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Finding rhythm through auditory imagery: an approach to Parkinson's Disease treatment[1][2]

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[2] **About the Author**
Jacqueline LaRivee is a recent graduate of Merrimack College, with a major in psychology and minor in music. This research paper was completed during her senior year as part of her Capstone project. Jacqueline aspires for a career in the helping professions and is also interested in Autism research.

Abstract

The following research article explores music therapy in the treatment of Parkinson's Disease (PD). The general interaction between the rhythmic properties of music and motor associated brain areas is discussed at length. These interactions provide a basis for understanding how music therapy can address the rhythmic impairments of the disease. Dance therapy, Musical Sonification, Rhythmic Auditory Stimulation (RAS) are three types of music-based therapies that have been found to be effective in treating the motor symptoms of PD. These therapies may be particularly effective for the PD population because they draw upon musical rhythm as an external pacing cue.While external pacing cues have been found to help PD patients entrain to rhythm, research has not yet explored how rhythm can be internalized over time. The current article proposes that the experience of Involuntary Musical Imagery (INMI) may offer patients a means of creating an internalized representation of rhythm that can be maintained beyond the therapeutic setting. Strategies to increase the occurrence of INMI are explored, accounting for individual differences and certain musical characteristics. In addition to advocating for music-based therapies in the treatment of PD, there also calls for increased research on how INMI may be incorporated into these therapies.

Keywords: Parkinson's Disease, Music, Neuroscience, INMI, Rehabilitation

Introduction

Music therapy is a clinical field that has grown wider in practice throughout the past two decades (Aldridge, 1994; Hillecke et al., 2005). In this therapeutic practice, various aspects of music are used to improve the health and well-being of clients (Center et al., 2013). Depending on the needs of the client, music therapy can promote communication, motor skills, relaxation, and rhythmic entrainment. Music therapy is commonly practiced in hospitals, rehabilitation centers, schools, and correctional facilities. The current review explores music therapy through the context of Parkinson's Disease (PD). A number of research studies have found that music therapy improves the motor symptoms of PD. The music-based therapies reviewed include dance therapy, musical sonification, and rhythmic auditory stimulation (RAS). These therapies help patients create an internal representation of rhythm, which can improve their rhythmic timing. The aim of this review is to advocate for music therapy in the treatment of PD, as it may be more likely than other therapies to lead to lasting improvement beyond the therapeutic setting. This may be true because music can allow the brain to internalize rhythmic patterns over time. The concept of auditory imagery is discussed in relation to the brain's ability to internalize rhythm. Increasing the occurrence of involuntary musical imagery (INMI) during music therapy may facilitate the process of internalizing and maintaining rhythm. The integration of auditory imagery with music therapy for PD has not been discussed in current literature, urging for further study on this relationship.

Basic neuroscience of musical perception

When discussing the process of internalizing music, it is primarily important to understand how musical perception occurs. Musical processing initially begins in the inner ears, as the sound is converted into an electrical signal (Geisler, 1998; Sarkamo et al., 2013; Weinberger, 2006). This signal then travels to the brain stem and then subsequently towards the thalamus, and out to auditory cortex and limbic areas (Ledoux, 2000; Weinberger, 2006). This processing is concerned with the coding of elementary attributes of individual sounds and sound components (Lotto & Holt, 2010; Warren, 2008). These include fundamental frequency, harmonics, and duration and loudness of individual notes in the melody.

Following auditory cortex activation, musical perception activates a wide variety of neuroanatomic structures in the temporal lobe (Patterson et al., 2002; Warren, 2008; Weinberger, 2004). As brain regions involved with musical perception are so widely distributed, no one single brain structure is exclusively dedicated to music (Perretz & Zatorre, 2005; Warren, 2008). The activation of brain structures is dependent on various factors; including the type of music, previous experience with the music (Pereira et al., 2011), and how actively the individual is participating in the musical experience (Weinberger, 2004). Each of these factors are taken into consideration when determining the extent to which an individual processes more complex musical components.

A network of auditory association areas process certain properties of complex sounds (Warren, 2008). This includes the planum temporale, which analyzes the acoustic patterns of spoken syllables, timbre of the voice or musical instrument, and information about pitch patterns (Griffiths & Warren, 2002). Another relevant structure involved in the more complex aspects of musical perception is the superior temporal gyrus. This region is activated when determining pitch changes and tracking the changes in a melody (Patterson et al., 2002). When perceiving and identifying familiar melodies, bilateral anterior portions of the temporal lobes, superior temporal regions, and parahippocampal gyri are activated (Satoh et al., 2006).

When perceiving higher order musical features (e.g harmonies, intervals, and rhythms) the inferior and medial prefrontal cortex, premotor cortex, superior temporal gyrus, and the inferior parietal lobe are involved (Janata et al., 2002). These structures are predisposed to mediate interactions between sensory, cognitive, and affective information. With that, they maintain "tonality maps," helping to shape expectations about the pitches that will be heard, given a preceding musical input. Maess et al. (2001) also found that harmonically clashing chords activated Broca's area and its right hemisphere homologue. With these areas being involved with syntactic analysis during auditory language comprehension, this finding illustrates that they may also be involved with the processing of musical syntax.

Beyond the more classic brain regions associated with musical processing, a number of other neural structures are involved with various aspects of musical engagement. The ability to keep track of the music as it is played over time involves attention and working memory systems. These systems are spread over prefrontal areas, the cingulate cortex, and inferior parietal areas (Sarkamo et al., 2013). During active music listening, regardless of whether listening to the musical piece as a whole, or focusing on a particular instrument, bilateral blood oxygen level dependent signals increased in the superior temporal gyrus, intraparietal sulcus, precentral sulcus, inferior sulcus and gyrus, and the frontal operculum (Janata et al., 2002). Thus, brain areas serving working memory, attention, semantic processing, target detection and motor imagery also enable attentive listening to music. When a listener hears familiar music, this triggers processing in episodic memory-associated areas such as the hippocampus, medial temporal areas, and parietal areas (Janata, 2002; Patel et al., 2003).

Musical processing provides insight as to how the brain represents information related to timing and sequencing. Music inherently consists of sequential auditory and motor information (Janata & Grafton, 2003). Perception and production of music involves a core circuit consisting of primary motor, premotor, lateral prefrontal, and cerebellar areas, which are involved with sequencing information. Examining music in relation to timing processes highlights the critical role of rhythmic processing in the perception and production of music.

Rhythmic Music Perception and neuroscience

The rhythmic properties of music are processed in areas of the brain distinct from those that process melodic properties. Rhythm is defined as the pattern of temporal intervals in a stimulus sequence (Grahn, 2012). Perceiving and producing rhythm is associated with motor areas of the brain, where rhythmic information is predominantly represented (Gordon et al., 2018). These areas include the premotor cortex, supplementary motor area, cerebellum, and basal ganglia (Hallam et al., 2016; Grahn & Brett, 2007). Each of these areas are thought to be involved with various aspects of movement and timing processes (Grahn, 2009, 2012; Hallam et al., 2016; Leow & Grahn, 2014). Activation in these areas and their networks allow listeners to perceive rhythm, move to the beat and produce music (Sarkamo et al., 2013; Zatorre et al., 2007) The two major motor networks associated with rhythmic movement are the basal ganglia-thalamo cortical and cerebello-thalamo cortical motor networks (Koshimori & Thaut, 2018).

In an FMRI study, Konoike et al. (2012) identified activations in the cerebellum, inferior parietal lobule, inferior frontal gyrus, and supplementary motor area when participants completed a working memory rhythmic task. Almost all of the activations were present during the encoding and retrieval of rhythmic information, suggesting that the working memory of rhythm is retained as information about bodily movements. A meta-analysis by Gordon et al

(2018) also identified consistent activation in the right primary motor cortex, right and left lateral premotor cortex, and the cerebellum during passive music listening. A number of these passive music listening experiments involved rhythmic perception tasks, suggesting that motor areas of the brain play a key role in perceiving rhythm.

In a neuroimaging study on pianists, Bengstsson and Ullen (2005) found that melodic processing activated the medial occipital lobe, the superior temporal lobes, the rostral cingulate sulcus, the putamen, and the cerebellum. Rhythmic processing was found to activate the lateral occipital and medial temporal cortex, the left supramarginal gyrus, the left inferior and ventral frontal gyri, the caudate nucleus, and the cerebellum. Studies of brain damaged patients also show that the perception of rhythm can be impaired without affecting melodic processing, suggesting that rhythm is represented by a distinct neural system (Parsons, 2006).

When assessing participants as they completed rhythm tapping tasks, Chen et al. (2006) found interactions between the posterior superior temporal gyrus and dorsal premotor cortex. They propose that activity in these posterior regions may be related to the detection of the emerging pattern of metric saliency. The superior temporal gyrus is suggested to encode the pattern of metric rhythms, while activity in the dorsal premotor cortex is suggested to integrate the auditory information with temporally organized motor actions. Taken together, the metric structure of a rhythm is an effective cue in driving motor behavior.

In examining the perception and reproduction of more complex music rhythms, Chen et al. (2008) found that during a finger tapping task, the pre-supplementary motor area, dorsal premotor cortex, dorsolateral prefrontal cortex, inferior parietal lobule, and cerebellum lobule VI were modulated with increasing metrical complexity of rhythms. This suggests that these brain regions are involved with processing more complex rhythms. Premotor and supplementary motor areas are involved with planning, voluntary control, and execution of movement (Grahn, 2009). Additionally, this network of brain areas may be relevant for intricate action plans that are required for music performance. Compared to non-musicians in the study, musicians also recruited the prefrontal cortex to a greater degree, possibly due to a superior ability to track, retrieve, manipulate and organize a rhythm's temporal information.

Listening to rhythm can give rise to a sense of pulse or beat, a series of regularly recurring psychological events that arise in response to a musical rhythm (Grahn, 2012). Rule based models of rhythmic perception propose that rhythm is represented by aligning pulses of an internal clock with the perceived beat in the rhythm (Hallam et al., 2016). Beat perception is a psychological response because it does not always have to coincide with stimulus onset. This psychological response is evidenced by the listener's ability to continue the beat through gaps or breaks in the music.

As rhythm contains metrical hierarchies that span the subsecond and supra second domain, perception of musical rhythm and meter may require an integration of automatic and cognitively controlled processes (Grahn, 2009). Rhythmic perception is thought to rely on interactions between auditory and motor systems, as studies have found interactions between the auditory and premotor cortex during rhythm processing (Chen, et al., 2006; Grahn & Rowe, 2009; Large et al., 2015). Beat and meter also increase communication within and between auditory motor networks (Hallam et al., 2016). This auditory-motor connectivity is apparent to a greater degree among musicians, compared to non-musicians (Grahn & Rowe, 2009; Hallam et al., 2016).

Entrainment models of rhythmic perception analyze rhythms as they unfold in real time. These models suggest that the perception of beat and meter arise due to properties of neural oscillations that result in certain frequencies being emphasized (Hallam et al, 2016; Large et al., 2015). Neural oscillatory processes in the rhythm domain may reflect communication between different brain regions, specifically sensory and motor regions (Grahn, 2009; Large et al., 2015). Large et al (2015) propose that the oscillatory sensory-motor interaction itself gives rise to the perception of pulse and meter. In turn, synchronization of perception and action with the underlying beat is facilitated (Janata & Grafton, 2003). It is also thought that attentional processes are embodied in the brain as oscillatory processes, which entrain to rhythmic processes in one's environment.

In examining neural oscillatory processes, Iversen et al. (2009) found that the motor system influences the interpretation of rhythms, even in the absence of overt movement. This was concluded as Beta responses, which are closely linked to motor processing, were stronger when a tone was imagined to be a beat. The Beta band is also linked to anticipation of regular, expected tones (Hallam et al., 2016). Beta and Gamma oscillations have also been found to occur during the processing of a beat (Fujioka et al., 2012). This synchrony occurs not only during a sequence of regularly presented tones, but also after unexpected omissions. These findings suggest an association between Beta and Gamma band synchrony and an endogenous anticipatory pulse/meter.

Cerebellum

As it integrates sensory and motor information, the cerebellum is involved with accurately moving in time with musical rhythm (Sakai et al., 2002).Generally, the cerebellum is involved with the processing of timing information (Molinari et al., 2007). The anatomical and physiological characteristics of the cerebellum may help it to facilitate rhythmic synchronization among segregated brain regions (Molinari et al., 2007). Sakai et al. (2002) evidence the role of the cerebellum in rhythmic timing, finding activation in the lateral cerebellum during the learning of a timing sequence. Patients with cerebellar damage also exhibit an impaired ability in completing perceptual motor timing tasks, suggesting that proper cerebellum function is necessary for the perception of event timing (Ivry et al., 2002). The cerebellum also plays a key role in absolute timing, where patterns of temporal intervals are encoded as a series of absolute durations (Leow & Grahn, 2014). When processing ongoing temporal structure, there has been found to be activation in the cerebellum, as well as prefrontal cortex, inferior frontal cortex, and superior temporal poles (Levitan, 2009).

It should be noted that the function of the cerebellum is not specific just to timekeeping. Rather, the sensory coordination hypothesis theorizes that the cerebellum acts as a global support system for sensory processing. Parsons (2001) identified a strongly correlated activation between the cerebellum and auditory cortex when participants performed classical piano pieces. Cerebellar activity was disassociated from motor components, implying that the cerebellum is involved with other sensory functions. Pitch processing may be one of these functions. Parsons (2001) identified cerebellar activations during pitch perception, suggesting that the cerebellum is involved with perceptual or cognitive processing of pitch. Impaired pitch processing was evident in those with cerebellar damage, highlighting the critical role of the cerebellum in pitch perception. Cerebellar activations were also present during rhythm discrimination tasks and were thought to support nonmotor sensory or cognitive processing.

In a subsequent study, Parsons (2001) identified strong activation in the cerebellum when participants completed error detection tasks that were either rhythmic, melodic, or harmonic. Activation was most prominent during the rhythmic task, suggesting that the cerebellum is highly involved in rhythmic processing. This activation was likely related to sensory and cognitive, rather than motor processes because there was little movement involved in the tasks.

The cerebellum is involved in a network for predictive feed-forward control during rhythmic processing (Gordon et al., 2018). Danielson et al. (2014) found that drum breaks within a groove-based rhythm activated the cerebellum, right inferior frontal gyrus, and the superior temporal gyrus. The drum breaks represented a change in the repeated pattern of the groove, which allowed for prediction error processes to occur. Activations in the cerebellum and other cortical areas during these breaks suggest that they play a role in updating rhythmic information for predictive processes. The cerebellum may even be active in musical prediction when no direct motor control is required (Gordon et al., 2018). Further, the feed-forward structure of the cerebellum is thought to increase the precision of speech and/or song production (Callan et al., 2007). Activation in the cerebellum during perception and production of speech and song suggests that the cerebellum is involved with processing motor and perceptual information related to these processes.

Basal Ganglia

Evidence also suggests that the basal ganglia, a group of structures involving motor control, action selection, and learning, is involved with musical rhythm. Rhythmic music strongly interacts with and affects the basal ganglia system (Brodal et al., 2017). Akin to the cerebellum, the basal ganglia plays a role in time perception. A neuroimaging study by Rao et al. (2001) found early activation in the basal ganglia and the right inferior parietal cortex during a time perception task. Since this activation occurred when time intervals were encoded, the basal ganglia may be involved with formulating representations of time.

Further neuroimaging studies have found that the basal ganglia is active during timing tasks that require tapping intervals from memory (Grahn, 2009). When tapping to the beat of complex rhythms, the basal ganglia interacts with working memory mechanisms in the ventrolateral prefrontal cortex (Kung et al., 2013). Pope et al. (2005) also suggest that the basal ganglia is involved with controlling force, which contributes to accurate timing. They found that time modulation of force in repetitive thumb-finger squeezes activated the basal ganglia, along with the primary motor cortex (PMC), supplementary motor area (SMA), thalamus and cerebellum.

Rhythmic music can also impact the connectivity of the basal ganglia with the reward system (Brodal et al., 2017).The basal ganglia represents a basis of interaction between rhythm and emotion processing, as they are both involved with the reward system and motor circuits (Cochrane et al., 2013). Some crossover between motor and affect processes can take place within these circuits, triggering an emotional reaction. The nucleus accumbens and caudate of the basal ganglia are associated with music-derived pleasure (Matthews et al., 2020). Groove (i.e. the pleasurable desire to move to music), is thought to rely predominantly on rhythmic expectations. Matthews et al., (2020) suggest that the sensation of groove is driven by a combination of motor and reward areas of the brain. The putaman, SMA, and premotor cortex generate an internal representation of the beat, which is then used by the caudate, prefrontal, and parietal regions to inform rhythmic expectations.

The emotion and rhythmic processing-mechanisms of the caudate nucleus contribute to rhythmic entrainment (Trost et al., 2014). Trost et al (2014) found that during a visuomotor task, consonant (i.e. pleasant) music facilitated target detection during a visuomotor task. Consonance also enhanced activity in attentional networks, while strong beats enhanced activity in the caudate nucleus. Both meter and consonance selectively interacted in the caudate nucleus, however meter effects were most apparent during dissonant music.

Studies have proposed that the basal ganglia generate an endogenous pulse, allowing the listener to “feel the beat” (Grahn, 2009) and predict upcoming intervals (Large et al., 2015). The basal ganglia play a key role in beat perception and selectively respond to beat (Leow & Grahn, 2014; Grahn & Brett, 2007; Grahn & Rowe, 2009; Kung et al., 2013). Grahn & Rowe (2009) found that the putamen, palladium and caudate respond more to rhythms containing a beat, in comparison to non-beat rhythms. More basal ganglia activity was also identified in conditions requiring more internal generation of the beat.

The basal ganglia is also thought to subserve both beat finding and continuation, depending on what is required of the task (Hallam et al., 2016). The basal ganglia appears to be more involved with beat continuation than beat-finding, as more activity is apparent when beat-based rhythms follow one after the other (Cameron & Grahn, 2014; Grahn & Rowe, 2013). When comparing conditions that required beat finding to those that required beat continuation and/or adjustment, Grahn & Rowe (2013) identified more activity in the basal ganglia during beat continuation, where internal generation of the beat can be accomplished. Less basal ganglia activity was apparent in the beat finding condition, where there is more difficulty in formulating predictions based on internal generation of the beat. These findings suggest that basal ganglia activity corresponds to the degree of predictability.

Kung et al. (2013) found activity in the basal ganglia both when participants identified the beat and tapped along to it, suggesting that similar basal ganglia resources are recruited during both beat perception and production. This activation was not modulated by beat strength, unlike activations in the cortical auditory, premotor and prefrontal areas. Therefore, it was suggested that the basal ganglia is involved in detecting auditory temporal regularity, or with associating auditory stimuli with a motor response.

Attention may be necessary in order to recruit basal ganglia activations associated with pulse perception. Chapin et al. (2010) found activations in the basal ganglia when participants were asked to selectively attend to complex rhythmic patterns. These activations were only present after the rhythms were presented a sufficient amount of times for pulse perception to occur. Together, these findings indicate that auditory to motor mapping requires both attention and time to develop.

The basal ganglia interact with the SMA and PMCduring beat perception (Grahn & Rowe, 2009). Motor information encoded by the basal ganglia may facilitate these cortical areas in the control of movement timing. In a study on rhythmic perception, Grahn & Rowe (2009) found that the presence of a beat was associated with greater connectivity between the putaman, SMA, and PMC. It was proposed that these areas interact within a network involved with predicting and generating beats, particularly under conditions that require internal generation of the beat.

Evidence suggests that the basal ganglia and SMA are involved in maintaining an internal representation of beat intervals, which enables forward predictions of the beat (Leow & Grahn, 2014). These areas have been found to be more activated when listening to rhythms at the same rate (beat continuation) compared to when rhythms change rate (beat adjustment). Grahn & Brett (2007) suggest that the basal ganglia and SMA mediate beat perception when induced by the temporal structure of rhythm. This is a possibility, as they found increased activation in these brain areas when participants reproduced rhythms in relation to a beat.

Cerebellum and basal ganglia: distinctions

The cerebellum and basal ganglia interact within a broader network of cortical regions (i.e PMC, SMA, sensorimotor cortex, superior temporal gyrus, and inferior frontal gyrus) to support temporal adaptation and anticipation during sensorimotor synchronization (Van der Steen et al., 2015). With lesions in these areas, individuals may have difficulty synchronizing their movements to an external rhythm. Lesion studies are particularly useful for identifying the unique functions of the cerebellum and basal ganglia within the broad motor network.

In a study on individuals with cerebellar and basal ganglia lesions, Van der Steen et al. (2015) found that the lesions generally impaired the precision of sensorimotor synchronization by increasing the variability of internal timekeeping processes. Cerebellar patients had a difficult time updating motor programs to maintain synchrony with tempo changes, suggesting that the cerebellum is specialized for automatic processes at short timescales. Similarly, Nozaradan et al. (2017) found that patients with cerebellar and basal ganglia lesions showed reduced tracking at beat frequency. This effect was particularly apparent for cerebellar patients in the rhythmic sequence played at the fastest tempo, which requires rapid and temporally precise event coding. Basal ganglia patients showed abnormal responses at beat frequency for the most complex rhythm, requiring more internal generation of the beat. Therefore, the cerebellum may be more involved with precise encoding of rapid temporal events, whereas the basal ganglia is involved with internal generation of the beat.

Basal ganglia lesions also impact temporal processing. Schwartze et al. (2010) found that individuals with basal ganglia lesions exhibited an impaired ability to detect tempo changes and perform attention-dependent error correction, particularly in response to tempo decelerations during a finger-tapping task. Damage to the basal ganglia may therefore impact the ability to evaluate temporal structure and predict upcoming events. As a result, individuals with basal ganglia lesions may be unable to compare rhythms, align motor behavior, or allocate attention.

While the basal ganglia is important for timing of events relative to a predictable beat, the cerebellum is involved with the perception of absolute timing intervals (i.e. timing of events not related to a beat) (Cameron & Grahn, 2014). This discrepancy is evident, as individuals with cerebellar damage have shown deficits in absolute, but not beat-based timing. Cerebellar regions have also been shown to activate during absolute timing, while the basal ganglia is active during beat-based timing.

The cerebellum may also play a role in neural computations related to rhythmic complexity (Thaut et al., 2008). Thaut et al. (2008) identified more cerebellar activation during polyrhythmic hemiola tapping tasks, whereas the basal ganglia was most active during the less complex isorhythmic tapping tasks. These findings suggest that the basal ganglia is more involved with basic timing and sequencing aspects of rhythmic motor performance, whereas the cerebellum serves sensory-motor functions that are important for more complex rhythmic tasks.

Rhythm in PD: a model of basal ganglia deficits

Basal ganglia and cerebellar function are drastically altered in individuals with Parkinson's Disease (PD). As a result, PD patients exhibit impaired rhythmic processing mechanisms. PD falls under the broad umbrella of dementia, which consists of disorders involving pervasive, progressive, and irreversible decline in cognitive function (Hamdy et al., 2019). PD specifically involves issues related to movement; these issues include tremors, bradykinesia, and rigidity (Dauer & Przedborski, 2003; Harris et al., 2016). It is also common for patients to exhibit a variety of speech impairments (Harris et al., 2016). The symptoms of PD are attributed to abnormal synchronous oscillating neuronal activity in the basal ganglia, as well as hyperactivity in cerebellothalamic pathways. (Bergman & Deuschl, 2002).

PD can be viewed as a model of basal ganglia deficits in rhythmic perception, based upon the apparent rhythmic disturbances of patients. The brains of PD patients exhibit differences in ways that they process rhythmic information. PD patients have shown hyperactivity in areas related to temporal auditory processing, specifically the bilateral planum temporale and inferior parietal lobule (Vikene, 2018). Hyperactivity in these areas may be related to basal ganglia dysfunction during rhythm processing. PD patients lack internal preparation of circuitries relevant to rhythmic processing, whereas healthy individuals are able to maintain the brain state necessary to process rhythms during silent periods between stimuli.

Through finger tapping tasks, PD patients have demonstrated impaired rhythm formation. Nakamura et al. (1978) found that compared to controls, PD patients lost their ability to follow rhythmic input stimuli at a critical frequency of 2.5 or 5 hz. From these findings, it was proposed that there may exist a random oscillation in the central nervous system with a mean frequency of 5~6 Hz that is excited and causes the rhythmic disturbances apparent in PD patients. These desynchronized finger tapping responses are deemed as the “hastening phenomenon,” which is especially apparent in tremor predominant patients (Yahalom et al., 2004). Yahalom et al. (2004) found that PD patients generally tapped at a significantly slower rate than controls when asked to tap at their fastest rate. On the other hand, patients showed improved performance when they were given an external pacing, as opposed to following their own internal clock.

With a damaged basal ganglia, PD patients exhibit impairments in discriminating changes in rhythm with a beat. These deficits are only apparent in beat rhythms as opposed to non-beat rhythms. This finding suggests that the ability to detect and generate an internal beat is compromised in PD patients (Grahn & Brett, 2008; Leow & Grahn, 2014). PD patients have also shown deficits in the perception of other temporal components of rhythm, such as meter and contour (Biswas et al., 2015). Biswas et al. (2015) found that PD patients showed impairments in discriminating beats, rhythm, and rhythmic contour. They also were also unable to perceive meter and beat in a musical context. These impairments may be associated with certain cognitive abnormalities of patients, as verbal working memory and focussed attention were correlated with rhythm perception.

Internalizing rhythm: a call for therapeutic approaches

Based upon the rhythmic disturbances of PD patients, it appears that the ability to internalize rhythm is significantly compromised as a result of basal ganglia damage. Therefore, it may be an ideal strategy to make rhythm explicit within therapies. This strategy can be integrated within music therapies for PD. Music may be an efficacious treatment modality for PD, as its rhythm can be used as an external pacing cue.

Research generally supports the inclusion of music in therapies for PD. Through a meta-analysis study, Barnish & Barren (2020) found that group performing arts interventions using active participation positively impacts speech, cognition, motor function, and quality of life of PD patients. These interventions include dance, music therapy, theater, and singing. Spina et al. (2016) also identified cognitive benefits for PD patients following 6 months of music therapy. Improvement was found on tests examining frontal lobe function, which comprises cognitive flexibility, processing speed, attention, and working memory.

Active music therapy has been found to benefit the motor symptoms of PD patients. Kogutek et al. (2021) identified improvements in gait when PD patients took part in Improvised Active Music Therapy sessions. This type of music therapy involves the music therapist improvising music with the patient and encouraging them to create a musical dialogue. Following participation in these therapy sessions, there was found to be overall improvement in mean gait velocity and man step time variability.

Pachetti et al. (2000) also identified motor improvements, specifically related to bradykinesia, as well as improved emotional status and activities of daily living in PD patients who took part in active music therapy sessions. These sessions involved improvisation of music between the therapist and patients, where patients played an active role in instruments and voice. These improvements were not apparent among those who took part in physical therapy sessions. Pachetti et al (2000) proposed that improvement in bradykinesia was due to the effect of external rhythmic cues, which may stabilize internal rhythm formation.

Rhythmic auditory stimulation

Prior studies have directly assessed the ability of external rhythms to prime movement areas of the brain in PD patients (Rose et al., 2019). This assessment involves a therapeutic strategy called Neurologic Music Therapy (NMT), which has the goal of improving motor skill (Bukowska et al., 2016). NMT comprises three different therapeutic strategies, the first of which is called rhythmic auditory stimulation (RAS). RAS uses metronomes or rhythmically enhanced familiar music to provide external cues for improving gait. For example, an individual will try synchronizing their footsteps to a steady metronome or musical beat while walking (Ready et al., 2019). The second therapeutic strategy of NMT is Patterned Sensory Enhancement (PSE) which uses complex musical elements to facilitate movements associated with activities of daily living (Bukowska et al., 2016). The last strategy is Therapeutic Instrumental Music Performance (TIMP), which is designed to simulate and facilitate functional movements through the use of musical instruments.

Bukowska et al. (2016) demonstrated that a combination of RAS, PSE, and TIMP is effective with regards to improving gait and other rhythmical activities for individuals with PD. In the study, PD patients practiced activities of daily living, balance, pre-gait and gait training using the techniques of each NMT component, incorporating music with a strong sense of rhythm. Compared to controls, patients receiving NMT exhibited significant improvements in gait. These improvements persisted even for several weeks after therapy completion.

NMT may also increase the functional connectivity of auditory and motor cortices in PD patients, thus leading to motor improvements. Buard et al., (2019) found that five weeks of NMT-based therapy lead to improvements in fine motor function among PD patients. These improvements were accompanied by increased coupling of auditory and motor cortices, suggesting that auditory-motor connections were improved and strengthened.

A vast amount of literature highlights the efficacy of RAS in improving the motor functions of PD patients. Using RAS, Thaut et al. (1996) increased cadence, stride length, and symmetry in gait patterns of PD patients. The RAS intervention consisted of walking a flat surface, stair stepping, and completing stop and go exercises to rhythmically accentuated music at three different tempos. On average, PD patients who underwent RAS training improved 25% in gait velocity for flat surface and incline walking. Participants who engaged in self-paced training also improved gait velocity, however to a lesser extent than those in the RAS training group. As improvements were apparent after only a 3 week period, RAS may provide benefits over a relatively quick span of time. Hayashi et al. (2006) also found that RAS therapy sessions improved gait speed and stride length in PD patients. These improvements were apparent even without any gait training, suggesting that the external stimulation of RAS enabled patients to internally generate the rhythm of gait. Patients also showed less depressive symptoms according to a self-rating scale after engaging in RAS.

RAS not only improves gait in the moment, but also helps to alter underlying neural mechanisms, which could support long term alterations in functions. Calabro et al. (2019) investigated the neurophysiological mechanisms underlying the sustenance of gait improvement by correlating EEG changes with behavioral (gait) changes following an RAS intervention. Observed clinical improvement in gait quality, balance, and number and length of strides was associated with greater improvement of fronto-centro parietal/temporal electrode connectivity, compared to those who did not take part in RAS gait training. PD patients have also shown strengthened right-lateralized auditory and cortico-cerebellar activity following RAS training (Koshimori & Thaut, 2018). Thus, RAS may be a useful intervention for PD, specifically because it leads to long term improvement at the neurological level.

RAS can also influence the anatomical and functional connectivity between auditory and motor areas, which may improve PD symptoms. (Koshimori & Thaut, 2018). Evidence suggests that auditory stimuli can influence motor pathways and networks associated with gait. These networks may then coordinate with each other to generate auditory-motor entrainment, with PD brains showing more reliance on external cueing during motor behavior.

Beyond gait performance, RAS can improve the entrainment and synchronization of individuals with PD. However, this improvement may only be apparent when musical melodies are implemented within the intervention. When comparing different types of auditory cues and movements during RAS training, Rose et al. (2019) found that musical melodies were more useful than metronomes in regards to synchronizing movements and maintaining entrainment in the absence of heard cues. Participants may have been better able to synchronize to musical melodies because they were more memorable and predictable. Therefore, the clarity and familiarity of music, in addition to its underlying rhythm, are important to RAS interventions.

Musical Sonfication

Another type of music-based therapy for PD is *Musical Sonfication* (MS). MS involves transforming kinematic variables, such as handwriting into music. Its purpose is to improve perception of movement irregularities (e.g. when the music changes) and to provide auditory guidance (e.g. when the music does not change; Veron-Delor et al., 2019). MS is particularly useful to PD because sonification engages the basal ganglia motor loop. Schmitz et al. (2013) found that when young non-athletic participants observed a swimmer model performing breastroke movements paired with sounds that matched the visual movement kinematics (i.e congruent sonification), they displayed better perceptual judgment of small differences in movement velocity. Participants also displayed pronounced connectivity of the superior temporal sulcus with basal ganglia, thalamus, and frontal motor regions. It was then concluded that the sonification of movements amplifies activity of the human action observation system, including subcortical structures of the motor loop.

Similar to RAS interventions, the involvement of music within MS therapy might make it particularly effective in treating PD. Veron-Delor et al. (2019) found that both background music and MS increased the movement frequency of PD patients during a handwriting task. When participants completed the task in complete silence without background music or MS, no such improvements were apparent. These findings further suggest that the most robust improvements in PD symptoms occur when music is incorporated within therapeutic interventions. These improvements may be explained by the ability to internalize rhythmic musical patterns and make motor predictions based upon them.

Dance therapy

Dance therapy is also widely utilized in the treatment of PD. The music component of dance may serve as an external cue to facilitate movement(Earhart, 2009). In general, dance can promote auditory, visual, and cognitive cues. Dance also involves the teaching of specific movement strategies and balance, which may be beneficial to patients. Certain dance qualities are proposed to alleviate specific symptoms of PD (Sharp & Hewitt, 2014). For example, the frequent movement and cessation, spontaneous directional changes, and movement speeds of Tango are thought to target movement initiation, turning, and bradykinesia. Ballet dancing can also promote posture, body alignment, projection of eye focus and limb extension, and whole body coordination.

Dance has been found to be highly effective in the treatment for PD. A meta-analysis by Aguiar et al., (2016) found that dance therapy generally has a positive impact on motor performance, mobility, balance, and quality of life. There appears to be immediate improvements in PD symptoms following dance interventions. Heiberger et al. (2011) found that disease severity, as evidenced by PD disease rating scale, significantly improved after only 1 hour of dance class. The most significant improvements were found in rigidity scores for arms and legs, finger taps, hand movements and facial expression.

Dance therapy also results in superior outcomes for PD patients compared to those who receive no intervention, or other types of interventions. A meta-analysis conducted by Sharp & Hewitt (2014) found that dance scores significantly improved motor scores, berg balance, and gait speed compared to no interventions. Dance was also superior to other exercise interventions in terms of improving berg balance and quality of life. Improvements in balance were also sustained at the intervention, suggesting long-term benefit.

In a study comparing dance therapy to traditional rehabilitation, De Natale et al (2017) found that dance therapy significantly improved some motor and cognitive tests in PD patients, whereas traditional rehabilitation showed non-consistent and non-continuous modifications. Cognitive improvements were also retained after follow-up, suggesting long-term impact on higher cortical functions. This long term benefit may be explained by the entertaining and active nature of dance, which is enjoyable to patients. Dance therapy appears to be well-liked by PD patients, as Michels et al. (2018) found that all participants who completed a dance therapy intervention enjoyed the intervention and felt they benefited from it.

The engaging and social qualities of dance may have the potential to impact the health-related quality of life of individuals with PD (Hackney & Bennett, 2014). Health-related quality of life refers to the patients' perception and evaluation of the impact and consequences the disease has on their life. A meta analysis conducted by Hackney & Bennett (2014) identified various studies which have found that dance can improve health-related quality of life in as quickly as 2 weeks. Improvements have still been apparent even among those with a severe and/or end stage neurological disorder. In particular, music therapy involving strongly rhythmic body movement has been found to improve scores on the PD Quality of Life questionnaire. Heiberger et al. (2011) also found benefits to quality of life when PD patients participated in 8 months of a dance intervention. Improvements were strongest in social life, health, body-feeling and mobility, state of mind, and everyday life.

There are several mechanisms by which dance is thought to improve health-related quality of life. One is that dance involvement may reduce social isolation of individuals with PD, encouraging active participation (Hackney & Bennett, 2014). Another is that dance can promote mental practice and motor imagery, which in turn may improve connections on neural pathways that facilitate health-related quality of life. In addition, there are physiological mechanisms by which dance improves health-related quality of life. The practice of dance facilitates activation of brain areas that normally show reduced activation in PD (Earhart, 2009). Rhythmic tango steps activate the putaman, an area affected by loss of dopamine in PD (Brown et al., 2006). By activating this area, dance may help to reduce depressive symptoms. Pinniger et al. (2013) support this possibility with findings of decreased states of anxiety, stress, and depression, in PD patients who participated in 2 weeks of tango. Tango can also serve as a means of focusing one's conscious attention on walking, as it has walking as its basic step.

Music based therapies: Future directions

Given the high efficacy of RAS, musical sonification, and dance therapy, music-based therapies should be advocated for in the treatment of PD. The success of music in alleviating PD symptoms may be explained by its ability to provide an external rhythm. As PD patients commonly express rhythmic timing deficits, it is beneficial for patients to receive these external rhythmic pacing cues. While external cues are helpful in alleviating rhythmic deficits, research has not yet explored mechanisms to enhance the internalization of rhythm. The ability to internalize rhythm is key to achieving long-term improvement in rhythmic timing. If patients are able to maintain an internal representation of rhythm over time, they may no longer need to rely on external cues for rhythmic accuracy.

Auditory imagery

The experience of auditory imagery reflects one way that rhythm can be internalized over time. Auditory imagery refers to the experience of "hearing" music in one's mind without it being explicitly played (Kraemer et al., 2005). One type of auditory imagery is voluntary musical imagery. Voluntary musical imagery refers to the ability to deliberately recall a musical memory (Likkanen et al., 2012). Another type is anticipatory imagery, which refers to the ability to predict the features of an upcoming sound based on prior experience.

A third type of auditory imagery is called involuntary musical imagery (INMI). INMI refers to the experience of unintentionally hearing music in one's head in the absence of external stimuli, otherwise known as having an "earworm." (Liikkanen, 2008). INMI can be considered alongside other self-generated thoughts such as mind wandering and daydreaming because it occurs without conscious control (Farrugia et al., 2015). Generation of self-generated thoughts may rely on spontaneous activity in the default mode network (DMN). This network includes the medial prefrontal cortex, posterior cingulate cortex, PHC, and ventral ACC. INMI may be most relevant to consider in regards to PD treatment, as it may allow patients to hold an internalized representation of rhythm in their brain without deliberate effort. As a result, they may express less reliance on external pacing cues.

Neuroscience of auditory imagery

Auditory imagery is specifically associated with activity in the auditory cortex. Kraemer et al. (2005) found activation in the primary auditory cortex and auditory association cortex during gaps of silence between which participants listened to familiar sections of music. This finding indicates that moments of silence, during which individuals imagine the musical melody, can elicit activity in the auditory cortex. The brain may be able to make predictions during these moments of silence. Using an EEG, DiLiberto et al (2021) studied how participants predicted upcoming music notes during periods of silence within Bach melodies, as well as when they imaged these melodies. The brain elicited similar prediction signals both when participants predicted upcoming notes during periods of silence and imagined the musical melodies. This finding indicates that melodic expectation mechanisms can still be encoded even while the individual is simply imagining the melody.

It is during these points of silence that listeners begin to form mental representations of the music, enabling them to predict upcoming lyrics and melodic components. Gaps of silence can thus be used to deliberately evoke musical imagery, as was explored by Gabriel et al. (2016). In this study, unexpected gaps of silence elicited various neural activations when participants listened to familiar and unfamiliar songs. These activations included sensory responses that are automatically evoked by periods of silence, attentional responses, and cognitive mechanisms.

Taken together, it appears that imagining music can evoke similar neural patterns to the experience of listening to it explicitly. Regev et al. (2020) provide further support for this phenomenon, finding that response patterns in the superior temporal gyrus during explicit listening of music were reactivated during musical imagery. Temporal response patterns in the auditory cortex during imagery became more similar to responses during musical perception when the musical imagery was accompanied by synchronous rhythmic tapping. These similarities were observed in additional associative areas of the superior temporal plane.

The tempo characteristics of INMI episodes can be thought to reflect their neural similarities to the experience of listening to music explicitly. Jakubowski et al. (2015) found that INMI that exists for music in a canonical version (i.e. has one original standard recording) is generally experienced at a tempo very close to that of the original recording. This finding was apparent even though participants had not heard the songs experienced as INMI in over a week. This suggests that INMI recalled from long-term memory are temporally precise and that the high veridicality for INMI tempo is not just true for music that was heard very recently.

With there being high consistencies between the neural experience of auditory imagery and explicit music listening, it appears that the brain is able to maintain accurate information about musical characteristics over time. This unique ability of the brain can be tapped into during the treatment of PD, with the goal of helping patients maintain accurate rhythmic information. With repeated exposure to music, patients may experience more frequent episodes of INMI. These episodes might then enable them to create an internal representation of rhythm, which can hopefully be maintained in the long term.

Auditory imagery in the treatment of PD

Auditory imagery is beneficial to call upon in the treatment of PD because it exercises motor areas of the brain that are implicated by the disease. Oullier et al. (2005) found that real and imagined rhythmic coordination of movement with auditory pacing sequences recruit the basal ganglia, premotor cortex, supplementary motor area, superior temporal gyrus, and cerebellum. By continually activating these brain areas through auditory imagery, perhaps motor related symptoms of PD will reduce.

Keller (2012) highlights further information about the working memory and motor systems involved with the experience of auditory imagery. These systems are relevant to the ways that patients plan and predict upcoming motor actions. Working memory is used with regards to holding mental representations of rhythm, pitch, timbral and/or intensity patterns. Motor control is involved through the mechanisms of action stimulation and internal models.

Action stimulation refers to the engagement of sensorimotor areas of the brain in the absence of overt movement. This experience may occur when imagining or observing the action. Internal models also rely on experience-based learning. They increase the efficiency of motor control by running slightly ahead of the executed action, allowing movement errors to be corrected in advance. With regards to music, internal models can trigger auditory and motor images of one's upcoming actions. This imagery can then facilitate the planning and execution of musical actions. When music is able to trigger auditory and motor images of a PD patient's upcoming actions, the patient may be better able to plan and execute a motor action.

Auditory imagery has in fact been found to elicit predictive mechanisms that enhance performance ability. Keller et al. (2010) found that the level of asynchronicity in movement between duos of pianists decreased with higher scores on an imagery assessment task. It was proposed that auditory imagery helped with predicting the time course of others' actions in a musical setting, thus facilitating sensorimotor synchronization. The predictive mechanisms of auditory imagery may extend to improving the general motor abilities of PD patients. By habitually using auditory imagery to internalize rhythmic patterns, patients may be better able to predict and execute movements in their day to day lives.

Enhancing auditory imagery

To further assess the relationship between auditory imagery and PD treatment, future studies may wish to assess whether individual differences in the experience of auditory imagery impact treatment outcomes. With INMI in particular, there are structural brain differences between those with increased versus decreased frequencies of INMI episodes. These structural differences are apparent in terms of cortical thickness. A study conducted by Farrugia et al. (2015) showed that the frequency of INMI episodes negatively correlated with cortical thickness in the right Heschl's Gyrus, a region that is associated with auditory perception and voluntary musical imagery.

There was also found to be decreased cortical thickness in the right inferior frontal gyrus, a region that is associated with pitch memory in individuals with increased INMI episodes. The authors suggest that the inferior frontal gyrus plays a role in suppressing unwanted INMI episodes, due to its inhibitory mechanisms. It is thought then that reduced cortical thickness in this area is linked to less inhibition of INMI episodes. In addition, higher gray matter volume in the right temporopolar and parahippocampal cortices was found in participants who reported higher disturbance by their INMI experiences. These structures are thought to be involved with affective processing and to communicate with other emotion-related areas of the brain (Farrugia et al., 2015).

It is also important to note that individual differences can influence the frequency, emotional characteristics, and emotional experience of INMI. A study conducted by Negishi & Sekigushi (2020) found that participants with more intrusive thoughts (obsessions) experienced

INMI more frequently. Further, the more obsessive-compulsive tendencies were reported, the less INMI experiences were reported as pleasant and likable.

Similar findings were identified by Mullensiefen et al. (2012). In this study, participants with higher obsessive-compulsive attributes displayed an increased frequency of INMI episodes. These individuals also reported that their INMI episodes were more worrisome, interfering, and hard to suppress. Musical experience was also found to impact the length and frequency of INMI episodes. Those with more singing experience reported increased lengths of episodes and those who most often listened to music reported experiencing INMI more frequently.

Certain personality traits are also associated with the frequency, enjoyability, and controllability of INMI. Negishi and Sekigushi (2020) found that participants who scored high for neuroticism were more likely to experience INMI. Floridou et al. (2012) also found that neuroticism correlated with certain INMI characteristics. Participants in this study who expressed more effort to get rid of INMI experiences displayed more neurotic tendencies. Individuals with more neuroticism also reported to enjoy INMI episodes less. By contrast, individuals who displayed bodily movements in a musical context (e.g. humming, singing, tapping) tended to enjoy INMI experiences more. Individuals who displayed more extraversion were found to control their INMI more easily.

As such, INMI may not be a possible therapeutic technique for all PD individuals. The impact of INMI on therapeutic outcomes may depend on the patient's experience with music and preexisting emotional and behavioral characteristics. Despite any preexisting characteristics, there may be some ways to increase the occurrence of INMI in the PD population. This may be accomplished by activating certain long and short-term memory processes. Williamson & Mullensiefen (2012) found that memory processes were linked to INMI frequency. Specifically, associations between music and situations, words, people, and other non-musical sounds were found to trigger the memory of a musical excerpt, which went on to be experienced as an earworm. In consideration of these findings, it may be beneficial to utilize music that patients may have a personal connection with during treatment interventions.

Another strategy may be to present patients with lyrical, rather than instrumental music. Flouridou et al. (2012) found that presentation of written lyrics could trigger INMI episodes and that recent activation of music into short term memory enabled the appearance of INMI. Further, a later study by Flouridou et al. (2014) found that lyrical music was more often experienced as INMI and that there was a recency effect with the last song presented.

Recency and repetition are important factors to consider when attempting to increase occurrence of INMI. Existing findings imply that patients need to be exposed to a song multiple times in a row or hear it very recently to experience it in an INMI episode. Examining the possible situational antecedents to INMI episodes, Williamson & Mullensiefen (2012) found that musical exposure was the most common trigger of INMI. This meant that participants often reported that music they recently heard appeared in an INMI episode later, or they might have heard the music multiple times prior to onset of an INMI episode. Byron & Fowles (2015) also found that frequency of music exposure related to INMI experience. Participants in the study who heard an unfamiliar stimulus song more frequently were more likely to experience that song as INMI than those who heard the song less frequently. There was also a recency effect, as participants reported to experience INMI more frequently in initial experience sampling forms compared to later forms. Lancashire (2017) also found that music heard most recently was more likely to be experienced as INMI. In the study, over half of INMI episodes resulted from having heard the music since the last point of contact.

Although recency is helpful in activating INMI, it is not a necessary condition for INMI occurrence. Liikanen (2012) found that music rehearsal in the near past was a more significant predictor of INMI than very recent activation of musical memories. This finding is consistent with the prolonged activation hypothesis, which states that consecutive memory activations for a piece of music build a high level of activation over time. With this idea in consideration, PD patients might benefit from repeated exposure to the same music to increase the occurrence of INMI. This music may comprise popular songs that patients are used to hearing frequently and have built up memories of over time, thus lending them more likely to experience INMI.

Incorporating popular music that follows conventional/simple melodic structure into therapeutic interventions may help to increase the occurrence of INMI. Jakubowski et al. (2017) found that songs which achieved greater success and more runs on music charts were reported more frequently as INMI. This may be because popular music is more frequently played on the radio, which gives listeners more instances to create internalized representations of it. Tunes that were faster in tempo were also more likely to be experienced as INMI. Patients may therefore benefit more from exposure to fast-paced popular music.

Additionally, Jakubowski et al. (2017) found that tunes with more common global melodic contour shapes were more likely to be experienced as INMI than those with less common pitch contours. Songs with a more conventional melodic structure may allow listeners to more easily form expectations and internalize the melody (Lancashire, 2017). On the other hand, the complexity of musical melody may not hinder the occurrence of INMI in patients with prior musical background. Lancashire (2017) found that only listeners with significant musical background experienced INMI in response to complex musical stimuli. In consideration of this finding, PD patients with less musical background should try to entrain to music with simple melodic structure.

Williamson & Mullensiefen (2012) also found that certain mind and body states were associated with INMI frequency. Live music was associated more with INMI, possibly because individuals reported higher levels of excitement, anticipation, and emotion during concerts. These heightened emotional states may have influenced memory encoding, as emotional memories are more easily encoded. If INMI is more easily triggered during heightened emotional states, PD patients may benefit more from live music exposure, or by pairing music with something that excites the body (e.g. dance).

It is important to keep in mind that the patient's arousal state may have an impact on the tempo characteristics of their INMI episodes. Jakubowski et al (2015) found a positive relationship between INMI tempo and subjective arousal. This finding suggests that INMI is able to interact with concurrent mood, as does perceived music. In another study comparing the characteristics of VMI and INMI, Jakubowski et al. (2018) found that INMI had more of an emotional impact than VMI, as the tempo of INMI affected arousal ratings, unlike VMI. A patient's affective state is therefore important to consider in regards to their INMI experience. If the goal is to increase movement speed, it may be best to use music that will heighten the patient's arousal state, which will increase the tempo of the internalized musical representation.

Pairing the music with motor-involved tasks is one strategy that may increase the arousal state of patients and the overall frequency of INMI occurrence. These tasks might involve humming, singing, and/or dancing along to the music. McCullough & Margulis (2015) found that participants who normally move or vocalize to music were significantly more likely to experience INMI. Given these findings, PD patients may more frequently and easily experience INMI when they habitually listen, vocalize, and dance to music. By incorporating these types of motor-involved tasks into therapeutic interventions and encouraging patients to partake in these tasks beyond the therapeutic setting, patients may be more likely to obtain long-term benefits.

Patients should not be under a state of high cognitive load during the time at which INMI is being induced. Floridou et al. (2014) suggest that states of high cognitive load suppress the occurrence of INMI. They found that as cognitive load gradually increased, INMI induction rate decreased. Instead, patients should be in a state of low cognitive load, which more easily elicits INMI episodes. Floridou & Mullensiefen (2015) found that activities characterized by low cognitive load (e.g. just waking up/going to sleep, traveling, housework, and physical movement) are found to favor mind wandering, which leads to INMI. Audio/visual activities and socializing were found to reduce the likelihood of mind wandering and subsequent INMI. This may be because INMI is competing for the same auditory processing resources that are engaged during these activities.

Based upon the existing information about INMI induction, there are a wide variety of factors to consider when utilizing INMI in the treatment of PD. These factors include individual neurological, psychological, physiological, and personality differences, as well as characteristics of the music itself. Careful consideration of these factors may lead patients with more success in maintaining rhythmic improvement over time.

Conclusion

This review has discussed how the complex interaction between music and the human brain plays into the success of music-based therapies. While music activates various areas of the brain, there is significant interaction between music and motor associated brain areas. There may be increased interaction in these areas because a large part of musical perception involves formulating representations of time based upon rhythm. In the context of music and rhythmic processing, music therapy in the treatment of Parkinson's Disease (PD) was discussed. Music may be especially helpful in the treatment of PD because the brain is responsive to its rhythmic qualities. With PD patients exhibiting rhythmic impairments, music may exercise their rhythmic processing abilities.

Music-based therapies such as dance therapy, musical sonification (MS), and rhythmic auditory stimulation (RAS) were discussed in relation to PD treatment. These therapies are highly effective in improving the movement synchronization and timing of patients and appear more successful than non-music therapies. One aim of this review was to explore why music-based therapies may be more effective in the treatment of PD than other therapeutic modalities and how resulting improvement from music therapy can be maintained over time. Music may be particularly effective in the treatment of PD because it is memorable, predictable, and easily internalized by the brain. The phenomenon of auditory imagery was discussed as a means of suggesting that the brain is wired to internalize and predict upcoming musical sequences. This ability can be expanded upon during the treatment of PD to help patients maintain an internalized representation of rhythm. Several different mechanisms were explored to increase the occurrence of involuntary musical imagery (INMI), which can hopefully allow for long term rhythmic maintenance. When rhythmic internalization is linked with movement, PD patients may be better able to anticipate their own upcoming motor actions. In general, there calls for increased advocacy of music in the treatment of PD, given its profound interaction with motor networks and its ability to be internalized by the brain.

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