Colour perception in ADHD

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Attention-deficit/hyperactivity disorder (ADHD) is associated with unexplained impairments on speeded naming of coloured stimuli. These deficits may reflect hypofunctioning retinal dopaminergic mechanisms impairing particularly blue–yellow colour discrimination. Colour perception and rapid colour naming ability were investigated in 14 children with ADHD and 13 healthy peers matched for age, gender, and IQ, using the Farnsworth–Munsell 100 Hue Test (FMT) and the Stroop-Colour-Word test. Children with ADHD committed more errors on the FMT, particularly on discrimination of colours along the blue–yellow axis, and were slower on Stroop subtests involving colour naming. However, the latter deficit was accounted for similarly by blue–yellow and red–green discrimination abilities. Blue–yellow colour perception problems in ADHD contribute to but do not fully explain the observed slowed colour naming. **Keywords:** Colour vision, attention-deficit hyperactivity disorder, dopamine, Stroop-Colour-Word test. **Abbreviations:** CBCL: Child Behavior Checklist; FBB-HKS: Fremdbeurteilungsbogen Hyperkinetische Störung; FMT: Farnsworth–Munsell 100 Hue Test; LPS: Leistungsprüfsystem.

Attention-deficit/hyperactivity disorder (ADHD) is a common childhood-onset disorder characterised by inattention, overactivity, and impulsiveness. The dopaminergic neurotransmitter system is believed to play a central role in its pathophysiology (e.g., Banaschewski et al., 2005; Castellanos & Tannock, 2002; Sagvolden, Johansen, Aase, & Russell, 2004; Taylor et al., 2004) By contrast to well-documented deficits in higher cortical functions, individuals with ADHD also exhibit unexplained problems in the speeded processing of coloured stimuli. For example, they exhibit slower naming speed for colours on various rapid naming tasks (e.g., the Rapid Automatized Naming Test, the Stroop-Colour-Word Test), but tend not to exhibit slower naming of letters, words, or digits (e.g., Rucklidge & Tannock, 2002; Tannock, Martinssen, & Frijters, 2000; van Mourik, Oosterlaan, & Sergeant, 2005). A recent study of selective attention to colour, using event-related potentials (ERP), found that boys with ADHD exhibit a *perceptual deficit* in selection between visual stimuli on the basis of *colour* (red versus blue) as well as in later (semantic) stages of visual selective attention (van der Stelt, van der Molen, Boudewijn Gunning, & Kok, 2001).

To date, there is no adequate explanation to account for these observed difficulties in rapid processing of coloured stimuli in individuals with ADHD. However, poor performance on tasks involving speeded colour processing may reflect subtle visual impairments as well as (or rather than) impairments in higher-order cognitive function (van Boxtel, ten Tusscher, Metsemakers, Willems, & Jolles, 2001). Colour perception is based on three cone photoreceptor types, maximally sensitive to long, middle and short wavelengths, that constitute two function-ally and anatomically distinct systems at the retina; a 'red–green' system and a 'blue–yellow' pathway. Colour perception is controlled, at least partly, by retinal dopaminergic neurons which are involved in controlling the coupling of horizontal and amacrine cell lateral systems, the organisation of the ganglion cell and the bipolar cell receptive fields and modulation of the physiological activity of photoreceptors (for reviews see: Djamgoz, Hankins, Hirano, & Archer, 1997; Hart, 1987; Masson, Mestre, & Blin, 1993; Witkovsky, 2004). Thus, retinal and central dopaminergic alterations may occur together and abnormalities of the dopaminergic system associated with ADHD may result in impaired colour perception which then may be expressed as slower colour naming (Tannock, Banaschewski, & Gold, under review).

A retinal deficit of dopamine is reflected particularly in alterations along the blue–yellow axis (Djamgoz et al., 1997; Hart, 1987; Masson et al., 1993). Moreover, a selective impairment of the blue–yellow vision system suggests a retinal location of the disturbance rather than a central one (Hart, 1987). Specific blue–yellow colour vision disturbances are found in various other disorders involving altered dopaminergic neurotransmission, such as Tourette syndrome (e.g., Melun, Morin, Muise, & DesRosiers, 2001), Parkinson's disease (e.g., Haug, Kolle, Trenkwalder, Oertel, & Paulus, 1995), and Huntington's disease (e.g., Büttner, Schulz, Kuhn, Blumenschein, & Przuntek, 1994). Converging changes of retinal dopamine levels associated with cocaine-withdrawal (e.g., Roy, Roy, Berman, & Gonzalez, 2003) and normal aging (e.g., Djamgoz et al., 1997) have also been associated with blue–yellow colour vision losses. Finally, acquired dyschromatopsias due to exposure to environmental pollutants (Gobba &

Cavalleri, 2003) usually impair blue–yellow colour discrimination, while congenital dyschromatopsias more frequently result in red–green deficits (Hart, 1987).

The objectives of the current study were to investigate colour perception in children with ADHD, as well as the relationship between colour perception and performance on a conventional neuropsychological task (Stroop Task) that requires speeded naming of coloured stimuli. Specifically, we hypothesised that children with ADHD will exhibit blue–yellow colour perception deficits associated with abnormalities in retinal dopaminergic neurotransmission (Tannock et al., under review).

Methods

A total of 27 children aged 8.0 to 13.0 years (14 children with ADHD, 13 controls; groups matched for age, gender and IQ) participated in the study, with informed consent of the child and parent. The study was approved by the local medical ethics committee.

The 14 children with ADHD-combined type were selected from sequential referrals to the outpatient clinic of the department of Child and Adolescent Psychiatry of the University of Göttingen. Diagnosis was based on information ascertained from clinical interview with the parents, teacher reports, behavior rating scales, and medical reports. Rating scales included the parent-rated Child Behavior Checklist (CBCL; Achenbach, 1991), and a German version of the ADHD symptom list (FBB-HKS; Bruehl, Doepfner, & Lehmkuhl, 2000). Those children using methylphenidate were free of medication for at least 48 hr before being tested.

Control children were recruited from local primary schools. They were included only if they never met a psychiatric diagnosis except a diagnosis of dyslexia. Additionally, the T-scores of the control children on the attention problems scale of the CBCL were required to be below 55. T-scores on the CBCL scales Delinquent and Aggressive Behaviour were required to be below 60.

All children underwent standardised IQ testing, as well as testing of spelling abilities and word fluency (LPS; Horn, 1983). All children were free of ophthalmologic disorders or congenital colour blindness and had a full-scale IQ above 85. Also, only 3 children in the ADHD group and 2 in the control group met diagnostic criteria for dyslexia.

ANOVAs were carried out to investigate possible group differences in IQ and confirm expected group differences in T-scores on the FBB-HKS (all $F > 49$; all $p < .001$) and CBCL scales (all $F > 8.3$; all $p < .01$, except subscales Thought Problems and Social Withdrawal: non-significant). The groups did not differ in their spelling abilities (df = 25, $F = .5$, ns) or word fluency (df = 25, $F = .0$, ns).

Colour discrimination ability was investigated binocularly using the Farnsworth–Munsell 100 Hue Test (FMT; Farnsworth, 1943), which is a widely used clinical instrument for measuring chromatic discrimination (Kinnear & Sahraie, 2002). It consists of four trays containing a total of 85 removable colour reference caps (incremental hue variation) spanning the visible spectrum. Colour vision abnormalities and aptitude were determined by the ability of the child to place the colour caps in order of hue. Error scores are measures of accuracy in arranging the caps so as to form a gradual transition in chroma between two anchor caps reflecting the number of misplacements. Blue–yellow and red–green partial error scores and the total error score were computed. All testing was performed under standard light conditions in the same room and at the same place. The illuminance was maintained at 325 lux, measured with a LT Lutron LX-101 Lux-meter.

We used the German version (Farb-Wort-Interferenztest) of the Stroop-Colour-Word Task (Bäumler, 1985). In the first condition, the speed of reading colour words (red, green, yellow and blue) is measured (Stroop-Word). In the second condition, the participant has to name the colours of four bars that are printed in these colours (Stroop-Colour). In the third condition, the participant is required to name the colours of colour-words that are printed in incongruous colours (Stroop-Colour/Word). Naming time and errors were recorded for each subtest separately. Additionally, a nomination score was calculated in terms of the difference in reaction times of reading of colour words and colour naming. The selectivity score depicts the ability to resist interference, which is calculated by subtracting the time for naming coloured bars from the time to name the colours of colour-incongruent words.

The groups were compared for differences in Stroop test and colour perception performance as indicated by the FMT using analyses of variance (ANOVAs) with 'group' as between-subjects factor and discrimination along 'colour axis' (BY: blue–yellow; RG: red–green) as within-subject factor. In case of significant interaction effects, subsequent t-tests were computed. Furthermore, subsequent ANCOVAs with the covariates BY, respectively RG, and Pearson correlations between Stroop Colour naming and BY, respectively RG, were calculated. All analyses were performed with SPSS 11.5.2.1.

Results

Analysis of error scores on the colour perception test (FMT) revealed a main effect of 'colour axis' (df = 25, $F = 9.7$, $p < .005$; partial eta^2 = .28), indicating an overall higher partial error score for blue–yellow than for red–green. There was a significant main effect of 'group', indicating that children with ADHD had a

Table 1 Sample description and results

Measure	Controls (N) N = 13 (2; 2)[a]		ADHD N = 14 (1; 3)[a]		ANOVA	
	Mean	SD	Mean	SD	F	p <
Full-scale IQ	108.9	10.0	104.4	7.6	1.8	ns
Age (years)	10.9	.7	110.5	1.0	1.2	ns
Spelling abilities (T-score)	49.9	13.1	46.9	9.0	.5	ns
Word fluency (n/3*min)	27.4	6.9	26.8	11.6	.0	ns
Farnsworth–Munsell 100 Hue						
Total error score	54.5	31.1	86.8	33.6	6.7	.016
Partial error score blue–yellow	28.6	19.1	50.4	22.0	7.5	.011
Partial error score red–green	25.9	12.9	36.4	15.1	3.7	.065
Stroop						
Word (sec/72 items)	44.5	10.4	56.9	26.6	2.5	ns
Colour (sec/72 items)	66.2	12.3	83.7	27.9	4.4	.047
Colour/Word (sec/72 items)	116.8	30.9	174.7	56.2	10.8	.003
Nomination[b] (t score)	52.0	7.5	51.6	12.5	.01	ns
Selectivity[bc] (t score)	53.8	8.4	47.4	13.7	2.1	ns

[a]Total number (number of girls; number of probands with dyslexia). [b]Note: higher t scores = >better performance. [c]Ability to resist interference.

higher Total Error Score than did controls (df = 1, $F = 6.7$, $p < .02$; partial eta^2 = .15). However, these main effects were modified by a significant interaction effect between the factors 'colour axis' and 'group' (df = 25, $F = 4.5$, $p < .05$; partial eta^2 = .28). Post hoc analyses revealed that the colour perception impairment of children with ADHD was particularly pronounced along the blue–yellow axis as opposed to the red–green axis (see Table 1), indicating that children with ADHD make more blue/yellow errors ($F = 7.5$, $p < .011$; partial eta^2 = .23) but not more red/green errors compared to normal controls; furthermore, children with ADHD make more blue/yellow errors compared to red/green errors (df = 13; $T = 3.1$, $p = .009$; partial eta^2 = .42), whereas the controls didn't differ in number of errors on both axes (df = 12; $T = 1.0$, $p = .331$).

Analysis of the Stroop data indicated that the two groups did not differ in the speed of naming words in the Word condition. However, the children with ADHD were significantly slower naming colours in both the Colour and Colour/Word conditions. The factor 'group' accounted for 14.8% of the variance of Stroop-Colour condition, corresponding to a large effect according to Cohen.

To determine whether colour perception abilities contribute to variance in the Stroop colour naming condition, Pearson correlations between Stroop-Colour naming and 'blue–yellow colour discrimination' (BY), respectively 'red–green colour discrimination' (RG), (for the total group and separately for ADHD and controls), as well as ANCOVAs with the covariates BY, respectively RG, were calculated. The correlations between Stroop Colour naming and colour discrimination (BY, RG) were all insignificant, probably because of small sample sizes. Interestingly, correlation coefficients were consistently larger for RG with Stroop-Colour naming than for BY with Stroop-Colour naming (ADHD: r_{RG}: = .27, r_{BY}:

$r = .19$; controls: r_{RG}: = .28, r_{BY}: $r = .1$; total group: r_{RG}: = .36, r_{BY}: $r = .31$). Correspondingly, ANCOVAs revealed partial eta squared values of .024 for the covariate BY, respectively .066 for the covariate RG, which can be regarded as a small effect size of the covariate BY according to Cohen ($f = .16$), respectively a medium ($f = .27$) effect size of the covariate RG.

Discussion

Children with ADHD exhibited more errors than their typically developing peers on a colour perception test (FMT), particularly with blue–yellow stimuli. Our finding is consistent with previous studies in other disorders involving altered dopaminergic mechanisms, which have found that discrimination along the blue–yellow axis (compared to the red–green axis) is particularly impaired (e.g., Büttner et al., 1994; Gobba & Cavalleri, 2003; Haug et al., 1995; Melun et al., 2001; Roy et al., 2003), indicating subtle problems in the blue–yellow mechanism and changes in retinal dopaminergic mechanisms.

The fundamental mechanisms causing a specific retinal impairment of colour discrimination along the blue–yellow axis in dopaminergic disorders remain unclear. Short wavelength sensitive cones may be more fragile than long and medium wavelength sensitive cones or their relative scarcity and anatomical distribution may be responsible for the greater vulnerability of the blue–yellow perception by alterations of the dopaminergic system (Djamgoz et al., 1997; Hart, 1987; Masson et al., 1993; Witkovsky, 2004).

A second and predicted finding was that children with ADHD were slower in naming the colours of stimuli on both the Colour and Colour-Word conditions of the Stroop, but did not differ in naming

speed on the Word condition, nor in Stroop interference. This result is consistent with findings from numerous studies reporting colour naming difficulties in children, adolescents and adults with ADHD (e.g., Banaschewski et al., 2005; Rucklidge & Tannock, 2002; van Mourik et al., 2005).

However, while the Stroop colour naming condition is dependent in part upon on intact visual function, we did not find robust evidence of a specific relationship between colour perception ability along the blue–yellow axis and colour naming on the Stroop. Rather, an equal amount of variance of the Stroop-Colour condition could be accounted by discrimination ability along the blue–yellow as along the red–green axis. Thus our findings mitigate the argument that colour perception has a substantial influence on Stroop performance.

Several methodological limitations must be considered when interpreting the findings from the present study. First, the children with ADHD were obtained through referrals to a paediatric psychiatry clinic and thus it is unknown whether findings are generalizable to non-clinical samples. Second, we used a 48 hr washout period prior to testing for those children receiving stimulant treatment, which might not have been of sufficient duration to ensure that there were not any residual effects of the stimulant drug on dopamine neurotransmission in children with ADHD. However, if this were the case, then the effect would be to attenuate rather than accentuate the group differences in colour vision. Third, we relied on a single clinical measure of colour perception (FMT), which requires the participant to sequence coloured caps on the basis of hue. FMT is often the clinical test of choice for assessing acquired colour vision defects (which typically affect the blue–yellow mechanism). However, it requires movement execution as well as sustained attention: motor impairments have been associated with FMT errors scores in patients with Parkinson's disease (e.g., Haug et al., 1995). But problems in attention and/or motor execution, which are associated with ADHD, would not account for the children's differential performance with blue–yellow versus red–green stimuli. Nonetheless, future studies should include additional measure of colour perception.

Conclusion

To our knowledge, this is the first study of colour perception in ADHD. Although distorted colour discrimination abilities may reflect alterations of more central mechanisms of the vision system as well, the present findings of specific blue–yellow colour perception problems suggest colour vision impairment that is related to retinal dopaminergic function in children with ADHD. However, performance deficits on Stroop colour naming seem not to be fully attributable to colour vision impairment. Further research on colour perception in ADHD is warranted, using more precise approaches to measurement that permit an evaluation of neuronal integrity, such as colour visual evoked potentials.

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