What Can Pictorial Representations Reveal about the Cognitive Characteristics of Autism?

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Abstract. In this paper, we develop a cognitive account of autism centered around a reliance on pictorial representations. This Thinking in Pictures hypothesis shows significant potential for explaining many autistic behaviors. We support this hypothesis with empirical evidence from several independent behavioral and neuroimaging studies of individuals with autism, each of which shows strong bias towards visual representations and activity. We also examine three other cognitive theories of autism—Mindblindness, Weak Central Coherence, and Executive Dysfunction—and show how Thinking in Pictures provides a deeper explanation for several results typically cited in support of these theories.

Keywords: Autism; cognition; mental imagery; visual reasoning; visual representation.

1 Introduction

Ever since its discovery in the 1940s by physician Leo Kanner, autism has been defined and diagnosed by the atypical behaviors that it produces. In particular, it is a developmental condition characterized by atypical social interactions, communication skills, and patterns of behavior and interests, as described in the American Psychiatric Association's Diagnostic and Statistical Manual of Mental Disorders [1]. While the specific causes of autism are not known, an etiological framework, shown in Fig. 1, has been traced out that leads from genetic and possibly environmental factors, through neurobiological development and cognitive functioning, and finally to behavioral manifestations (adapted from [2]).

Many theories have attempted to give a cogent account of the changes in cognitive functioning that lead to the behavioral characteristics of autism. Some prominent theories include: Mindblindness, which hypothesizes that individuals with autism lack a "theory of mind," i.e. they cannot ascribe mental beliefs to other people [3]; Weak Central Coherence, which posits a bias towards local instead of global information processing [4]; and Executive Dysfunction, which suggests that individuals with autism have deficits in executive functions such as planning, mental flexibility, and inhibition [5].

However, many individuals on the autism spectrum have given introspective descriptions that are quite different from the above theories. One of the most

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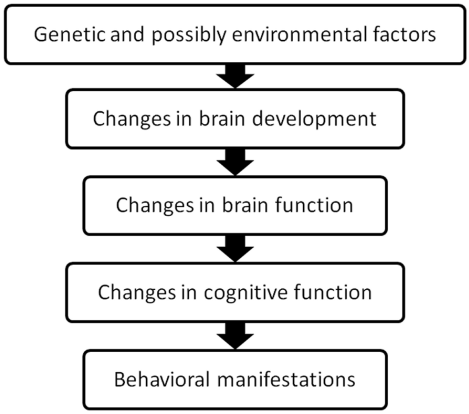

Fig. 1. Hypothesized etiology of autism, adapted from [2]

famous is the account by Temple Grandin in her book Thinking in Pictures [6]. Grandin, a high-functioning adult with autism, states that her mental representations are predominantly visual, i.e. that she thinks in pictures, and that this representational bias affects how she performs a range of cognitive operations, from conceptual categorization to the interpretation of complex social cues. Numerous other individuals with autism have also informally reported being aware of similar biases in mental representation, suggesting that Grandin is not an isolated case.

While Grandin's account of visual thinking has been primarily an introspective study, we aim to show that the Thinking in Pictures hypothesis does, in fact, represent a very powerful way to look at cognition in autism. We begin by considering what it might mean to think in pictures and how this would differ from typical cognition. Second, we present relevant empirical data from a range of literature, including behavioral and neurobiological studies of individuals with autism. Third, we examine how Thinking in Pictures relates to other cognitive theories of autism. Fourth, we examine current cognitive theories of visual thinking and identify several open issues.

2 What Does It Mean to Think in Pictures?

The literature on cognition uses numerous terms to talk about several different kinds of internal representations, e.g. modal, amodal, multimodal, digital, discrete, descriptive, verbal, linguistic, propositional, symbolic, sub-symbolic, analogical, imagistic, pictorial, depictive, visual, spatial, etc. It does not help that different authors often use a single term to mean very different things, and sometimes the same author uses the same term to mean different things. Instead of trying to define all these terms here, we specify what we mean by Thinking in Pictures using a minimal characterization that is sufficient for stating our hypothesis about autistic cognition.

Our characterization of Thinking in Pictures uses Paivio's dual-encoding theory of cognition as its starting point [7]. A knowledge representation can generally be unwound into *content* and *encoding* (i.e. form), where content pertains to *what* knowledge is being represented, and encoding refers to *how* that knowledge is represented. We define pictorial representations as having two key properties, as illustrated in Fig. 2:

1. Encoding is analogical in that it maintains a structural isomorphism between what is represented and how it is represented.
2. Content pertains to the appearance of objects, including both "what" and "where" information.

Verbal representations, in contrast, have the following properties:

1. Encoding is propositional.
2. Content can be arbitrarily assigned based on inferential needs.

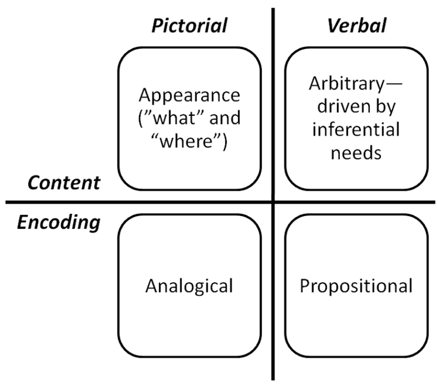

Fig. 2. Properties of content and encoding for pictorial and verbal knowledge representations

This characterization of pictorial and verbal knowledge representations imposes several interesting constraints on the types of knowledge that can be represented in each encoding and the kinds of inferences that can be drawn from each representation. Because pictorial representations are restricted to appearance-related content, it is difficult to explicitly represent abstractions such as causality, intention, or type/token relationships. Causality, for example, is at most implicit in a pictorial representation. However, these types of abstractions can easily be represented with propositions in a verbal representation. On the other hand, because pictorial representations maintain a structural correspondence between representation and content, certain inferences can be made more efficient or effective by exploiting this additional information. For instance, certain spatial inferences can be performed much more quickly using analogical representations than with propositions.

2.1 Our Hypothesis

Given the above characterization of pictorial thinking, we can now state our core hypothesis about autistic cognition more precisely:

1. Typical cognition uses both pictorial and verbal representations for different tasks.
2. Autistic cognition does not use verbal representations for typically verbal tasks.
3. For a subset of these typically verbal tasks, autistic cognition uses pictorial representations as a compensatory mechanism.
4. This difference in representation between typical and autistic cognition leads to observable effects on behavior.

Based on this Thinking in Pictures hypothesis, we expect that the limitations on content imposed by pictorial representations would lead to atypical behaviors and diminished performance on certain tasks. In Sect. 3.1, we describe how these sorts of representational limits can account for many of the characteristic behaviors of autism.

However, we also expect from our hypothesis that tasks or behaviors that can be performed pictorially would not be affected to the same extent. Furthermore, the additional inferential power lent by pictorial representations from their property of structural correspondence would lead to improved performance on tasks that exploited this information. Section 3.2 outlines several independent, empirical studies that support these expectations.

Finally, Sect. 3.3 presents results from neuroimaging studies that show a neurobiological basis for specifying a distinction between the uses of pictorial versus verbal representations in the autistic population.

2.2 Our Methodology

In addition to establishing a general consistency with existing empirical evidence (which we address in this paper), our Thinking in Pictures hypothesis suggests a specific methodology to further investigate tasks that can be performed pictorially. In particular, while current "deficit" accounts of cognition in autism can explain diminished performance on certain tasks, it is harder to explain performance across a wide range of tasks, for instance to account for the so-called "islets of ability" often observed in the autistic population.

However, the four postulates of the basic Thinking in Pictures hypothesis suggest a different methodology for classifying task performance. First, consider the spaces $\boldsymbol{P}$ and $\boldsymbol{V}$ (as illustrated in Fig. 3) of all tasks and behaviors that are typically performed using pictorial and verbal representations, respectively. Some of the tasks in $\boldsymbol{P}$ should straightaway correspond to some of the "islets of ability" seen in autism. Also, for some subset $\boldsymbol{V_1}$ of the tasks that typical cognition performs using verbal representations, individuals with autism can compensate using pictorial representations instead. If we can identify tasks in $\boldsymbol{V_1}$, then the Thinking in Pictures hypothesis should be able to make specific

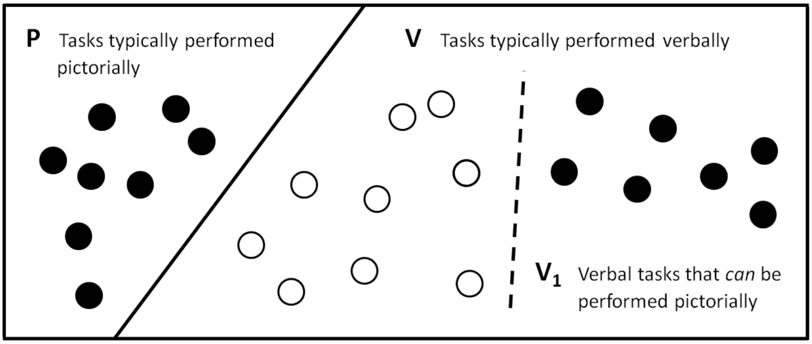

Fig. 3. Tasks typically performed pictorially and verbally, with a subset of verbal tasks that *can* be performed pictorially

predictions about how individuals with autism will perform on these tasks in comparison to typically developing individuals, based solely on the information-processing properties of pictorial versus verbal representations.

In future work, we plan to identify tasks in these subsets and use computational experiments to generate predictions based on our Thinking in Pictures hypothesis. These predictions can then be evaluated in light of real-world performance on the same tasks by individuals with autism.

3 Thinking in Pictures and Autism

The Thinking in Pictures hypothesis outlined in this paper is supported by a significant amount of existing empirical evidence. In the following three subsections, we present the results of several, independent studies that provide evidence from behavior, cognition, and neurobiology, respectively.

3.1 Behavioral Evidence

The definition of autism is centered on three areas: social interaction, communication, and stereotyped patterns of behavior and interests. Each of the following paragraphs addresses a subset of the behaviors in each area, which are listed in the DSM-IV-TR [1].

Atypical social behaviors of autism include a lack of seeking to share enjoyment with others and a lack of social or emotional reciprocity. Both of these types of behavior rely on an ability to infer the mental states of others, which is a highly abstract concept that cannot easily be represented pictorially and has been shown to be impaired in many individuals with autism [8]. Without this concept, individuals with autism would have difficulty in desiring to induce certain mental states in others, like enjoyment, and in reciprocating or even perceiving emotional or social intentions.

Communication issues in autism include the delayed development or inappropriate use of language along with deficits in imaginary play. Thinking in Pictures explicitly allows for problems in verbal language development. Regarding imaginary play, it has been shown that symbolic play in typically developing children evolves from using objects that share perceptual similarity with the target representation to objects that are perceptually dissimilar [9], suggesting a progression from play that is perceptually grounded to play that is free from perceptual constraints. Accordingly, imaginary play deficits in autism could be explained by an atypical adherence to pictorial representations during play.

Finally, autism is also characterized by stereotyped patterns of behavior and interests, such as a preoccupation with parts of objects or an adherence to nonfunctional routines. Function, as mentioned previously, is an abstract concept not well-suited to pictorial representations. Without functional interpretations, object use by children with autism could remain centered on visual features, within the sensorimotor-based frameworks of early developmental play [10]. Several studies have indeed shown less [11] or less complex [12] functional play in children with autism compared to their typically developing peers. Also, as noted previously, pictorial representations do not provide for the explicit representation of causality, which could lead to nonfunctional routines, for instance if routines were structured temporally instead of causally.

3.2 Cognitive Evidence

Memory and Access. We discuss the results of three experiments that examined the uses of pictorial versus verbal representations in individuals with autism as compared to typically developing individuals. First, in studies of word recall tasks in the typical population, the recall of short words is generally better than the recall of longer words, but this effect can be eliminated by articulatory suppression, suggesting that verbal encoding is used to some extent [13]. Furthermore, this effect is still seen if pictures are used instead of words, but only in subjects of a certain age [14]. In one study of this type of picture recall task in children [15], the pictures had either long or short labels, and subjects were asked to either remain silent or verbalize each label. As expected, the control group performed significantly better with the short labels than with the long labels, and whether they verbalized the labels had no effect. In contrast, the autism group exhibited a much smaller word-length effect overall, and the effect was smaller in the silent condition than in the verbalizing condition. These results suggest that the children with autism verbally encoded the pictures to a lesser extent than did the control group, and also that their use of verbal encodings increased when prompted to verbalize the labels.

The second experiment looked at the effects of articulatory suppression on a task-switching test [15]. Children were given a sequence of pairs of numbers to add or subtract alternately, and they either had to remain silent or to repeat “Monday” as a form of articulatory suppression (AS). The control group performed far better when they were silent than under AS. However, the autism group showed no difference between the silent and AS conditions, suggesting that they did not use verbal representations to guide their task-switching.

The third experiment looked at a word-completion task in which semantic priming was provided using either picture or word cues [16]. The control group performed similarly under both conditions, but the autism group performed much better with picture cues than word cues. This suggests that the individuals with autism were better able to retrieve verbal information through pictorial representations than through other verbal representations.

Together, results from these three experiments suggest that individuals with autism use pictorial representations in several tasks that typically recruit verbal representations. They seem to encode pictures pictorially until required to produce a verbal representation and also to rely more on pictorial representations than verbal ones for recall, task-switching, and semantic retrieval.

Classification. As discussed earlier, pictorial representations do not support the explicit formation of type/token (i.e. prototype) categories. In [17], individuals with autism were shown under a variety of tasks to exhibit fairly typical abilities in concept identification but significantly lower abilities in concept formation, which relies on the use of prototypes. Another study showed a preference in individuals with autism for categorizing objects based on physical attributes instead of on more abstract qualities, namely for sorting books by color instead of by genre as typically developing individuals did [18].

Visual Attention and Reasoning. Much empirical evidence has shown that individuals with autism are adept at certain tasks relying on pictorial modes of processing. One such task is the Embedded Figures Task (EFT), in which a small, simple shape must be found within a larger figure. Numerous studies have shown that individuals with autism are often more accurate [19] or more efficient [20] on the EFT than typically developing individuals.

Recent studies have looked at another visual search task in which a target must be found amid a group of distracters that share either shape alone (feature search) or shape or color (conjunctive search) [21][22]. Results showed that individuals with autism had significantly faster search times than typically developing individuals and, unlike the control group, had the same search times under both feature and conjunctive search conditions. Even more unusual were findings that, while typically developing individuals showed a characteristic linear increase in search time as the number of distracters increased in conjunctive search, the increase in search times for the autism group remained fairly flat.

These results suggest that individuals with autism might be using fundamentally different visual search strategies than the typical population. While the view of Thinking in Pictures presented in this paper does not explicitly propose a model for visual attention, these results could be explained by attentional strategies that are not mediated by verbal representations, which might be more efficient for certain tasks.

Finally, while many of these types of studies cast their findings as evidence for isolated skills or “islets of ability” in individuals with autism, recent research has suggested that, given the opportunity to reason pictorially, individuals with autism can exhibit significantly higher measures of general intelligence than shown on standard tests. In particular, a study conducted using groups of both children and adults with autism demonstrated that their performance on Raven's Progressive Matrices fell into dramatically higher percentile ranges than their performance on Wechsler scales, a discrepancy not seen in the typically developing control groups [23]. In fact, whereas a third of the children with autism fell into the mentally retarded range on the Wechsler scales, only 5 percent did so on the Raven's test, with a third of them scoring at the 90th percentile or higher (as compared to none in this range on the Wechsler scales). Raven's Progressive Matrices, while a pictorial test, is cited in this study as requiring inference, planning, control, and other complex abilities. This result is strongly in accord with our Thinking in Pictures hypothesis, which provides for the pictorial execution of all of these high-level reasoning processes.

3.3 Neurobiological Evidence

We discuss two neuroimaging studies using functional MRI that show neurobiological evidence for our Thinking in Pictures hypothesis. The first study looked at differences in brain activation between individuals with autism and typically developing individuals when they had to answer true/false questions about high or low imagery sentences [24]. High imagery sentences included statements like, "The number eight when rotated 90 degrees looks like a pair of eyeglasses," while low imagery sentences included statements like, "Addition, subtraction, and multiplication are all math skills." The control group showed a significant difference between the high and low imagery conditions, with the high imagery condition eliciting more activity from temporal and parietal regions associated with mental imagery as well as from inferior frontal regions associated with verbal rehearsal. In contrast, the autism group showed similar activation in both conditions, with less activity in inferior frontal language regions than the control group in the high imagery condition, and greater activity in occipital and parietal visual regions in the low imagery condition. These results suggest that individuals with autism rely on visuospatial brain regions to process both high and low imagery sentences, unlike typically developing individuals who use these areas more for high imagery sentences and use verbal areas for low imagery sentences.

The second fMRI study looked at the differences in brain activation between individuals with autism and typically developing individuals while they performed the Embedded Figures Task (EFT) which, as described earlier, is a visual search task [25]. While many brain regions showed similar activation between the two groups, the control group showed greater activation than the autism group in prefrontal cortical regions that are associated with working memory and serial search. In contrast, the autism group showed greater activation in occipito-temporal regions that represent low level visual processing and have been linked to mental imagery (and possibly motion). These results suggest a difference in high-level attentional strategy between individuals with autism and typically developing individuals while performing the EFT, with typically developing individuals recruiting a serial search strategy and individuals with autism using an imagery-based strategy.

4 Other Cognitive Theories of Autism

4.1 Mindblindness

Mindblindness hypothesizes that individuals with autism lack a "theory of mind," or ability to ascribe beliefs to other beings [3]. This limitation could lead to atypical social and communicative behaviors. The classic study used in support of this theory is the false-belief task, in which two characters (typically dolls named Sally and Ann) are shown alongside two baskets. Sally places a marble in her basket and exits the room, after which time Ann switches the marble from one basket to another. When Sally returns, the subject is asked in which basket Sally will search for her marble. Responding that Sally will look in the first basket, where she still supposes the marble to be, requires ascribing a false belief to Sally, i.e. a belief that does not match the state of the real world.

The original study [8] looked at three groups for this task: children with autism, children with Down's syndrome, and a control group. Both the Down's syndrome group (who had a lower mean verbal mental age than the autism group) and the control group (who had a lower mean physical age than the autism group) averaged percent-correct scores in the mid-80s, while the autism subjects scored only in the mid-20s.

While Mindblindness holds that theory of mind is a distinct mental mechanism [3], one can also consider representations in general. As mentioned in Sect. 2, the explicit formation of concepts like intentionality or mental states is difficult using pictorial representations. If these concepts were made accessible through pictorial representations, for instance through diagrams or metaphors, then we would expect to see improvements in theory of mind capabilities. A recent study [26] used cartoon-drawn thought-bubbles to teach children with autism about mental states. After this training, most of the children passed standard false-belief tasks that they had previously failed as well as other theory of mind tasks. However, this study did not compare training using pictorial aids versus training using verbal aids, which would have provided a more compelling case for the importance of the pictorial nature of the training.

In addition, a dissociation has been found between children with autism and typically developing children in their abilities to represent different kinds of "false" states. In [27], two groups of children were tested on false belief tasks, in which subjects had to reason about beliefs that did not match the state of the real world, and on false photograph and false map tasks, in which subjects had to reason about external visual representations that did not match the state of the real world. The control group performed well on the false belief tasks but poorly on the false photograph and false map tasks. As expected, the autism group performed poorly on the false belief tasks, but they actually outperformed controls on the photograph and map tasks, suggesting that, while impaired in understanding false beliefs, the children with autism had access to richer pictorial representations or stronger pictorial reasoning skills than the control group.

4.2 Weak Central Coherence

Weak Central Coherence hypothesizes that individuals with autism have a limited ability to integrate detail-level information into higher-level meanings, or are at least biased towards local instead of global processing [4]. This trait is presumed to account for some of the stereotyped patterns of behaviors and interests in individuals with autism. Also, superior performance on certain tasks like the EFT is explained with the rationale that in individuals with autism, reasoning is unhindered by potentially distracting gestalt perceptions.

However, as described above, these results can also be explained under the Thinking in Pictures hypothesis by enhanced visual attentional strategies that exploit the properties of pictorial representations. Other evidence for Weak Central Coherence often includes verbal tests, such as deficits in homograph pronunciation in sentence contexts (as cited in [4]). These tests, while putatively measuring local, word-level versus higher-order, sentence-level processing, can also be interpreted as tests of verbal reasoning skills, which would be impaired under the Thinking in Pictures account.

4.3 Executive Dysfunction

The final cognitive theory of autism that we discuss is Executive Dysfunction, which hypothesizes that individuals with autism have limitations in their executive functions such as planning, mental flexibility, and inhibition, among others [5]. Many studies cited in support of the Executive Dysfunction theory include verbal tests of memory and inhibition and sorting-based tests of mental flexibility. However, in the Thinking in Pictures account, we would expect to see atypical performance in these verbal and category-dependent areas.

Furthermore, as cited earlier, a recent study [23] showed that both children and adults with autism performed considerably better on Raven's Progressive Matrices than on Wechsler scales of intelligence. Raven's Progressive Matrices are deemed to test fluid intelligence, which includes "coordinated executive function, attentional control, and working memory" (as described by that study). Therefore, these results do not seem to indicate a general executive dysfunction in individuals with autism.

One possible explanation, using our Thinking in Pictures hypothesis, is that individuals with autism have deficits in executive functions that are verbally mediated but not in executive functions that are (or *can* be) pictorially mediated. This view is consistent with current models of working memory that propose two distinct storage components—the phonological loop and the visuospatial sketchpad—that operate under a central executive [28]. This model is discussed in more detail in Sect. 5.1.

5 Cognitive Theories of Pictorial Representations

In this section, we present interpretations of our Thinking in Pictures hypothesis using three existing theories of pictorial and verbal representations. In particular, we look at how each theory would formulate 1) pictorial representations, 2) verbal representations, and 3) differences in inferential power between the two.

5.1 Working Memory

In [28], Baddeley summarizes his three-component model of working memory, which consists of a central executive and two memory buffers: the phonological loop and the visuospatial sketchpad.

1. The visuospatial sketchpad is the short-term storage system for pictorial representations. Subsystems for visual versus spatial representations are differentiated, as suggested by behavioral dissociations on psychological tasks on visual (pattern) span and spatial span. This distinction is also linked to dynamic (spatial) versus static (pattern) representations.
2. The phonological loop is the short-term storage system for acoustic and phonological representations. Linguistic representations used in the phonological loop correspond to our definition of verbal representations, although other, purely acoustic representations do not.
3. Because the two buffers are presumed to comprise distinct neural subsystems, one could differentiate 1) operations performed within each representational buffer as well as 2) tasks for which each buffer is typically recruited. In particular, because quantitative properties of each buffer have been identified through numerous behavioral studies, the presence (or absence) of these properties could shed light on whether a particular buffer is, in fact, being recruited. The breakdown of standard predictions (whether for augmented or diminished performance) is generally taken to imply that another, non-standard strategy is being used on a given task.

5.2 Mental Imagery

In [29], Kosslyn describes a model of mental imagery, which is the recreation of an experience that resembles actually perceiving an object or an event.

1. Long-term memory contains two kinds of deep knowledge representations: analogical and propositional. Analogical representations are skeletal, individual, and hierarchically organized. Propositional representations capture information about categories and qualitative spatial locations and relations. Mental images are recreated in the short-term storage system through the retrieval and combination of both analogical and propositional representations from long-term memory.
2. Kosslyn does not directly provide an account of verbal representations in short-term memory. However, since part of long-term memory is formulated as propositions, we interpret using verbal representations as operating directly on these representations.

3. The construction of mental images enables a range of inferences such as finding an object in an image, changing image resolution, rotation, etc. Kosslyn does not, however, directly address the issue of different kinds of inferences being drawn by different kinds of representations.

5.3 Computational Imagery

In [30], Glasgow and Papadias present a computational model of imagery. Although not a cognitive theory per se, their computational model makes more precise and detailed commitments that are generally consistent with Kosslyn's model of mental imagery.

1. Pictorial representations are instantiated using two working-memory buffers: one for visual information contained in a 3D occupancy array, and another for spatial information contained in a 3D symbolic array. While the visual representation is purely pictorial and depictive, the symbolic array uses a combination of pictorial and verbal information and is therefore classed as descriptive, because elements in the array are words linked to semantic long-term memory, which is represented using propositions.
2. Glasgow and Papadias do not directly provide for the use of verbal representations in working memory. However, they do formulate long-term memory using propositions. Within this scheme, we interpret using verbal representations as operating directly on these propositional representations.
3. Although the information in each representation may be derivable from the other, "the representations are not computationally equivalent" because inferencing will operate at different efficiencies within each. However, in this formulation, the only difference between using each type of representation will be efficiency; Glasgow and Papadias do not allow for any differences in the actual inferences that can be made, because they consider only visuospatial content in their verbal representations.

5.4 Perceptual Symbol Systems

In [31], Barsalou presents a case for perceptually grounded representations in cognition. Perceptual symbols are set up in contrast to amodal symbols (e.g. propositions), which are defined as being "nonperceptual" and arbitrary, in that the symbol does not bear any structural relation to what it represents.

1. Pictorial representations are easy to formulate in the perceptual symbol system framework: they are just representations that correspond to the visual perceptual modality. Barsalou does not separate visual from spatial knowledge; we can assume that any such distinctions would match the underlying neural architecture, since perceptual symbols in this scheme are instantiated in the neural correlates of the actual perceptual events that they represent.
2. Barsalou talks about verbal representations in long term memory as consisting of "a schematic memory of a perceived event, where the perceived event is a spoken or a written word." How these word memories function as

verbal representations is through becoming "associated with simulators for the entities and events to which they refer." Presumably these "entities and events" are other perceptual symbols (e.g. visual, olfactory, emotional, etc.) that represent perceptions of things in the world.
3. Barsalou does not directly address the types of inferences that might be carried out in each type of representation. In general, the operations on perceptual symbols use the functionality of a simulator for each symbol. One would have to define classes of simulators for each type of representation in order to make predictions about specific inferences.

5.5 Open Issues

These cognitive theories raise several issues for our account of autistic cognition:

– Where does the change in representation between typical cognition and autistic cognition occur—long term memory or working memory or both?
– Why do individuals with autism use pictorial representations? Is it a deficit in verbal subsystems? A strength in pictorial subsystems? Or something else altogether?
– Can individuals with autism recruit verbal subsystems at all for these tasks? I.e., is it an actual deficit or just a bias that can be overcome by increased attention and/or training?
– Is autistic pictorial cognition the same as typical pictorial cognition, or is it fundamentally different?

6 Conclusion

In this paper, we have developed the Thinking in Pictures hypothesis about cognition in autism. At the minimum, behavioral, cognitive, and neuroimaging evidence suggests that Thinking in Pictures is a cogent alternative explanation of autistic cognition, alongside current accounts. We posit further that Thinking in Pictures has significant strengths not found in existing theories, both in terms of its explanatory breadth regarding the behaviors of autism as well as the depth to which it can account for many different pieces of empirical data.

Of course, the range of autistic behaviors that any of these theories, including Thinking in Pictures, can explain of and by itself remains an open issue, as does the question of whether a theory might apply more to one particular subset of the autistic population than another. It is possible that a full cognitive account of autism requires a combination of theories or the identification of specific subgroups of individuals on the autism spectrum beyond what has already been established in the literature.

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