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# Beating Dyslexia: Can Specialised Interventions Be Developed for Reading Difficulty Rooted in an Auditory Rhythmic Deficit?

Ruby Topping
*University of Durham*

## ABSTRACT

Currently, no diagnostic test or treatment is any more effective for developmental dyslexia than for poor reading ability of any other cause (Elliott & Grigorenko, 2013). This paper argues for classification and treatment of reading difficulties by their aetiological bases, as opposed to behavioural symptoms. Furthermore, this review article investigates the place of a rhythmic deficit conception of reading difficulty in the wider context of current practice and research. It looks in particular at reading difficulties rooted in temporal auditory processing deficits. These deficits are hypothesised to underlie many cases of developmental dyslexia (Flaugnacco et al., 2014). The article reviews existing literature on temporal and spectral auditory processing deficits and their impacts on phonological development (Fraser et al., 2010; Snowling & Hulme, 2012; Goswami, 2018). It investigates the use of therapies which use musical rhythm and metre to create something akin to an ethological “supernormal” stimulus, which exaggerates the properties of the acoustic signal useful for speech processing. These stimuli can, in theory, prime the brain for later stochastic processing of language using rhythmic and metrical landmarks (Goswami 2018, Cancer et al., 2019). This article concludes that rhythmic interventions delivered prior to phonological training could maximise its impact for the large number of dyslexic individuals whose difficulty stems from a rhythmic auditory processing deficit.

## 1. SOUND FOUNDATIONS

Developmental dyslexia is characterised by a specific and long lasting difficulty in decoding written text, in individuals with adequate instruction in reading, and no sensory or neurological deficits (Snowling & Hulme, 2012). This widely accepted description of developmental dyslexia tells us what the disorder looks like and what it is not, i.e. poor teaching, or bad eyesight. Because of the heterogeneity of present neurobiological deficits and the complexity of social stigma around poor reading, however, there is low consensus as to the root causes of dyslexia. The hypothesis I will develop in this article is the most widely accepted, which posits a core congenital deficit in auditory processing, particularly temporal and rhythmic processing.

Phonics-based teaching programmes are proven to be consistently effective for those with a dyslexia diagnosis. Why should we then characterise dyslexia, which presents most obviously as a reading difficulty, as a rhythmic disorder? In short, some scholars assert that the current diagnosis of dyslexia has limited validity and usefulness, necessitating a reconception of reading difficulty. There are two key reasons for this. Firstly, dyslexia is currently diagnosed by its primary presenting symptom of poor reading alone, not its aetiology. Secondly, current interventions for dyslexia are thus no more effective for dyslexic individuals than for those with another kind of reading difficulty. Alternative terminology and diagnostic methods that isolate temporal auditory issues from the relatively complex and variable symptom of ‘poor reading’ may lead to the development of more effective intervention.

Though the phonological awareness deficit underpinning most instances of dyslexia is thought to arise from congenital neurodevelopmental abnormalities, evidence suggests that appropriate training can effect change in brain systems and function, improving symptoms (Sulkes, 2018). One appropriate intervention may be rhythmic training. Most dyslexic children who present with poor reading also present with difficulties in musical tasks like rhythm replication and metrical perception (Huss et al., 2011). Music training can effect changes in primary auditory brain regions thus improving processing of sound features that play a major role in speech processing, thereby reducing the impact of the disorder on reading (Cancer, 2019).

## 2. AUDITORY PROCESSING IN DYSLEXIA

Developmental dyslexia, in a majority of cases, is thought to consist of a core deficit in phonological awareness (the ability to attend to, discriminate, remember, and manipulate the sound units of spoken language) which has a significant indirect impact on the acquisition of reading (Lyon et al., 2003; Fraser et al., 2010; Snowling & Hulme, 2012). Reading is, cognitively speaking, a re-coding of visual information into the target phonological information. Phonological awareness deficits, then, could be described as information gaps on the ‘target’ side of the code. Temporal and spectral auditory processing abilities are key to phonological development, and improving these is therefore an important treatment aim (Steinbrink et al., 2019).

The phonological deficit is not the only major deficit associated with dyslexia. A large brain imaging study of individuals diagnosed with dyslexia (Pernet et al., 2009) suggests a multifocal explanation. Reading involves magnocellular (processing moving visual stimuli), auditory, working memory and motor processes. The presenting symptom of poor reading may therefore be caused by deficits in any one of these areas, or any combination thereof. Pernet and colleagues also note, however, that the most prevalent differences in dyslexic brains are involved in or related to phonological processing (2009). This article will work with the understanding that reading difficulties originate with auditory processing deficits for most, but not all, with a dyslexia diagnosis. In other words, there is a very large sub-population of those with a dyslexia diagnosis whose primary presenting symptom of reading difficulty originates with a temporal auditory processing deficit, to whom this review article is relevant.

It could be said that individuals with a diagnosis of developmental dyslexia perceive and react equally atypically to certain elements of both music and speech sounds. Correspondingly, the same neural processes applied to music, particularly those for processing rhythm, also play a major role in the use of language. Both music and language require processing of complex spectral features, and the brain abstracts many of the same types of information from each type of acoustic signal in order to process it. Rise time, for instance, the name given to the time it takes for a signal to reach peak amplitude, has structural significance in both kinds of stimuli. In music, it differentiates timbres and affects metrical perception. Rise time is also used in speech perception to distinguish different voice onset times, which differentiate sounds like /sh/ and /ch/, /p/ and /b/. Rise time perception is also used to perceive syllabic segmentation and stress, as patterns of syllables are manifest in sound signals as periodic patterns of amplitude modulation (AM) (Flaugnacco et al., 2014). Cortical entrainment, which describes a constant phase relationship between the cortical signals and the acoustic amplitude envelope, is also used for prediction and perception in both rhythm and speech (Goswami, 2011). Also relevant to both speech and music are skills of segmentation and grouping (Petkov et al., 2005), and also working memory, which affects the predictive facet of auditory processing. It can be said that many of the same auditory processes underlie the encoding of both speech and music, indicating that music training may have a significant indirect impact on speech processing.

## 3. TEMPORAL AUDITORY PROCESSING IN DYSLEXIA

Poor temporal processing of both linguistic and musical stimuli has been found in those with a dyslexia diagnosis (Flaugnacco et al., 2014). For instance, children with developmental dyslexia have difficulties in segmentation and grouping in speech and music (Petkov et al., 2005). They also show greater variability when asked to tap along to a metronome (Thomson & Goswami, 2008) or a song (Overy et al., 2003). Thirdly, they tend to over anticipate cued stimuli by as much as 100ms, compared to their control matched peers (Wolff, 2002). It has been argued that almost precisely opposite to congenital amusia, sufferers of which are "in time but out of tune", dyslexics are "in tune, but out of time" (Goswami, 2013).

In her paper on the "Temporal Sampling Framework" (TSF), Goswami explains how temporal processes are applied to speech (2018). Amplitude envelopes, rise times and rates of salient events are extrapolated from the AM of the speech signal. These form a kind of "skeleton" for phonological development, helping to inform parsing of the acoustic signal (2018).

For speech processing, important rates of cell-oscillation are delta (1–3 Hz), theta (4–8 Hz), beta (15–30 Hz), and gamma (> 30 Hz) (Poeppel, 2014). These correspond to rates of meaningful language events in normal speech, like stressed syllables and syllables. According to dynamic attending theory, this abstracted amplitude envelope (AE, seen below in red) cues increases in attention at points where key acoustic information conveying phonology is delivered. Peaks in the AE do, indeed, correspond to consonant onsets and vowel formants. Leaving neural oscillation aside for now, it can be seen from this graphic that an ability to perceive the pulse and rhythm of salient events in speech may be crucial to predictive and thus dynamic attending aspects of speech encoding. And, as we have seen, early impaired speech encoding can impede later phonological development and thus reading ability.

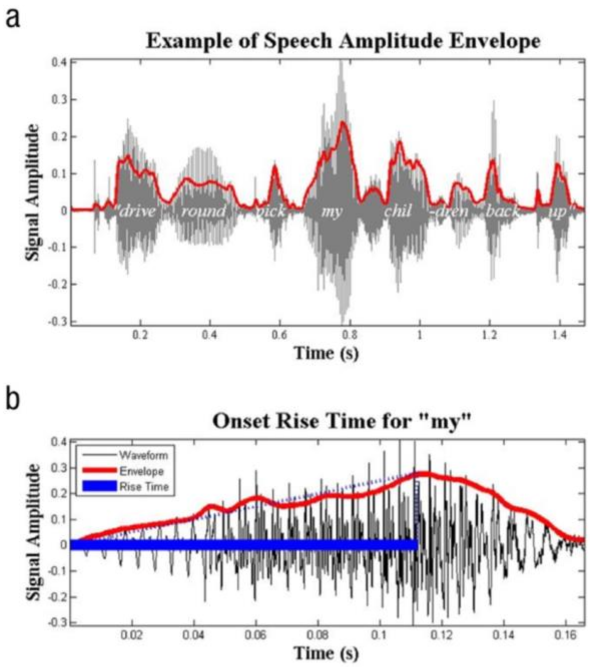


Figure 1: Taken from Goswami (2018): a visualisation of the amplitude envelope of a speech signal (grey), showing how amplitude envelope (red) and periodically occurring rise times (blue) correspond to salient linguistic events

Goswami (2018) posits that dyslexic children's processing deficits come from difficulties perceiving slower rates of AM variation, which are important for musical beat perception. A significant difference in syllable stress perception, which occurs at 2Hz (Arvaniti, 2009), has been found in dyslexic undergraduates and age-matched controls (Leong et al., 2011). A later study (Goswami et al., 2013) found that nine-year-old children with dyslexia performed significantly worse than younger seven-year-old reading-age matched controls, in a task which asked children to match abstracted syllable stress patterns to given words. This finding using reading-age-matched participants suggests that perception on the 2Hz level is one of the most significant difficulties present in speech perception in children with dyslexia, while the finding of Leong and colleagues suggests the persistence of this difficulty into adulthood. Musical beat stress perception (Huss et al., 2011;

Goswami et al., 2013) has been found to predict up to 43% of unique longitudinal variance in reading comprehension, controlling for age and IQ. These lower frequencies (<2.5Hz) correspond to the same range which might be perceived as musical 'beats' (<180BPM). For this reason, beat perception and entrainment may provide areas for training which have the most significant impact on language processing.

Lab studies can be seen to demonstrate the importance of temporal over spectral information for speech intelligibility. Shannon and colleagues (1995) extracted amplitude envelopes from a limited number of low-frequency spectral channels from recorded speech, in order to generate what the authors call a "dynamic temporal pattern". This pattern was then used to artificially modulate white noise. Participants' speech recognition of this stimulus, which lacked spectral cues, was nonetheless "near-perfect" (Shannon et al., 1995). Leong and Goswami (2015) note that infants learn to parse the speech signal using temporal cues, and this reliance on rhythm and stress would seem to persist into adulthood. Indeed, when healthy adult listeners are presented with speech stimuli whose 2-9Hz landmarks have been removed, speech recognition is near impossible (Doelling et al., 2014). These lab studies indicate that temporal cues at low frequencies in speech are both necessary and sufficient for speech recognition. Impaired perception of temporal cues could therefore adequately account for the poor reading present in dyslexia.

These findings are suggestive, but a finer conception of the temporal envelope's role in communicating phonology is needed for it to have therapeutic relevance. It is clear that the acoustic information transmitted by the temporal envelope is more important than temporal fine structure for communicating phonological information. However, it is unclear where this information is located within the temporal envelope. Currently, it remains to be found which particular timescales within the temporal envelope, and which particular statistics extracted from these, are the key carriers of phonological information.

Narrowing down the particular temporal acoustic cues useful to phonology is likely to enlighten the nature of phonological deficits in dyslexia. This may inform therapies which improve reading as an indirect effect of treating the underlying temporal auditory processing deficit. Currently, intensive phonetics teaching is used to reduce the impact of the behavioural symptom of poor phonological awareness. Specific temporal auditory training presents an avenue for therapies which could have a broader impact, targeting cognitive subprocesses which may generalise to improvements in both reading and other perceptual areas.

Goswami uses the particular pattern of temporal auditory deficits to further suggest that heterogenous perceptual deficits observed in dyslexics may be accounted for by a low-level rhythmic entrainment process (2011, 2018).

## 4. THE TEMPORAL SAMPLING FRAMEWORK FOR DYSLEXIA

The Temporal Sampling Framework for dyslexia (TSF) suggests that several difficulties present in dyslexic individuals could be accounted for by a lower-level rhythmic neuropsychological function (Goswami, 2011; 2018). She argues that rhythmic entrainment behaviours, various phonological deficits, magnocellular function, noise exclusion, sluggish attention shifting, and cerebellar function are all consistent with impaired neural oscillatory phase-locking in the auditory cortex. This is because the process of oscillatory phase-locking, while temporal itself, modulates other processes, including visual and attention processes necessary to reading. The brain is impaired both in processing periodic stimuli, and resolving sensory information which is encoded in the brain on multiple timescales. To put it simply, the various perceptual difficulties of dyslexia may be underpinned by the brain's ability to phase-align with periodic stimuli from both itself and the outside world.

There is evidence that phonological development is underpinned by temporal encoding, as distinct from temporal auditory awareness. Auditory temporal order discrimination, an indicator of the precision of the temporal encoding within the auditory system, has been linked to reading (Griffiths, Hill, Bailey, & Snowling, 2003). Furthermore, children who exhibit phonological deficits struggle to identify a tone when it's followed by a burst of loud noise. They have, in auditory processing terms, a low backward masking threshold (Kraus & Tierney 2013). The same participants perform well when the tone and the noise are presented at the same time (Montgomery et al., 2005). This excludes the possibility of perceptual difficulty being caused simply by spectral complexity. Taken together, these results indicate rather that phonological perception is tied to aspects of internal temporal encoding.

The TSF can, for example, explain difficulty perceiving phonemes, in conjunction with the more established Multi-Time Resolution Model (MTRM) of speech processing. Internal temporal encoding governs several kinds of perceptual processing via the MTRM, indicating that rhythmic training can generalise to improvements in many perceptual modes affected by dyslexia. The MTRM can be described as "the sliding and resetting of intrinsic temporal windows on privileged time scales" (Luo & Poeppel, 2012). In this model, a speech sound signal is processed concurrently on different timescales by separate, dedicated streams, which entrain to the sound stimulus. Indeed, cell networks in the auditory cortex form a hierarchy which reflects privileged timescales in the speech signal (Goswami, 2018). Their firing pattern aligns with particular salient phases of a tonal or rhythmic stimulus (Konishi, 2008). That is, neurons in each stream become entrained to the periodic stimulus at different levels of the metrical hierarchy. The information is then combined after extraction, for subsequent computation at the lexical level (Hickok & Poeppel, 2007). In brief, auditory processing requires the resolution of competing information on different acoustic features of the same phoneme at multiple time and frequency scales. When the internal resolution of diverse temporal information is impaired, so is phonemic perception. This resolution of stimuli into the perceptual model requires phase-locking at the Theta or Delta rates. Thus, it could be that the same lower-level impairment underlies both poor perception of an external periodic stimulus, and internal resolution of temporally coded information. Rhythmic musical interventions employ and strengthen these high-level processes of information integration. They may therefore have impacts beyond reading and into other sensory processing areas affected in dyslexia.

## 5. FROM RHYTHM TO READING

As previously discussed, there is a broad proposed chronology to the causal link between temporal auditory processing issues and dyslexia. Indeed, poor phonological awareness before any reading instruction predicts poor reading skills years later (Puolakanaho et al., 2007). This is strong evidence for a pre-existing auditory system deficit independent of the effect of reading instruction. An initial (either genetic or early developmental) limitation in temporal processing can affect subsequent phonological processing and phoneme-grapheme mapping, which are both critical skills when learning to read (Colling et al., 2017; Lallier et al., 2017).

To call it linear, however, would be to oversimplify. The relationship between brain structure and environment is complex and bi-directional. Learning to read is a key contributor to phonological awareness (as well as the inverse effect previously discussed). Pernet and colleagues' (2009) view of healthy development might be summarised as one of mutual reinforcement, where a healthy brain seeks out environmental stimuli to encode and drive development at appropriate stages.

Development of specialised interventions is a viable aim, though, as reading difficulties which are congenital can be broadly distinguished from reading difficulties which have more environmental causes. Tasks which examine language subprocesses like rise time perception show clear differences. Reading-age-matched children with and without a diagnosis of dyslexia perform significantly differently on rise time perception tasks (Goswami, 2018). Despite having the same reading speed and accuracy, the dyslexic subgroup of children displayed difficulties in auditory perception. Because of data like this, it can be said that brain abnormalities in some dyslexic subjects do not "allow the normal course of environmentally driven structural modulation to develop" (Pernet et al., 2009). Some structural modulation may therefore be provoked by exceptional stimuli. "Supernormal" stimuli, which provide exaggerated forms of the necessary perceptual cues, may promote the structural modulation necessary to reading. Nursery rhymes, for example, are naturally occurring supernormal stimuli which may be useful in intervention, whose musical rhythm exaggerates a regular pattern of speech stress (Goswami, 2018).

## 6. WHY STUDY THIS?

Elliott and Grigorenko (2014) note that poor readers with and without a diagnosis are, respectively, supported or penalised-despite tests for dyslexia being based on nothing other than poor reading. What is the function of a term distinguishing dyslexic individuals from other poor readers, if neither current diagnosis nor treatment are capable of doing this? Its current function is to separate those who can access expensive diagnostic tests, and those who can't. It therefore needs to be modified significantly or retired. Elliott and Grigorenko therefore call for the class-fraught "dyslexia label to be replaced by more detailed descriptors of specific literacy skills and deficits underpinning reading difficulty" (2014). I propose that specific identification and intervention for deficits in auditory processing could have the indirect effect of improving reading ability without unnecessary stratification.

Elliot and Grigorenko note "the similarity of the aetiological bases of reading difficulties that cannot be attributed to poor schooling" found in their meta-analysis (2014). In other words, current criteria for classifying poor readers do not yield distinctive neurobiological profiles. This is further support for shifting diagnostic weight away from behavioural symptoms, and onto specific cortical subprocesses or sensory deficits which underlie poor reading. In light of the complex interaction between hereditary auditory deficits and environmental factors discussed above, the penultimate section of this essay attempts to situate music therapies in relation to current interventions for dyslexia.

## 7. MUSIC THERAPY FOR READING DEVELOPMENT

Music training may represent an expedient way of enhancing facets of sound processing ability such as pitch, timbral and rhythmic perception, and auditory working memory. Literature suggests that this training can, by extension, maximise reading progress in those whose difficulties are rooted in the encoding of sound stimuli.

Music therapy can influence structural brain changes which improve language processing. Music making is highly challenging to perception of complex spectral features: instrumental practice aims at mastering modulation of fine-grained acoustic features like pitch, timing and timbre (Kraus & Chandrasekaran, 2010). Because of its challenging nature, musical training can bring about broader changes in the functional organisation of the brain, including positive transfer from music to speech. Longitudinal studies have shown that musical training has a direct impact on brain regions responsible for sound processing. For example, after a 15-month period of intense musical training, structural changes were observed in subjects' primary auditory brain regions (Hyde, 2009). In another 9-month study, 8-year olds given musical training showed enhanced pitch discrimination when exposed to speech-based stimuli, showing that the skill of auditory discrimination developed in musical training is generalised to other kinds of sound processing (Moreno et al., 2009). These changes in perception of acoustic features like pitch and timbre can lead to improvements in phonological perception, as they are critical to discriminating between phonemes and decoding prosodic information. There is evidence that these positive effects of musical training on auditory processing extend into adulthood. For example, when brain stem activity in adult musicians is compared with that of non-musicians, representations of pitch and formants are more accurate (Wong et al., 2007). So, musical training in a broad sense can lead to improved phonological perception, a key ability underpinning developmental dyslexia.

It has been argued that integrating rhythmic training into reading interventions will maximise their effectiveness (Bolger et al., 2013). The question is at what stage will rhythmic intervention give the most benefit, when administered alongside phonological teaching-based interventions?

If poor reading comes from difficulty attending to salient periodic speech events, exercises which link the strong metrical structure cues found in music to language will contribute to improved reading. Metrical poetry and nursery rhymes are existing examples of stimuli which link musical and linguistic metrical structure (Goswami, 2018). When stimuli are aligned with a regular periodic stimulus, participants display faster performance in tasks in a variety of perceptual modes (Bolger et al., 2013). As “rhythm is more overt in music than in language” (Bhide et al., 2013), it may be easier for dyslexic subjects to process nursery rhymes than speech alone. Exposure to these stimuli, which have exaggerated AM envelopes aligned to phonological cues, may also prime the brain for later stochastic processing of language using its rhythmic and metrical prosodic patterning.

This hypothesis has been tested in trials of a therapy called Rhythmic Reading Training (RRT). However, effect sizes are not as large as the theory would suggest. Reasons for this, and directions for further study, will be explored in this final section.

## 8. A SPECIFIC RHYTHMIC THERAPY FOR READING DIFFICULTY CAUSED BY AN UNDERLYING PHONOLOGICAL DEFICIT?

RRT combines rhythmic and phonological approaches, and there is evidence suggesting it improves reading through improved auditory perception. It is a computer-based therapy consisting of exercises with a rhythmic background. The exercises target reading subprocesses: phonological awareness, phoneme-grapheme mapping, and lexical recognition. Trainees adjust their reading speed to an isochronous rhythm with a gradually increasing tempo. In a small-scale study (n=19) of Italian speaking children with a diagnosis of dyslexia, its efficacy was shown to be comparable to non-rhythmic approaches (Cancer et al., 2019). Analysis of the specific changes in various cognitive subprocesses after the intervention showed that trainees’ progress in reading speed was related to improved rhythm and auditory discrimination abilities, as well as improved verbal working memory. In short, improved auditory perception predicted improvement in reading, whereas improved attention did not (Cancer et al., 2019).

The small effect sizes do not appear promising, and rhythmic therapies appear at best equal to phonologically based ones, if with differently weighted effects. However, the study of RRT is in its infancy, and I assert that there are certain flaws in the methodology which prevent these studies from being taken as conclusive disproval of the efficacy of rhythmic reading therapies.

Firstly, the correlation found in this study alone is no guarantee of directionality. As phonetic and auditory modelling is changed in musicians (Wong et al., 2007), it is also improved with the acquisition of reading (Seidenberg et al., 2019). Further studies including an unseen control group are therefore needed to exclude the possibility that the changes found are driven by normal development. Studies will need to overcome the ethical consideration that all poor readers should receive some kind of intervention (Bhide et al., 2013). Rhythmic reading interventions could therefore be compared with, for example, reading training alone, play-based interventions that challenge working memory, and art therapies which challenge visual attention. These comparisons, interpreted collectively, can isolate rhythmic auditory development from these other relevant facets, yielding a more accurate assessment of the relative effectiveness of rhythmic interventions.

Secondly, it may be that no noticeable difference has been found between these therapies and non-rhythmic ones because of over-reliance on flawed selection criteria. Where lab studies show correlations between impaired rhythmic and phonological skills, this study uses a dyslexia diagnosis as a participant selection criterion. Most had at least one comorbid SLD (dyscalculia, dysgraphia), and the IQ of participants ranged from 80-110, some below average, by some measures. If a critical attitude is taken toward diagnosis based on behavioural symptoms (Elliott & Grigorenko, 2014), Cancer and colleagues’ selection criteria arguably do not guarantee that poor reading was due to a phonological or congenital auditory deficit. Baseline rhythm discrimination was found to predict the impact of RRT, indicating that improved rhythmic auditory processing was a mechanism by which the impact of reading interventions was maximised. Lack of phonology or rhythmic discrimination-based selection criteria may therefore explain the lack of significant difference found between phonological interventions and RRT in this study.

Along similar lines, the negligible difference between the two kinds of interventions may also be attributed to the simultaneous deployment of rhythmic and phonological teaching-based training. Music therapies have been shown to improve the auditory awareness on which phonological development is built. Bhide and colleagues suggest that musical training perhaps ought to precede reading training, because “musical intervention trains the rhythmic perception and rhythmic entrainment skills that, by hypothesis, are important for the development of phonological awareness” (2013). Prior exposure to rhythmic activities, which require entrainment to various periodic stimuli, may therefore prime the brain for the later auditory processing that phonological teaching-based therapies require. Sequential application may therefore be key to maximising impact.

## 9. CONCLUSIONS

A strong case has been made that poor reading despite adequate instruction is commonly, but not exclusively, underpinned by impaired auditory discrimination. In particular, rhythmic auditory discrimination at low frequencies (>180 BPM), including rise time, is implicated in common issues with prosodic perception, phonemic perception, and reading speed and accuracy. Difficulty attending to salient periodic speech events seems to be a major factor impacting phonological awareness and the key cause of poor reading for many.

It would therefore follow that exercises which aid in linking the metrical structure of music and language will contribute to improved reading. However, results found have so far been equal to current phonological teaching-based interventions. I argue that this is because poor reading is not exclusively underpinned by rhythmic auditory discrimination. Rhythmic training is therefore not hypothesised to be universally effective for the treatment of poor reading, but only for the substantial sub-group who have a rhythmic auditory deficit.

Correlated improvement has been shown between in rhythmic auditory awareness and reading, and between baseline rhythmic awareness and improvements in reading, after administering RRT. This supports the hypothesised effectiveness of such therapies for a certain sub-group of the dyslexic population whose difficulties are rooted in an impaired cognitive process of temporal encoding.

It is already apparent that changes in diagnostic practice will be key to the employment of rhythmic training in reading intervention. Current diagnoses do not correspond to distinctive neurobiological profiles (Pernet et al., 2009), leading scholars like Elliott and Grigorenko to be sceptical of tailored programmes of intervention for weak or deficient cognitive processes. They argue for the use of "the most effective evidence-based interventions, irrespective of supposed aetiology" (2014). This is a useful guard against hasty introductions of new 'specialised' therapies for dyslexia, in a system where the term serves much to protect the self-esteem of some poor readers, with others (often those from less advantaged backgrounds) becoming collateral damage. However, to conclude firmly that one kind of intervention works for all poor readers would be premature. I argue that the use of rhythmic training has the potential to impact specifically those whose reading difficulty is underpinned by rhythmic auditory deficits, when accompanied by future diagnostic developments.

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