Dyslexia and Music: Measuring Musical Timing Skills

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Over the last few decades, a growing amount of research has suggested that dyslexics have particular difficulties with skills involving accurate or rapid timing, including musical timing skills. It has been hypothesised that music training may be able to remediate such timing difficulties, and have a positive effect on fundamental perceptual skills that are important in the development of language and literacy skills (Overy, 2000). In order to explore this hypothesis further, the nature and extent of dyslexics' musical difficulties need to be examined in more detail. In the present study, a collection of musical aptitude tests (MATs) were designed specifically for dyslexic children, in order to distinguish between a variety of musical skills and sub-skills. 15 dyslexic children (age 7–11, mean age 9.0) and 11 control children (age 7–10, mean age 8.9) were tested on the MATs, and their scores were compared. Results showed that the dyslexic group scored higher than the control group on 3 tests of pitch skills (possibly attributable to slightly greater musical experience), but lower than the control group on 7 out of 9 tests of timing skills. Particular difficulties were noted on one of the tests involving rapid temporal processing, in which a subgroup of 5 of the dyslexic children (33%) (mean age 8.4) was found to account for all the significant error. Also, an interesting correlation was found between spelling ability and the skill of tapping out the rhythm of a song, which both involve the skill of syllable segmentation. These results support suggestions that timing is a difficulty area for dyslexic children, and suggest that rhythm skills and rapid skills may need particular

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attention in any form of musical training with dyslexics.

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INTRODUCTION

It is well established that dyslexic children have difficulties with phonological skills, a problem that interferes with the development of reading and spelling (Bradley and Bryant, 1983; Snowling, 1987). However, the nature and cause of this phonological difficulty is under debate, along with theories of the best remediation strategies for such a problem. Some theorists believe that the problem is speech-specific (e.g. Mody, Studdert-Kennedy, & Brady, 1997), while other theorists suggest that the phonological difficulties are a symptom of a different underlying cause. For example, Tallal, Miller, and Fitch (1993) have suggested that a deficit in rapid temporal processing can cause specific auditory perception problems, leading to specific phonological perception problems. Stein and Talcott (1999) also suggest that dyslexics have problems with transient auditory processing, caused by a magnocellular processing deficit. Nicolson, Fawcett, and Dean (1995) propose that there is an underlying deficit in cerebellar processing, causing difficulties with the automatisation of skill-learning generally. They propose that a lack of well-timed, automated, motor skills inhibits the normal development of articulatory gestures, thereby inhibiting the development of phonological awareness and literacy skills (see Nicolson, Fawcett, & Dean, 2001, for an outline of this argument).

A common element of these theories, is the conviction that timing skills, and particularly rapid timing skills (and to some extent motor timing skills), are a fundamental problem area in dyslexia. The full extent and nature of such timing deficits are yet to be established, but the variety of findings in this area suggest that the subject of timing warrants further investigation. Over the last few decades, researchers have found difficulties with time estimation (Nicolson, Fawcett, & Dean, 1995), rhythm tapping (Wolff, Michel, Ovrut, & Drake, 1990; Wolff, 2001), detecting complex timing patterns (Kujala *et al*., 2000), rapid automatised naming (Denckla & Rudel, 1976; Wolf, 1991), rapid temporal processing (Tallal, Miller, & Fitch, 1993), auditory temporal sensitivity (Witton *et al*., 1998), rapid speech perception (Wood & Terrell, 1998), visual flicker (Lovegrove, 1993) and visual motion detection (Talcott, Hansen, Assoku, & Stein, 2000). Consequently, dyslexia-related timing deficits have at different times been hypothesised as underlying visual and auditory perception problems, motor co-ordination problems, and fluency and automatisation problems, all of which have been proposed as adversely affecting the development of language and literacy skills.

Perhaps surprisingly, there have been relatively few suggestions for the remediation of such timing deficits, outside the domain of speech. Within the domain of speech, it has been claimed that auditory training using artificially slowed-down speech sounds can lead to improved speech perception (Tallal *et al*., 1996). This idea has been echoed by Blythe (1998), who discusses singing as a natural way of slowing down and highlighting speech sounds. Sutton (1993), and

Tomatis (1991, discussed in Gilmour, 1999) have also suggested forms of music listening and music making as tools for increasing auditory sensitivity and preventing or remediating speech and language difficulties. Music making is an activity requiring very accurate auditory and motor timing skills, and thus presents a potential tool for remediation in these specific areas. Music making is also a multi-sensory activity, and it is well recognised that multi-sensory training is a valuable form of teaching for dyslexic children (Hornsby & Miles, 1980; Hulme, 1981). In addition, Douglas and Willatts (1994) have found that music lessons can have a positive effect on the reading skills of poor readers, while a preliminary study by Overy (2002) found that a programme of musical activities had a positive effect on dyslexic children's rapid temporal processing skills, phonological skills and spelling skills.

If musical activities are to be considered as useful in the dyslexia classroom, dyslexic children's difficulties with musical timing need to be further examined. A small amount of research already exists in this area; for example Ganschow, Lloyd-Jones, and Miles (1994) interviewed six dyslexic musicians, and found that they all reported difficulties with rhythm, while Oglethorpe (1996) has reported dyslexic children's problems with maintaining a steady beat, and experimental studies have found difficulties with rhythm copying (Atterbury, 1985) and rhythm perception. A wide range of other musical difficulties is also discussed in a recent collection of essays on this topic (Miles & Westcombe, 2001). However, the specific nature of dyslexics musical timing difficulties has not been investigated in detail: no clear distinctions have been made between pulse and rhythm skills, fast processing and slow processing, and perceptual and motor skills, for example. This makes it difficult to know where the focus of a music remediation program should lie.

Design of the Study

The aim of the present study was to compare different types of musical timing skills amongst dyslexic children and control children, in order to identify whether there is a particular area in which music remediation work should concentrate. For this purpose, an independent groups, repeated measures, experimental design was adopted. In addition, a series of musical aptitude tests (MATs) was designed specifically for use with dyslexic children.

MUSICAL APTITUDE TESTS

There are several musical aptitude tests currently available (for example Seashore, 1960; Bentley, 1966; Gordon, 1965; Wing, 1968), which were analysed in detail before designing the MATs. These tests tend to focus on listening skills, divided into components such as pitch, rhythm, timbre, and melody perception. The tests often involve long periods of concentration and the answer sheets are often quite complicated to understand. Thus, the tests were decided to be generally unsuitable for dyslexic children, who can have difficulties concentrating for long periods at a time, and with filling out unfamiliar, complicated forms.

For the MATs, it was decided to conduct the tests on a one-to-one basis with each child, and to measure different types of performance skills as well as listening skills. A limitation of this design is that, in order to accommodate a greater variety of tests whilst keeping the contact time reasonably low for school visits (two sessions of 15/20 min/child, plus literacy tests), each type of test is constrained to relatively few items, thus reducing the sensitivity of the measurement. However, an advantage of the design is its potential to separate out some of the sub-skills underlying basic musical tasks such as rhythm copying. Once the most problematic sub-skills have been identified, future testing may focus on these areas more intensively.

In an initial study (Overy, 2000), a small number of musical aptitude tests were designed. These tests were conducted with a class of 28 children age 6–7, who were all screened for risk of reading difficulties using the dyslexia screening test (DST) (Fawcett & Nicolson, 1996) and the dyslexia early screening test (DEST) (Nicolson & Fawcett, 1996). The musical test scores of the 6 children with a strong risk of reading difficulties were then compared with the 16 children with no risk of reading difficulties. Results showed that the strong risk children scored significantly lower on all the tests involving timing skills, and particularly on the test of rhythm copying ($p < 0.001$), but did not score significantly differently on the test involving pitch skills. Following these results, more extensive musical aptitude tests (MATs) were designed, involving a greater variety of skills, and including a measurement of musical experience (in consideration of the fact that musical abilities are influenced by levels of exposure and training). A short description of each test is given below.

Rhythm skills

Rhythm copying: (14 test items)	A short rhythm was presented over headphones, and the child copied it on the keyboard. This was repeated at increasing levels of difficulty.
Rhythm discrimination: (12 test items)	Two rhythms were presented over headphones, and the child reported whether they were the same or different. This was repeated at increasing levels of difficulty.
Song rhythm:	The child tapped the rhythm of Happy Birthday on the keyboard, whilst singing the words.

Metre skills

Tempo copying: (5 test items)	A steady beat of 8 taps was presented over headphones, and the child copied the speed as accurately as possible on the keyboard. This was repeated at varying different speeds, from 48 bpm (beats/min) to 240 bpm.

Tempo discrimination: (12 test items)	Two different tempi were presented, with 8 beats each, and the child reported whether the second tempo was faster or slower than the first. This was repeated at increasingly fast speeds, from 64 to 800 bpm.
Song beat:	The child tapped to the beat (pulse) of Happy Birthday, whilst singing the words.

Rapid skills

Note order detection: (10 test items)	Initially, it was established that the child could recognise and label a little note (C5, a high pitch) and a big note (C2, a low pitch).[1] Then, both notes were presented in rapid succession, and the child reported which note came first. This was repeated at decreasing inter-stimulus-intervals (ISIs), from 400 to 30 ms.
Note number detection: (10 test items)	A number of taps (2, 3 or 4) were presented in rapid succession, and the child reported how many taps were heard. This was repeated at decreasing ISIs, from 1000 to 75 ms.
Note number discrimination: (10 test items)	Two groups of taps were presented, each with 2, 3, 4 or 5 notes. The child reported whether the two groups had the same or different number of notes. This was repeated at decreasing ISIs, from 500 to 79 ms.

Pitch skills

Melody discrimination: (10 test items)	Two short, 3-note melodies were presented, and the child reported whether they were the same or different. This was repeated at increasing levels of difficulty.
Pitch discrimination: (14 test items)	Two individual pitches were presented, and the child reported whether they were the same or different. This was repeated at decreasing frequency intervals (from a tone to 1/16 of a tone).
Pitch matching: (3 test items)	First, the child was given time to become familiar with the pitches of 5 marked notes on the keyboard (C3 to G3). A single pitch was then presented over headphones, and the child selected the identical pitch on the keyboard. The child was given as much time as required to find the correct note, and was allowed to try all the notes before making a final choice. This was repeated with two other notes.

[1] The labels of ‘high’ and ‘low’ were avoided, as children often confuse these concepts when applied to pitch (possibly because there is an association with volume level). The playful labels of ‘big’ and ‘little’ were understood very quickly.

Other measures

Song:	The child sang Happy Birthday.
Timbre discrimination: (10 test items)	Two different instrumental sounds (computer simulated) were presented over headphones, and the child responded with same or different. This was repeated with a variety of different timbres, including pitched and non-pitched instruments.
Musical experience:	It is very difficult to evaluate musical influences, but an attempt was made to provide an objective assessment. The child was asked about their music lessons at school, whether they were learning to play a musical instrument, whether they sang in a choir, whether there was a piano in their house at home, and whether any member of their family played a musical instrument.

Scoring

All the forced choice tests (rhythm discrimination, tempo discrimination, note order detection, note number discrimination, melody discrimination, pitch discrimination and timbre discrimination), as well as rapid note detection, rhythm copying and pitch matching, were simply scored as correct or incorrect. The rapid note detection test was also scored in terms of the amount of error made (for example, if a child reported hearing 4 notes when there were only 2, they scored an error of 2). The tempo copying performances were recorded using MIDI,[2] converted into inter-onset-intervals (IOIs), and scored in terms of deviation from the beat (out of 10). Singing, song rhythm, song beat and the conversations about musical experience were all recorded, and scored out of 5.

Protocol

It was crucially important for the children to be interested in the tests, in order for them to listen carefully and concentrate. Throughout the development of the MATs, it became apparent that the order of the tests and the manner of presentation had a large impact on the performance of the children. For example, beginning with a chorus of Happy Birthday was discovered to be a good way of dispelling the initial nerves often associated with musical performance or testing, and a good lead into using the keyboard to tap the rhythm and the beat of the song. In general, it was useful to introduce a skill as a doing activity before it was introduced as a listening activity (for example, rhythm copying immediately before rhythm discrimination), so as to ensure full comprehension of the task. In order to maintain interest and concentration, it was important to break up the listening activities with as much variety as possible, such as using the keyboard for a performance test, or introducing the conversation about musical experience.

[2] MIDI (musical instrument digital interface) is a communication protocol for transferring note and timing information between keyboards, synthesisers and computers.

It was also important not to have too many forced choice tests in a row, in order to avoid boredom, guessing and attempts to work out the pattern. Other tactics were also employed, such as putting smiley coloured stickers on the keyboard to identify the notes to be used, using DJ-style headphones, and letting the children play with the keyboard drum kit buttons as a reward. No training was given prior to administration; each test simply had a few practice items, to make sure that the child fully understood the task.

METHOD

Participants

16 dyslexic children were recruited from an independent boys school. One child's data were excluded from the analysis, due to his exhibiting severe concentration difficulties. This resulted in an experimental group of 15 dyslexic boys (age 7–11). 18 control children (also boys) were selected from another school in Sheffield (matched for age), and these children were tested for IQ, reading and spelling skills. Children exhibiting possible signs of dyslexia, low IQ, or very high IQ were excluded from the data, in order to form a better-matched control group. This resulted in a control group of 11 boys (age 7–10). The mean ages, reading and spelling standard scores and IQ's of both groups of children are shown in Table 1.

It can be seen from Table 1 that the mean ages of the 2 groups are well-matched, although the dyslexic group has a larger age range than the control group. The dyslexic group has low literacy scores (despite the high level of special needs support given by their school), while the control group has high literacy scores, particularly in reading. The IQ scores are relatively well-matched, considering that dyslexic children are known to under-perform on IQ tests such as coding, digit span and vocabulary (resulting in their characteristic spiky profile, Miles, 1983).

Materials

Wechsler Objective Reading Dimensions (*WORD*) (*Rust*, *Golombok*, & *Trickey*, 1993) The single word reading and spelling tests from the WORD were used. Scores on these tests are converted into standard scores (SS), where 100 indicates average achievement for the age group.

Table 1. Mean, standard deviation and range of the age, reading standard score and spelling standard score of the dyslexic and control groups.

		Age	Reading SS	Spelling SS	IQ
Controls	Mean	8.9	118.1	106.7	115.7
($n = 11$)	S.D.	0.9	8.9	14.1	9.6
	Range	2.6	34	44	35
Dyslexics	Mean	9.0	88	90.5	109.1
($n = 15$)	S.D.	1.1	7.4	5.7	12.2
	Range	3.6	26	18	41

Wechsler Intelligence Scale for Children (*WISC-III*) (*Wechsler et al*., 1992)
The short form of the WISC was used with the control children, which involves 5 tests: picture completion, similarities, block design, vocabulary and coding.

Musical aptitude tests (*MATs*)
These tests were designed specifically for the study, as described above.

Apparatus

The MATs were conducted using StudioVision music software on a Macintosh Powerbook 3400c, connected to a Yamaha PSR 330 electronic keyboard, listened to through Vivanco Airspace DX300 headphones. The timbre test was played on a Panasonic XBS stereo system. For the tempo copying test, the MIDI data was analysed using POCO software (Honing, 1990).

Procedure

The control children were tested on the short form of the WISC, and all children were tested on the WORD and the MATs. Testing was conducted individually, in sessions of about 20 or 30 min, over the course of 3 weeks.

RESULTS

In order to compare the performance of the two groups, the mean scores were calculated and compared on each test, and a number of one-tailed, independent groups *t*-tests were conducted on the data, with the prediction that the dyslexic group would score significantly lower on the tests involving timing skills. Where the results were significant at the two-tail level, this is reported accordingly. Effect sizes were calculated by finding the difference between the two means, and dividing by the standard deviation of the control group.[3] The calculation of effect sizes is recommended by the APA (2001), as it allows for comparisons to be made across studies, regardless of sample size, design and analysis. Correlation significance was analysed using Fisher's r–z, with 95% confidence intervals.

Literacy tests

The mean standard scores on the WORD tests of reading and spelling were much lower for the dyslexic group than for the control group, as would be expected. The difference in means was significant in both cases [($t_{24} = 9.42, p < 0.001$, two-tailed) and ($t_{24} = 4.06, p < 0.001$, two-tailed) for reading and spelling, respectively].

[3] In common with investigations where one group is a 'special' population, the standard deviation of the control group is considered a more appropriate measure than the standard deviation of both groups.

Musical aptitude tests

The MATs raw scores were converted into percentage scores, in order to ease comparison across tests. Figure 1 shows the mean of both groups on each test, grouped by skills (pitch, metre, rhythm, rapid) and by outcome (dyslexics scoring higher or lower than controls).

The difference in mean score between the two groups was not large in most cases. This may have been, in part, due to the limited number of items per test, and the relatively small sample size. It may also have been that the dyslexic group's slightly greater musical experience (a mean score of 54.7%, compared to the control group's 45.5%) influenced their performance, thus decreasing the predicted differences on the timing skills tests. Nevertheless, despite the lack of large differences between the two groups, there was a clear pattern to the results: the dyslexic group scored lower than the control group on rhythm skills and rapid skills tasks, but higher than the control group on pitch skills tasks, as shown in Figure 1. Conforming to this pattern, the dyslexic group scored lower than the control group on the task of timbre discrimination (which is hypothesised to involve rapid temporal processing skills during the initial

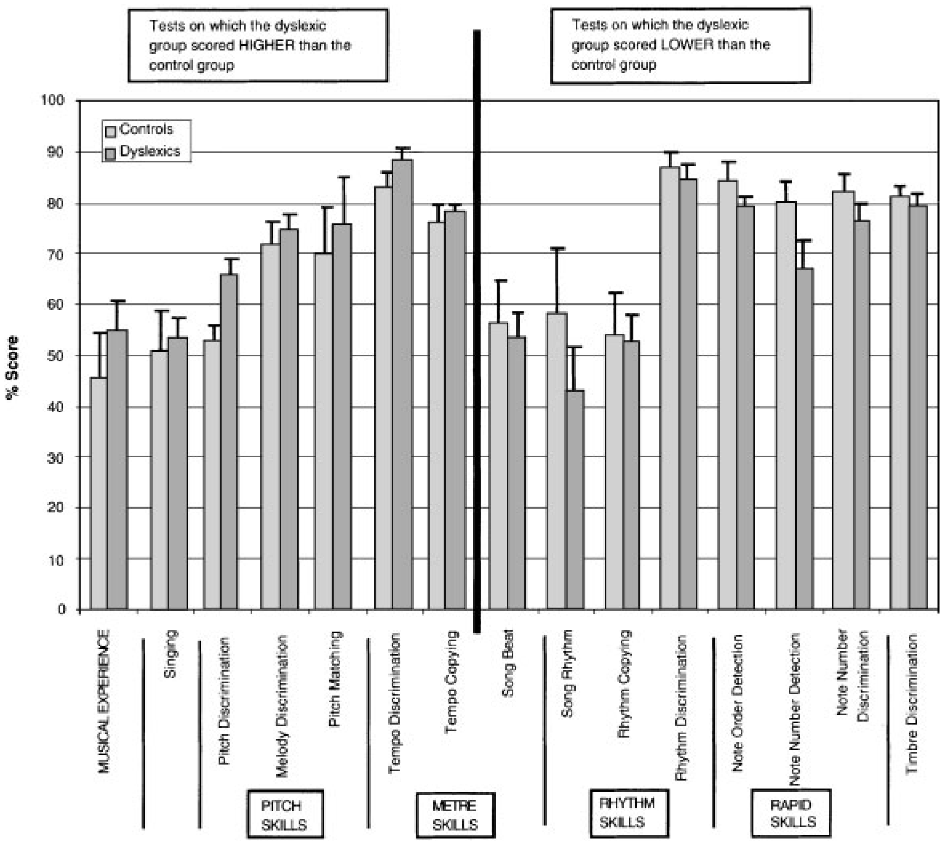

Figure 1. Bar chart to show the mean and standard error of the MATs scores of the dyslexic and control groups.

transient of the sound), and slightly higher than the controls at singing (which involves pitch skills). Performance on the metre skills tasks was less clear: on the relatively complex task of tapping the beat while singing, the dyslexics scored lower than the controls, but on the more simple tempo perception and tempo copying tasks the dyslexic group scored slightly higher than the controls. The only statistically significant difference between the two groups was on the test of pitch discrimination, on which the dyslexic group out-performed the control group ($t_{24} = 2.94, p < 0.01$, two-tailed).

In order to distinguish more clearly between the general types of musical skill, the MATs were grouped into their respective categories of pitch, metre, rhythm and rapid skills, and the scores were combined. The mean scores are shown in Figure 2.

It can be seen clearly from Figure 2 that the group of dyslexic children scored lower than the control group on rhythm skills and rapid skills, but higher than the control group on pitch skills, and very slightly higher on metre skills. It was established that the difference in scores on the rapid skills tests was significant ($t_{24} = 1.91, p < 0.05$), while the other differences were not significant [($t_{24} = 0.86$, ns), ($t_{24} = 0.43$, ns) and ($t_{24} = 1.34$, ns) for rhythm, metre and pitch, respectively].

The timing tests were also regrouped in terms of motor skills (tempo copying, rhythm copying, song beat and song rhythm) and perceptual skills (tempo discrimination, rhythm discrimination, note order detection, note number detection, note number discrimination), in order to examine whether there was a particular difficulty in either of these areas. The mean scores are shown in Figure 3.

The dyslexic group scored lower on both motor and perceptual timing skills tasks, but the differences were not found to be significant [($t_{24} = 0.67$, ns) and ($t_{24} = 1.15$, ns) for motor and perceptual skills, respectively].

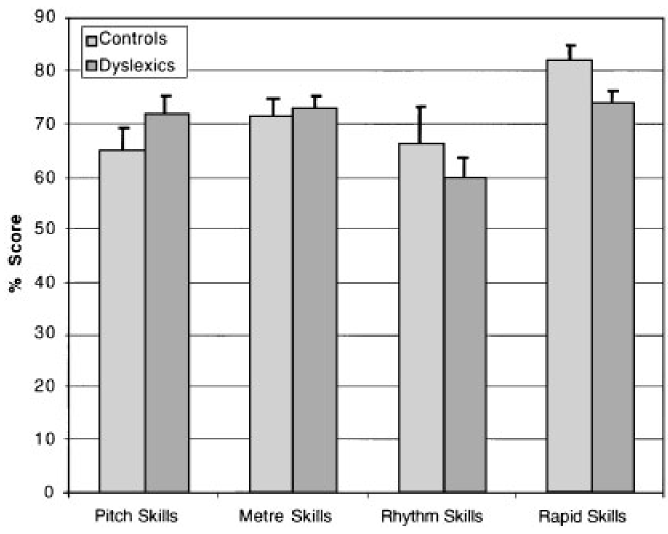

Figure 2. Bar chart to show the mean and standard error of the dyslexic and control groups scores on the grouped MAP tests.

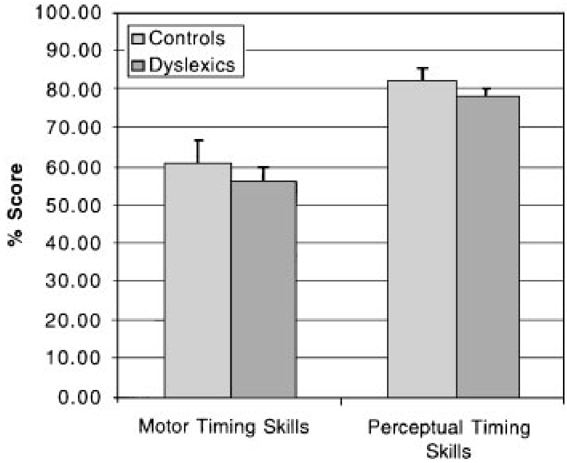

Figure 3. Bar chart to show the mean scores and standard error of the dyslexic and control groups on the grouped motor timing and perceptual timing tests.

The effect sizes of the differences in performance between the two groups on the MATs are shown in Table 2. An effect size of 0.2 is considered mild, 0.5 is considered moderate, and 0.8 is considered large (Cohen, 1988; National Reading Panel, 2000).

A particularly large effect size emerged out of the high scores of the dyslexic group on the test of pitch discrimination (1.22), while the clearest difficulty area for the dyslexic group was on the tests involving rapid (0.72), perceptual (0.43) temporal processing skills, including note number detection (0.99), note number discrimination (0.5), and note order detection (0.35). Song rhythm also presented as one of the more prominent difficulty areas (0.37).

Considering the difference in performance between the two groups on the rapid skills tasks, the errors on these tasks were analysed in more detail. Firstly, it was noted that the inter-stimulus-intervals (ISIs) at which the dyslexic group had more difficulties than the control group were in the region of 50–100 ms on the note order detection task, 100–125 ms on the note number detection task, and 80–120 ms on the note number discrimination task. It was also noted that the dyslexic children made larger errors when estimating the number of notes heard on the note number detection tasks, usually overestimating rather than underestimating (82% of the dyslexics errors were overestimations, compared with 62% for the control group). This tendency to make larger errors was found to amount to significantly more error made by the dyslexic group than the control group on the note number detection task ($t_{24} = 1.78, p < 0.05$).

Individual effect sizes were also calculated for each dyslexic child on each test, by subtracting the individual score from the mean of the controls, and dividing by the standard deviation of the controls. Interestingly, a clear subgroup of 5 dyslexic children emerged with very large negative effect sizes on the test of note number detection (2.24, 4.47, 2.24, 2.98, 3.73). These children were found to account for all the significant difference in error on the note number detection test, as well as the significant difference between the two groups on the combined rapid skills tests. The children were slightly younger than average (mean age 8.4),

Table 2. Effect sizes of the difference in scores between the dyslexic and control groups on the individual MATs and the grouped MATs (shown in italics)

Effect size	Tests on which dyslexics scored HIGHER than controls		Tests on which dyslexics scored LOWER than controls	
Large	Pitch discrimination	(1.22)	Note number detection	(0.99)
Moderate			*Rapid skills*	(0.72)
			Note number discrimination	(0.50)
Mild	*Pitch skills*	(0.49)	*Perceptual timing skills*	(0.43)
	Tempo discrimination	(0.43)	Song rhythm	(0.37)
	Musical experience	(0.30)	Note order detection	(0.35)
			Rhythm skills	(0.28)
			Timbre discrimination	(0.27)
			Motor timing skills	(0.23)
			Rhythm discrimination	(0.20)
No effect	Melody discrimination	(0.19)	Song beat	(0.11)
	Pitch matching	(0.19)	Rhythm copying	(0.05)
	Tempo copying	(0.15)		
	Metre skills	(0.12)		
	Singing	(0.09)		

but their scores were markedly lower than any of the control children, including the youngest control child of 7.6 years.

Another test that required further analysis was the task of tempo copying, which was conducted at 5 different speeds. Performances were analysed using POCO software, which converted the MIDI recorded sound files into inter-onset-interval (IOI) values. These IOI values were scaled according to the tempo that was being copied, so that a value of 1.0 always represented perfect beat accuracy. Error was calculated as deviation from 1.0, and was compared between the two groups over the 5 speeds (Figure 4).

Performance was quite variable, with controls showing slightly more error overall.[4] However, the only significant difference between the two groups was at the speed of 80 bpm (beats per minute) (750 ms/beat), where the dyslexic group made the most error ($t_{24} = 1.92, p < 0.05$), with most children tending to tap too slowly (87% of dyslexics, compared with 46% of controls). Another form of accuracy considered was steadiness of the beat, which was measured by calculating the standard deviation of the IOIs for each child at each tempo. Overall, the dyslexic group showed greater steadiness than the control group, although there was no significant difference between the two groups ($t_{24} = 1.27$, ns). It was also noted that some children did not complete the full total of 8 taps at every tempo, which may have had the effect of improving their score (as deviation from the beat tends to increase with number of taps). The mean number of missed taps for each group at each tempo is shown in Table 3.

[4] For the purposes of Figure 1, the error scores were converted into percentage scores, such that an error of 0 received a score of 100%, and an error of 0.5 or more received a performance score of 0%. There was only 1 instance of an error of more than 0.5.

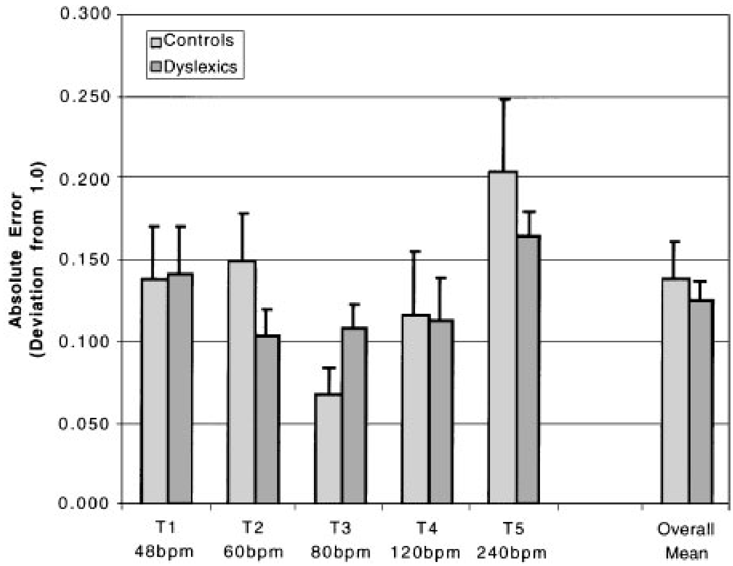

Figure 4. Bar chart to show the mean error (and standard error) of the dyslexic and control groups on the tempo copying tests.

Table 3. Mean number of missed taps per child at each tempo, for the dyslexic and control groups

		48 bpm	60 bpm	80 bpm	120 bpm	240 bpm	Overall mean
No. of missed tapes per child	Dyslexics	1.07	1.27	0.93	0.40	0.40	0.82
	Controls	0.27	0.09	0.36	0.00	0.46	0.24

There was a clear tendency for the dyslexic group to miss more taps than the control group, an effect which was found to be significant ($t_8 = 2.94, p < 0.05$, two-tailed). The biggest differences between the two groups were apparent at the slower speeds, suggesting that the dyslexic children had trouble keeping track of how many notes they had played when the time involved was longer. Thus, it is possible that the dyslexic children's tempo copying scores were artificially improved by their poor performance in completing the number of taps required.

Finally, a correlation matrix was created using the MAP and WORD scores of all the children, in order to identify any potential connections between particular types of skill. Table 4 shows the significant correlations, in order of strength.

There were some highly significant correlations between tests involving similar skills, such as WORD reading and spelling ($p < 0.0001$) an rhythm copying and rhythm discrimination ($p < 0.001$). There were also significant correlations between musical experience and basic musical skills, such as rhythm copying ($p < 0.005$) and singing ($p < 0.01$). A particularly interesting correlation was noted between WORD spelling and song rhythm ($p < 0.005$), while another interesting and highly significant correlation was found between rhythm copying and note number detection ($p < 0.0001$). There were also two negative correlations,

Table 4. Significant correlations between the MATs, WORD and IQ scores of all the children

Test 1	Test 2	*r* value	Significance level
WORD reading	WORD spelling	0.748	<0.0001
Rhythm copying	Note number detection	0.680	<0.0001
Song rhythm	Song beat	0.636	<0.001
Rhythm copying	Rhythm discrimination	0.637	<0.001
Musical experience	Rhythm copying	0.592	<0.005
Singing	Song beat	0.550	<0.005
Age	Rhythm copying	0.537	<0.005
WORD spelling	Song rhythm	0.536	<0.005
Rhythm copying	Note number discrimination	0.528	<0.005
WORD reading	Pitch discrimination	−0.518	<0.01
Pitch matching	Timbre discrimination	0.517	<0.01
Musical experience	Singing	0.508	<0.01
Rhythm discrimination	Note number detection	0.502	<0.01
WORD spelling	Pitch discrimination	−0.501	<0.01
Note number detection	Note number discrimination	0.465	<0.05
Musical experience	Song beat	0.440	<0.05
Age	Note number detection	0.434	<0.05
IQ	Rhythm copying	0.433	<0.05
Song rhythm	Tempo discrimination	0.397	<0.05

between pitch discrimination and both WORD reading ($p<0.01$) and spelling ($p<0.01$). Age was found to correlate with rhythm copying ($p<0.005$) and note number detection ($p<0.05$), while IQ correlated only with rhythm copying ($p<0.05$).

DISCUSSION

The results of the MATs showed an overall trend for the dyslexic group to score lower than the control group on the tasks involving timing skills (as predicted), and higher than the control group on the tasks involving pitch skills (which was not predicted). There are two possible ways of interpreting these results. The first is to suggest that the dyslexic group's higher score on the measure of musical experience indicates a potential advantage on the MATs, which was reflected in the pitch tests but not in the timing tests, due to dyslexics difficulties with timing skills. This interpretation implies that the difference in scores between the two groups on the timing tests would have been larger (and possibly more significant) were it not for the dyslexic group's slightly greater musical experience.

A second interpretation could be that the results were not significantly affected by musical experience, and that the dyslexic group showed real evidence of superior pitch skills, as indicated on the task of pitch discrimination ($p<0.01$). Backhouse has noted a heightened sense of pitch in some dyslexic musicians (Backhouse, 2001). Pitch is also known to be processed predominantly in the right hemisphere of the brain (Zatorre, 1984, 1992), and dyslexics' cortical abnormalities are generally thought to be focused in the left-hemisphere (Galaburda *et al.*, 1985, 1987), thus leading to a greater reliance on the right hemisphere (West, 1991). Deutsch (1970) has demonstrated that language processing (of spoken numbers) does not interfere with memory for pitch, suggesting that the two skills involve different cognitive structures. Interestingly, Deutsch (1978) has also found that left-handers show better pitch memory than right-handers, and particularly left-handers with a mixed hand preference (which is often associated with reading disability, e.g. Zurif & Carson, 1970). However, other researchers have noted links between the processing of pitch and the processing of language prosody (e.g. Patel, Peretz, Tramo, & Labrecque, 1998) while Baldeweg, Richardson, Watkins, Foale, and Gruzelier (1999) have found that dyslexics can have difficulties with pitch processing.

Consequently, it is difficult to favour either interpretation of the dyslexic group's relatively strong performance on the pitch skills tasks. Nevertheless, the pattern of difficulties with musical timing is quite clear.

Interpretation of the timing difficulties

The main difficulty area for the dyslexic group seemed to be the tests involving rapid auditory skills ($p < 0.05$), especially the test of note number detection, where the dyslexic group made significantly more error ($p < 0.05$), usually by over-estimating of the number of notes heard. An interesting finding was the existence of a subset of 5 dyslexic children (33% of the group) who accounted for almost all of the error on this task, with the remaining 10 dyslexic children showing no impairment. This incidence is similar to the 4 out of 17 dyslexic children (24%) found to have rapid auditory processing problems by Marshall *et al*. (2001), and partially supports suggestions that these children may actually represent a sub-type of dyslexia. It should be noted, however, that the mean age of the subset of children in this study was slightly lower than that of the whole dyslexic group, and that their difficulties were not so evident on the forced choice rapid skills tests.

The dyslexic group was also found to show significantly more error when copying a tempo of 80 beats per minute ($p < 0.05$). The latter result partially supports Oglethorpe's observation that dyslexic children can have difficulties with maintaining a steady beat (Oglethorpe, 1996), although there were no significant differences found at speeds slower or faster than 80 bpm. It is possible that, being close to the often quoted natural tapping speed of 100 bpm (Clarke, 1999), 80 bpm is a particularly sensitive indicator of natural tapping ability (as opposed to tapping ability at different speeds which may have been developed through musical experience). Further testing would be required to explore this speculative hypothesis though, with longer periods of tapping than the 8 beats used in this study.

A particularly interesting finding was the correlation between song rhythm and spelling ($r = 0.54, p < 0.005$). The process of tapping to the rhythm of a song is actually a form of syllable segmentation, and thus reflects a type of phonological awareness that is used in spelling. For example, the rhythm of Happy Birthday corresponds directly to the onset of each syllable in the text, as shown in Figure 5.

Interestingly when the dyslexic and control groups were analysed separately, the correlation between song rhythm and spelling was nearly twice as strong in

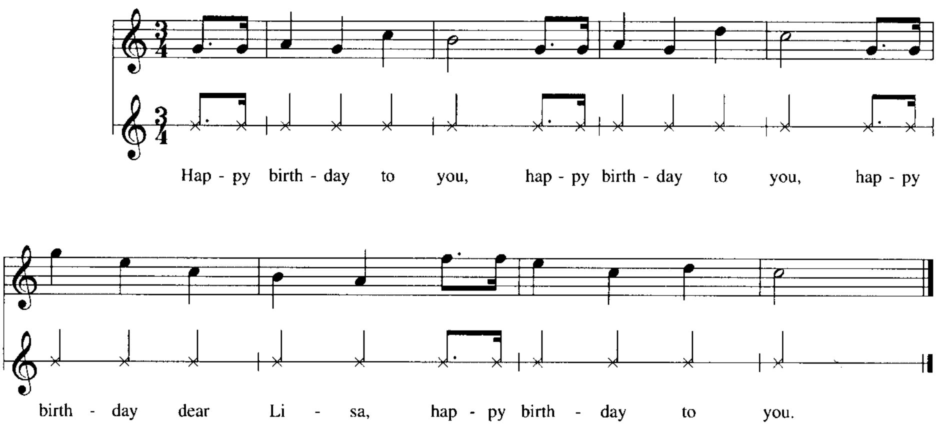

Figure 5. Diagram to show how the rhythm of Happy Birthday corresponds with the onset of each syllable of the text.

the control group ($r = 0.662, p = 0.024$) as in the dyslexic group ($r = 0.37$, ns), where the relationship was non-significant. This implies that the dyslexic children did not employ syllable segmentation as a phonological strategy in their spelling to the same extent as the controls. It may also be reasoned that learning to tap the rhythm of a song could present a valuable activity in the development of syllable segmentation skills, and subsequently spelling skills. Thomson (1990) found that integrating the task of syllable tapping into phonological training improved spelling performances, while Overy (2002) found that a programme of musical activities that focused on rhythm skills (including the rhythm of songs) had a positive effect on phonological skills and spelling performance.

SUMMARY AND CONCLUSIONS

The results of this study support claims that dyslexic children can experience difficulties with musical timing skills. The relatively small sample size, the limited number of items per test, and the slightly greater musical experience of the dyslexic group made it difficult to assess the true nature and extent of these timing difficulties, and the interpretations are therefore made cautiously. However, there were clear indications that rapid timing skills and rhythm skills are areas of particular difficulty for dyslexic children, while tempo skills seem less problematic, and pitch skills seem relatively strong.

An interesting finding was the identification of a subgroup of 5 dyslexic children (33%) who experienced severe difficulties on a test of rapid temporal processing. While these children are a minority in the present study, it is clearly an important research priority to identify the incidence of this problem in the wider population of dyslexic children. Another interesting finding was the correlation between spelling ability and the skill of tapping out the rhythm of a song, both of which rely to some extent on phonological segmentation skills. The fact that this relationship was stronger in the control group than in the dyslexic group, coupled with the fact that the control group scored higher on both tests, suggests that children who are able to extract the rhythm of a song may have a phonological advantage when approaching spelling.

It is proposed that musical activities, based on songs and rhythm games, may provide a valuable medium in which to develop dyslexic children's timing skills and language skills. Such activities have a particular advantage of being non-literacy based, thus removing the frustrations that may be associated with reading and writing activities. In addition, musical activities are potentially extremely enjoyable, providing opportunities for group work, fun and humour as well as rewarding musical experiences and skill development.

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