Factors affecting frequency discrimination by poor readers.

Peter Bailey†, Yvonne Griffiths‡, Nick Hill‡ and Maggie Snowling†
† Department of Psychology, University of York, UK
‡ Department of Psychology, University of Essex, UK
E-mail: pjb1@york.ac.uk, ymg@essex.ac.uk, nickhill@essex.ac.uk, mjs19@york.ac.uk

ABSTRACT

Experiments on frequency discrimination by groups of poor readers have produced mixed results: some show impairments relative to normal-reading control groups, whilst others show no reliable group differences. It remains unclear to what extent these differences in outcome are attributable to individual differences in the severity of a sensory processing deficit associated with dyslexia, or to use of different psychophysical procedures that make different demands of higher-level cognitive processes such as memory and attention, which may be compromised in dyslexia. To explore these issues, pure-tone frequency difference limens (DLFs) were measured for groups of dyslexic adults and normal-reading controls in conditions incorporating a range of procedural manipulations. Dyslexic and control participants' DLFs did not differ reliably when the procedure involved 4-interval trials, but dyslexics' DLFs were larger than controls using 2-interval trials. The *relative* difference between dyslexic and control participants' DLFs found using 2-interval trials did not differ systematically across conditions involving a fixed or roving standard frequency, long or short duration stimuli, long or short interstimulus intervals, or interstimulus intervals that were either silent or included interpolated tones. The results suggest no obvious link between elevated DLFs and impaired short-term pitch memory in these dyslexic participants.

1. INTRODUCTION

One way of approaching the question of whether in general reading performance is associated with auditory performance is to undertake large-scale studies involving hundreds of participants who complete test batteries that include tests of basic auditory capabilities and of reading ability. Such studies have provided a fairly unequivocal answer: although there is considerable individual variation in auditory performance and in reading skill, there is no systematic relationship between the two [1].

In the light of this, one might be surprised to find reports that groups of dyslexic adults perform less well than normal-reading controls on basic auditory tasks such as, for example, frequency discrimination and detection of modulation [2,3,4]. However, there are also reports of failures to find differences between dyslexic and control participants on these tasks [5]. The differences in outcome may be attributable in part to differences in the severity of dyslexia in the participant sample, but may also arise as a result of differences in aspects of the psychophysical procedures used, such as the trial structure, the amount of practice given and the availability of feedback. For example, France et al [3] demonstrated an influence of trial structure (2-interval vs. 7-interval) on the magnitude of differences between pure-tone frequency difference limens for dyslexic and control listeners.

Such results raise questions about the extent to which differences between good and poor readers' psychophysical thresholds directly reflect fundamental limitations in low-level sensory processing [6], or are the result of demands made by the psychophysical tasks on higher-level cognitive processes that may have been compromised in dyslexia. Even highly constrained psychophysical tasks require attentional and memory processes, and there is much still to be understood about the impact of dyslexia on such processes in the context of threshold estimates.

The experiment reported here was designed to examine the effects of different psychophysical procedures on estimates of difference limens for frequency (DLFs) in a group of adult dyslexic listeners and a group of normal-reading controls. The procedural variants we explored were chosen primarily to place varied demands on auditory memory, and included manipulations of (i) the trial structure (either 2-interval or 4-interval), (ii) the presence or absence of trial-to-trial variation in the frequency of the standard stimulus, (iii) the stimulus duration, (iv) the interstimulus interval, and (v) the presence or absence of interferer tones interpolated in the interstimulus interval. We sought to determine whether the magnitude of any differences found between dyslexic and control participants varied across the conditions. A secondary motivation was to replicate with more severely impaired dyslexic participants the essential features of one of the key conditions that in a previous experiment [5] did not show a difference between participant groups.

2. EXPERIMENT

2.1 PARTICIPANTS

12 dyslexic adults and 12 normal-reading controls matched in age and nonverbal IQ were selected for the study. Participants were recruited from the university student population and from the general population. The selection

ISBN 1-876346-48-5 © 2003 UAB

criteria required that all dyslexic participants had to obtain a standard score below 90 and all control participants a standard score above 100 on the Wide Range Achievement Tests (WRAT) single word spelling test. The mean standard score was 83 (range 56-90) for the dyslexic group and 112 (range 98-120) for the control group. Additionally, participants' audiometric pure-tone thresholds were required to be less than 20 dB HL in the range 250-8000 Hz.

Both groups completed a battery of literacy and phonological tasks. The literacy tests were: WRAT test of single word reading, Test of Word Reading Efficiency (TOWRE) word and nonword reading speed, nonsense passage reading, WRAT single word spelling, and writing speed. The phonological tests were: spoonerisms, rapid auditory naming (RAN), and digit span. Performance of the dyslexic group on all of these tests was reliably lower than that of the control group, and was consistent with that of other samples of dyslexic adults reported in the literature.

2.2 STIMULI

The stimuli were sinusoids with onset and offset cosine-squared ramps of duration equal to 5% of the total duration, which was either 400 ms or 20 ms, according to condition. The (mean) frequency of the standard signal was 1 kHz. Signals were created in digital form with a sampling frequency of 44.1 kHz and amplitude quantization of at least 16 bits, and were converted to analog waveforms with a LynxOne sound card. They were presented to the right channel of a pair of Sennheiser HD580 headphones at 65 dB SPL.

2.3 PROCEDURE

Frequency difference limens were measured in six conditions using a two-alternative forced-choice adaptive procedure that targeted thresholds corresponding to 75% correct [7]. A single run of the procedure consisted of 60-trials, with an individual listener's threshold for each condition defined as the geometric mean of six such runs. Each condition was preceded by a brief sequence of practice trials. Feedback was provided after every trial. Participants were tested in four sessions held on separate days. The conditions are summarized in Table 1.

	Trial type	Standard Frequency	Stimulus Duration (ms)	ISI (ms)
A	4I	Fixed	400	400
B	2I	Fixed	400	400
C	2I	Roved	400	400
D	2I	Roved	20	400
E	2I	Roved	400	2800
F	2I-int	Roved	400	2800

Table 1: Summary of experimental conditions.

Condition A used a 4-interval trial structure (4I), with the target tone presented in either the second or third interval with equal probability. The standard tone was presented in the other three intervals of the trial. Conditions B-F employed a two-interval trial structure (2I). For both trial types listeners were required to indicate the interval containing the (higher frequency) target tone. In both conditions A and B the frequency of the standard stimulus was fixed at 1 kHz. In the remaining conditions the frequency of the standard stimulus was 'roved', that is, selected randomly on each trial from the range 900 – 1100 Hz. Apart from the use of a roving standard, condition C was identical to condition B. In all conditions apart from D the duration of the tones was 400 ms; in condition D tone duration was reduced to 20 ms. In conditions A-D the interstimulus interval within a trial (ISI) was 400 ms. Condition E was similar to condition C, but employed a longer ISI of 2800 ms. Condition F also used an ISI of 2800 ms, but two irrelevant interferer tones were presented during the interstimulus interval on each trial. The interferer tones were similar to the standard and target tones in duration and level, and were roved in frequency in the same range. The first interferer tone began 800 ms after the offset of the first interval of the trial, and interferer tone ISI was 400 ms.

2.4 RESULTS

Mean DLFs for the dyslexic and control groups are shown in Figure 1.

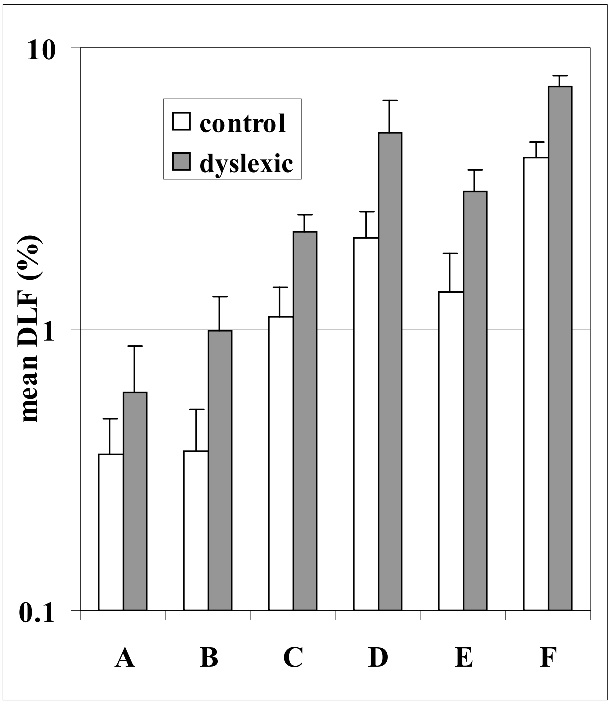

Figure 1: Mean frequency difference limens for the dyslexic and control groups, shown on a logarithmic scale. Error bars show standard errors.

A series of 2 by 2 mixed design analyses of variance was performed to examine for the two participant groups the effects of trial structure (conditions A vs. B), roving frequency standard (conditions B vs. C), stimulus duration (conditions C vs. D), ISI (conditions C vs. E) and interferer tones (conditions E vs. F). The analyses were carried out on log transformed data.

Trial structure (conditions A and B). There were main effects of group [F(1,22)=5.5, p<0.05] and condition [F(1,22)=8.7, p<0.01], and also a significant interaction between the two [F(1,22)=7.7, p<0.05]. Further analysis of the interaction showed that DLFs for the two groups did not differ when measured using 4-interval trials [F(1,23)=2.7, p=0.12], but dyslexic listeners' thresholds were elevated when measured using 2-interval trials [F(1,23)=7.8, p<0.05].

Roving frequency standard (conditions B and C). DLFs were higher when the standard frequency was roved from trial to trial [F(1,22)=106.1, p<0.001], and dyslexic listeners' DLFs were higher than controls [F(1,22)=7.6, p<0.05]. There was no interaction [F(1,22)=2.5, p=0.13].

Tone duration (conditions C and D). DLFs were higher for short duration tones [F(1,22)=71.6, p<0.001], and dyslexic listeners' DLFs were higher than controls [F(1,22)=7.2, p<0.05]. There was no interaction. [F < 1].

ISI duration (conditions C and E). DLFs were higher for longer ISIs [F(1,22)=10.0, p<0.01], and dyslexic listeners' DLFs were higher than controls [F(1,22)=6.7, p<0.05]. There was no interaction [F < 1].

Interferer tones (conditions E and F). DLFs were higher when intereferer tones were presented in the ISI [F(1,22)=71.8 p<0.001], and dyslexic listeners' DLFs were higher than controls [F(1,22)=10.0, p<0.01]. There was no interaction [F < 1].

3. DISCUSSION

Dyslexic participants had elevated DLFs for all conditions involving 2-interval trials, but did not differ significantly from the control group in the condition involving 4-interval trials. The absence of a group difference in the latter condition is consistent with our previous findings [5], and, given the relatively more severe impairment in the dyslexic participants in the current experiment, increases our confidence that the outcome of that earlier study was not simply a consequence of relatively mild impairment in that dyslexic sample.

Four interval and 2-interval trials present a participant with different challenges. There are several reasons why the former might lead to better performance, particularly with relatively untrained listeners. For example, unlike 2-interval trials, 4-interval trials can be approached as an 'odd one out' problem, so it is less important that the participant apprehends the nature of the cue that determines correct choice of interval on a trial. The three repetitions of the standard stimulus on each 4-interval trial might be expected to improve performance by consolidating the representation of the standard stimulus frequency in auditory memory. It is also possible that the auditory patterns formed by the four tones in a 4-interval trial are more distinctive than those formed by the two tones in a 2-interval trial.

Our data do not allow us to determine which if any of these factors made 2-interval trial performance poorer for dyslexic but not for control listeners in this experiment. But the force of the finding that trial structure influenced the dyslexic group's performance more than that of controls (see also [3]) is that it suggests one should be wary of attributing group differences in psychophysical thresholds simply to a basic sensory impairment associated with dyslexia.

Each of the other procedural manipulations in the experiment led to reliable elevation of DLFs. Performance was worse for both groups of participants when (i) the standard frequency was roved between trials, compared with fixed standard frequency, (ii) the tone duration was decreased from 400 ms to 20 ms, (iii) the interstimulus interval was increased from 400 ms to 2800 ms, and (iv) interferer tones were interpolated between observation intervals during the ISI.

These are not unexpected results. Roving the standard frequency across trials is likely to impact on performance because it increases uncertainty and limits the development of long-term memory for standard stimulus frequency [8]. Decreasing tone duration is known to impair frequency discrimination performance [9], as is increasing interstimulus interval [10], plausibly as a result of memory trace decay, and adding tones in the interstimulus interval [11], plausibly as a result of memory trace interference.

In each case dyslexic participants' DLFs were larger than those of controls, but as scrutiny of Figure 1 suggests, and the absence of analysis of variance interactions confirms, the relative magnitude of threshold elevation for dyslexic participants relative to controls across conditions B—F is fairly consistent. This suggests that the dyslexic participants were no more susceptible than controls to the effects of stimulus uncertainty, stimulus duration or auditory memory trace decay and interference. Although it is a side issue in the context of this experiment, we note that the absence of a specifically greater impairment for dyslexic participants when tone duration was 20 ms is inconsistent with claims that dyslexia is associated with a deficit in rapid auditory processing [12].

4. CONCLUSIONS

Dyslexic and control participants showed similar frequency discrimination performance when the psychophysical procedure involved 4-interval trials, but dyslexic participants showed reliably poorer performance than controls when the procedure involved 2-interval trials. The absence of a reliable group difference in one condition suggests that limitations on performance in psychophysical tasks for dyslexic participants may not derive solely from a basic sensory impairment. However, the origins of dyslexic listeners' impaired performance in other conditions remain

 ISBN 1-876346-48-5 © 2003 UAB

unclear. Our data suggest that whatever the stimulus or task factors are that contribute to the elevated thresholds seen for dyslexic listeners in the conditions involving 2-interval trials, they do not seem to be related in any simple way to impairments in auditory memory.

ACKNOWLEDGEMENT

This work was supported by the Wellcome Trust through project grant No. 55671.

REFERENCES

[1] C. S. Watson and G. R. Kidd "On the lack of association between basic auditory abilities, speech processing and other cognitive skills" *Seminars in Hearing,* vol.23, pp. 83-93, 2002.

[2] K. I. McAnally and J. F. Stein "Auditory temporal coding in dyslexia." *Proc R Soc Lond B Biol Sci*, vol. 263, pp. 961-965, 1996.

[3] S. J. France, B. S. Rosner, P. C. Hansen, et al. "Auditory frequency discrimination in adult developmental dyslexics." *Perception and Psychophysics*, vol. 64, pp. 169-179, 2002.

[4] C. Witton, J. B. Talcott, P. C. Hansen, et al. "Sensitivity to dynamic auditory and visual stimuli predicts nonword reading ability in both dyslexic and normal readers." *Current Biology*, vol. 8, pp. 791-797, 1998.

[5] N. I. Hill, P. J. Bailey, Y. M. Griffiths, and M. J. Snowling "Frequency acuity and binaural masking release in dyslexic listeners." *Journal of the Acoustical Society of America*, vol. 106, pp. L53-L58, 1999.

[6] B. A. Wright, R. W. Bowen and S. G. Zecker "Nonlinguistic perceptual deficits associated with reading and language disorders." *Current Opinion in Neurobiology,* 2000; vol.10, pp. 482-486, 2000.

[7] J. J. Zwislocki and E. M. Relkin "On a psychophysical transformed-rule up and down method converging on a 75% level of correct responses." *Proc Natl Acad Sci U S A*, vol. 98, pp. 4811-4814, 2001.

[8] C. S. Watson "Uncertainty, informational masking, and the capacity of immediate auditory memory." in *Auditory processing of complex sounds*, W. A. Yost & C. S. Watson (Eds.), N.J.: Lawrence Erlbaum Associates, 1987.

[9] B. C. J. Moore "Frequency difference limens for short-duration tones." *Journal of the Acoustical Society of America,* vol. 54, pp. 610-619, 1973.

[10] J. D. Harris, "The decline of pitch discrimination with time." *Journal of Experimental Psychology,* vol. 43, pp. 96-99, 1952.

[11] T. Pechmann and G. Mohr "Interference in memory for tonal pitch: implications for a working-memory model." *Memory & Cognition,* vol. 20, pp. 314-320, 1992.

[12] P. Tallal "Auditory temporal perception, phonics, and reading disabilities in children." *Brain & Language,* vol. 9, pp. 182-198, 1980.