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Colour discrimination and categorisation in Williams syndrome

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ABSTRACT

Individuals with Williams syndrome (WS) present with impaired functioning of the dorsal visual stream relative to the ventral visual stream. As such, little attention has been given to ventral stream functions in WS. We investigated colour processing, a predominantly ventral stream function, for the first time in nineteen individuals with Williams syndrome. Colour discrimination was assessed using the Farnsworth-Munsell 100 hue test. Colour categorisation was assessed using a match-to-sample test and a colour naming task. A visual search task was also included as a measure of sensitivity to the size of perceptual colour difference. Results showed that individuals with WS have reduced colour discrimination relative to typically developing participants matched for chronological age; performance was commensurate with a typically developing group matched for non-verbal ability. In contrast, categorisation was typical in WS, although there was some evidence that sensitivity to the size of perceptual colour differences was reduced in this group.

1. Introduction

Atypical colour perception is reported in a number of neurodevelopmental disorders. For example, individuals with Autism show reduced colour memory, reduced chromatic discrimination, but typical categorical perception of colour (Franklin, Sowden, Burley, Notman, & Alder, 2008; Franklin et al., 2010), whilst reduced blue–yellow chromatic discrimination is reported in attention deficit hyperactivity disorder (Banaschewski et al., 2006).

Williams syndrome is a rare genetic disorder, in which visuo-spatial functioning is impaired relative to verbal abilities (Jarrold, Baddeley, & Hewes, 1998). Colour perception has not previously been explored in WS. This is because the visuo-spatial deficit in WS has been attributed to atypical dorsal stream functioning (e.g. Atkinson et al., 2001), and colour perception has broadly been classified as a ventral stream function (e.g. Beauchamp, Haxby, Jennings, & De Yoe, 1999). It has therefore been assumed that colour perception is typical in WS. However, a brief review of the WS literature, and the literature on colour perception, questions this assumption on a number of grounds, which we detail below. The current study assessed colour perception across a battery of tasks to provide a comprehensive account of colour perception in WS.

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First, we explore ventral stream processing in WS. Ventral stream activation in WS is certainly less impaired than dorsal stream function in WS and a number of studies have shown typical activation in individuals with WS when carrying out tasks that are associated with the ventral stream (e.g. Mobbs et al., 2007). However, the ventral stream cannot be described as 'intact'. For example, Grice et al. (2003) demonstrated atypical neural activation in the ventral stream in WS when participants were presented with illusory contours, which suggests that these stimuli were being processed in an atypical manner. Relatedly, taking a brain network approach it is important to recognise that there is much structural and functional cross-talk between dorsal and ventral streams (Van Essen, Anderson, & Felleman, 1992), and so it stands to reason that a deficit in the dorsal stream in WS could impact ventral stream functions. In support of this, Sarpal et al. (2008) report impaired functional connectivity between the parahippocampal gyrus (ventral stream) and parietal cortex (dorsal stream) in WS.

Second, we consider the cortical activation associated with colour perception. Colour perception involves multiple areas of visual cortex and although activation is predominantly in the ventral stream, Claeys et al. (2004) reported dorsal activation in the Intraparietal Sulcus (IPS) and dorsal premotor cortex during a colour perception task. Exploration of primary visual cortex in WS is limited to area V1 where Galaburda, Holinger, Bellugi, and Sherman (2002) report increased cell packing and neuronal size in WS autopsy specimens, compared to control brains. The IPS is an area in WS cortex which has repeatedly been shown to be atypical in both function (Meyer-Lindenberg et al., 2005) and structure (Kippenhan et al., 2005). These findings, therefore, provide further impetus for exploring colour perception in WS.

To explore basic perceptual discrimination of colour hues, we used a widely employed colour vision test, the Farnsworth-Munsell 100 hue test (Farnsworth, 1943). This task enables one to establish overall level of chromatic discrimination as well as to determine whether chromatic discrimination shows any distinct patterns of deficit for either the red–green or blue–yellow colour axes. Colour vision on these two axes is described as the two 'cardinal directions' in colour space (Krauskopf, Williams, & Heeley, 1982) and derive from two physiologically distinct subsystems. The 'red–green' subsystem reflects a comparison of signals from retinal cone photoreceptors that are sensitive to signals from long- (L-) versus signals from medium- (M-) wavelengths. The 'blue–yellow' subsystem reflects a comparison of signals from photoreceptors that are sensitive to short-wavelengths, with the combined signals from long and medium-wavelength cones. These two subsystems extend beyond the retina to the pathways from the retina to the cortex. In the Farnsworth-Munsell 100 hue test, the participant is asked to put 85 coloured caps, which vary incrementally in hue around the hue circle, in order. The test is commonly used to assess accuracy of chromatic discrimination, and due to simple instructions and low task demands it is also suitable for use with children (e.g., Roy, Podgor, Collier, & Gunkel, 1991; Verriest, Van Laetham, & Uvijls, 1982), even for children as young as 5 years old (e.g. Kinnear & Sahraie, 2002). This test has been successfully used with people with Attention Deficit Hyperactivity Disorder (Banaschewski et al., 2006) and children with Autism (Franklin et al., 2010), but had not previously been used with people with WS. The average IQ in WS is approximately 60 (Farran & Karmiloff-Smith, 2012) and so to determine whether participants understood what was required of them, we also included a control task in which participants arranged a series of achromatic, grey caps sequentially from white to black (as in Franklin et al., 2010).

A second motivation for investigating colour perception in WS was tentative evidence from previous research that colour categorisation in WS may be atypical. In an investigation of spatial categories in WS, Farran and Jarrold (2005) included a matching-to-sample colour categorisation task as a control task. The design of the colour task was confounded by differences in the perceptual distance between a blue prototype and blue exemplars, compared to the green stimuli. The blue exemplars were more similar to the blue prototype than the green exemplars were to the green prototype, i.e. 'green' trials were harder than 'blue' trials. However, this confound revealed an interesting, albeit marginal effect which merits controlled exploration. The WS group showed impaired categorisation when matching exemplars to the green category prototype, relative to non-verbal matched typically developing control children. A tentative conclusion from this is that the WS group did not have as strong colour categorisation as the TD group, and hence were more influenced by differences in perceptual distance than the TD group.

To further investigate this, in the current study, we included three additional tasks. The first is a replication of the matching-to-sample task employed by Farran and Jarrold (2005), correcting for the confound in perceptual distance by equating the distance of exemplars to the prototypes in chromatic perceptual space. Participants viewed a series of target coloured squares flanked by a blue prototype and a green prototype square and were asked whether the target was more similar to the square to the left or to the right. To explore potential differences in perceptual versus verbal categories, in a second categorisation task, participants viewed a randomised sequence of target squares only and were asked to verbally classify each square as green or blue.

The third task was a further measure to investigate the proposal that the WS group were more influenced by the perceptual distances between colours than the TD group in Farran and Jarrold's (2005) study. Here, we used a visual search task, where participants were asked to locate target coloured circles amongst distracters, when the perceptual chromatic difference between targets and distracters was either large or small. If increased weighting of perceptual distance can explain the atypical pattern of performance on Farran and Jarrold's matching-to-sample task, then we would expect a greater effect of perceptual distance on search accuracy in the WS group compared to control participants. Comparing overall performance for WS and controls on the chromatic search task also provides a second test, in addition to the Farnsworth-Munsell 100 hue test, of whether chromatic discrimination is generally reduced in WS.

If one follows the assumption that colour perception is typical in WS, it is possible that individuals with WS will show the same patterns of performance as chronological age matched typically developing participants. However, in order to take task