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Visually-based temporal distortion in dyslexia

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ABSTRACT

In this study, we show that invisible flicker adaptation reduces the perceived duration of a subsequently viewed stimulus in control subjects, but not in dyslexics. Dyslexics, like controls, show apparent duration compression after 20 Hz flicker and show normal shifts in apparent temporal frequency after adaptation. However a subgroup of the test group, scoring low on both a test of phonological skill (spoonerisms) and a test of literacy (NART), show an apparent temporal expansion after 5 Hz flicker adaptation, a finding not previously seen in controls. Recent studies have linked genes conferring susceptibility to a cluster of language and sensory deficits to anomalous neural migration, providing a tentative biological basis for dyslexia. However it has proved difficult to establish a clear link between sensory deficits and impaired reading. The results presented here point to an abnormal adaptation response within the early precortical stages of the magnocellular pathway, occurring in tandem with a deficit in word-level cognitive processing, providing psychophysical evidence for anomalous cortico-thalamic circuits in dyslexia.

1. Introduction

Dyslexics have been reported as having visual deficits that could contribute to their reading difficulties. Studies employing psychophysical (Cornelissen, Richardson, Mason, Fowler, & Stein, 1995; Lovegrove, Bowling, Badcock, & Blackwood, 1980), fMRI (Ben-Shachar, Dougherty, Deutsch, & Wandell, 2007; Demb, Boynton, & Heeger, 1997; Eden et al., 1996) and anatomical (Livingstone, Rosen, Drislane, & Galaburda, 1991) techniques have ascribed these visual impairments to a deficit in the magnocellular system (Stein, 2001) although the role of the magnocellular system in dyslexia is controversial (Ramus, 2003).

fMRI studies have indicated abnormal responses in dyslexics to motion in the MT/V5 complex (Ben-Shachar et al., 2007; Eden et al., 1996; Eden & Zeffiro, 1998) and V1 (Demb et al., 1997; Demb, Boynton, & Heeger, 1998). Anatomical evidence from post-mortem examinations of the brains of dyslexics (Galaburda & Livingstone, 1993; Livingstone et al., 1991) indicate abnormalities in magnocellular, but not parvocellular layers of the LGN and not in the corresponding input layers of the visual cortex (Jenner, Rosen, & Galaburda, 1999). There is also evidence of greater numbers of ectopias and microgyri, the results of abnormal cell migration, in the left perisylvian cortex of dyslexic brains (Galaburda, LoTurco, Ramus, Fitch, & Rosen, 2006; Galaburda, Sherman, Rosen, Aboitiz, & Geschwind, 1985), which may be the primary cause of the abnormalities seen in the LGN (Galaburda et al., 2006; Ramus, 2004), since male mice with induced microgyria have thalamic abnormalities and concomitant sensory disorders (Galaburda et al., 2006). Despite the anatomical evidence, psychophysical tests of magnocellular function in dyslexia have led to equivocal results (Ramus, 2003). Tasks have been criticised as not isolating magno cells (Skottun, 2000) or, as in the case of motion coherence threshold tasks, requiring high-level extrastriate cortical motion processing (Skottun & Skoyles, 2006) well beyond the point at which magno and parvo streams interact. Although the LGN division has been considered to be a facet of two distinct processing pathways from the retina through the cortex, recent evidence points to a combination of magno and parvo streams as early as the first synapse after the input layers of V1 (Sincich & Horton, 2004). Ideally a psychophysical test of the magnocellular hypothesis should target properties specific to magno cells in the retina and LGN.

Magno cells are tuned to higher temporal frequencies than parvo cells. The high temporal frequency cut-off of cells in the rather heterogeneous koniocellular layers of the LGN tends to be intermediate between parvo and magno cells (Xu, Ichida, Allison, Boyd, & Bonds, 2001). In addition the high temporal frequency cut-off of

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LGN cells is around 20 Hz higher than cells in primary visual cortex (Foster, Gaska, Nagler, & Pollen, 1985; Hawken, Shapley, & Grosof, 1996; Hicks, Lee, & Vidyasagar, 1983). Therefore it is possible to bias processing in favour of the precortical magnocellular pathway by stimulating the visual system with temporal frequencies that are high enough to be beyond the pass-band of typical cortical neurons outside the input layers of V1 (at which point magno and parvo streams may combine) but which would still provide a signal in the LGN (Hawken et al., 1996; Solomon, White, & Martin, 1999). Furthermore, it has been reported that the contrast gain changes resulting from fast and slow adaptation at high temporal frequencies affect magno cells but are absent or nearly so in parvo cells (Benardete & Kaplan, 1999; Shapley & Victor, 1978; Solomon, Peirce, Dhruv, & Lennie, 2004). Specifically, Solomon et al. (2004) have recently reported a slow adaptation effect in which the magno cell response to an 11 Hz drifting grating is reduced after 45 Hz counterphase flicker but not after 1 Hz adaptation. Thus, as they point out, high frequency adaptation can be used to select the magno pathway.

Adaptation of magno cells could have multiple perceptual consequences. Recently we have shown that adaptation to a 20 Hz visual flicker results in an apparent temporal compression of subsecond intervals of 10 Hz flicker placed in the adapted retinal location. Compression after adaptation to 5 Hz was small or absent. These temporal effects are independent of the orientation of the adaptor, consistent with a precortical locus (Johnston, Arnold, & Nishida, 2006). It has previously been reported that dyslexics are impaired on a temporal duration discrimination task (Nicolson, Fawcett, & Dean, 1995) although a recent study failed to replicate this observation (Ramus, Pidgeon, & Frith, 2003). In our case we are interested not in temporal discrimination, a measure of subjects' precision, but in perceived duration – a temporal illusion. We hypothesized that if dyslexics have a magnocellular deficit then the changes in temporal duration judgement, we have previously attributed to adaptation of the magno pathway, may not occur at the high temporal frequencies that selectively adapt magno cells.

2. Methods

We investigated the influence of spatially localised flicker adaptation on time perception. In Experiment 1, we measured the perceived duration of a visual stimulus after adapting to an invisible flicker in normal subjects. In Experiments 2 and 3, dyslexics and normal controls judged the duration (Experiment 2) or temporal frequency (Experiment 3) of visual stimuli after adapting, in separate sessions, to a 0, 5, 20 or 60 Hz flicker.

2.1. Subjects

Five adult subjects (four males, one female) aged between 19 and 30, with normal or corrected to normal vision, participated in Experiment 1. Eleven developmental dyslexic subjects (six males and five females) and 10 control (five males and five females) subjects, who had no reported reading difficulties, participated in Experiments 2 and 3. The dyslexic subjects were all recruited from the UCL Dyslexia Assessment and Support Centre (DASC). They had all been assessed by the Centre and judged to be deserving of extra time in university examinations on account of their disability. The criteria used by DASC in their assessment are those published in the DfES Working Group Guidelines (2005)[1]: a history of difficulty with the acquisition of literacy skills; persisting difficulty with reading, writing and expression; evidence of an underlying cognitive defect such as phonological awareness; exclusion of other factors such as sensor impairment or educational opportunities and any discrepancy between underlying ability and attainment was also taken as supporting evidence. All of the first four criteria need to be met for a dyslexia diagnosis and the 5th criterion is generally met by university students. Some students arrive at UCL with an existing post-16 assessment and some arriving with a pre-16 assessment require a top-up assessment. All students who present with dyslexia are interviewed and tested by DASC. The great majority are given a full assessment in order to determine the level of disability and appropriate time concession. The full assessment utilises a battery of psychometric tests including WRAT4 reading and spelling; prose reading (oral and silent) and handwriting speed; TOWRE words and non-words; digit span; digit and letter naming; spoonerisms; précis and WASI vocabulary, similarity and matrices. DASC then makes a clinical judgement about the existence and severity of the deficit in each case. Later we recruited additional controls from the normal student population and dyslexic subjects from DASC making 17 dyslexic and 16 controls in total, with the dyslexic group consisting of nine male and eight female subjects aged between 18 and 29 and the non-dyslexic group consisting of six male and ten female aged between 20 and 28. Post-hoc tests showed the groups were matched for age and for IQ (Tables 1 and 2).

2.2. Psychometric tests

All subjects completed three psychometric tests: the National Adult Reading Test (NART), the spoonerisms test from the Phonological Assessment Battery (Fredrickson, Frith, & Reason, 1997) and a short test from the Ravens Advanced Progressive Matrices (APM) collection (Raven, Raven, & Court, 1998). The NART (Nelson, 1983) was used to test for literacy. It is comprised of a series of 50 irregular words increasing in difficulty. The subject is asked to read out the words as they thought they should be pronounced and the number of words mispronounced are recorded. Since all the words are irregular it assessed reading ability via the lexical route. The spoonerisms test was used to identify dyslexics with poor phonological skills. The test consisted of two parts, each with a time limit of 3 min. In the first part the subject was given a word and a sound, and was asked to replace the first sound of the word with the new sound given. In the second part two words were given and the subject was asked to swap round the first sounds of each word (e.g. Ben found→Fen bound). Each part had three practice questions followed by 10 test questions, and the number of correct responses was recorded. The final test, the APM test, tested for intelligence, and consisted of 12 different patterns. Each pattern had a piece missing and the subject was required to pick, out of 8 possibilities, which would be the best fit in terms of the continuity of the pattern. This test had a time limit of 10 minutes and again the number of correct responses was recorded. For each test the subject was asked to work as quickly and as accurately as possible, and the time taken to complete each test was recorded. The spoonerisms test and the NART were used to define a subgroup (9 subjects) of dyslexics who scored poorly on either or both of these psychometric tests.

2.3. Apparatus

Stimuli were displayed in a darkened room on a Clinton Monoray screen, equipped with a fast phosphor, which had a resolution of 800 × 600 pixels and a refresh rate of either 100 Hz (50 Hz adaptation) or 120 Hz (60 Hz adaptation). It was driven by a VSG 2/5 visual stimulus generator (Cambridge Research Systems).

2.4. Procedure

In Experiment 1, subjects had to compare the duration of a flickering Gaussian comparison stimulus against a standard. An adapting flicker was displayed on one side of fixation (centred 2.2° of visual angle to the left of a central fixation point) for 20 s with 10 s top-up adaptation between trials. The temporal frequency of the adapting flicker was just above the flicker fusion threshold that was individually determined for each subject before starting the experiment. The threshold value was 50 Hz for two subjects (AB, RJ) and 60 Hz for three subjects (AA, AK, JW). The Michelson luminance contrast of the flicker was also adjusted individually (AA = 95%; AB = 68%; AK = 96%; JW = 92%; RJ = 69%) to make sure that the adaptor was invisible. After the adaptation phase, the comparison and the standard were displayed sequentially (the order of presentation was randomized). The duration of the standard stimulus (displayed in the same spatial position as the adapting flicker) was fixed across trials (500 ms). The duration of the comparison stimulus (shown on the unadapted side) was varied in seven steps between 350 and 700 ms. The temporal frequency was set to 10 Hz and the luminance contrast to 100% for both standard and comparison. At the end of each test trial, subjects were asked to report which of the two stimulus intervals was perceived to be briefer. Subjects were instructed to keep fixation on the centre of the monitor for the whole duration of the experimental session. For each subject, a psychometric function indicating the percentage of trials in which the standard was judged as shorter than the comparison was determined. Each data point was the average of 20 repetitions. All the subjects were also tested in a control condition without adaptation.

In Experiment 2, the procedure we used to measure perceived duration in dyslexic and control subjects was the same as in Experiment 1, except that the frequency of the adapting flicker could be 0, 5, 20 or 60 Hz and the duration of the comparison stimulus was varied between 100 and 1000 ms. Michelson contrast was 100%. In this experiment the highest frequency shown was 60 Hz. We did not measure the flicker fusion frequency (FFF) for each subject individually to keep testing time within bounds but 60 Hz was close to or above the FFF for all subjects, particulary after a period of adaptation. Each data point on the psychometric function was the average of 10 trials.

In Experiment 3, subjects were asked to judge temporal frequency, instead of duration, after flicker adaptation. Otherwise the adapting frequencies and the procedure were the same as in Experiment 2. The temporal frequency of the standard

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[1] DfES: SpLD Working Group 2005/DfES Guidelines http://www.dfes.gov.uk/studentsupport/uploads/SPLDG%20Final%20report%20rev.doc.