians can also be categorised on how they studied music: self-taught (ST) or formally trained (FT). There are pre-existing assumptions that FT musicians have a more refined skill set compared to ST musicians as they would have been carefully guided on technique, how to read difficult notation, ways to overcome certain difficulties and many more that ST musicians would unlikely get. Unfortunately, there is little existing research regarding how much of a difference in ability exists between non-musicians, ST musicians, and FT musicians.

A recent study has found that FT musicians had a higher accuracy for detecting out-of-key and out-of-tune notes compared to both ST and non-musicians.[38] ST musicians performed better than non-musicians, however, their results were not as accurate as FT musicians. These differences are not due to frequency of practice, training length, or education levels as these characteristics have been matched across groups. Therefore, this suggests that ST musicians exhibit advantages over nonmusicians with regards to auditory processing tasks, however, they were still disadvantaged against FT musicians.

Implications of Music Therapy in The Healthcare System

Music therapy (MT) is an evidence-based intervention encompassing a broad range of techniques utilised in a

[37] Tervaniemi, M., Janhunen, L., Kruck, S., Putkinen, V., & Huotilainen, M. (2016). Auditory profiles of classical, jazz, and rock musicians: Genre-specific sensitivity to musical sound features. *Frontiers in psychology*, *6*, 1900.

[38] Zendel, B. R., & Alexander, E. J. (2020). Autodidacticism and music: Do self-taught musicians exhibit the same auditory processing advantages as formally trained musicians?. *Frontiers in Neuroscience*, *14*, 752.

therapist-patient relationship to promote individualised goals depending on each patient. Music therapy is not typically used on its own, but rather in conjunction with more traditional pharmaceutical treatments to enhance its effect. This review discusses music therapy's effect on dyslexia, attention-deficit hyperactivity disorder (ADHD), and autism spectrum disorder (ASD).

Dyslexia

Dyslexia is a learning disability that affects spelling and reading abilities despite regular comprehension and intelligence with its prevalence being around 3-10%.[39] Amongst a variety of languages, children with dyslexia struggle with poor phonological processing skills.[40] These phonological deficits may be due to impaired processing of formant transitions. Formant transitions are rapid changes in frequency that occur during the transition between one speech sound to another. This impairment can result in difficulties in discriminating between similar speech sounds, leading to phonological deficits, resulting in difficulties in reading and spelling.

There is not a single prevalent type of music therapy for dyslexic patients, but numerous techniques are used in combination with each other to optimise the outcome. These include rhythmic entrainment to improve timing and coordination, melodic intonation therapy to improve speech and language production, and auditory discrimination training to improve phonological awareness and reading abilities. A recent study tested the effects of auditory discrimination training on dyslexic patients.[41] It was found that musically trained children tended to perform better at i) detecting pitch and envelope changes in speech (variations in the amplitude/volume of a sound), ii) vocabulary and reading abilities, iii) segmenting a new language and iv) had an overall enhanced verbal intelligence as compared to children without musical training.

From these studies, it was concluded that musical training significantly improved reading skills among children who had dyslexia. Reading speed increased in both musically trained and untrained groups. However, only the musically trained group improved in reading accuracy. This improvement was not limited to reading text but also pseudo-word reading (the ability to read unfamiliar, made-up words that follow phonetic patterns) which is considered difficult to train and is often found to be impaired in adults who have dyslexia.[42] Therefore, music therapy has been seen to have positive effects on language learning capabilities, and more specifically in dyslexic individuals.

Attention-Deficit Hyperactivity Disorder (ADHD)

ADHD is characterised by the difficulty to pay attention, hyperactivity and impulsivity. This disorder often overlaps with other psychiatric disorders such as anxiety, depression, and learning disabilities.[43] Adolescents with ADHD are more perceptible to other psychiatric disorders due to social, family, and academic impairments

[39] Snowling MJ, Hulme C. Annual research review: the nature and classification of reading disorders—a commentary on proposals for DSM-5. J Child Psychol Psychiatry. 2012; 53(5):593–607. doi: 10.1111/j. 1469-7610.2011.02495.x PMID: 22141434

[40] Ziegler JC, Goswami U. Reading acquisition, developmental dyslexia, and skilled reading across languages: a psycholinguistic grain size theory. Psychol Bull. 2005; 131(1):3–29. PMID: 15631549

[41] Magne C, Schön D, Besson M. Musician children detect pitch violations in both music and language better than non-musician children: Behavioral and electrophysiological approaches. J Cogn Neurosci. 2006; 18(2):199–211. PMID: 16494681

[42] Martin J, Colé P, Leuwers C, Casalis S, Zorman M, Sprenger-Charolles L. Reading in French-speaking adults with dyslexia. Ann Dyslexia. 2010; 60(2):238–264. doi: 10.1007/s11881-010-0043-8 PMID: 20872102

[43] Posner J, Polanczyk GV, Sonuga-Barke E. Attention-deficit hyperactivity disorder. Lancet. 2020;395(10222):450–62.

and in other areas of life. As a result, it is crucial to implement methods to assist in relieving the strains of ADHD in order to help improve the individuals' life.[44]

Common music therapy methods for individuals with ADHD include structured music activities to improve attention and self-regulation skills, improvisational music therapy to promote self-expression and emotional regulation, attention-building techniques to foster attention span and cognitive flexibility among other techniques. Recent studies have found that the integration of improvisational music therapy resulted in a statistically significant increase in serotonin expression in the participants with ADHD.[45] Serotonin is a neurotransmitter which plays a crucial role in regulating mood. The findings from this study showed that music therapy for individuals with ADHD can help prevent the development of depression through induction of a positive effect. Physiologically, following improvisation and positive self-expression activities, ADHD individuals who partook in music therapy showed significantly lower systolic blood pressure (SBP), diastolic blood pressure (DBP), and heart rate (HR) levels. SBP refers to the pressure exerted on the arteries when the heart contracts while DBP refers to the pressure between heartbeats when the heart is at rest. Low SBP and DBP are beneficial for physiological health as it reduces the individual's risk for various health complications like cardiovascular diseases and hypotension while also enhancing brain functions by improving cerebral blood flow.

Music therapy can be beneficial in alleviating depression in individuals with ADHD, while simultaneously strengthening their ability to cope with difficulties or challenges they might face.[46] In fact, it is encouraged to implement music therapy alongside conventional pharmaceutical treatments as music therapy can help increase the effectiveness of the treatments.[47]

Autism Spectrum Disorder (ASD)

ASD encompasses a diverse group of conditions. It is often characterised by some degree of difficulty in social interactions and communication as well as atypical patterns in behaviours such as difficulty in transitioning between one task and another. Recently, advancements in music therapy have been utilised by clinicians working with ASD patients to improve many of their symptoms whilst also encouraging their fascination in music.[48] The main goals of music therapy for children with ASD is to increase eye contact, verbalisation of needs, and the ability to adapt to routine changes.

Improvisational Music Therapy (IMT) is the most common music therapy method for children with ASD. This is where the therapist and the child play tuned and untuned musical instruments to express rhythm, melodies and understand timbre. During this interaction, the therapist synchronises and communicates with the child through mirroring their musical expressions. Within studies, IMT has had positive impacts on individuals with ASD including increased levels of social engagement, longer emotional synchronicity and initiation of

[44] Bussing R, Mason DM, Bell L, Porter P, Garvan C. Adolescent outcomes of childhood attention-deficit/hyperactivity disorder in a diverse community sample. J Am Acad Child Adolesc Psychiatry. 2010;49(6):595–605.

[45] Park, J. I., Lee, I. H., Lee, S. J., Kwon, R. W., Choo, E. A., Nam, H. W., & Lee, J. B. (2023). Effects of music therapy as an alternative treatment on depression in children and adolescents with ADHD by activating serotonin and improving stress coping ability. *BMC Complementary Medicine and Therapies*, *23*(1), 1-14.

[46] Powell V, Riglin L, Hammerton G, Eyre O, Martin J, Anney R, et al. What explains the link between childhood ADHD and adolescent depression? Investigating the role of peer relationships and academic attainment. Eur Child Adolesc Psychiatry. 2020;29(11):1581–91.

[47] Posner J, Polanczyk GV, Sonuga-Barke E. Attention-deficit hyperactivity disorder. Lancet. 2020;395(10222):450–62.

[48] Reschke-Hernández, A. E. (2011). History of music therapy treatment interventions for children with autism. Journal of Music Therapy, 48(2), 169–207.

engaging behaviours.[49] Studies have also found that IMT leads to decreased stress levels, increased self-esteem, reduced anxiety, more positive reaction to peers[50], and increased verbal[51] and non-verbal communication skills. Another recent study has found that implementation of IMT over a 12-week period reported improvements in joint attention bids (the intentional action of directing someone else's attention to a specific object, event, or topic of interest; a crucial aspect for social interaction and communication), joint visual attention, and eye contact duration.[52] The study even found that emotional and responsiveness behaviours were significantly more frequent and longer than the children who were placed in the toy play condition.

Family Centred Music Therapy (FCMT) is another commonly applied therapy method, with the aim of increasing the engagement between children with ASD and their family members. This method shares the same foundations with IMT. However, FCMT just has a more family-focused centric framework. Common activities include greeting songs, specific music activities, and free explorations within the medium of music. These were chosen as they promote joint attention, group interactions, and cooperative group experiences.[53] FCMT was found to improve social interactions within the household, community and parental relationships. During numerous interviews, parents have described how FCMT has encouraged a closer connection with their child.

A recent study investigated the effectiveness of music-based intervention for ASD individuals with regards to understanding the emotions of happiness, sadness, anger, and fear.[54] The individuals were taught emotions by singing a song composed by the therapist that had lyrics which referenced the target emotion. The researchers found that the participants' emotional understanding improved between the pre-test and the post-test evaluations.

Overall, low-functioning individuals with ASD were found to have greater improvements compared to high-functioning individuals with ASD.[55] Additionally, numerous studies have also found that singing or listening to songs elicit improvements in behaviour for individuals with ASD. Therefore, it can be concluded that music therapy brings positive benefits for individuals with ASD.

A recent study investigating speech and song processing in low-functioning children with ASD found that Broca's area, a brain region typically under-activated in those with ASD, was significantly more activated during song processing, suggesting that musical stimuli can be more effective in assisting children with ASD.[56]

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[49] Vaiouli, P., Grimmet, K., & Ruich, L. J. (2015). "Bill is now singing": joint engagement and the emergence of social communication of three young children with autism. Autism, 19(1), 73–83.

[50] Hillier, A., Greher, G., Poto, N., & Dougherty, M. (2012). Positive outcomes following participation in a music intervention for adolescents and young adults on the autism spectrum. Psychology of Music, 40(2), 201–215.

[51] Ghasemtabar, S. N., Hosseini, M., Fayyaz, I., Arab, S., Naghashian, H., & Poudineh, Z. (2015). Music therapy: an effective approach in improving social skills of children with autism. Advanced biomedical research, 4.

[52] Kim, J., Wigram, T., & Gold, C. (2008). The effects of improvisational music therapy on joint attention behaviors in autistic children: A randomized controlled study. Journal of Autism and Developmental Disorders, 38(9), 1758–1766. doi:10. 1007/s10803-008-0566-6

[53] Allgood, N. (2005). Parents' perceptions of family-based group music therapy for children with autism spectrum disorders. Music therapy perspectives, 23(2), 92–99.

[54] Katagiri, J. (2009). The effect of background music and song texts on the emotional understanding of children with autism. Journal of Music Therapy, 46(1), 15–31. doi:0022-2917-46-1-15 [pii]

[55] Lim, H. A. (2010). Effect of "developmental speech and language training through music" on speech production in children with autism spectrum disorders. Journal of music therapy, 47(1), 2–26.

[56] Lai, G., Pantazatos, S. P., Schneider, H., & Hirsch, J. (2012). Neural systems for speech and song in autism. Brain, 135(3), 961–975. doi:10.1093/brain/awr335

Furthermore, structural imaging studies of the cerebellum have repeatedly depicted that autism is associated with white matter differences, abnormally lower cerebellar vermal volumes, and reduced size of cerebellar hemispheres.[57] In addition to cognition, the cerebellum has an important role in affective (emotional) responses as well as gross and fine motor skills. In light of this, attention and motor deficits in ASD can be direct indicators of cerebellar dysfunction and abnormal cortico-cerebellar connectivity. Thus, it can be deduced that music-based development training will provide positive benefits for individuals with ASD to assist in training attention and motor control as music increases synchronisation of widespread networks in the brain.

Discussion

The various studies reviewed demonstrate that music does evoke behavioural, social and psychological benefits not only in patients suffering from disorders but also in healthy individuals. This is not exclusive to just playing an instrument, or receiving music training but encompasses exposure to music as well. Musical skills have been shown to be applicable to non-musical domains as well. Due to the out-of-the-box thinking essential for composing or arranging music, musicians tend to be more creative, which is a transferable skill across domains. A gap in literature surrounds whether the personality differences found are correlation or causation. On one hand, music training might have prompted the musician to be more extraverted due to the performance nature of music. On the other hand, individuals who are more open-minded might be more inclined to pursue music training. This topic has been discussed in other studies but not in detail, and can be an interesting avenue of continued research. More research should be done to investigate whether the relationships previously found are correlation or causation. More research can be carried out in examining the Mozart effect. Existing literature has been questioned due to the contrast in conditions. More specifically, the comparison condition (no music or relaxation tape) stimulates the brain significantly less compared to listening to Mozart, which might have confounded the results. Therefore, a fairer test should be carried out. This can include comparisons between music of different genres (jazz, classical, rock) to investigate whether the style of music affects concentration and/or result in an IQ increase.

The benefits of music therapy are quite wide ranging. Both short-term and long-term advantages have been depicted and tested and these skills have been shown to be present across domains. Improvements have been found in general creativity, cognition, and personality. In addition, music training has also been seen to benefit the brain, encouraging neural plasticity and greater brain connectivity.

Music therapy has massive implications for individuals with dyslexia, ADHD, and ASD. There are a multitude of MT techniques, which can be catered to each disorder, and for each patient. There is not a one shoe fits all policy when it comes to MT, as therapies are usually tailored to the patient's needs. This bespoke solution for individual cases is beneficial as it means that all patients' needs are met. However, it causes difficulty in understanding which element of the therapy is most beneficial and becomes difficult to pick a starting point. For example, insight on the needs of different age groups, cultures or disorder types can be useful in terms of quickly assisting each individual, and curating a therapy plan for each patient in a more timely manner.

It should be noted that although this review includes a plethora of studies, it is not all encompassing. The literature within music cognition is quite expansive, thus, the studies mentioned in this review have been filtered from a wide variety. As the field is very scattered, there are inconsistent protocols from study-to-study, and no proper consensus is established within the field, which poses challenges in coming to a collective agreement for the topics mentioned.

Through this review, we focused on differences between musicians and nonmusicians, musicians of different genres, and music therapy. There is hardly any research about differences between musicians who are

[57] Wang, S. S. H., Kloth, A. D., & Badura, A. (2014). The cerebellum, sensitive periods, and autism. Neuron, 83(3), 518–532. doi:10.1016/j.neuron.2014.07.016

self-taught and formally trained. This avenue of research is quite interesting, as music is generally believed to be beneficial for humans but it is unclear whether the way it is learnt can influence these benefits. Furthermore, music training can be quite expensive and not every household can afford it. Structured research into this can help demonstrate whether being formally trained has more value than just the musical knowledge gained, and how more efforts can be made to engage individuals in partaking music related activities.

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