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Author(s)	Shanagher, Louise;Elliott, Mark
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# AN INVESTIGATION OF COGNITIVE DYSMETRIA IN DEVELOPMENTAL DYSLEXIA

Louise Shanagher and Mark A. Elliott

*Department of Psychology, National University of Ireland Galway, Newcastle, Galway, Co. Galway, Ireland*

## Abstract

*An alternative to theories positing visual or phonological deficits, the “cognitive dysmetria” hypothesis proposes the aetiology of dyslexia to take the form of a general functional coordination deficit or cognitive dysmetria. The term “dysmetria” describes a general impairment in the temporal correlation of brain activity. The purpose of the current research was to investigate the empirical basis for this idea in an experimental task designed to measure simultaneity thresholds. Twenty children diagnosed with developmental dyslexia, alongside twenty, age and IQ matched controls, undertook a series of threshold determination procedures designed to measure the location of simultaneity thresholds in time and the influence of subthreshold synchrony upon perceived simultaneity. It was concluded that there was no significant difference in simultaneity thresholds for dyslexics in comparison to controls, indicating no evidence of a cognitive dysmetria. Dyslexic readers did perform significantly differently to controls on the experimental task. The results are discussed with reference to weak synchronisation and extended visual persistence in dyslexia. The possibility that the results might indicate a temporal processing deficit is also discussed.*

According to the International Classification of Diseases (WHO, 1992), developmental dyslexia is defined as a specific disability in learning to read and to spell despite at least normal intelligence, adequate instruction and sociocultural opportunity. Dyslexia may be accompanied by sensory deficits in either visual or auditory modalities which are believed to differentially impair orthographic and phonological processing. The existence of both visual and auditory impairments (often not in the same individuals) has led theories of dyslexia to be roughly divisible into those assuming language related deficits and those assuming visual deficits to be at the core of the disorder .

An alternative theory proposes the aetiology of dyslexia to take the form of a general functional coordination deficit or cognitive dysmetria, a term which describes a general impairment in the temporal correlation of brain activity (Andreasen et al., 1996). Aside from supporting experimental evidence (Becker, Elliott & Lachmann, 2005), the case for dyslexia as a manifest form of dysmetria is also suggested by its relatively high prevalence in patients suffering schizophrenia a disease now widely considered to result from a general deficit in the functional coordination of neuronal activity (Tononi & Edelman, 2000). It has also been suggested from experimental work that dyslexia relates to the inefficient synchronization of neural activity (Becker et al., 2005).

The “Perceptual Moment” describes the interval in time in which we perceive the moment “as now”. Two or more stimuli perceived within this interval are considered as appearing simultaneously, whilst two or more stimuli separated by some time greater than this interval are experienced as separate events in time. A typical measure of the perceptual moment is the maximum time difference for temporal order discrimination of the successive presentation of two or more stimuli. Using a method of this sort the present research attempts to measure variations in the perceptual moment of dyslexic readers in comparison to healthy controls. Such variations in performance may indicate an abnormal quantization of perceptual timing which might be attributed to an underlying cognitive dysmetria.

This interval in time will be determined using a paradigm introduced by Elliott, Shi and Sürer (2006). Using this paradigm Elliott et al. also examined the effects of subthreshold synchrony and subthreshold asynchrony on the perception of simultaneity. It was demonstrated that the presentation of subthreshold synchrony immediately prior to target stimulus presentation biased judgement of the temporal relation (synchronous or asynchronous) between two target stimuli. The thresholds for judging the targets to have appeared simultaneously remained unaffected by the prior presentations of either subthreshold synchrony or asynchrony indicating that synchrony is not only relevant for spatial, but also for temporal grouping. The present research also aims to investigate the effects of subthreshold synchrony ( $SB_S$ ) or subthreshold asynchrony ( $SB_A$ ) on perception of simultaneity. It is anticipated that the presence of  $SB_S$  and  $SB_A$  will affect the performance of dyslexic readers differently than controls as the topdown influence regulating the exact timing of perceptual moments might be dysfunctional in dyslexic readers.

### **Method**

A total of 40 children, 5 female, 15 male dyslexic readers 5 female, 15 male normal readers. The participant's ages ranged from 7 to 15 years, ( $M = 12.34$  years). The groups were matched according to age and intelligence.

All stimuli were generated and the experimental procedure executed by means of custom software driving a Cambridge Research Systems ViSaGe 2/3 graphics card, installed in an IBM, compatible PC running Windows XP. Stimuli were presented on a (21") monitor with refresh rate set to 100Hz. The stimuli consisted of two vertical and parallel grey bars, which increased their luminance on two separate occasions. The two bars increased in luminance with variable stimulus onset asynchronies (SOAs) in the range 0ms (i.e. simultaneously) to 110ms. For subthreshold presentations eight flanking bars were used to mask the first changes in luminance. The flankers were organized such that each of the targets had a 4-flanker mask with the flankers positioned in a circle around the targets at horizontal angles of  $0^\circ$ ,  $90^\circ$ ,  $180^\circ$  and  $270^\circ$  and separated by 20 degrees of visual angle. Each flanker was of the same size as the target but was oriented pseudo-randomly at either  $45^\circ$  or  $-45^\circ$ .

The perceived simultaneity or temporal asynchrony of the bars was measured by means of two-alternative forced choice task in which the participants were asked to indicate by pressing the relevant key on a keyboard, whether the two bars increased in luminance simultaneously or asynchronously. The experiment was carried out in three parts, in the first part of the experiment the lower simultaneity threshold for each participant was determined, flankers were not present. In the second part of the experiment the upper simultaneity threshold was measured, flankers were present. In the third part flankers were present, and it was determined whether a  $SB_S$  change in luminance and/or a  $SB_A$  change in luminance would influence judgements of perceptual simultaneity or asynchrony and whether this may vary in the dyslexic group in comparison to the control group.

### **Results and discussion**

Average simultaneity thresholds for the dyslexic group following exposure to  $SB_S$  were revealed at 61 ms ( $SD = 11$  ms) and following exposure of  $SB_A$  were 53 ms ( $SD = 26$  ms). Average simultaneity thresholds for the comparison group following exposure to  $SB_S$  were revealed at 70 ms ( $SD = 19$  ms) and were 62 ms ( $SD = 18$  ms) following exposure to  $SB_A$ . Independent t-tests showed that there was no significant difference for simultaneity thresholds

following exposure to either  $SB_S$  or  $SB_A$  between the two groups,  $t(25) = 2.578$ , Cohen's  $d = 0.9512$ , and  $t(25) = .113$ , Cohen's  $d = 0.0452$ , respectively.

In a next step it was examined whether the findings of Elliott et al. (2006) could be replicated for the present data and whether there was any difference in this effect between the two groups. This difference alongside an apparent reduction in the frequency of simultaneity reportage for the dyslexic participants was examined by means of a univariate three-way analysis of variance (ANOVA) with main factors for group (dyslexic and non dyslexic), premask ( $SB_S$  and  $SB_A$ ) and SOA with 12 levels, (0 ms, 10 ms, 20 ms, 30 ms, 40 ms, 50 ms, 60 ms, 70 ms, 80 ms, 90 ms, 100 ms, 110 ms). The dependant variable was the adjusted percentage of simultaneity reported.

There was a statistically significant main effect for group, ( $F(1, 600) = 82.43, p < .001, \eta_p^2 = .12$ ), indicating that the control group tended to report simultaneity more frequently than the dyslexic group. The analysis also revealed a statistically significant main effect for SOA, ( $F(11, 600) = 123.15, p < .001, \eta_p^2 = .693$ ), reflecting the shape of the psychometric function (i.e., simultaneity reportage decreased quasi-linearly as SOA increased). There was a statistically significant main effect for premask stimuli, ( $F(1, 600) = 15.20, p < .001, \eta_p^2 = .025$ ), both groups reported simultaneity more frequently after the prior presentation of  $SB_S$  in comparison to the prior presentation of  $SB_A$ . The analysis revealed a statistically significant interaction effect between subthreshold stimuli and SOA ( $F(11, 600) = 4.06, p < .001, \eta_p^2 = .062$ ), indicating a difference in simultaneity reportage after the prior presentation of  $SB_S$  in comparison to  $SB_A$  until threshold and then a convergence of the two functions thereafter. No other effects were significant.

In post-hoc analysis, simple-main effects were examined for the pair wise comparisons of  $SB_S$  and  $SB_A$  at each level of SOA (i.e., the analysis sought to break down the 2-way interaction revealed in the main ANOVA calculation). This analysis revealed significant or borderline-significant differences between the frequency of  $SB_S$  and  $SB_A$  reportage for SOAs up to 50 ms which were not found for SOAs of 60 – 110 ms (significant differences were:  $F(1, 624) = 23.233, p < .00; F(1, 624) = 21.875, p < .00; F(1, 624) = 19.803, p < .00; F(1, 624) = 19.803, p < .00; F(1, 624) = 8.350, p = .04$  and  $F(1, 624) = 7.593, p = .06$  for SOAs of 0 ms, 10 ms, 20 ms, 30 ms, 40 ms, and 50 ms, respectively). These results indicate that simultaneity reportage significantly differed following the presentation of  $SB_S$  in comparison to  $SB_A$  up until a level of SOA that lay at the lower boundary of the simultaneity threshold.

The current experiment revealed that simultaneity thresholds did not vary significantly with respects to whether participants were dyslexic or normal readers. In fact, simultaneity thresholds occurred at slightly shorter SOAs for the dyslexic participants relative to controls, suggesting against an experience based dysmetria in dyslexia. In spite of this, the data did reveal that dyslexic readers exhibit some quite different patterns of visual processing performance. Of particular interest is the finding that, for short SOAs, the dyslexic readers reported simultaneity significantly less frequently than normal readers. This is surprising because for the shortest SOAs, one might expect the default response to be simultaneous. Even though simultaneity reportage was more frequent for dyslexic readers at 0 ms than at other SOAs, it was not close to the near 100% frequency found in control performance.

Significant differences were revealed in the ANOVA between the  $SB_S$  and  $SB_A$  conditions. If it is assumed near 100% simultaneity reportage in the 0ms, comparison data to be a baseline measure of simultaneity reportage, this would entail the differences between  $SB_S$  and  $SB_A$  to result from the likelihood of a simultaneity report being reduced following  $SB_A$ . In addition, dyslexic readers seem slightly more susceptible to the disruptive effects of  $SB_A$  for short SOAs compared with normal readers (67% vs. 72%) although simultaneity

reports following  $SB_S$  are substantially reduced in comparison with control performance (86% vs. 97%).

These differences may be explained with reference to a theory proposed by Sperling, Lu, Manis and Seidenberg, (2005) called “the noise exclusion hypothesis”. This theory proposes that dyslexic individuals would show performance deficits in tasks where there is a high level of external noise and will perform normally in tasks where there are low levels of external noise. If this theory is correct then it could be concluded that dyslexics have difficulty disambiguating relevant information from perceptual noise, and by extension integrating the correct perceptual information into fully coherent representations whilst simultaneously filtering external noise. In the present context this seems to suggest that the source of systems noise lies in the inefficient synchronization promoted by the paired  $SB_S$  stimuli, which might become “bound” together to form a simultaneity by virtue of neuronal synchronization.

In the present context the trend to synchronisation is weaker in dyslexic as opposed to normal readers, and neurons which are ordinarily part of the same synchronised assembly might not all fire in close temporal proximity. By this account and by virtue of some degree of asynchrony across the neuronal assembly coding the  $SB_S$  stimuli, the likelihood of perceiving the target pairing as simultaneous in dyslexic readers may be reduced as a function of system noise arising from weak synchronization and the presence of non-synchronous patterns of activity across the two target stimuli. In summary, the noise hypothesis relates to the fact dyslexics may have difficulty processing relevant, from irrelevant information and this may be due to weaker trends for neurons to synchronise in dyslexic readers. This hypothesis is supported by the fact dyslexics appear to be more susceptible to the disruptive effects of  $SB_A$  which we equate with systems noise.

In the current discussion this hypothesis is broadly consistent with the discussion of the data presented by Elliott et al. (2006). They have shown that  $SB_S$  and  $SB_A$  bias the judgements of the temporal relations between a visible pair of targets presented either simultaneously or with small SOAs from 0 to 28ms; however simultaneity thresholds were left unchanged. It was hypothesised that these findings might represent a tendency for brain activity in early visual areas to synchronise following the prior presentation of  $SB_S$  and therefore increase the likelihood of simultaneity reportage. It could also be argued that in a similar way exposure of  $SB_A$  before apparition of the target stimulus might desynchronise neural activity and thus may decrease the tendency to report simultaneity at a subthreshold level. If the neurons in a given cell assembly are desynchronised by prior exposure of  $SB_A$ , and if synchronisation for dyslexic readers is weaker than normal readers it would be expected that simultaneity reportage would be less probable for the dyslexic readers after the prior exposure of  $SB_A$ . This is exactly what was found in the present study. In sum, it appears that synchronization is impaired for dyslexic readers and this why they show performance deficits in tasks where there are high levels of external noise.

One of the most interesting findings of the current study is that there was a difference in the slope of the psychometric functions between dyslexic and comparison groups, the slope for controls being steeper than that for dyslexics. This may indicate longer visual persistence for dyslexics consistent with the conclusions of other authors (Lovegrove, Heddle & Blackwood, 1980; Lovegrove, Heddle & Slaghuis, 1980). This is interesting for the following reasons:

Considering together the near identical thresholds with variations in the frequency of simultaneity reports for short SOAs there are also differences in the slopes of the psychometric functions between the dyslexic and normal readers. What’s more, in spite of these differences, both slopes pivot on nearly exactly the same threshold and although dyslexics report synchrony less frequently for shorter SOAs, there is less of a reduction in

efficiency of simultaneity reportage over SOA in comparison to controls. This may be interpreted in the following way: Although dyslexics report synchrony overall less frequently than controls (at shorter SOAs) the shallower slope of the  $SB_S \times SOA$  function indicates that the frequency of simultaneity reportage is relatively resistant to reduction with increasing SOA as compared with the control data. What is interesting about this pattern of effects is that the psychometric functions converge at close to threshold with the functions appearing to pivot on the threshold itself. This tends to suggest that, while subthreshold synchronization is subject to noise (probably in the form of a weak synchronization with many neurons failing to align their spikes to within some critical interval of time), the relative strength of persistence of the synchronized code is dependent upon the position in time of the simultaneity threshold. By this account, relatively strong subthreshold synchronization with a correspondingly high activation value (such as that revealed in the control data) will rapidly reduce in strength as SOAs approach threshold. One can equate this with an ability to rapidly desynchronize, a process necessary for avoiding the perseveration of information across eye movements, for example. On the other hand, relatively weak subthreshold synchronization with a correspondingly low activation value (such as that revealed in the dyslexic data) will take longer to reduce in strength. Considering this, we might deduce that in addition to weak synchronisation, dyslexic readers have problems desynchronizing synchronized neuronal assemblies.

This idea is certainly consistent with the idea that prolonged visual persistence causes information from successive eye movements to become partially fused, thereby rendering graphemic information in one fixation difficult to properly disambiguate from that brought over from a previous fixation. However, on this account one cannot equate the simultaneity threshold with the overall time taken to move and fixate the eyes. Instead the psychometric functions are pivoted on some process occurring at some stage later than an eye movement and almost certainly related to the access of information into consciousness.

Alternatively it could be argued that dyslexics tendency to report synchrony less frequently than controls for short SOAs may reflect a temporal processing deficit. Research by Tallal (1980) has demonstrated similar temporal processing deficits to those found in the present study in the auditory modality. In Tallal's study subjects heard two tones, when asked to judge their temporal order dyslexic readers demonstrated some impairments when SOAs were short however when SOAs were longer this impairment disappeared. The present research replicated Tallal's in the visual modality. This indicates that the deficit found for dyslexics in the present research may be modality independent while the existence of a general temporal processing deficit could explain why dyslexics sometimes show problems in the visual and otherwise in the phonological domains.

Despite the fact that no coherent conclusion can be made on the present research, numerous doors have been opened, leading us a little closer to the answer of the most preliminary research question this study set out to investigate, what is it that causes developmental dyslexia? What was found was that, this answer is not as straightforward as first conceived, something that seems to be becoming characteristic of dyslexia research. Despite this it is clearly evident that dyslexics do exhibit visual perceptual deficits over very short intervals in time and that these deficits do relate to a threshold which is relatively robust and not influenced substantially by their disorder. That this influence may be supermodel arises in consideration of the fact that noise exclusion deficits occur both in visual and auditory modalities (Brady, Shankweiler & Vanns, 1983) and Tallal's (1980) experiments which were largely replicated by the present results in the visual modality. A definite conclusion that can be made is that whatever is causing the perceptual problems in dyslexia, it is resolved by the time a "perceptual moment" is achieved and after this point in time dyslexics perform in a near identical manner to controls. In this respect, the findings of the

current research lend support to current endeavours such as the use of temporally modified speech, in training programmes proposed for dyslexic children. Furthermore, in light of the present results it seems plausible that by manipulating the temporal characteristics of visual stimuli, dyslexic readers performance could be considerably improved in various developmental speech and reading problems.

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