Dual coding of object relations: An alternative framework for understanding perceptual processing in autism?

Alastair D. Smith[1]

Elizabeth Milne[2]

1. School of Psychology, University of Nottingham, UK

2. Department of Psychology, University of Sheffield, UK

Correspondence should be addressed to either:

- Dr Alastair D. Smith, School of Psychology, University of Nottingham, University Park, Nottingham NG7 2RD, UK; Email: alastair.smith@nottingham.ac.uk.
- Dr Elizabeth Milne, Department of Psychology, University of Sheffield, Western Bank, Sheffield S10 2TN, UK; E-mail: E.Milne@Sheffield.ac.uk.

Abstract

Humphreys (1998) presented a model of attentional selection that was based on within- and between-object relations. In this paper we argue that the model may offer a more principled, flexible, and tractable approach to understanding perceptual differences in autism than current leading accounts (i.e. theories of Weak Central Coherence and Enhanced Perceptual Functioning). We briefly review these accounts before making a case for the necessity of an alternative conceptualisation. We then review the underlying principles of the Dual Coding account, and explore whether it can be applied to findings in autism research. Since the model focuses on attentional mechanisms, rather than perceptual processing, we argue that it may provide a more valid foundation for understanding the relationship between local and global perception in existing autism research findings, which tend to be reported in the absence of fundamental differences in visual perception. It is also firmly rooted in empirical evidence from typical and atypical populations, allowing scientists to make predictions about visual behaviour that can be applied across groups, and in a manner that is fully consistent with existing knowledge about perception. Irrespective of how convincing the reader may find this argument, we believe that it befits Glyn Humphreys' scientific heritage to show how his work might still provide a clear and elegant solution to a controversial issue.

KEYWORDS: Dual Coding; perceptual organisation; autism; Weak Central Coherence; Enhanced Perceptual Functioning

At the tail-end of the 20th Century, Glyn Humphreys published a model of object processing that specified two parallel routes to coding spatial relations within and between visual features (Humphreys, 1998). Perhaps in homage to Paivio's (1990) theory of mental representations, this was dubbed a Dual Coding account. Like all of Glyn's writing, the paper is elegant, pellucid, and beautifully understated. Accordingly, it is well-cited and has made an important impression on neuropsychological studies of visual and attentional function. In the present paper, we make the argument that this impact has perhaps been too modest, and that the Dual Coding account has the potential to bring balance to equivocal theories and findings within autism research.

Autism Spectrum Disorder is a neurodevelopmental condition that is diagnosed on the basis of difficulties with social communication, along with restricted patterns of behaviour and interests (American Psychiatric Association, 2013). Much contemporary autism research focuses on perceptual and cognitive features of the condition, with particular interest in visuospatial perception (for a review see: Simmons et al., 2009). Because of the pattern of strengths and weakness exhibited by people with autism, it has been suggested that atypicalities in perceptual organisation (i.e. visual processing of parts, wholes, and their relationship) may contribute to some of the behavioural features of the condition. Here we briefly review theories of visuospatial processing in autism, before then providing an overview of the Dual Coding account and elucidating how it differs. Finally, we ask if dual coding could provide a more useful approach for autism research and explore how it might be applied to existing controversies in the literature.

Perceptual organisation in autism

Perhaps the first empirical observation of visuospatial atypicality in autism came from a study by Shah and Frith (1983), who found that children with autism were faster than matched controls at the Embedded Figures Test, where one is required to locate a local shape embedded within a more complex global figure. This was later followed by a study from the same group, reporting a similar

superiority in the Block Design task (Shah and Frith, 1993). On the basis of these findings, the researchers argued that autism is associated with a particular skill in segmenting visual forms, based on greater attention to detail and a reduced primacy of the Gestalt. This interpretation has been supported by autistic performance in tasks across a variety of paradigms, including visual search (O'Riordan et al., 2001), the perception of Navon figures (Plaisted, Swettenham, & Rees, 1999), and drawing production (Booth et al., 2003).

The broad pattern of behaviours in these tasks has given rise to two major theories of visuospatial processing in autism, both focusing on a processing advantage for local elements. The Weak Central Coherence (WCC) theory (Frith, 1989; Frith and Happé, 1994; Happé & Frith, 2006) was based on the principle of a global deficit – people with autism have difficulty integrating part elements into a global Gestalt, thus resulting in a detail-focused processing style. This was thought to account for a broad variety of behavioural features; for example, just as it might affect a preference for processing local letters in a Navon figure, it could also affect the extraction of gist from language (Happé, 1997) and preference for activities that are consistent with a detail-focussed perceptual style (Briskman et al., 2001). In contrast to this approach, the Enhanced Perceptual Functioning (EPF) account (Mottron & Burack, 2001; Mottron et al., 2006; Wang et al., 2007) was explicitly couched in visuo-perceptual superiority in autism, proposing that enhancements in bottom-up feed-forward processing mechanisms (e.g. detection, discrimination) lead to a system that defaults to the local level. The EPF account is distinguished from the original WCC position because global processing is seen to be intact but not 'mandatory' (as it is in typical individuals), whereas WCC proposes a specific deficit in the processing of global information (Mottron et al., 2006).

These theories have since formed the basis for many investigations into visual processing in autism, and evidence has been proffered in support of both accounts (for reviews see: Behrmann et al., 2006; Simmons et al., 2009; Van der Hallen et al., 2015). For example, it has been reported that thresholds

for motion coherence are higher in autism, which is suggestive of atypical global processing and therefore supports a WCC account (e.g. Pellicano et al., 2005). Equally, studies of hierarchical processing using Navon figures have reported intact global precedence effects in autism, alongside interference from local details, which supports the EPF position of intact global processing in combination with local bias (e.g. Rinehart et al., 2000). The general pattern of findings has, however, been equivocal, and whilst some studies have demonstrated local superiorities or global deficits in autism, others have reported no difference between autistic and typical groups at either level (e.g. Edgin & Pennington, 2005; White & Saldaña, 2011). This heterogeneity is further exacerbated by the fact that many studies differ in terms of the level of functioning of their autistic participants, the protocols by which they match their typical comparison group, and the exact paradigm that they employ (Simmons et al., 2009; Smith et al., 2016). Accordingly, neither theory could be said to adequately account for, or appropriately integrate, the full picture of research findings (Van der Hallen et al., 2015).

In response to this changing field, the proponents of both accounts have modified the theories from their original conception (Happé & Booth, 2008; Mottron et al., 2013), and they have become more conceptually similar. Both theories now converge on the principle of a local bias, rather than any kind of global deficit, and the WCC position also concedes that global information may be processed separately from local detail. The most recent rethinking of WCC (Happé & Booth, 2008) suggests that they may be processed separately, and in parallel, although this is not supported by reference to existing models of perceptual organisation. In contrast, the most recent description of EPF (Mottron et al., 2013) does not specifically describe whether local and global processing occurs in parallel in autism, or whether global processing depends on an initial integration of local elements. Both the WCC and the EPF accounts could be said to employ terminology that enables them to incorporate equivocal findings – i.e. people with autism are not 'obliged' to attend to the global percept and, instead, are more likely to demonstrate a 'preference' for the local level. Both theories therefore

acknowledge that people with autism can process stimuli at both levels, but propose that they might sometimes do so differently from neurotypical individuals. Naturally, it is arguable that such caution is necessary when attempting to describe a very heterogeneous condition that has yielded equally heterogeneous behavioural findings. However, it means that neither theory necessarily requires revision in the face of evidence that fails to demonstrate local superiority, or global impairment, in people with autism. Moreover, such terminology is a is a rather imprecise way of describing hierarchical processing in the absence of any further specification, and it may be that thinking about perceptual organisation solely in terms of local and global levels is artificially constraining.

The case for an alternative approach

The difficulties that WCC and EPF have with accounting for the full range of findings is indicative of a number of important issues, both in terms of the heterogeneity of the behavioural effects that they attempt to explain and the nature of the theories themselves (Simmons et al., 2009). Although they were both conceived to account for the same core phenomena (i.e. detail focus and a reduced primacy of the Gestalt), the theories have been specified at very different levels. WCC is a broad cognitive account of visuospatial processing and, therefore, does not seek to describe any mechanisms by which autistic individuals might prioritise, or be biased towards, visual information at the local level. For example, although Happé & Booth (2008) incorporated the premise of a separate stream for global processing to the WCC theory, it was described in no more specific terms than that. In contrast to WCC, the EPF account has much greater focus on the neural mechanisms that might underlie local superiorities, and incorporates findings from studies of low-level and mid-level perception, as well as functional neuroimaging. However, as stated earlier, it is agnostic on the relationship between local and global levels. Of course, this difference in empirical focus is not itself problematic, although it arguably makes these incumbent theories rather poorly-matched opponents when scientists seek to understand their data. Furthermore, it is perhaps fair to say that neither theory has been specified in relation to existing models of perceptual organisation from related fields in psychology. Marr's

computational model of object recognition (Marr, 1982), Feature Integration Theory (Treisman, 1988), and the Reverse Hierarchy Theory (Ahissar & Hochstein, 2004), for instance, all provide established accounts of normative processing, and it is interesting that they have not been called upon to help elucidate the functions being described.

Equally interesting is the fact that reports of atypicalities of hierarchical processing in other populations have not been incorporated into our existing models of visuospatial perception in autism. The study of perceptual organisation has a long history in neuropsychology, and there are many accounts and models of local and global perception derived from a variety of different populations, including people with dementia (e.g. Massman, et al., 1993), viral infection (Martin et al., 1995), and stroke (Lamb, Robertson, & Knight, 1990). A particularly apposite example comes from integrative agnosia, a perceptual disorder most clearly and intricately described by Glyn Humphreys and Jane Riddoch in their studies of patient HJA (Humphreys & Riddoch, 1987; Riddoch & Humphreys, 1987). HJA presented with object agnosia (i.e. he was unable to recognise visually-presented objects in the absence of low-level perceptual dysfunction or memory deficit) that was specifically related to an inability to integrate local elements into a global form. This is relevant to the current discussion because integration of visual parts into meaningful wholes is exactly the process that WCC identified as being impaired in autism. However, the fact that HJA's visual impairment is so much more profound than the effects that are sometimes reported in the autism literature suggests that the processes underlying atypical perception are very different between these populations (furthermore, his integrative deficit resulted in a default to the global level: Riddoch et al., 2008). It may be for this reason, then, that theories and findings from neuropsychology have not been taken into account in autism research (although there is a brief reference to HJA in: Mottron et al., 2006).

The difference between neuropsychological accounts of hierarchical perception and those proffered by WCC and EPF perhaps demonstrates a core challenge in autism research. Namely, although people

with autism may demonstrate a bias to the local level, sometimes to the apparent detriment of global perception, they do not demonstrate a perceptual dysfunction *per se* (e.g. an integrative deficit is not associated with object recognition impairment). Whilst this might therefore suggest that neuropsychology cannot provide any relevant insights here, we think that this is a massive oversight: neuropsychology not only gives us a fundamental framework for understanding perceptual organisation in the same behaviours and tasks, but it has also provided formal means to consider the relationship between local and global forms in atypical processing. This is something that is missing from mainstream autism research: indeed, Van der Hallen et al (2015) state that there is still no operationalisation in autism research of what constitutes global and local levels, and we argue that this very conceptualisation may have unnecessarily constrained existing theories. Instead, we suggest that a model founded in normative behaviour, and refined by evidence from neurological patients, could potentially provide a framework for formally understanding atypicalities in integrative behaviour in the absence of clear support for either superior local processing or inferior global processing in autism (Van der Hallen et al., 2015).

The Dual Coding account

On the basis of findings from studies of visual attention, across typical and atypical participants, Glyn Humphreys presented the Dual Coding account of object coding, with particular reference to the neural locus of the underlying mechanisms (Humphreys, 1998). The model was conceived as an alternative to existing accounts of object recognition that were based either on space (i.e. elements in the same spatial location are selected for attention: Posner, 1980; Treisman, 1988) or objects (i.e. elements that are part of the same apparent form are selected: Baylis & Driver, 1993; Duncan, 1984). Since the two concepts are not necessarily mutually exclusive (i.e. spatial attention can bias object selection, and object-based attention can bias spatial orienting), Humphreys proposed that they could be conjoined by, instead, making a distinction between within- and between-object coding. Within-object coding refers to the computation of individual elements as being separate parts of the same

object. In contrast, between-object coding refers to the representation of elements as individual objects in their own right. Certain classes of object support the two descriptions concurrently; so, for example, a bunch of grapes can be coded in a between-object framework as a set of individual objects (the grapes) and in a within-object framework as elements within a larger object (the bunch).

This distinction was rooted in earlier studies of the grouping mechanisms that support efficient visual search behaviour (e.g. Donnelly, Humphreys & Riddoch, 1991; Duncan & Humphreys, 1989; Humphreys, Quinlan & Riddoch, 1989). Studies such as these challenged the typical distinction between parallel grouping of non-target items in single-feature search, and serial integration of visual features in conjunction search (e.g. Treisman & Gelade, 1980). Instead, they argued that perceptual similarities between targets and non-targets modulate grouping and, therefore, the efficiency of search. So, when non-targets present a homogeneous set of features, they are likely to be uniformly segregated from target items as a separate group (i.e. they have a strong within-object representation). When non-targets possess a conjunction of features, they may be grouped with target items when they share a feature with them – this engenders effortful serial search because there are strong within-object associations between target and non-target. However, when the similarity between heterogeneous non-targets is greater than the similarity between targets and non-targets, parallel search can still be observed (i.e. search time is flat across set size because there are stronger between-object distinctions to dissociate target and non-target). Thus, there is parallel encoding of both single features between elements (i.e. between-object coding) and conjunctions of features (i.e. within-object coding), the latter being the foundation of successful object recognition (Donnelly et al., 1991).

The core thrust of the formal account of Dual Coding (Humphreys, 1998) was the demonstration that these parallel computations can become dissociated following brain damage. For instance, Humphreys & Riddoch (1995) reported data from patient JR, who presented with visual neglect (i.e.

hemispatial inattention) to a different side of space depending on how spatial relations were coded. When reading a word aloud he would make a left-neglect error (substituting the initial letter for another), whereas he would make a right-neglect error when identifying each letter individually (omitting the final letter). When identifying a word, each letter is represented as part of the same string, and so JR manifested within-object neglect for the task. Conversely, the identification of individual letters involves the letters being represented as single objects, thus leading to between-object neglect in JR's performance. Parallel computation is supported by the fact that JR could identify an element in one form of task that was previously misidentified in another; thus, one representation does not serve as the input for the other.

Humphreys & Heinke (1998) dissociated within- and between-object representations across patients, rather than within the same case. They evaluated a group of five patients who all neglected the left side in standard clinical tasks, such as drawing from memory. One experimental test involved the discrimination of sex from photographs of faces. In a within-object condition patients were presented with a single face which was either male, female, or a chimeric face (formed by aligning the left and right halves of opposite-sex faces). The task was to state whether the face was male, female, or a chimeric example. In a between-object condition, patients were presented with two whole faces, one on either side of the midline. At the start of each trial the patient looked away and either one or both faces were replaced. The task was to state which faces had been replaced, and also to state the sex of the new faces. Humphreys & Heinke found that some patients showed neglect for the chimeric faces, with no neglect in the two-object task (within-object neglect). Other patients showed no neglect of the chimerics, but failed to detect the left or right face when two were present (between-object neglect). This double-dissociation is consistent with the existence of two forms of representation, and on the basis of lesion analysis it was suggested the two forms of neglect are associated with contrasting sites of damage: in inferior frontal (within-object neglect) and posterior parietal (between-object neglect) regions. This finding is in line with the assertion that within-object representations are

assimilated within the ventral stream whereas between-object representations are assimilated within the dorsal stream (Humphreys, 1998). However, this is nuanced by the fact that within-object neglect can occur after putative dorsal lesions (Humphreys & Heinke, 1998), which has been suggested to occur due to the role that dorsal areas may play when attention is required to switch from one part of an object to another.

Applying Dual Coding to autism research

The application of a Dual Coding approach to understanding visual selection may offer clear benefits to our conceptualisation of visual perception in autism. Aside from the fact that the autism literature presents no operationalisation of what exactly constitutes local and global levels, current models are unclear on the relationship between them. A Dual Coding approach shifts the theoretical focus away from local and global processing, to within- and between-object relations. This shares some conceptual similarity with the distinction drawn between local and global levels of processing (Smith, 2016) – the relationship between local elements in a hierarchical figure (e.g. a Navon letter) can be described by between-object representations (i.e. the local letters are represented as objects in their own right), whereas the global letter can be described by within-object representations (i.e. the local elements are all parts of the same multi-element object). Importantly, however, because the Dual Coding theory describes the allocation of attentional resources rather than perceptual processing *per se*, neither process is itself directly responsible for perceiving local or global visual information. This level of explanation therefore provides a theoretical basis for predicting atypicalities of visual behaviour that can be present in the absence of clear processing differences. In autism, apparent atypicalities in integrative behaviour appear to be manifest in the absence of an overt perceptual deficit, which suggests that a local bias does not necessarily have ramifications for object recognition (c.f. Riddoch et al., 2008). However, if we posit that perceptual differences in autism occur in the allocation of visual attention within- and between objects then typical and atypical function across many different populations can be reconciled in the same broad model of human visuospatial

behaviour. By positing that within- and between-object representations are computed in parallel, the Dual Coding approach also offers a formal mechanism for predicting that one stream can operate in an atypical fashion, whilst the other is unchanged (i.e. one does not act as an input into the other). So, for example, function of the within-object coding stream might differ in people with autism, whereas function of the between-object coding stream could be equivalent to that of typical controls.

Existing findings regarding visuospatial processing in autism could be reconsidered in light of the dual-coding account, and are broadly consistent with the notion of a bias towards between-object coding and away from within-object coding in autism. For example, superior performance on the embedded figures task (e.g. Pellicano et al., 2006; Shah & Frith, 1983) might relate to a particular skill in coding between-object relations, or it could reflect decreased primacy of attention to within-object relations. Aspects of autistic performance in visual search tasks could also be accounted for in this manner. For example, O'Riordan et al. (2001) found that search for a tilted line amongst vertical distractors was equally efficient for autistic and typical groups, whereas only the typical group showed a relative decrement when searching for a vertical target amongst tilted distractors. This suggests that attentional selection in the autistic group was unaffected by the manipulation of factors that affected within-object representations (which is conceptually equivalent to the configuration of elements in the array). Again, one could interpret this in terms of a bias towards between-object coding, or a relative deficit in within-object coding. The question ultimately requires empirical study, although the fact that there is no reliable configural impairment in autism suggests that a bias towards between-object coding may be more likely.

An alternative approach is to suggest that there is a reduction in the ability to switch between within- and between-object representations in autism (see: Mann & Walker, 2003, White, O'Reilly & Frith, 2009). For example, responding to different levels of a Navon stimulus requires participants to switch between judgements based on within-object relations (i.e. the global letter) and judgements based

on between-object relations (i.e. the local letters). Differences observed in autistic participants may therefore result from difficulty switching between the two, or a greater efficiency in switching from one to the other. For example, Rinehart et al. (2000) reported that children with autism demonstrated the same global interference effects as typical controls, where they were slower to respond to local stimuli when they were incongruent with the global form. However, unlike typical children, autistic children also demonstrated a local interference effect, where incongruent local information increased response times to global information. The authors argued that this may reflect difficulty shifting to a different level of processing, such that autistic children continued to process the local letter after the global letter had been identified. This tallies with findings from White et al. (2009), who found that autistic children were particularly slow at 'zooming out' when switching to the global level, and leads to the prediction that switching from between-object to within-object levels is atypical in autism.

The fact that behavioural effects in autism may differ according to the task in hand, or to the stimulus, can be accommodated by the Dual Coding approach – some objects are more likely to engender one form of processing over another, but this can then change when their properties are modulated, such as when grouping cues are altered (e.g. Donnelly et al., 1991; Han et al., 2005; Smith & Gilchrist, 2005). Therefore, perception of a given stimulus may be may either be affected or unaffected, depending on whether factors more strongly support a within- or between-object solution. So, for example, an autistic individual might perform equivalently to a typical control when making a perceptual discrimination between grouped stimuli (favouring a within-object solution) but may perform differently when drawing a copy of a grouped stimulus (favouring a between-object segmentation of parts for sequential reproduction). This broad principle chimes with a recent meta-analysis of perceptual organisation in autism (Van der Hallen et al., 2015). The authors found that there was no clear support for either superior local processing or inferior global processing. Instead, they argue that the speed at which people with autism perceive the global form is modulated by local properties, such that it can take longer when there is interference from local details. This echoes the earlier visual

search work of Duncan & Humphreys (1989) and Humphreys et al. (1989), placing as much onus on the nature of the stimulus and the task in hand as it does on the processing capabilities of the perceiver.

Beyond the specification of the mechanisms underlying attention to detail in autism, the Dual Coding account offers the potential to further discuss potential neural substrates of perceptual difference between autistic and neurotypical populations. Despite our broad assertion that there are few reliably-reported perceptual abnormalities in autism that fundamentally impair or enhance basic visual perception, there is certainly growing evidence for a range of perceptual atypicalities. For example, a number of studies have reported decreased Gestalt perception in autism (e.g. Bölte et al., 2007; Brosnan et al. 2004), which has led to theories that dorsal stream impairments are at the functional root of abnormal responses to the global form (e.g. Atkinson & Braddick, 2005; Pellicano et al., 2005; Sutherland & Crewther, 2010). However, this may not map so easily onto the putative relationship between within- and between-object coding and the dorsal and ventral streams. As stated earlier, within-object coding is broadly conceived as a ventral stream function, whereas between-object coding is subserved by the dorsal stream (Humphreys, 1998). If, then, visual behaviour in autism were to be conceived as a within-object impairment (i.e. autism is associated with a focus on parts rather than the Gestalt), one would perhaps posit atypicality in ventral stream function, which would be at odds with those theories that implicate the dorsal stream. However, Humphreys & Heinke (1998) did identify the role that dorsal areas play when switching attention between different parts of an object, which means that there could perhaps be a relationship between dorsal impairments and switching between representations in autism (Rinehart et al., 2000; White et al., 2009). This is further supported by reports of altered BOLD activation when viewing faces or complex patterns in individuals with autism, which has been taken to suggest functional imbalances between the dorsal and ventral visual streams (Hubl et al. 2003). At the very least, therefore, these findings provide some anatomical

plausibility to considering a Dual Coding account in developing a clearer understanding of visuospatial processing in autism.

This issue is far from trivial, however, and we note that it is perhaps impossible for any perceptual theory to adequately account for the full heterogeneity of findings in the literature. Whilst a number of studies report perceptual anomalies in autism, their precise nature remains elusive and results across studies have not been consistent. It is therefore very difficult to build a coherent picture of typical or atypical perception in autism on the basis of extant experimental work. For instance, some studies find evidence for reduced perception of coherent motion in random dot kinematograms (Milne et al., 2002), or reduced perception of biological motion in autism (Blake et al., 2003), whereas other studies do not (Jones et al., 2011; Saygin et al., 2010). Other domains, such as orientation discrimination can appear to be enhanced in autism although, again, results are inconsistent (Dickinson et al., 2016; Shafai et al., 2016). Given the variation in research findings, it is impossible to reconcile all of this work with our proposal of the Dual Coding Account. However, many of the existing studies investigating perception in ASD have utilised a 2AFC experimental design, and recent work has raised the possibility that parameters underlying decision making rather than perceptual differences may explain task differences between those with and without ASD. For example, using the Drift Diffusion Model to model the processes involved in making forced choice decisions regarding stimulus orientation, Pirrone et al. (2017) found that adults with and without ASD did not differ in their perceptual sensitivity, but rather in their level of conservativeness when making a decision. If this finding extends to perceptual judgments other than orientation discrimination then the implications are significant and suggest that many conclusions regarding altered perceptual sensitivity in ASD may need to be revisited. This highlights the importance of developing theoretical frameworks, such as that presented here, coupled with careful experimental approach, to guide understanding of the way in which perception and attention may vary in ASD.

Conclusion

We have argued that the Dual Coding account presented by Humphreys (1998) might offer a more principled, flexible, and tractable approach to understanding atypical perceptual behaviour in autism than the present incumbent theories (i.e. WCC and EPF). Application of this model is not an attempt to provide an alternative account of visual perception in autism; rather, we suggest that existing debates in autism research might benefit from a focus on attentional mechanisms, rather than basic perceptual ones. Since the Dual Coding model is based on the allocation of attention within and between objects, it can account for differences in some visuospatial behaviours that occur in the absence of clear perceptual strengths or weaknesses. This may therefore reflect the existing autism research literature more accurately than the models that are usually employed. Importantly, the Dual Coding account is founded in empirical findings from both typical and impaired populations, which means that one can make clear predictions about behaviour that are firmly rooted in both function and neural underpinning.

The veracity of this position must now rest upon further empirical and theoretical endeavour. First, we need to undertake a more thorough review of the extant literature in order to gauge how well the Dual Coding theory can be applied across the range of extant findings, and under what circumstances the questions asked, or paradigms employed, allow us to distinguish between this approach and others. This will, no doubt, produce some controversies, such as the aforementioned relationship between within- and between-object coding and the dorsal and ventral streams. Second, we should formally test the theory by generating predictions that are specific to the Dual Coding theory, and by observing effects that could not be accounted for by either WCC or EPF. In some respects, this is not as easy to achieve as one might hope, since the incumbent theories are sufficiently flexible to accommodate both the presence and absence of visuospatial difference in autism. As a result, it may be that one needs to look towards tasks that require participants to specifically allocate attention to within- or between-object features, but using stimuli that would not implicate the local and global

distinctions that have been drawn by other theories. For example, an Intradimensional/Extradimensional (ID/ED) task could be employed, requiring participants to respond on the basis of perceptual features shared by stimuli (i.e. a within-object cue) and to ignore an irrelevant perceptual cue that distinguished them (i.e. a between-object cue). At a later reversal stage, the previously negative cue (i.e. the between-object cue) would then be positive, thus challenging the participant to shift their attentional set away from the positive features (i.e. within-object cues) from the previous stage. One could therefore predict a difficulty in acquiring a within-object attentional set in autism, or a particular difficulty in tasks that required them to shift from a between-object set to a within-object one. A similar task has been employed by Yerys et al. (2009) to assess executive components of set-shifting in children with autism, which provides a useful precedent for this kind of approach.

It is important to note here that we are not proffering Dual Coding as an omnibus account of behavioural atypicalities in autism. This contrasts with more recent theories that have attempted to provide unifying mechanisms for a variety of features. For instance, Rosenberg, Patterson, & Angelaki (2015) suggest that a reduction in neuronal inhibition (i.e. through altered divisive normalisation processes) is responsible for the perceptual components of autism. So, when a global response to a Navon figure is required, people with autism experience reduced inhibition of the competing local representation, compared to typical perceivers. The authors then go on to argue that this mechanism can also account for social aspects of the condition. Alternative theories are based more on the application of existing knowledge to perceptual and social decisions. For example, Sinha et al. (2014) posit that autism is associated with impairments in prediction processes, whereas Pellicano & Burr (2012) focus on a reduced influence of previous experience (i.e. attenuated Bayesian priors). Whilst all of these theories offer formal mechanisms that carry the potential to integrate perceptual, cognitive, and social behaviours, they are not specified at a level that can accommodate the heterogeneity of current perceptual findings in the literature. As a result, we argue that the Dual

Coding model might occupy a useful position where it can perhaps more accurately describe visual-cognitive features of autism whilst remaining agnostic to the lower-level mechanisms that give rise to atypical performance (whether they are described at a neuro-computational level or a Bayesian one).

Just as we have argued that existing perceptual models are relatively underspecified, and have not fully attempted to incorporate existing knowledge of perceptual organisation from other fields of psychology, we conceded that this general treatise is likely guilty of both criticisms itself. However, we feel that it is a fitting tribute to the legacy of Glyn Humphreys' contributions to demonstrate how his work still has the potential to revolutionise our subject and shine a light on some murky theoretical debates. Equally, just as Glyn's approach to science was very much as a polymath, the future of autism research depends on the incorporation of knowledge and approaches from allied fields of the psychological sciences.

References

Ahissar, M., & Hochstein, S. (2004). The reverse hierarchy theory of visual perceptual learning. *Trends in Cognitive Sciences, 8,* 457-464.

American Psychiatric Association. (2013). *The Diagnostic and Statistical Manual of Mental Disorders: DSM 5.* Arlington, VA: bookpointUS.

Atkinson, J., & Braddick, O. (2005). Dorsal stream vulnerability and autistic disorders: The importance of comparative studies of form and motion coherence in typically developing children and children with developmental disorders. *Cahiers de Psychologie Cognitive, 23,* 49–58.

Baylis, G. C. & Driver, J. (1993). Visual attention and objects: evidence for hierarchical coding of location. *Journal of Experimental Psychology: Human Perception and Performance, 19*, 451-470.

Behrmann, M., Thomas, C., & Humphreys, K. (2006). Seeing it differently: Visual processing in autism. *Trends in Cognitive Sciences, 10,* 258–264.

Blake, R., Turner, L. M., Smoski, M. J., Pozdol, S. L., & Stone, W. L. (2003). Visual recognition of biological motion is impaired in children with autism. *Psychological Science, 14(2),* 151-157.

Bölte, S., Holtmann, M., Poustka, F., Scheurich, A., & Schmidt, L. (2007). Gestalt perception and local-global processing in high-functioning autism. *Journal of Autism and Developmental Disorders, 37,* 1493-1504.

Booth, R., Charlton, R., Hughes, C., & Happé, F. (2003). Disentangling weak coherence and executive dysfunction: Planning drawing in autism and attention–deficit/hyperactivity disorder. *Philosophical Transactions of the Royal Society B: Biological Sciences, 358*, 387–392.

Briskman, J., Frith, U., & Happe, F. (2001). Exploring the cognitive phenotype of autism: weak "central coherence" in parents and siblings of children with autism: II. Real-life skills and preferences. *Journal of Child Psychology and Psychiatry*, *42*(03), 309-316.

Brosnan, M. J., Scott, F. J., Fox, S., & Pye, J. (2004). Gestalt processing in autism: failure to process perceptual relationships and the implications for contextual understanding. *Journal of Child Psychology and Psychiatry, 45*, 459-469.

Dickinson, A., Bruyns-Haylett, M., Smith, R., Jones, M., & Milne, E. (2016). Superior orientation discrimination and increased peak gamma frequency in autism spectrum conditions. *Journal of Abnormal Psychology, 125(3)*, 412-422.

Donnelly, N., Humphreys, G.W. & Riddoch, M. J. 1991 Parallel computation of primitive shape descriptions. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 561 - 570.

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review, 96(3)*, 433-458.

Duncan, J. 1984 Selective attention and the organization of visual information. *Journal of Experimental Psychology: General, 113*, 501-517.

Edgin, J. O., & Pennington, B. F. (2005). Spatial cognition in autism spectrum disorders: Superior, impaired, or just intact? *Journal of Autism and Developmental Disorders*, *35*(6), 729-745.

Frith, U. (1989). *Autism: Explaining the enigma*. Oxford: Basil Blackwell.

Frith, U., & Happé, F. (1994). Autism: Beyond "theory of mind". *Cognition, 50(1),* 115–132.

Han, S., Jiang, Y., Mao, L., Humphreys, G. W., & Qin, J. (2005). Attentional modulation of perceptual grouping in human visual cortex: ERP studies. *Human Brain Mapping, 26(3),* 199-209.

Happé, F. G. (1997). Central coherence and theory of mind in autism: Reading homographs in context. *British Journal of Developmental Psychology*, *15*(1), 1-12.

Happé, F. G., & Booth, R. D. (2008). The power of the positive: Revisiting weak coherence in autism spectrum disorders. *Quarterly Journal of Experimental Psychology, 61*, 50 – 63.

Happé, F., & Frith, U. (2006). The weak coherence account: Detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 36(1),* 5–25.

Hubl, D., Bölte, S., Feineis–Matthews, S., Lanfermann, H., Federspiel, A., Strik, W., ... & Dierks, T. (2003). Functional imbalance of visual pathways indicates alternative face processing strategies in autism. *Neurology, 61(9),* 1232-1237.

Humphreys, G. W. (1998). Neural representation of objects in space: A dual coding account. *Philosophical Transactions of the Royal Society of London B: Biological Sciences, 353(1373),* 1341-1351.

Humphreys G. W., & Heinke, D. (1998). Spatial representation and selection in the brain: Neuropsychological and computational constraints. *Visual Cognition, 5(1-2),* 9-47.

Humphreys, G. W., Quinlan, P. T., & Riddoch, M. J. (1989). Grouping processes in visual search: Effects of single- and combined feature targets. *Journal of Experimental Psychology: General, 118,* 258-279.

Humphreys, G. W., & Riddoch, M. J. (1987). *To see but not to see: A case study of visual agnosia*. Psychology Press.

Humphreys, G. W. & Riddoch, M. J. 1995 Separate coding of space within and between perceptual objects: evidence from unilateral visual neglect. *Cognitive Neuropsychology, 12,* 283 - 312.

Jones, C. R., Swettenham, J., Charman, T., Marsden, A. J., Tregay, J., Baird, G., ... & Happé, F. (2011). No evidence for a fundamental visual motion processing deficit in adolescents with autism spectrum disorders. *Autism Research, 4(5),* 347-357.

Lamb, M. R., Robertson, L. C., & Knight, R. T. (1990). Component mechanisms underlying the processing of hierarchically organized patterns: inferences from patients with unilateral cortical lesions. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16(3)*, 471-483.

Martin, E. M., Pitrak, D. L., Robertson, L. C., Novak, R. M., Mullane, K. M., & Pursell, K. J. (1995). Global-local analysis in HIV-1 infection. Neuropsychology, 9(1), 102-109.

Mann, T. A., & Walker, P. (2003). Autism and a deficit in broadening the spread of visual attention. *Journal of Child Psychology and Psychiatry*, *44*(2), 274-284.

Marr, D. (1982). *Vision: A computational investigation into the human representation and processing of visual information*. New York, NY: Henry Holt and Co. Inc.

Massman, P. J., Delis, D. C., Filoteo, J. V., Butters, N., Salmon, D. P., & Demadura, T. L. (1993). Mechanisms of spatial impairment in Alzheimer's disease subgroups: Differential breakdown of directed attention to global-local stimuli. *Neuropsychology, 7(2),* 172-181.

Milne, E., Swettenham, J., Hansen, P., Campbell, R., Jeffries, H., & Plaisted, K. (2002). High motion coherence thresholds in children with autism. *Journal of Child Psychology and Psychiatry, 43(2),* 255-263.

Mottron, L., Bouvet, L., Bonnel, A., Samson, F., Burack, J. A., Dawson, M., & Heaton, P. (2013). Veridical mapping in the development of exceptional autistic abilities. *Neuroscience and Biobehavioral Reviews, 37,* 209–228.

Mottron, L., & Burack, J. (2001). Enhanced perceptual functioning in the development of autism. In J. A. Burack, T. Charman, N. Yirmiya, & P. R. Zelazo (Eds.), *The development of autism: Perspectives from theory and research* (pp. 131–148). Mahwah, NJ: Erlbaum.

Mottron, L., Dawson, M., Soulieres, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: An update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders, 36(1)*, 27–43.

O'Riordan M. A., Plaisted K. C., Driver J., & Baron-Cohen S. (2001). Superior visual search in autism. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 719–730.

Paivio, A. (1990). *Mental representations: A dual coding approach*. Oxford University Press.

Pellicano, E., & Burr, D. (2012). When the world becomes 'too real': a Bayesian explanation of autistic perception. *Trends in Cognitive Sciences*, *16(10)*, 504-510.

Pellicano, E., Gibson, L., Maybery, M., Durkin, K., & Badcock, D.R. (2005). Abnormal global processing along the dorsal visual pathway in autism: a possible mechanism for weak visuospatial coherence? *Neuropsychologia, 43,* 1044–1053.

Pellicano, E., Maybery, M., Durkin, K., & Maley, A. (2006). Multiple cognitive capabilities/deficits in children with an autism spectrum disorder: 'Weak' central coherence and its relationship to theory of mind and executive control. *Development and Psychopathology, 18*, 77–98.

Pirrone, A., Dickinson, A., Gomez, R., Stafford, T., & Milne, E. (2017). Understanding perceptual judgment in autism spectrum disorder using the drift diffusion model. *Neuropsychology, 31(2),* 173-180.

Plaisted, K., Swettenham, J., & Rees, L. (1999). Children with autism show local precedence in a divided attention task and global precedence in a selective attention task. *Journal of Child Psychology and Psychiatry, 40(5)*, 733-742.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3-25.

Riddoch, M. J., Humphreys, G. W., Akhtar, N., Allen, H., Bracewell, R. M., & Schofield, A. J. (2008). A tale of two agnosias: distinctions between form and integrative agnosia. *Cognitive Neuropsychology, 25*, 56-92.

Riddoch, M. J., & Humphreys, G. W. (1987). A case of integrative visual agnosia. *Brain, 110(6),* 1431-1462.

Rinehart, N. J., Bradshaw, J. L., Moss, S. A., Brereton, A. V., & Tonge, B. J. (2000). Atypical interference of local detail on global processing in high-functioning autism and Asperger's disorder. *Journal of Child Psychology & Psychiatry, 41*, 769–778.

Rosenberg, A., Patterson, J. S., & Angelaki, D. E. (2015). A computational perspective on autism. *Proceedings of the National Academy of Sciences, 112(30),* 9158-9165.

Saygin, A. P., Cook, J., & Blakemore, S. J. (2010). Unaffected perceptual thresholds for biological and non-biological form-from-motion perception in autism spectrum conditions. *PloS ONE, 5(10)*, e13491.

Shafai, F., Armstrong, K., Iarocci, G., & Oruc, I. (2015). Visual orientation processing in autism spectrum disorder: No sign of enhanced early cortical function. *Journal of Vision, 15(15)*, 18.

Shah, A., & Frith, U. (1983). An islet of ability in autistic children: A research note. *Journal of Child Psychology and Psychiatry, 24,* 613–620.

Shah, A., & Frith, U. (1993). Why do autistic individuals show superior performance on the block design task? *Journal of Child Psychology and Psychiatry, 34,* 1351–1364.

Simmons D. R., Robertson A. E., McKay L. S., Toal E., McAleer P., Pollick F. E. (2009). Vision in autism spectrum disorders. *Vision Research, 49,* 2705–2739.

Sinha, P., Kjelgaard, M. M., Gandhi, T. K., Tsourides, K., Cardinaux, A. L., Pantazis, D., Diamond, S. P., Held, R. M. (2014). Autism as a disorder of prediction. *Proceedings of the National Academy of Sciences, 111(42),* 15220-15225.

Smith, A. D. & Gilchrist, I. D. (2005). Within-object and between-object coding deficits in drawing production. *Cognitive Neuropsychology, 22*, 523-537.

Smith, A. D., Kenny, L., Rudnicka, A., Briscoe, J., Pellicano, E. (2016). Drawing firmer conclusions: Autistic children show no evidence of a local processing bias in a controlled copying task. *Journal of Autism and Developmental Disorders*, *46 (11)*, 3481-3492.

Sutherland, A., & Crewther, D. P. (2010). Magnocellular visual evoked potential delay with high autism spectrum quotient yields a neural mechanism for altered perception. *Brain, 133*, 2089-2097.

Treisman, A. (1988). Features and objects: the 14th Bartlett memorial lecture. *Quarterly Journal of Experimental Psychology, 40A,* 201–237.

Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12,* 97-136.

Van der Hallen, R., Evers, K., Brewaeys, K., Van den Noortgate, W., & Wagemans, J. (2015). Global processing takes time: A meta-analysis on local–global visual processing in ASD. *Psychological Bulletin, 141(3),* 549 – 573.

Wang, L., Mottron, L., Peng, D., Berthiaume, C., & Dawson, M. (2007). Local bias and local-to-global interference without global deficit: A robust finding in autism under various conditions of attention, exposure time, and visual angle. *Cognitive Neuropsychology, 24(5),* 550–574.

White, S., O'Reilly, H., & Frith, U. (2009). Big heads, small details and autism. *Neuropsychologia*, *47*(5), 1274-1281.

White, S. J., & Saldaña, D. (2011). Performance of children with autism on the Embedded Figures Test: a closer look at a popular task. *Journal of Autism and Developmental Disorders*, *41*(11), 1565-1572.

Yerys, B. E., Wallace, G. L., Harrison, B., Celano, M. J., Giedd, J. N., & Kenworthy, L. E. (2009). Set-shifting in children with autism spectrum disorders reversal shifting deficits on the Intradimensional/Extradimensional Shift Test correlate with repetitive behaviors. *Autism, 13(5),* 523-538.