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Review

Into the groove: Can rhythm influence Parkinson's disease?☆

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ABSTRACT

Previous research has noted that music can improve gait in several pathological conditions, including Parkinson's disease, Huntington's disease and stroke. Current research into auditory-motor interactions and the neural bases of musical rhythm perception has provided important insights for developing potential movement therapies. Specifically, neuroimaging studies show that rhythm perception activates structures within key motor networks, such as premotor and supplementary motor areas, basal ganglia and the cerebellum – many of which are compromised to varying degrees in Parkinson's disease. It thus seems likely that automatic engagement of motor areas during rhythm perception may be the connecting link between music and motor improvements in Parkinson's disease. This review seeks to describe the link, address core questions about its underlying mechanisms, and examine whether it can be utilized as a compensatory mechanism.

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"Every disease is a musical problem; every cure is a musical solution" (Novalis).

In the seventeenth century, the English physician William Harvey described animal movement as "the silent music of the body" (Harvey, 1627–1959). Walking, swimming, crawling, flying, and other complex types of animal movement enable efficient exploration of different habitats, and although each is an inherently distinctive method of locomotion, all share a natural equipoise and fluency enabling swift sensorimotor responses to the environment. This smooth, graceful, "melodic" flow of movement is compromised in patients with Parkinson's disease.

One of the cardinal symptoms of Parkinson's disease (PD) is diminished ability in walking or gait. Patients demonstrate difficulty regulating stride length (Morris et al., 1996), reduced velocity, 'freezing' of gait and increased cadence or step rate (as demonstrated in Fig. 1) (Knutsson, 1972). Despite the success of pharmacological therapies in ameliorating some features of PD, gait deficits can be resistant to medication and over time become one of the most incapacitating symptoms (Blin et al., 1990).

One origin of gait impairment is deficient internal timing, the mechanism that precisely times and coordinates every movement

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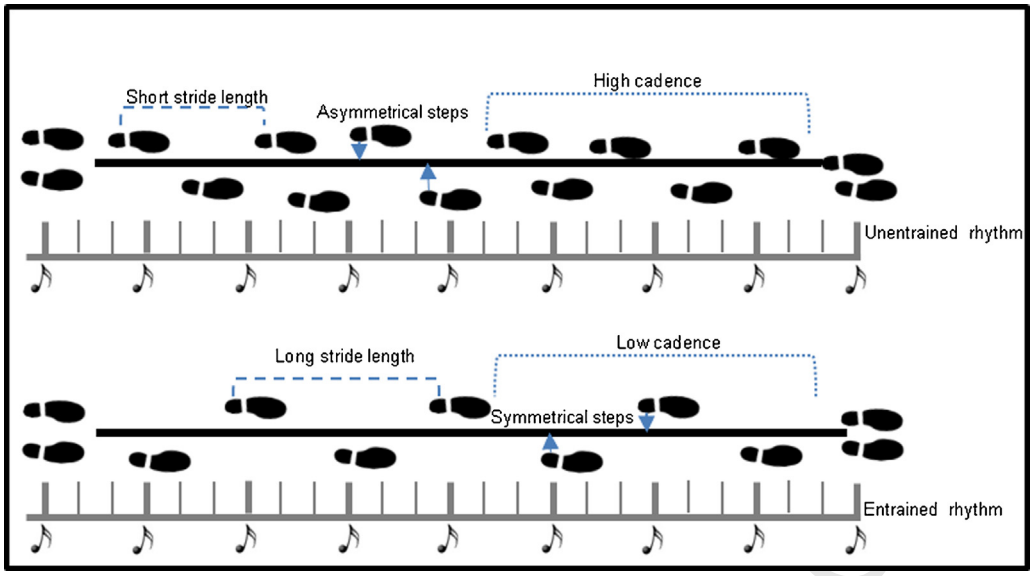

Fig. 1. Schematics of various gait parameters in PD patients with and without rhythm entrainment. The top section depicts a walking pattern before training, characterized by short stride, high cadence, and asymmetry of the steps, which are not synchronized with the music beats. The lower section shows entrainment of gait to the rhythmic beats, with longer stride length, lower cadence, and more symmetrical steps, typical of a more stable gait.

of our body (Jones et al., 2008; Wearden et al., 2008). In PD, the irregular timing of walking pace suggests a disturbance of coordinated rhythmic locomotion (Ebersbach et al., 1999; Skodda et al., 2010; Thaut et al., 2001). Music rehabilitation program make use of acoustic stimuli that enhance the connection between rhythmical auditory perception and motor behaviour (Thaut, 2005), and aim to elicit sustained functional changes to movement in patients, improving quality of life and reducing reliance on medication (Rochester et al., 2010b). Although the beneficial effects of music on gait in PD were initially reported some years ago (Miller et al., 1996; Thaut et al., 1996), more recent work has used music to complement pharmacological therapy. A number of studies have demonstrated that musical rhythm can improve gait and there is general agreement about the promising value of music therapy in PD (Arias and Cudeiro, 2008; Fernandez del Olmo and Cudeiro, 2003; Lim et al., 2005; Rochester et al., 2009; Satoh and Kuzuhara, 2008; Thaut and Abiru, 2010).

However, the scientific basis for the effects of music and rhythm on gait needs reviewing. A precise description of how music influences motor function is essential for designing effective therapeutic programmes in PD. Furthermore, alternative measures, such as neurosurgical treatments, are not suitable for all patients, are expensive and may result in additional complications, which make their application or widespread use challenging. Additionally, pharmacological therapy does not solve gait problems in the long term. After years of examining the effectiveness of rhythm on PD, it is now necessary to discuss: (1) what makes rhythm effective, (2) what other tools, such as neuroimaging, have added to current music-motor knowledge and, (3) which questions remain unanswered regarding motor rehabilitation for PD. In this review we discuss the effects of music on movement, provide an explanatory framework of the neural mechanisms that underlie the processing of musical rhythm, describe how rhythm triggers the motor network, and link this evidence to different Neurological Music Therapies (NMT) assayed to date.

1. Why is rhythmically modulated sound a good therapeutic key for tuning motor function in PD?

The improvement of patients' gait in the presence of external regulatory rhythmical stimuli has been known for over forty years: early studies described functional connections between the auditory and motor system (Rossignol and Jones, 1976). Years later, Thaut and colleagues described how rhythmical auditory stimulation could influence the motor system (through muscle entrainment to auditory stimuli) in PD patients, improving gait parameters such as speed, cadence and stride length (Thaut et al., 1996). These findings were confirmed by other studies (Hurt et al., 1998; McIntosh et al., 1997; Miller et al., 1996; Thaut et al., 2001) that showed that beneficial effects on walking speed persist (albeit briefly) even after stimulus presentation has stopped (McIntosh et al., 1998; Nieuwboer et al., 2009a).

A systematic review (Lim et al., 2005) of the use of rhythmic stimuli in PD supports the effectiveness of auditory stimulation compared to other types of stimulation such as visual, somatosensory (tactile), or combined auditory and visual cues. Studies using auditory cues provided reliable evidence for improved walking speed, stride length and cadence. Although both visual and auditory stimuli may improve gait in PD (Lim et al., 2005), the characteristics of the human auditory system make it a better therapeutic target for two main reasons: (i) reaction times for auditory cues are 20–50 ms shorter than for visual or tactile cues; (ii) the auditory system has a strong bias to detect temporal patterns of periodicity and structure, compared to other sensory systems (Thaut et al., 1999a).

Temporal patterns, or timing mechanisms, are necessary for coordinating precise and structured movements (e.g. handwriting, typing, talking, and walking). In pathological conditions, if faulty timing processes lead to impaired motor performance, musical rhythm could be used to influence the motor system: The temporal sensitivity of the auditory system in combination with the strong temporal characteristics of music (rhythm) can potentially provide a regularizing temporal input to the motor system. Most NMTs have used a strong 'beat' to help initiate movement. A beat is a series of regular, recurring acoustical events. Phenomenologically, beat (or pulse) can be considered a percept; "a response to patterns of timing and (depending on the theorist) stress in the acoustic rhythm" (p. 190) (Large, 2008) which generates a strong temporal expectation of subsequent beats. Although the beat is initially derived from the auditory stimulus, rhythm can also induce an internally generated sense of beat and once the pattern has been established it can continue in the mind of the listener even when the rhythm pauses (Benjamin, 1984; Lerdahl, 1983; Palmer and Krumhansl, 1990). The

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