Towards personalised music-therapy; a neurocomputational modelling perspective

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***Abstract*—Music therapy has emerged recently as a successful intervention that improves patient outcomes in a large range of neurological and mood disorders without adverse effects. Brain networks are entrained to music in ways that can be explained both via top-down and bottom-up processes. In particular, the direct interaction of auditory with the motor and the reward system via a predictive framework explains the efficacy of music-based interventions in motor rehabilitation. In this manuscript, we provide a brief overview of current theories of music perception and processing. Subsequently, we summarise the evidence of music-based interventions primarily in motor, emotional and cardiovascular regulation. We highlight opportunities to improve quality of life and reduce stress beyond the clinic environment and in healthy individuals. This relatively unexplored area requires an understanding of how we can personalise and automate music selection processes to fit individual needs and tasks via feedback loops mediated by measurements of neuro-physiological responses.**

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MUSIC IS UNIVERSAL ACROSS CULTURES and similar to language it has expressive and motivational roles. Fundamental properties in music composition are the presence of a rhythmic structure and in music perception is one's innate ability to synchronise to the rhythm, called **sensorimotor synchronisation (SMS)** [1]. Rhythm and synchronisation also facilitate human communication by modulating attention, which is observed even in an infant's perception and response to musical stimulus [1]. Intriguingly, several neuro-developmental and neurological disorders are linked to deficiencies related to rhythm, timing, and synchrony processing [2]. In fact, rhythm and time perception involves interactions between the auditory and motor systems.

The use of music has become an integrated tool in the daily lifestyle for adults via streaming platforms and portable devices that can provide personalised playlists according to users' music preferences. Hence its therapeutic benefits and application in a clinical setting have been confirmed in well-controlled randomised trials [3]. To optimise and personalise the efficacy of these methods to specific patient groups and to improve well-being in healthy adults, it is imperative to understand which specific characteristics in music can give rise to its therapeutic benefits. Equally important is to enable biofeedback via intelligent algorithms that take into account the neurophysiological responses of the individual.

The application of music to support some form of rehabilitation in a clinical setting, known as music therapy, was considered to be a social science. However, with recent advances in cognitive brain imaging, models of music perception have been developed that can benefit both patients and healthy humans. Understanding the effects of music on brain dynamics can help us shape music therapy techniques. In this review, we summarise the key concepts behind models of musical perception and processing that underpin current evidence from brain imaging studies and explain the efficacy of music-based therapy in a broad range of clinical and psychiatric disorders. Firstly, we discuss how communication between the auditory-motor networks and external rhythmic cues in an **oscillatory neurodynamics model** achieves a sufficient level of entrainment as demonstrated by synchronisation to the beat of the music [4]. We highlight Neural Resonance Theory (NRT) as a generalised framework for describing music perception as dynamic systems of coupled neural oscillators. This formulation allows the incorporation of developmental principles by changing the strength of coupling between oscillators to reflect Hebbian Plasticity. Finally, we explore three major formulations of predictive-coding models, namely the Predictive Coding Model of Music (PCM), the Predictive Coding model of Rhythmic Incongruity (PCRI) and the Action Simulation for Auditory Prediction (ASAP). In these models, musical perception is the result of expectations, generated from prior experiences and knowledge, compared to the sensory input.

Subsequently, we summarise current evidence of music-based interventions in neurorehabilitation, as well as regulation of affective states and cardiovascular function. Finally, we highlight key challenges in automating and personalising music-based interventions in the community. A vital consideration of the implementation of music therapy is that positive effects are limited in duration. In other words, in patients with movement disorders, for example, the improvements in gait parameters will decrease if the treatment is discontinued. Current evidence suggests that music therapy could be an ideal intervention to apply in the community with patients being able to continue practising exercises with minimal equipment and effort to execute. Nevertheless, it also highlights the importance of ensuring that the intervention is supported such that patients are encouraged to continue to maintain the beneficial rewards.

Models of Music Perception and Processing

Early works on understanding how music affects the brain and its potential therapeutic benefits have focused on rhythm and entrainment. Entrainment is a universal phenomenon that describes the process of interaction between independent rhythmical processes. One example is in the coupling of the musical beat and index tapping as modelled according to the Haken-Kelso-Bunz (HKB) model [5]. Importantly, entrainment does not necessarily require in-phase synchronisation between rhythms of matching periods. Different rhythms can entrain in hierarchical or polyrhythmical relationships. In particular, the levels of the oscillatory hierarchy can be reflective of the rhythmical structure, such that the period of the oscillation is proportional to each level of note duration. Polyrhythm is the simultaneous presence of two or more rhythmically contrasting rhythms in which an unequal number of beats is spaced out equally within the same measure, for example, three beats, known as triplets, against two beats (three-against-two). This can be represented in the oscillatory model as lower levels of the rhythmic structure may exist in anti-phase with one another but be in-phase with higher levels creating the polyrhythmical structure.

Neural entrainment is shown to be evident in rehabilitative techniques, for example, auditory rhythmic patterns can entrain movement in patients with motor disorders [6]. Although the biological basis of neural entrainment is not fully understood, temporal modulation of the beta band (13-35 Hz), which dominates oscillations in sensorimotor and motor areas of the brain is thought to play a key role [6]. The phase relationship is maintained even after the stimulus stops, which provides an anticipatory mechanism that is used to predict the next beat.

These observations have led to an **oscillatory neurodynamics model** representation of nonlinear brain responses induced by a musical stimulus [4]. The oscillatory neurodynamics model assumes that rhythm is a hierarchical structure of coupled 'active, self-sustained oscillator' [7]. The oscillator's role is to synchronise with the external rhythms such that the phase of the oscillator becomes a representation of the beat onset in the rhythmic sequence. The coupling of multiple oscillators gyrating at different periods, represents the different temporal levels of the metrical structure, with the time at which the coinciding peaks of the different levels of oscillators representing the 'strong' beats. Furthermore, there exists a 'sensitive region' within the oscillator's period acting as a representation of the likelihood of the beat falling within that time period. As a result of this region, temporal fluctuations that occur in natural performances are processed without it affecting the perception of the overall tempo. Large and Palmer [7] indicate that it is the coupling of the multiple oscillators that provides support for its beat-tracking ability. It represents the relationship between metrical levels such that one can stabilise another should it begin deviating [7]. In other words, the model provides a computational depiction of our ability to overlook temporal fluctuations for expressive quality, whilst also adapting our beat perception if the beat is consistently heard outside of our 'sensitive region' of prediction.

Closely linked with the oscillatory neurodynamic model, **the dynamics of attending (DAT) theory** specifies entrainment between attending rhythms to the auditory rhythms to track time-varying events [8]. In particular, attentional focus increases at points that are predictable and temporally regular [8], therefore enhancing processing. Subsequently, the neurodynamical model is perceived as a theory of prediction. Predictions are 'actively made' in an anticipatory manner as a result of its time-delay characteristics [5], for example, in the listener's ability to anticipate the next beat before it is heard [6].

The **Neural Resonance Theory (NRT)** defines entrainment as coupled neural oscillators that obey the laws of mathematical dynamical systems of oscillation such that they are *physical* oscillations and not a representation of the external musical rhythm [1]. Tichko et al., [1] propose a developmental theory grounded in NRT with **Hebbian Plasticity** to present a dynamical system of perception that encompasses neurodevelopmental principles. The external musical oscillations are proposed to resonate with the biophysical oscillations in a law-governed manner, such that structural regularities become established in perception, action and attention [1]. The additional process of Hebbian Plasticity serves to attune the oscillations with the environment through adjustments of the coupled oscillators. The development of dynamic memories of complex rhythmic patterns is the result of changes in amplitude and phase relationship between coupled oscillators, representing the strength of the synaptic connection of 'neurons that wire together, fire together'. Application of this theory to model infants' perception and development of musical rhythm has proven that the oscillatory neurodynamics model encompasses both bottom-up (perception is built solely on received sensory information from the environment) and top-down processes (prior knowledge and experience is used to shape perception and interpret sensory inputs). Infants that received auditory-vestibular training, in the form of bouncing, shaped their neural response when tested on unaccented rhythms, suggesting that a combination of multiple sensory inputs will elicit stronger resonance. Developmental plasticity was reflected in stronger auditory-vestibular oscillatory connections achieved during the training phase [1]. Tichko's et al., [1] contemporary application of neurocomputational models to explain music perception at a neural-pathway level is an example of new advances in modelling musical perception. While both neurocomputational (low-level neuronal processes) and higher-level cognitive models are important for understanding music perception and cognition, each has limitations. Detailed computations that model the relationships between neural networks might not be captured in their full complexity in high-level cognitive models from a macro-level perspective. However, neurocomputational models may provide too isolated an account of music perception and therefore fail to cope with large-scale integration of neuronal systems that explain behavioural responses.

Whilst, the oscillatory neurodynamics model explains musical perception under mathematical dynamic systems of neuronal entrainment, the **Predictive coding of music model (PCM)** exploits active inference, stating that perception, action and learning can be modelled as a recursive Bayesian process. The predictive-coding of musical characteristics such as melody, rhythm and harmony and its link to music perception, action, learning and emotions illustrates music listening from a top-down perspective. Expectations are generated from previous experience and therefore *inferred* by contextual factors such as cultural background, musical competence and individual traits [9]. **Prediction errors**, defined as the difference between the *predicted* and the *actual* sensory input, are attempted to be minimised through the statistical weighting of each prediction error based on their expected *precision* [9]. The internal model is proposed to be constructed of a *hierarchical structure* of networks such that prediction errors ascend through the levels to update higher levels of processing and result in predictions being cascaded down to resolve lower-level prediction errors [10]. This top-down and bottom-up communication serves to continuously update the model and therefore minimises variational *free-energy* [11]. **Event-related potentials (ERPs)** such as the **mismatched negativity (MMN)**, particularly its amplitude, can be used as preattentive markers of predictive errors [9]. MMN occurs as a response to an auditory "oddball" or deviance from the established structure.

The **Predictive Coding of Rhythmic Incongruity (PCRI) model** [9], is introduced as a formal application of the PCM for musical rhythm exclusively. The PCRI model explains the feelings of "wanting to move with the music", known as groove, under the experience of 'incongruent' note onset that disturbs the regular flow of rhythm (syncopation) and the listener's urge to 'correct' these prediction errors [9]. Neuroimaging findings support the pleasurable notion of 'groove' with activations in the motor and reward networks including the basal ganglia [12].

The **Action Simulation for Auditory Prediction (ASAP)** hypothesis suggests that 'pure' beat perception also involves generations of simulated motor actions [13], despite no physical movement. The ASAP model explains the listener's readiness to 'move' [6] as a result of a predictive process. Patel and Iversen [13] hypothesise that there exists a two-way relationship between the auditory and motor planning regions. Specifically, the temporal information of auditory stimuli is initially received by the auditory regions and communicated to the motor region, whereby the timing of this communication influences the period of the signals within the motor planning regions. This in turn allows neural activity within the motor cortex to be entrained to the beat, known as the 'simulated action'. Finally, the motor regions return this signal to the auditory regions to facilitate predictions of subsequent incoming beat times [13]. In other words, the motor planning region of the brain facilitates the perception of musical beats by 'simulating' the periodic 'action'.

One limitation of the theory is that it does not explain how our perception is translated into physical movements or the computations that take place behind the predictions [4]. Instead, it is assumed that the movements are a natural consequence of the motor planning regions influencing nearby regions responsible for the governing of movement [13]. In other words, the model does not consider our ability to detect the beat amongst the rhythm or give weight to the listener's ability to isolate the pulse within a rhythmic sequence, unlike in the neurodynamical models previously described. Both the predictive-coding approach and the neurodynamical model individually do not provide a comprehensive account of musical perception from a neurological perspective. Vuust et al. [9] propose that perhaps a combination of the two models could provide a more satisfactory modelling of our musical perception and processing.

Another intriguing observation is that predictable music is not necessarily associated with pleasure [14] - instead this is most commonly met with feelings of annoyance. One resolution to this conundrum rests upon music's 'epistemic offering' [10]. Cheung et al., [11] propose that the retrospective and prospective states of expectation - surprise and uncertainty respectively, are important additions to understanding the role of musical pleasure in the predictive-coding model. Activations of the nucleus accumbens (NAcc) and the use of the dopaminergic pathway were proposed to facilitate musical pleasure by directing the listener to 'want to find out what happens next' to resolve the uncertainty in the music. Cheung et al., [11] suggest that the level of dopamine release represents the precision or inverse of uncertainty, of the prediction errors in the free-energy principle.

The threshold of pleasurable 'surprise and uncertainty' can be modelled by a power law of temporal fluctuations, as proposed in the **1/*f* distribution** [14]. The conclusion deduced from an extensive collection of compositions ranging across four centuries and several genres of Western music that obeyed this 1/*f* rhythmic structure suggests that this fractal relationship could be key to accomplishing the 'right level' of synchronisation for enjoyment. Despite, the 'uncertainty' that is proposed to derive pleasure in fractal structure, listeners are still able to anticipate temporal fluctuations as modelled by the neurodynamical model [15]. This anticipatory behaviour is suggested to be guided by the long-term structures and not dependent on musical skill or training [15].

Music in Neuro-rehabilitation and Regulation of Emotional and Cardiovascular Systems

One of the most natural and inherent responses to music is to synchronise our bodily movements to the rhythmic structure. The effortless and often subconscious onset of movement is an example of the deeply ingrained relationship between the motor and auditory processing networks [13]. Therefore, it is not surprising that this biological relationship has been exploited in the field of motor rehabilitation [16]. In neurological disorders, despite continuous pharmacological advances, gait/motor impairments notably can be resistant to medication, often only contributing to symptomatic relief as opposed to remedying the underlying pathology [17]. Furthermore, with all pharmacological interventions, there can be harmful side-effects to health and quality of life, for example, toxicity and loss of drug efficacy [17].

One branch of music therapy that centres around neurorehabilitation is **Neurologic Music Therapy (NMT)** which is defined as 'the therapeutic application of music to cognitive, sensory and motor dysfunction due to neurological disease of the human nervous system' [3]. An example of a NMT used for cognitive rehabilitation is **Music Sonification Therapy** which has been frequently employed in stroke rehabilitation. Sonification is broadly defined as the use of non-speech audio to represent information [18]. The musical intervention improves motor abilities that have been affected by a neurological disorder such as stroke by retraining gross motor functions through the use of repeated movements of the affected limb [18].

One of the most common techniques to obtain gait harmony in music therapy is the application of **Rhythmic Auditory Stimulation (RAS)**. RAS takes advantage of our natural driving force to move as a response to listening to music and utilizes the coupling of the auditory-motor networks to promote a stable and adaptive walking pattern in patients with gait deficits as a result of some neurological conditions such as stroke, Parkinson's disease or traumatic brain injury or general effects of ageing [19]. Characteristics of an abnormal gait pattern include shuffling, decrease in walking speed, shorted stride length and asymmetric stride durations [17] which often leads to high risks of falls. RAS is built on the entrainment of motor functions to the external timekeeper in the musical stimuli. The synchronisation between the external beat and steps indicates a phase-lock and entrainment of the auditory and motor system [16].

There is a large body of research underpinning the use of rhythm and music-based interventions for the neuro-rehabilitation of a large range of neurological and neuro-developmental disorders. Recent randomised controlled trials have shown that music-based interventions are effective in motor rehabilitation in a variety of conditions [6]. Seebacher et al., [20] report that RAS during walking results in significant improvements in cognitive and physical fatigue as well as quality of life of patients with multiple sclerosis. Tong et al., [21] showed significant improvement in post-stroke patients' upper-limb motor function. Sihvonen et al. [19] also summarise results from 16 randomised trials in stroke-related neurological disturbances, which showed significant improvement in gait training with musical support. Music therapy has also resulted in improvements in speech and cognitive recovery for stroke patients [19]. In patients with Parkinson's disease, music therapy with a coupling between movement and music has shown consistent and clinically significant results in improving motor symptoms [19]. Exposure to music has also shown a significant reduction in seizures in epileptic patients [19]. For detailed reviews on music-based interventions, the reader can refer to Janzen et al. [6], which provides a comprehensive summary of studies on music and motor rehabilitation, whereas Sihvonen et al. [19] provides a review on music interventions in neurological rehabilitation and Steen et al. [22] summarises current progress in music interventions for dementia. A graphical summary of the distribution of publication years and the number of participants included in each study can be found in Figure 1. Furthermore, Figure 2a and 2b illustrate the distribution of firstly, the intervention used and the participant's diagnosis and secondly, the diagnosis against the improvements observed.

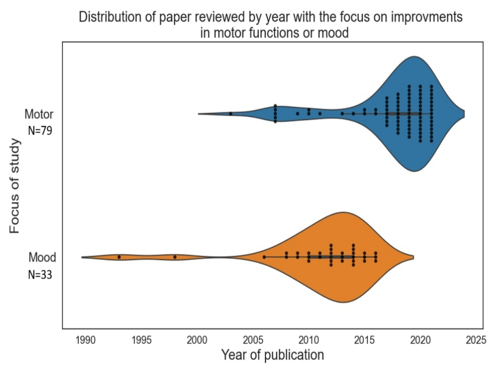
Music also has a strong established anthropological and sociological role in society, conventionally associated mood-regulating properties [3]. It is commonly accepted as one of the strongest tools used to arouse an affective state or provoke an emotional response [23], with this property being one of the most cited reasons why listeners value music [24]. There is strong evidence that suggests that music interventions can improve the outcome of patients with depression as well as alleviate depressive symptoms interleaved with other neurological disorders such as dementia and Parkinson's disease. A recent meta-analysis of seventeen randomised control trials with patients with dementia suggests that music-based interventions improved symptoms of depression whereas it was unclear whether it improved the overall quality of life, agitation and cognition [22].

One goal of music listening, in a therapeutic context, is to reduce stress and increase feelings of relaxation that can be achieved via the engagement of the parasympathetic branch of the autonomic nervous system [25]. Kulinski et al. [26] provide a summary of several studies that show how cardio-respiratory variables, such as heart rate (HR), heart rate variability (HRV), blood pressure (BP) and respiration are modified with music-based interventions. Evidence also shows that music has positive effects on physical performance and endurance.

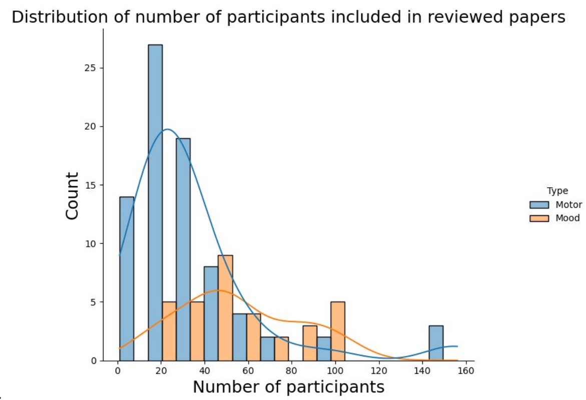
Music-based interventions can also have a profound effect on work environments. Occupational stress and mental health problems are considered a 'Health Epidemic of the 21st Century' by WHO organisation [27]. Large experiments on more than 600 participants in occupational settings demonstrated that just 10 minutes of music listening improved working memory along with self-perceived stress and measures of sustained attention [27].

Shaping Music-based Interventions

Music emerges as a powerful way to improve health outcomes and well-being without pharmacological interventions in both patients and healthy people. One of the key principles of music therapy is that it is tailored to the participant's condition, goal and abilities [6] such that it is



(a) Distribution of publication years and the primary focus of the study.



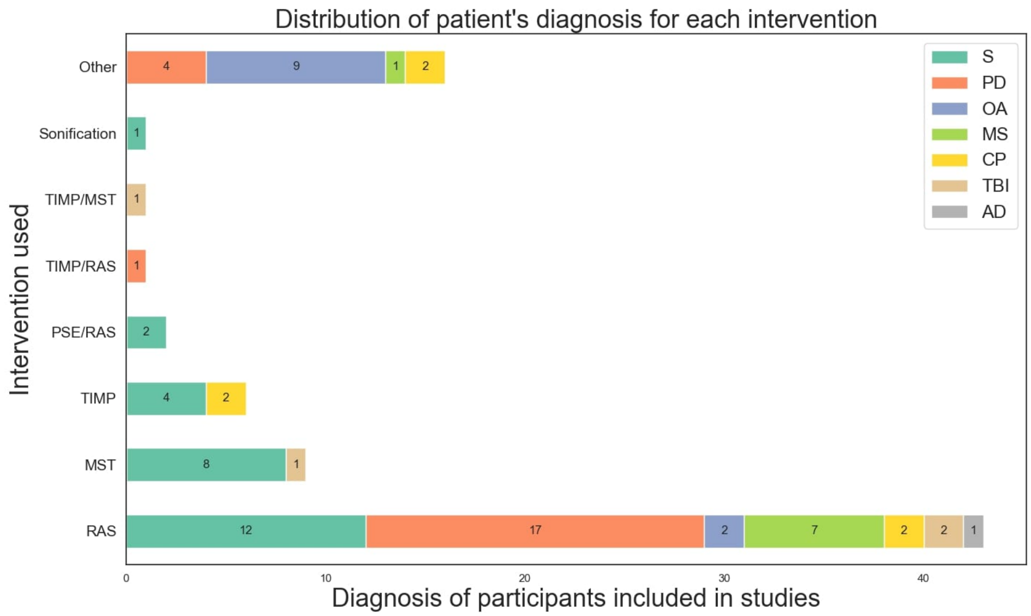
(b) Distribution plot of the total number of participants.

Figure 1: Distribution of the publication year and number of participants in papers reviewed in [6], [19], [22]

not a 'one-size-fits-all approach'. Therefore, one challenge is selecting the musical features that would optimise the efficacy of music therapy. For example, the initial cadence or tempo is an important factor in the effects of the intervention in gait rehabilitation. Too slow of an internal cadence can lead to prolonging the time for a movement to be made and increases the danger of motion reinvestment, which implicates conscious control [17]. Automatic motor processes become disrupted and additional attentional resources are then required [17]. On the other hand, too fast of an initial tempo can lead to exceeding the participant's current physical capabilities which could lead to worsening conditions, feeling of disheartening and demotivation and place the participants into a state of high-stress [17]. In RAS, the rhythmic cues are chosen to coincide with the participant's initial cadence and incrementally increased or decreased by 5-10% once the movement speed is entrained [6]. Setting the baseline as the participant's current or natural frequency enhances kinematic stability promoted by rhythmic entrainment as the initial movement parameters are optimised and stabilised [3]. Furthermore, in a review conducted by Janzen et al., [6] it was commented that the inconsistency of the effect of auditory cues on stride length variability across different studies could be due to the result of not tailoring initial cadences to the participant's baseline. They highlight the demand for additional research into optimising RAS cadence individually and taking into consideration external factors such as participants' previous musical training and rhythmic abilities [6].

In the most fundamental form, musical stimuli are often simply metronome beats that yield promising results in improving spatiotemporal gait parameters, such as stride length, velocity, cadence and symmetry [16]. However, these positive effects were not permanent as shown by a significant decrease in spatiotemporal gait parameters (velocity and stride length significantly decreasing) once the RAS-training was discontinued [28]. This emphasises the need for continuous intervention so that it can be implemented in a community setting for patients to continue training in their own homes for these effects to be maintained. Janzen et al. [6] conducted a withdrawal/discontinuation design study in which when the participants entered an 8-week discontinuation of RAS-training, during which the number of falls significantly increased and significantly decreased again once RAS-training resumed in week 16.

Incorporating an emotional-motivational quality of music as a desirable secondary effect could be the solution to enhancing music therapy as a long-term intervention [3]. Key features that have been explored are the level of beat perception, familiarity and level of groove perceived, often characterised by strong, salient beats [29][30]. Higher levels of beat salience reduce the need for beat finding, therefore, reducing cognitive demands of synchronisation during RAS and positive effects on stride velocity and length.



(a) Discrete distribution of participant's diagnosis against interventions used in [6], [19]
RAS = Rhythmic Auditory Stimulation, MST = Music-supported Therapy, TIMP = Therapeutic Instrumental Music Performance PSE/RAS = Patterned Sensory Enhancement/Rhythmic Auditory Stimulation, RAS/TIMP = Rhythmic Auditory Stimulation/Therapeutic Instrumental Music Performance, TIMP/MST = Therapeutic Instrumental Music Performance/Music-supported Therapy. 'Other' includes studies that either did not specify the type of music intervention, instrumental training or playing and/or music listening.
Further description of each intervention can be found in [3] and [6]

(b) Discrete distribution of improved outcomes against participant's diagnosis in [6], [19], [22].
S = Stroke, PD = Parkinson's Disease, OA = Older Adults, MS = Multiple Sclerosis, CP = Cerebral Palsy, TBI = Traumatic Brain Injury, D = Dementia.

Figure 2: Discrete distributions of papers reviewed in [6], [19], [22]

Familiarity modulates musical pleasure by exploiting the anticipation built from cultural or personal influence from previous exposure. In other words, a sense of predictability or familiarity is perceived to be pleasurable [31]. Musical pleasure derived from familiar music is correlated with increased blood oxygen level dependence (BOLD) in the reward systems, including the NAcc and putamen [32]. It can be argued that the mechanisms that underlie the effectiveness of music-based interventions in episodic memory are driven by the reward brain network [33]. Familiarity in the musical pieces can trigger long-term autobiographical memories unique to each listener and revive feelings associated with the people, location and conditions that were connected to the experience as shown in activations in the hippocampus [25]. This factor can play an important role in neuro-degenerative processes that affect episodic memory such as in dementia and Alzheimer's disease. Tichko et al., [34] observed strong neural entrainment in older adults listening to self-selected music, suggesting that familiarity and the associated pleasure in music listening can aid in preserving neural connections employed in rhythmic perception that may have deteriorated as a result of ageing. Additionally, there is strong evidence that vocal music listening enhanced verbal memory recovery in stroke patients that suffer from aphasia [35], in addition to improvement in anxiety and depression [25].

One prevailing challenge when exploring the benefits of listening to music, in particular the listener's emotional response, is that often researchers are reliant on the use of subjects' feedback through self-reports that map the stimulus to a small set of predefined emotions [36]. These are subjective and influenced by social and cultural norms, often only taking into consideration four to five types of discrete emotions, which is difficult to obtain regularly in relation to the musical time scale. Subsequently, as the result of the reliance on the subject's feedback through self-reports when listening to music, there is difficulty in distinguishing and validating if these reports are of felt or perceived emotions.

Other methods include measuring physiological data including electrodermal activity, blood volume pulse, skin temporal and pupil dilation. For example, decreases in heart and respiratory rates can signal a reduction in feelings of stress and anxiety [37]. Although physiological data can provide a measure of emotional arousal, they are arguably an indirect measure of the autonomous nervous system function, which might undermine the effects of music entrainment on other major brain networks. Perhaps, a combination of physiological recordings with cognitive screening might be able to result in more accurate models of brain function modulation via brain-computer interfaces. In this way, research can shed light on which elements of the musical structure have a significant effect on music-based interventions.

There exists a compromise between the ability to accurately record brain activity and carry out experiments such that they are ecologically valid. The integrated use of music in daily lifestyle suggests we do not use music solely for entertainment purposes but also as a secondary function as aiding concentration on the main task, for example, whilst studying or working. Students report that music enhances concentration and it also encourages motivation and enjoyment of completion of the main task [24]. In the same way that the choice of music is important for effective neurorehabilitation, the choice of background music is critical to prevent distraction and undesirable effects. Again, the deciding factor in what makes a piece of music 'good for concentration' seems to point to the listener's preference and an optimal level of enjoyment in comparison to other aspects such as genre [38]. This has led to the proposition of automated recommending systems of background music while working. For example, FocusMusicRecommender [38] creates an automatic playback function to support maintaining concentration on the main task by taking away the need for the user to select songs during work.

There is a compromise between moderate levels of enjoyment that would motivate the listener to focus on the main task and high levels of arousal that could distract them. Therefore it was recommended to focus on selecting songs that users may not like or dislike in an aim to maintain concentration [38]. Only recently it was recognised the need to personalise therapeutic music to an individual needs [39]. It remains elusive how this can be measured outside laboratory settings. One suggestion is the use of crowdsourcing to evaluate the use of music interventions in the workplace [27]. This involves mobile apps that measure sustained attention, working memory and perceived stress through the completion of cognitive games. An advantage of this method is that it might remove response biases related to social acceptance. The field of crowdsourcing in music interventions has recently shown evidence of good potential but there are still several open questions on how to personalise music interventions online to enhance their acceptance and efficiency.

An important implication of the connection between auditory and reward systems is that this motivates a reinforcement learning framework that influences the predictive coding model. Recently, it has been demonstrated that neuronal pathways between auditory and reward systems drive learning by musically elicited 'reward prediction errors' [40]. This is demonstrated in the individual differences in learning rates and explains why music-personalisation can play an important role in music-based interventions. In patients with Alzheimer's disease, it was suggested that the acute arousal and consequently enjoyment of patient-selected music resulted in greater benefits in cognition and behaviour compared to clinician-chosen music [25].

However, the notion of enjoyment is complex in itself. It might naively be assumed that listeners would not express musical pleasure from a piece that evoked a negative emotional response, but as Vuust et al., [9] suggest, valence and enjoyment are not equated. We cannot presume that just because a piece of music evokes a negatively valence emotion, the listener does not enjoy it. In fact, sadness has been cited as the eighth most common emotion [9], with reports that it provides a cathartic release and therefore eases feelings of aggression [24]. This dissociation supports the important role of predictability in enjoyment rather than the specific emotion evoked. Furthermore, evidence from cardiovascular physiology suggests that emotional arousal has stronger effects than the emotional valence of the underlying music piece [26]. Therefore, it might be more appropriate and effective to explore the notion of 'enjoyment' as opposed to a specific emotional response.

This is an easier measurement for participants to report since it does not require a complex mapping between stimulus and affect. Additionally, it can be measured through physiological responses that reflect increased heart rates and perspiration [9]. These responses are also associated with activations in the reward system such as dopamine release in the striatal system - including the caudate associated with anticipation and the NAcc correlated with feelings of reward [9]. Secondly, it is arguably easier to manipulate the musical 'grammar' or 'syntax' to create desired effects of expectations violated or fulfilled while listening to music and therefore notions of enjoyment.

In general, the field of music therapy arguably lacks standardisation. Different associations emphasise different requirements such as the involvement of a qualified music therapist or health practitioner to supervise sessions [22]. Consequentially, this has led to some literature adopting the term **Music-Supported Therapy (MST)** as often studies do not comprise a qualified music therapist. Furthermore, a 'researcher-friendly' dataset of musical extracts does not currently exist for widespread use [23]. One step towards a more standardised proposed solution is the employment of existing datasets related to musical mood, allowing ease of comparison of validity in results and methodology [23].

Conclusions

In the field of music therapy, the use of music has been shown to exceed its archetypal characteristic of simply mood regulation and entertainment purposes. Advances in the use of music to support neuro- and physical rehabilitation prove that it is a compelling contender to current interventions used in the healthcare sector. Building from models of rhythm perception and processing, concepts of predictive-coding and oscillatory relationships between neural networks have been adopted to entrain patterns of stability in gait abnormalities, promoting faster and less variable strides. Further positive secondary outcomes include improvement in overall quality of life, feelings of motivation and reduction in feelings of stress. Despite promising results, the importance of tailoring interventions was also discussed, including the initial pulse of rhythmic stimuli to match the participant's natural cadence, such that maximal gain can be extracted. Choosing the 'correct' musical stimuli was shown to be crucial to avoid an increase in cognitive load and causing mental fatigue. However, this was noted to have its own additional challenges. The development of effective interventions that do not rely on medication and can be transferred into the community easily provides an encouraging prospect for long-term treatment that can eventually replace or complement traditional methods.

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