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The tale is in the tail: An alternative hypothesis for psychophysical performance variability in dyslexia

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Abstract. Dyslexic groups have been reported to display poorer mean performance than groups of normal readers on a variety of psychophysical tasks. However, inspection of the distribution of individual scores for each group typically reveals that the majority of dyslexic observers actually perform within the normal range. Differences between group means often reflect the influence of a small number of dyslexic individuals who perform very poorly. While such findings are typically interpreted as evidence for specific perceptual deficiencies in dyslexia, caution in this approach is necessary. In this study we examined how general difficulties with task completion might manifest themselves in group psychophysical studies. Simulations of the effect of errant or inattentive trials on performance produced patterns of variability similar to those seen in dyslexic groups. Additionally, predicted relationships between the relative variability in dyslexic and control groups, and the magnitude of group differences bore close resemblance to the outcomes of a meta-analysis of empirical studies. These results suggest that general, nonsensory difficulties may underlie the poor performance of dyslexic groups on many psychophysical tasks. Implications and recommendations for future research are discussed.

1 Introduction

Over the past two decades, much effort has been made to unravel the biological underpinnings of the reading difficulties experienced by individuals with dyslexia. One area that has attracted considerable research activity has been the attempt to identify any perceptual concomitants of dyslexia. A number of perceptual deficits have been proposed to exist in dyslexia, both in the visual (eg Lovegrove et al 1986; Stein and Walsh 1997) and auditory (eg Farmer and Klein 1995; Tallal 1980) domains. However, the exact nature of these deficits and the role they might play in dyslexia continues to be the subject of active debate (Hogben 1997; Hulme 1988; Ramus 2003; Rosen and Manganari 2001; Skottun 2000; Studdert-Kennedy and Mody 1995).

Much of the evidence for perceptual anomalies in dyslexia is drawn from studies comparing the performance of groups of dyslexics and normal readers on psychophysical tasks. As is commonplace in psychology, the results of a *t*-test or analysis of variance (ANOVA) are typically reported, with little or no consideration given to the nature and distribution of individual differences within the groups. Where such data are made available, perusal of the distribution of scores reveals a remarkably consistent pattern. Invariably there is considerable overlap between scores, such that the majority of individuals from both groups perform within the same range. Typically though, the distribution of scores is more variable for the dyslexic group than for the comparison group of normal readers. This is often due to a small number of individuals who perform very poorly. The scores of these individuals form an extended tail of the distribution and contribute unduly to overall differences in mean performance between the groups (eg Cornelissen et al 1995; Heath and Hogben, in press; Heath et al 1999; Hill et al 1999; McArthur and Hogben 2001; Tallal 1980; Walther-Müller 1995; Witton et al 2002).

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Two examples of this pattern of results are shown in figure 1. In both cases the distribution of thresholds in the dyslexic group is noticeably skewed by the presence of a few extreme scores. As a result, the mean threshold for the dyslexic group is higher than that for the control group, despite the fact that the majority of dyslexics perform within the normal range [9 of 12 in (a), 14 of 17 in (b)].

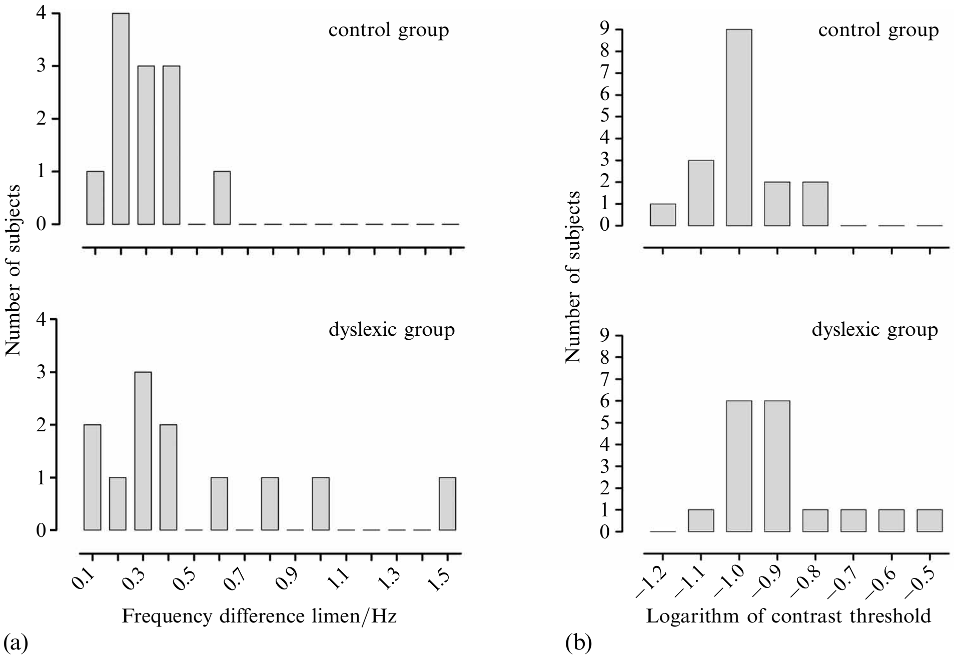

Figure 1. Comparison of the distribution of thresholds in control (upper graphs) and dyslexic (lower graphs) groups in two independent studies. Data in (a) are replotted from Hill et al (1999), figure 1. Data in (b) are replotted from Walther-Müller (1995), figure 4.

Though traditional approaches to group psychophysics tend to downplay individual differences within groups, the variability of performance seen in dyslexic groups has been noted by several dyslexia researchers (eg Hogben 1996; McArthur and Bishop 2001). Accordingly, proponents of both visual (eg Stein et al 2000) and auditory (eg Farmer and Klein 1995; Tallal 1980) deficits acknowledge that such problems seem to be restricted to a subset of the dyslexic population. But what is it that makes these individuals in the tail of the distribution different from other individuals with dyslexia? Identifying the factors that produce large variability in dyslexics' scores on perceptual tasks is key to understanding the group differences that are commonly found. To date, in most attempts to tackle this issue it has been assumed that variability in performance most likely stems from some form of inherent heterogeneity in dyslexia.

It is possible that dyslexia is not a unitary disorder, but rather encompasses different forms of reading difficulties. Accordingly, one might imagine that a particular perceptual deficit might be restricted to a certain subtype of dyslexia. A sensible approach then, is to consider the variability of psychophysical performance within the framework of existing classification systems of dyslexia. By far the best known subtyping distinction in dyslexia is between difficulties with phonological decoding (the sublexical conversion of graphemes to phonemes) and difficulties with orthography-based lexical retrieval (eg Boder 1973; Castles and Coltheart 1993). Unfortunately, attempts to utilise this distinction in studies of perceptual abilities have thus far failed to provide much clarity.

A good example can be seen in the literature dealing with impairments of visual-contrast sensitivity and motion processing in dyslexia, commonly interpreted as evidence for deficient magnocellular processing. While some evidence has pointed towards a particular relationship between visual deficits and poor phonological decoding (Borsting et al 1996; Hogben 1996; Slaghuis and Ryan 1999), other studies have failed to find evidence for such a relationship (Ridder et al 2001; Williams et al 2003). Complicating the picture further are claims that visual sensitivity is actually more closely related to orthographic skill than phonological skill in unselected samples (Au and Lovegrove 2001; Talcott et al 2000). Overall, efforts to disentangle the relationship between component reading skills and perceptual abilities have been limited by the fact that measures of the former tend to be highly correlated.

Another possible source of heterogeneity in dyslexia stems from the fact that individuals with reading problems often experience difficulties in other areas as well. In any given sample of dyslexic readers, one might also find evidence of a range of other concomitant difficulties, such as language impairment, attention-deficit hyperactivity disorder, and developmental coordination disorder. Perhaps the variability in psychophysical performance seen in dyslexic groups simply reflects this comorbid mixture. Unfortunately, there is a dearth of published research on influences of comorbidity on psychophysical performance, and what little evidence is available does not seem to offer a satisfactory solution.

Results of the two studies we conducted suggest that performance in certain auditory tasks is particularly poor in groups with both a reading disability and an oral language disorder. Heath et al (1999) found significant differences between control and dyslexic groups on an auditory temporal-order judgment task only when the dyslexic group also experienced language delays. Likewise, McArthur and Hogben (2001) found that evidence for impaired auditory backward masking in children with specific language impairment was confined to a group who also displayed poor reading accuracy. While such results seem encouraging, the authors of both studies point out that even the comorbid groups show considerable variability in performance. As is so often seen in dyslexic groups, the majority of individuals in comorbid groups perform just as well as controls. Again we are left with the question of just what is different about individuals in the tail of the distribution.

In this paper, we consider an alternative hypothesis for psychophysical-performance variability in dyslexia. Rather than reflecting heterogeneity of specific perceptual processes within the dyslexic population, we ask whether the commonly seen patterns of results might stem from more general, nonsensory difficulties in dyslexic groups. Simulations of the effect of confusion or inattention on task performance have been used in the past to successfully model apparent impairments of visual-contrast sensitivity in dyslexic groups (Davis et al 2001; Peli and García-Pérez 1997; Stuart et al 2001) and also the poorer performance of children on a number of auditory tasks (Wightman and Allen 1992; Wightman et al 1989). Here we extend this work to consider the contribution of such factors to studies of perceptual functioning in dyslexia on a wider scale. First, we simulate the effect of errant trials on group performance distributions for typical psychophysical tasks. We then explore the relationship between the relative variability of performance in dyslexic and control groups, and the magnitude of differences between the respective group means.

2 The effect of errant trials on performance variability

We define an 'errant trial' as a trial on which any nonperceptual factor, such as momentary inattention, distraction, or confusion prevents the observer from responding as accurately as predicted from his or her psychometric function. We simulated the effect of errant trials on performance variability on a hypothetical two-alternative forced-choice (2AFC) task, similar to those typically used to estimate psychophysical thresholds for detection or discrimination. We introduced a fixed probability that any given trial would be errant, resulting in the observer guessing with a 0.5 probability of success. The underlying psychometric function remained unchanged throughout, such that the probability of a correct response on properly attended trials was given by a logistic function of the form:

$$P(I) = 0.5 + 0.5\left(1 + \exp\frac{X - I}{S}\right)$$

where I is the stimulus intensity level, X is the threshold value (arbitrarily fixed at 50) and S is a parameter determining the slope of the function (fixed at 5). Threshold estimates were determined by an adaptive PEST procedure (Taylor and Creelman 1967) converging on 75% correct performance. Each simulated run consisted of 70 trials, with the threshold calculated by taking the mean stimulus intensity following the fourth reversal. One hundred threshold estimates were made for each of 11 levels of simulated errancy, with nonconverging functions discarded and rerun.

Results of the simulation are presented in figure 2. With low levels of errancy, threshold estimates were clustered around the true threshold, with small amounts of variability either side of this value. Increasing the probability of errant trials resulted in considerable changes to the distribution of scores. While the majority of estimates remained close to the true threshold, more and more runs returned inflated threshold values, skewing the distributions. As a result, we see a systematic positive relationship between the degree of errancy and both the mean and the variability of threshold estimates (see figure 3).

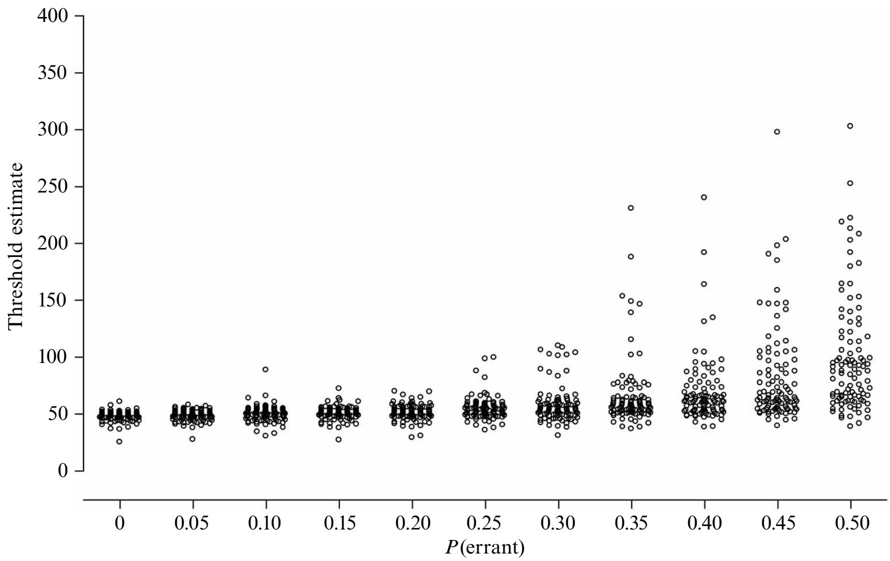

Figure 2. Distributions of simulated threshold estimates for different levels of errancy.

The distribution of thresholds produced by simulating the effect of errant trials on performance clearly mirrors the type of results commonly seen in dyslexic groups. A couple of points warrant mentioning here. First, as all threshold estimations were based on an identical psychometric function, variability in performance is produced in the absence of any actual variability in perceptual functioning. Second, similar patterns of variability to that seen in dyslexic groups were produced by making multiple threshold estimates at a constant level of errancy. Because each score is based

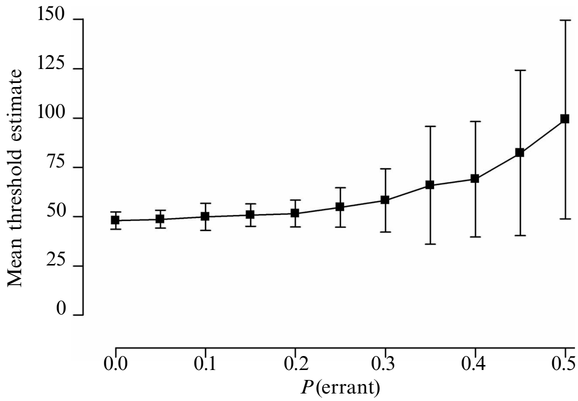

Figure 3. Mean simulated threshold estimate, plotted as a function of degree of errancy. Error bars depict ± 1 standard deviation.

on the same level of errancy, this variability does not reflect individual differences in the number of errant trials either. Rather, it seems that the position of the errant trials within the adaptive run is the prime determinant of how much the threshold estimate is shifted away from its true value.(1)

3 The relationship between unequal variability and effect size

The results of the simulation suggest an alternative hypothesis for psychophysical performance variability in dyslexia. Rather than reflecting individual differences in task-specific perceptual functioning, such variability may be the result of coupling general task-completion difficulties with adaptive psychophysical methods.(2) As skewing a distribution will also shift the mean, one prediction of this hypothesis is that there should be a systematic relationship between the relative variability of dyslexic and control groups, and the size of the difference between their respective means. To explore this possibility we conducted a meta-analysis of studies comparing dyslexic and normal readers on psychophysical tasks.

To obtain a manageable number of studies we restricted the meta-analysis to two of the most widely used classes of visual tasks seen in the relevant literature: motion coherence and contrast sensitivity for sinusoidal gratings (see Appendices A and B). Relative variability of performance was estimated by dividing the standard deviation for the dyslexic group by the standard deviation for the control group and taking the logarithm of this ratio. Accordingly, a positive logarithm of the ratio indicates relatively more variability in the dyslexic group while a negative logarithm of the ratio indicates relatively more variability in the control group. Of the group comparisons reviewed, 34 provided the data needed to allow this calculation. Figure 4 shows a frequency plot of relative variability for the available experiments. If performance variability in the normal and dyslexic reader populations were equivalent, we would expect to find the logarithm of standard-deviation ratios for the sampled experiments to be symmetrically distributed around 0. However, we see a substantial bias with dyslexic groups showing more variable performance in most instances.

(1) As the probability of any given trial being errant was independent of all other trials, one would expect some variability in the actual number of errant trials in a run, even within a fixed level of *P*(errant). However, the pattern of results presented here is independent of this fluctuation. Modeling errancy as a *fixed proportion* of errant trials produces identical results, provided the position of missed trials within the run remains random.

(2) While we used a PEST procedure in the simulations reported here, the results presented are not specific to this particular adaptive method. Similar outcomes also result by modeling errancy on simple up–down staircase procedures (eg Levitt 1971).

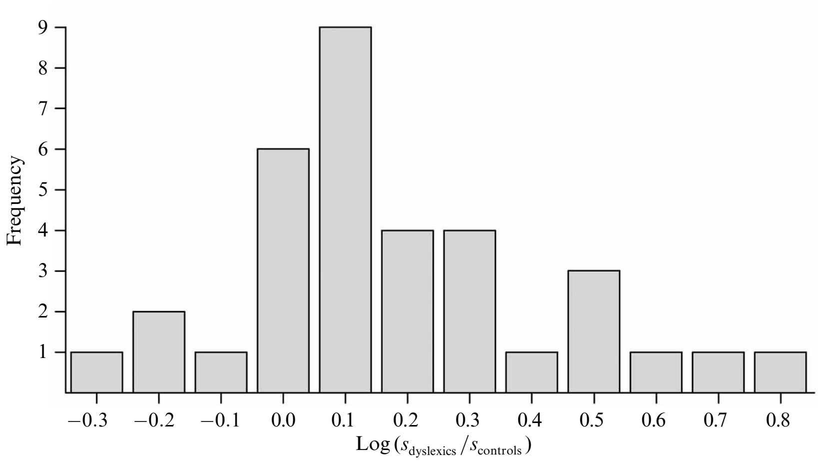

Figure 4. Frequency distribution of relative variability ratios obtained in the meta-analysis. A logarithm ratio of zero indicates equal performance variability in control and dyslexic groups.

To quantify the magnitude of the difference in mean performance between the two groups we then calculated a standard measure of effect size for each experiment. Cohen's *d* was calculated by the formula:

$$d = \frac{M_1 - M_2}{\frac{1}{2}(s_1 + s_2)} \ ,$$

where M_1 and M_2 are the respective group means and s_1 and s_2 are the respective group standard deviations (adapted from Cohen 1988). Comparisons in which mean dyslexic performance is worse than controls were assigned positive values of *d*, whereas negative values of *d* were used to indicate superior performance by the dyslexic group.

When effect size was correlated against the logarithm of standard-deviation ratio, we found a strong positive relationship between the two measures ($r = 0.69$, $p < 0.05$). As seen in the scatter plot in figure 5, effect sizes tend to be clustered around zero when variability is roughly equal in the two groups. By contrast, most of the large, significant differences between the two groups came from experiments where the dyslexic group showed substantially more variability in performance. These results support the general contention that differences between mean performance in dyslexic and control groups are systematically related to the relative variability in the two groups. Indeed, the meta-analysis suggests that large differences between groups occur when (and perhaps only when) there is a large mismatch in variability between the two groups.

To provide a more direct comparison between the prediction of the simulation and the empirical data we ran a series of meta-analyses of simulated group 'studies'. Each simulated study consisted of a comparison between twenty-five control and twenty-five dyslexic participants. Procedures for threshold estimation were identical to the simulation described earlier. For a given study, the value of P(errant) for the dyslexic group was set by drawing a random number from a uniform distribution in the interval [0, 0.4], while control subjects were assumed to have no errant trials. These values were chosen to produce relative variability ratios within a similar range to that seen in the empirical meta-analysis. Once thresholds for both groups in a study had been simulated, calculations of the effect size and the logarithm of standard-deviation ratio were made.

Figure 6 shows the resultant scatter plots for six simulated meta-analyses, each panel representing the simulation of 25 independent 'studies'. In all cases, we see a strong positive correlation between the relative variability in the simulated groups and the effect size of the group-mean comparison, similar to that seen in the empirical meta-analysis.

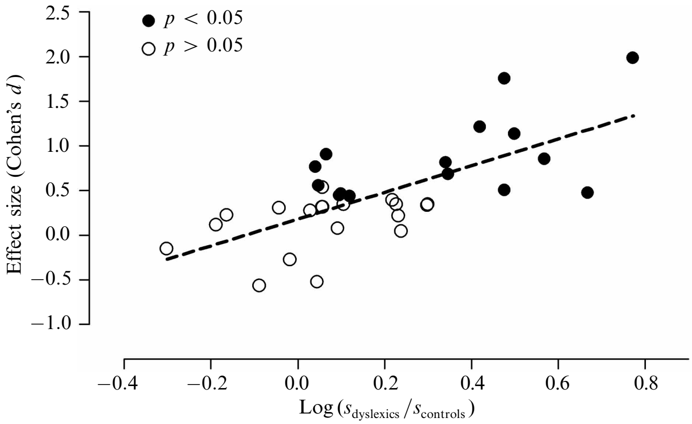

Figure 5. Effect sizes for the dyslexic versus control group comparisons in the meta-analysis, plotted against the logarithm of relative variability ratio. Filled symbols indicate statistically significant group differences ($p < 0.05$); unfilled symbols indicate non-significant differences ($p > 0.05$).

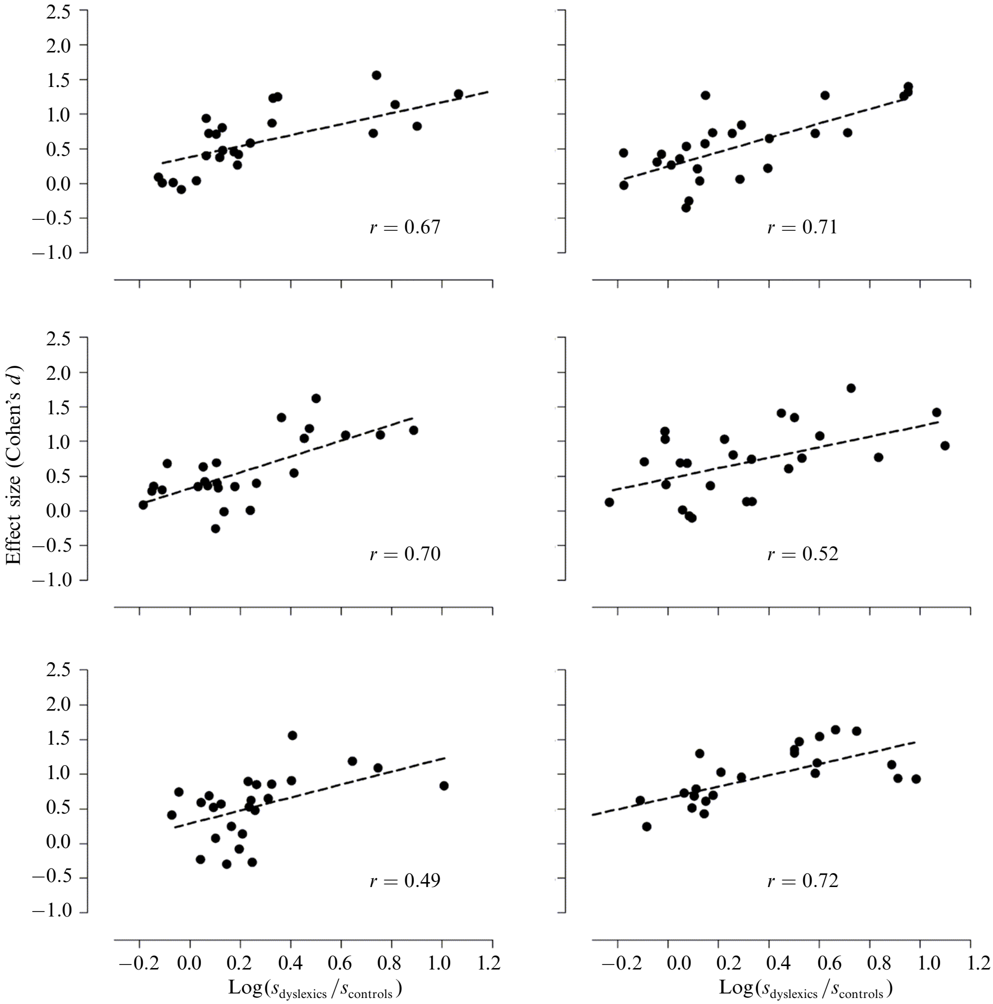

Figure 6. Simulated relationship between the effect size of group differences and the logarithm of relative group variability.

4 Discussion

In attempts to explain the variability of psychophysical performance in dyslexic groups it is typically assumed that skewed performance distributions reflect the presence of a subset of individuals with task-specific perceptual deficits. However, these characteristic patterns of variability could also result from dyslexic groups having general difficulties with performing perceptual tasks. In the present study, we simulated the effect of errancy on performance for a typical psychophysical task. Introducing a fixed probability of errant trials produced similar variability of threshold estimates to that typically seen in dyslexic groups. Depending on where random responses occur within a run of trials, threshold estimates may either accurately approximate the value of the true perceptual threshold or become grossly exaggerated.

A consequence of the variability produced by errancy is that it also inflates estimates of mean group performance. Accordingly, we would expect errant performance in dyslexic groups to result both in increased group variability and in poorer mean performance relative to controls. Relationships between relative group variability and the magnitude of group-mean differences predicted by our simulation bore close resemblance to the outcome of a meta-analysis of actual group studies. These results suggest that general, nonsensory difficulties may well explain the poor performance of dyslexic groups on many psychophysical tasks.

We have been careful not to single out inattention or any other factor as the basis for errant trials, as a number of subtle task difficulties could feasibly produce similar outcomes. To complete any experimental trial, an observer must interpret the instructions of the task, identify and monitor the relevant aspects of the stimulus, form a decision on the basis of the available information held in memory, and generate the appropriate response. Difficulties or inconsistencies at any stage of this process could manifest themselves as either random or reliably incorrect answers. While errant trials resulted in random responses in our simulation, simulating the effect of reliably incorrect responses will produce similar outcomes, albeit more rapidly. In the case of a 2AFC task, a 5% probability of reliably incorrect responses will produce a similar effect to a 10% probability of random (chance) responses.

A strength of the simulation presented here is that it is remarkably simple. To produce patterns of results similar to that seen in dyslexic groups we simply introduced a fixed probability that any given trial would result in a random response. In practice, the expression of general task difficulties is likely to be more complex. One would expect that difficulties might vary with factors such as task complexity, quality of instructions and practice, and the availability of feedback. Additionally, errant trials may occur in blocks, rather than randomly throughout a run. Rather than providing a definitive explanation of psychophysical variability in dyslexia, the purpose of this paper is to highlight that general, nonsensory difficulties ought to be considered as a plausible hypothesis. The simple finding of a significant between-group difference in performance on some psychophysical task should not be automatically accepted as evidence for a deficit in a sensory or perceptual system.

On the basis of the present findings, it is impossible to rule out the possibility that a minority of dyslexic individuals do have specific perceptual deficits. In this case, results of psychophysical experiments would vary considerably depending on how many impaired individuals happened to be in the sample of dyslexics. Such sampling fluctuations might predict the observed relationship between relative group variability and effect size, provided the proportion of impaired individuals remains low. However, one would expect that on rare occasions a large proportion of deficient individuals might be sampled. In these instances we would expect to find large differences between dyslexic and control groups without a considerable mismatch of variability. This was never the case in the studies included in the present meta-analysis (see figure 5).

On the basis of available evidence, it is difficult to determine whether heterogeneity of specific perceptual processes or errant task performance underlies performance variability in dyslexia. Nonetheless, it is possible to distinguish between these hypotheses in principle, as both make testable predictions about the nature of the variability.

If poor performance on a psychophysical task results from perceptual deficiency, such performance should remain stable over time. According to this hypothesis, the same individuals should form the tail of the distribution when repeated measurements are made on a task. By contrast, poor performance due to general nonsensory difficulties need not be so stable. A feature of our simulation of errant trials is that it predicts reduced reliability of participants in dyslexic groups. While figure 2 shows distributions of scores with groups characterised by varying degrees of errancy, each distribution could in principle apply to a single participant performing multiple threshold estimates. If task errancy is the cause of poor psychophysical performance in dyslexic groups, poorer test – retest reliability relative to control groups should also result. Indeed, according to our simple simulation, different dyslexic individuals could appear as outliers each time the group is tested.

Findings of inferior performance by dyslexic groups on a number of different psychophysical tasks are often cited as converging evidence for some general impairment of visual, auditory, or pan-sensory processing (eg Farmer and Klein 1995; Stein et al 2000; Talcott et al 1998). In addition to predicting reliably poor performance within tasks, these theories predict that the same individuals should show impaired performance when tested on different tasks. An appropriate test of such theories then is to examine the identity of individuals falling in the tail of the distribution for each task. While multitask studies are becoming increasingly common, sufficient information to allow this comparison is seldom provided.

Another important consideration is the effect of practice on psychophysical task performance. If poor performance on a task is due to general difficulties with task completion, one would expect that performance should improve if the subject is given adequate training. According to a purely nonsensory hypothesis, practising individuals to the point where task performance becomes stable should also have the effect of removing the tail of the distribution for the dyslexic group. Thus, we would expect to find no differences between dyslexic and control groups if all individuals are given sufficient practice. By contrast, findings that deficient performance by dyslexic individuals is impervious to practice would strengthen the evidence for a perceptual deficit.

5 Conclusions

Findings of differences between dyslexic and control groups have been reported on a large number of psychophysical tasks. Typically though, these differences in mean performance result from a minority of dyslexic individuals who perform poorly. Given this variability, it is essential that investigations of perceptual functioning in dyslexia place more emphasis on differences at the level of the individual observer. Performance variability in dyslexic groups may reflect individual differences in the specific perceptual processes targeted by a given task. However, the results of the present study suggest that typical patterns of variability could also be an artifact of more general difficulties with performing tasks. For progress in this area to be made, it is essential that more attention be given to the identity of dyslexic individuals falling in the tail of group distributions, and the factors contributing to their poor performance.

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Appendix A. Coherent motion studies included in the meta-analysis.

Reference	Dyslexic group		Control group		$\text{Log}\,(s_{\text{dyslexics}}/s_{\text{controls}})$	Cohen's d	p
	M (s)	n	M (s)	n			
Cornelissen et al (1995)	13.27 (3.92) for children	29	9.98 (3.36) for children	29	0.07	0.90	< 0.05
	12.67 (6.02) for adults	29	9.12 (2.74) for adults	29	0.34	0.81	< 0.05
Talcott et al (1998)	18.10 (10.48)	18	10.30 (3.31)	18	0.50	1.13	< 0.05
Raymond and Sorensen (1998)	39.80 (17.20) in children	10	19.90 (2.9) in children 23.40 (3.48) in adults	10	0.77 (child contrast)	1.98	< 0.05
Everatt et al (1999)	26.50 (18.05)	16	11.38 (6.85)	16	0.42	1.21	< 0.05
Hill and Raymond (2002)	4 frame condition: 16.60 (3.53)	7	4 frame condition: 15.50 (2.13)	7	0.22	0.39 based on means	> 0.05
	10 frame condition: 9.70 (3.02)		10 frame condition: 9.80 (1.74)		0.24	0.04 based on means	> 0.05
Amitay et al (2002)	Brief slow condition: 15.3 (10.9)	20	Brief slow condition: 11.80 (12.0)	30	−0.04	0.31	> 0.05
	Brief fast condition: 5.5 (6.6)		Brief fast condition: 3.8 (3.3)		0.30	0.34	> 0.05
	Long slow condition: 15.1 (9.3)		Long slow condition: 12.6 (5.5)		0.23	0.34	> 0.05
	Long fast condition: 8.6 (4.9)		Long fast condition: 6.2 (2.2)		0.35	0.68	< 0.05
Edwards et al (in press)	0.24 deg/s condition: 0.59 (0.22)	21	0.24 deg/s condition: 0.43 (0.20)	24	0.04	0.76	< 0.05
	1.21 deg/s condition: 0.33 (0.24)		1.21 deg/s condition: 0.26 (0.21)		0.06	0.31	> 0.05
	7.29 deg/s condition: 0.45 (0.24)		7.29 deg/s condition: 0.41 (0.14)		0.23	0.21	> 0.05
Ramus et al (2003)	54.7 (19.6)	16	60.4 (20.4)	16	−0.02	−0.28	> 0.05

Note: M, mean; s, standard deviation.

Appendix B. Contrast sensitivity studies included in the meta-analysis.

Reference	Dyslexic group M (s)	n	Control group M (s)	n	$\text{Log}\,(s_{\text{dyslexics}}/s_{\text{controls}})$	Cohen's d	p
Lovegrove et al (1989)	2 cycles deg^{-1} 6 Hz condition: 0.006 (0.006)	58	2 cycles deg^{-1} 6 Hz condition: 0.004 (0.002)	62	0.48	0.50	< 0.05
	2 cycles deg^{-1} 20 Hz condition: 0.015 (0.014)		2 cycles deg^{-1} 20 Hz condition: 0.011 (0.003)		0.67	0.47	< 0.05
	8 cycles deg^{-1} 20 Hz condition: 0.085 (0.063)		8 cycles deg^{-1} 20 Hz condition: 0.051 (0.017)		0.57	0.85	< 0.05
Hill and Lovegrove (1993)	**Experiment 1**	10	**Experiment 1**	5			
	0.3 cycle deg^{-1} condition: 2.23 (0.31)		0.3 cycle deg^{-1} condition: 2.25 (0.25)		0.09	0.07	> 0.05
	6 cycles deg^{-1} condition: 1.17 (0.30)		6 cycles deg^{-1} condition: 1.52 (0.1)		0.48	1.75	< 0.05
	Experiment 2	12	**Experiment 2**	12			
	0.3 cycle deg^{-1} condition: 2.39 (0.10)		0.3 cycle deg^{-1} condition: 2.34 (0.09)		0.05	−0.53	> 0.05
	6 cycles deg^{-1} condition: 1.97 (0.27)		6 cycles deg^{-1} condition: 1.80 (0.33)		−0.09	−0.57	> 0.05
Hayduk et al (1996)	Adults	19	Adults	19			
	2 cycles deg^{-1} 33 Hz condition: 8.60 (3.49)		2 cycles deg^{-1} 33 Hz condition: 7.60 (3.05)		0.06	0.31	> 0.05
	12 cycles deg^{-1} condition: 10.50 (6.54)		12 cycles deg^{-1} condition: 8.80 (6.10)		0.03	0.27	> 0.05
	Children	24	Children	35			
	2 cycles deg^{-1} 33 Hz condition: 4.90 (2.81)		2 cycles deg^{-1} 33 Hz condition: 4.20 (1.41)		0.30	0.33	> 0.05
	12 cycles deg^{-1} condition: 4.4 (1.62)		12 cycles deg^{-1} condition: 4.80 (3.23)		−0.30	−0.16	> 0.05

Appendix B (continued)

Reference	Dyslexic group		Control group		Log $(s_{\text{dyslexics}}/s_{\text{controls}})$	Cohen's d	p
	M (s)	n	M (s)	n			
Olson and Datta (2002)	1 cycle deg^{-1} 1 Hz condition: 1.73 (0.29)	66	1 cycle deg^{-1} 1 Hz condition: 1.84 (0.22)	124	0.12	0.43	< 0.05
	1 cycle deg^{-1} 10 Hz condition: 1.81 (0.29)		1 cycle deg^{-1} 10 Hz condition: 1.93 (0.23)		0.10	0.46	< 0.05
	8 cycles deg^{-1} 1 Hz condition: 0.83 (0.29)		8 cycles deg^{-1} 1 Hz condition: 0.98 (0.26)		0.05	0.55	< 0.05
	8 cycles deg^{-1} 10 Hz condition: 0.78 (0.30)		8 cycles deg^{-1} 10 Hz condition: 0.90 (0.24)		0.10	0.44	< 0.05
Ramus et al (2003)	0.5 cycle deg^{-1} 15 Hz condition: 1.48 (0.11)	16	0.5 cycle deg^{-1} 15 Hz condition: 1.45 (0.16)	17	−0.16	0.22	> 0.05
	8 cycles deg^{-1} 0 Hz condition: 2.03 (0.15)		8 cycles deg^{-1} 0 Hz condition: 2.01 (0.23)		−0.19	0.11	> 0.05
Edwards et al (in press)	1.87 (0.23)	21	1.94 (0.18)	24	0.11	0.34	> 0.05
Amitay et al (2002)	480 (175)	30	567 (153)	30	0.06	0.53	< 0.05

Note: M, mean; s, standard deviation.

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