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# How Thinking in Pictures Can Explain Many Characteristic Behaviors of Autism

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***Abstract*—In this paper, we develop a cognitive account of autism centered around a reliance on pictorial representations. First, we put forth the hypothesis that individuals with autism "think in pictures," and we discuss supporting empirical evidence from several independent behavioral and neuroimaging studies, each of which shows a strong bias towards visual representations and activity. Second, we show that Thinking in Pictures has significant potential for explaining many behavioral characteristics of autism, as they are defined by the *DSM-IV-TR* diagnostic criteria.**

## I. Introduction

Autism 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* (*DSM-IV-TR*) [1]. While the 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 characterize 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 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.

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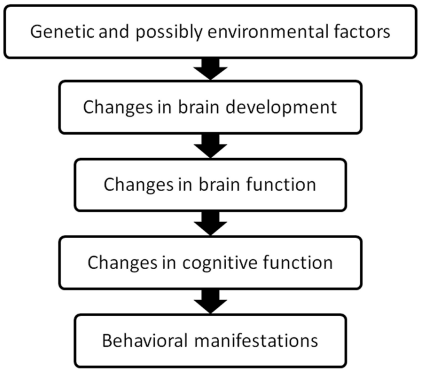


Fig. 1. Hypothesized etiology of autism, adapted from [2].

While Grandin's account of visual thinking has been primarily an introspective study, we aim to show that Thinking in Pictures does, in fact, represent a very powerful way to look at cognition in autism. In particular, we set forth two hypotheses regarding this view:

1) Many individuals with autism "think in pictures."
2) Thinking in Pictures causes (from a cognitive standpoint) many autistic behaviors.

In this paper, we examine each of these hypotheses in detail, first providing definitions and specifying an experimental methodology (Sections II and IV), and then presenting preliminary supporting evidence (Sections III and V).

## II. What Does It Mean to Think in Pictures?

The literature on cognition uses numerous terms to talk about different kinds of internal representations (e.g. modal, amodal, digital, analog, descriptive, depictive, linguistic, propositional, symbolic, imagistic, etc.). Unfortunately, the same term is often used to mean very different things. Instead of trying to address this vast vocabulary here, we specify what we mean by Thinking in Pictures using a minimal characterization that is sufficient for stating our hypothesis about autistic cognition.

We use Paivio's dual-encoding theory of cognition as a starting point [7]. A knowledge representation can generally be unwound into *content* and *encoding*, where content pertains

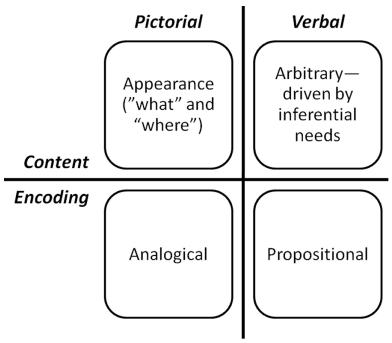


Fig. 2. Content and encoding for pictorial and verbal representations.

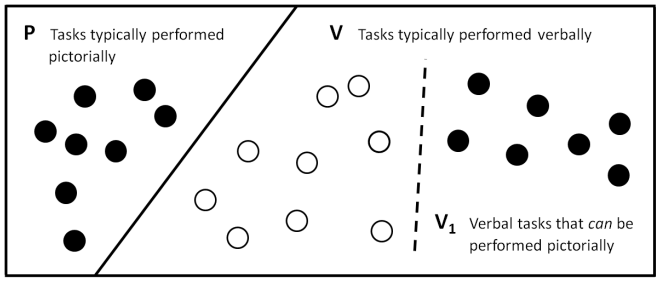


Fig. 3. Tasks typically performed pictorially and verbally, with a subset of verbal tasks that *can* be performed pictorially.

to *what* knowledge is being represented, and encoding refers to *how* it 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 properties:

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

These characterizations impose interesting constraints on the types of knowledge and inferences supported by 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.

### A. Hypothesis #1

Given these characterizations, we now state our first 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 to compensate.
4) This difference in representation between typical and autistic cognition leads to observable effects on behavior.

Based on this hypothesis, we expect that the limitations on content imposed by pictorial representations would lead to atypical behaviors and diminished performance on certain tasks. However, we also expect 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 could lead to improved performance on tasks that exploited this information.

### B. Our Methodology for Hypothesis #1

In addition to establishing a general consistency with existing empirical evidence, our first 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 so-called "islets of ability." However, consider the spaces $\mathbf{P}$ and $\mathbf{V}$ (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 $\mathbf{P}$ should straightaway correspond to some of the "islets of ability" seen in autism. Also, for some subset $\mathbf{V_1}$ 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 $\mathbf{V_1}$, then the first Thinking in Pictures hypothesis should be able to make specific 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 this hypothesis. These predictions can then be evaluated using real-world experiments.

## III. Evidence for Thinking in Pictures as a Characterization of Cognition in Autism

### A. Cognitive Evidence

*1) Memory and Access:* We discuss the results of three experiments that examined the uses of pictorial versus verbal representations. First, in studies of word recall tasks in the typical population, the recall of short words is generally better than of longer words, but this effect can be eliminated by articulatory suppression, suggesting that verbal encoding is

used to some extent [8]. Furthermore, this effect is still seen (in subjects of a certain age) if pictures are used instead of words [9]. In one study of this type of picture recall task in children [10], the pictures had long or short labels, and subjects were asked to remain silent or to verbalize each label. As expected, the control group performed significantly better with short 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 greater 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 [10]. Children were given a sequence of pairs of numbers to add or subtract alternately, and they had to remain silent or to repeat "Monday" as 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 [11]. 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.

*2) Classification:* As discussed earlier, pictorial representations do not support the explicit formation of type/token (i.e. prototype) categories. In [12], individuals with autism were shown under various tasks to exhibit fairly typical abilities in concept identification but 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 as typically developing individuals did [13].

*3) Visual Attention and Reasoning:* Much empirical evidence has shown that individuals with autism are adept at certain pictorial tasks, such as the Embedded Figures Task (EFT). Numerous studies have shown that individuals with autism are often more accurate [14] or more efficient [15] 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) [16] [17]. 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 take advantage of the structural correspondence property of pictorial representations or are not mediated by verbal representations, which could prove more efficient for certain tasks.

Finally, while many of these types of studies cast their findings as evidence for "islets of ability" in 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 [18]. 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 this Thinking in Pictures hypothesis, which provides for the pictorial execution of high-level reasoning processes.

### *B. Neurobiological Evidence*

We discuss two neuroimaging studies using functional MRI that support this Thinking in Pictures hypothesis. The first study looked at brain activation in individuals with autism and typically developing individuals when they had to answer true/false questions about high or low imagery sentences [19]. 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 individuals with autism and typically developing individuals while they performed

the Embedded Figures Task [20]. While many brain regions showed similar activation between the groups, controls showed greater activation than the autism group in prefrontal cortical regions associated with working memory and serial search. In contrast, the autism group showed greater activation in occipito-temporal regions that represent 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 on the EFT, with typically developing individuals recruiting a serial search strategy and individuals with autism using an imagery-based strategy.

## IV. What Does It Mean to Cause Autistic Behavior?

Ever since its discovery in the 1940s by Leo Kanner, autism has been defined and diagnosed by the atypical behaviors that it produces. In particular, the current diagnostic criteria for autism given in the *DSM-IV-TR* [1] specify impairments in social interaction, communication, and patterns of behavior or interests, along with a specific age of onset and stipulations for differential diagnoses. These criteria are shown in Table I.

However, because the diagnostic criteria are based on empirical observations, not all individuals with autism exhibit all of these criteria, and the specific behaviors used to fulfill a particular criterion can vary considerably. Also, in addition to similar criteria for the other pervasive developmental disorders (e.g. Asperger's and PDD-NOS), there are many comorbid conditions that can occur alongside autism (such as sensory sensitivity issues or seizure disorders), increasing the diversity of presentations in autism [21]. And finally, specific behaviors occur within a developmental framework that includes changing behavioral patterns over time.

Given these considerations, it is important to remember that these criteria represent an attempt not to fully describe autism but rather to describe those behaviors that best differentiate autism from other conditions, with the specific goal of effecting a diagnosis in a clinical, observational setting [21]. In particular, while the *DSM* criteria have changed significantly over time, the central "triad" of social, communicative, and patterns-of-behavior impairments has remained autism's most salient feature. Even in his original 1943 work, Leo Kanner described his case studies with a focus on social interaction and communication impairments along with atypical adherence to routines and fixation with objects [22].

### A. Hypothesis #2

Even though the behavioral criteria shown in Table I do not characterize autism completely or apply uniformly to all diagnosed individuals, we can use them as a starting point for developing causal explanations of autistic behavior. More specifically, for a cognitive theory to form a *causal* link in the etiology shown in Fig. 1 (as opposed to a theory that merely *characterizes* the cognition of individuals with autism), the theory should account for the specific classes of behaviors listed in Table I. Using this approach, we can state our second hypothesis regarding autistic cognition as follows:

1) Thinking in Pictures leads to many autistic behaviors listed as diagnostic criteria in the *DSM-IV-TR*.

TABLE I
*DSM-IV-TR* DIAGNOSTIC CRITERIA FOR "AUTISTIC DISORDER" [1]

**A) A total of six (or more) items from (1), (2), and (3), with at least two from (1), and one each from (2) and (3):**

(1) Qualitative impairment in social interaction, as manifested by at least two of the following:

a) marked impairment in the use of multiple nonverbal behaviors such as eye-to-eye gaze, facial expression, body postures, and gestures to regulate social interaction
b) failure to develop peer relationships appropriate to developmental level
c) a lack of spontaneous seeking to share enjoyment, interests, or achievements with other people (e.g., by a lack of showing, bringing, or pointing out objects of interest)
d) lack of social or emotional reciprocity

(2) Qualitative impairments in communication as manifested by at least one of the following:

1) delay in, or total lack of, the development of spoken language (not accompanied by an attempt to compensate through alternative modes of communication such as gesture or mime)
2) in individuals with adequate speech, marked impairment in the ability to initiate or sustain a conversation with others
3) stereotyped and repetitive use of language or idiosyncratic language
4) lack of varied, spontaneous make-believe play or social imitative play appropriate to developmental level

(3) Restricted, repetitive, and stereotyped patterns of behavior, interests, and activities, as manifested by at least one of the following:

1) encompassing preoccupation with one or more stereotyped and restricted patterns of interest that is abnormal either in intensity or focus
2) apparently inflexible adherence to specific, nonfunctional routines or rituals
3) stereotyped and repetitive motor mannerisms (e.g., hand or finger flapping or twisting, or complex whole-body movements)
4) persistent preoccupation with parts of objects

**B) Delays or abnormal functioning in at least one of the following areas, with onset prior to age 3 years: (1) social interaction, (2) language as used in social communication, or (3) symbolic or imaginative play.**

**C) The disturbance is not better accounted for by Rett's Disorder or Childhood Disintegrative Disorder.**

### B. Our Methodology for Hypothesis #2

While it is often hard to provide empirical support for a particular cognitive theory, it is even more difficult to tie cognitive processes to specific everyday behaviors that they might generate. Simply proposing a causal linkage is not enough. Instead, some specific, *testable* claims must be generated that uniquely point to the cognitive theory in question.

To do this, we first consider the space of all tasks/behaviors, as was illustrated in Fig. 3. We would expect that the typical counterparts of each behavior expressed in the *DSM-IV-TR* diagnostic criteria for autism would fall within the space

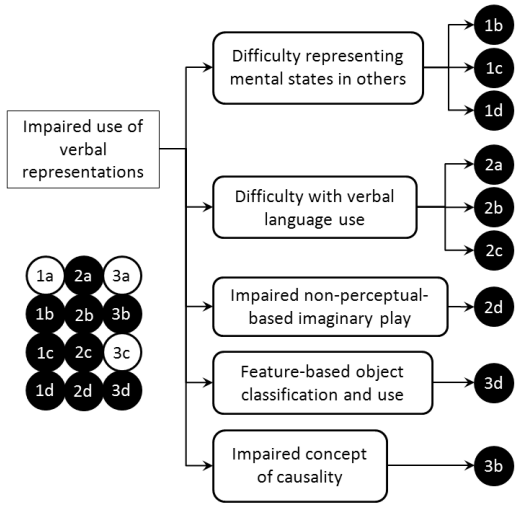


Fig. 4. Mechanisms by which the first Thinking in Pictures hypothesis can lead to autistic behaviors listed in the *DSM-IV-TR* diagnostic criteria.

V of behaviors that are typically performed using verbal representations. So, using developmental theories of typically developing individuals, we can ascertain whether this in fact holds true for each behavior. Then, substituting pictorial for verbal representations may suggest a corresponding pictorial mechanism that shows how Thinking in Pictures causes this atypical behavior in autism.

The second step of the methodology is to generate testable claims based on each mechanism. For example, the Mindblindness theory of autism, which posits that many of the atypical social interactions in autism are caused by an inability to ascribe beliefs to other people, has anchored itself on the classic Sally-and-Ann and Smarties false belief tasks. Similar tasks can be devised to highlight the roles of pictorial and verbal representations in components of cognitive processing that are deemed necessary for each behavior.

## V. Thinking in Pictures and the *DSM-IV-TR* Diagnostic Criteria

In this section, we look at some general mechanisms by which the first Thinking in Pictures hypothesis can lead to many of the behaviors of autism represented by the *DSM-IV-TR* diagnostic criteria. We leave for future work a more rigorous treatment of the above methodology. Fig. 4 shows a summary of the general mechanisms proposed in this section, along with their related diagnostic criteria.

### *A. Social Issues*

Atypical social behaviors of autism include a failure to develop peer relationships, a lack of seeking to share enjoyment with others, and a lack of social or emotional reciprocity (1b, 1c, and 1d). In the Mindblindness theory of autism [3], these social difficulties have been ascribed to an inability to conceptualize mental beliefs in other people, and significant empirical evidence has indicated impaired theory-of-mind abilities in individuals with autism through tasks like the false belief test.

However, whereas Mindblindness holds that theory of mind is a distinct mental mechanism, 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 [23] 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.

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 [24], two groups of children were tested on false belief tasks and on false photograph and false map tasks. The control group performed well on the belief tasks but poorly on the photograph and map tasks. As expected, the autism group performed poorly on the belief tasks, but they actually outperformed controls on the photograph and map tasks. These results suggest that children use distinct conceptual structures to represent false beliefs versus complex pictorial information, and that the children with autism had access to these rich pictorial structures.

### *B. Communication*

Thinking in Pictures explicitly allows for problems in verbal language development (2a). Other language issues, such as the inability to initiate or sustain conversations (2b) and the idiosyncratic use of language (2c) have been posited, in the Executive Dysfunction theory of autism, to stem from deficits in generativity, among other general executive function impairments [25]. However, as cited earlier, a recent study [18] 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 Thinking in Pictures is that individuals with autism have deficits in executive functions that are verbally mediated but not in those 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 [26]. In particular, measures of generativity have been correlated with verbal language abilities in individuals with autism and other language-specific conditions [27].

Finally, regarding difficulties with imaginary play (2d), 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 [28], suggesting a progression from play that is perceptually grounded to play that is free from

perceptual constraints. Also, symbolic play in children with autism has been linked to language abilities [29]. Accordingly, imaginary play deficits in autism could be explained by difficulties in verbally mediated symbolic play, alongside (or leading to) a focus on pictorial object characteristics.

### C. Stereotyped Patterns of Behavior

Autism is also characterized by stereotyped patterns of behavior, such as a preoccupation with parts of objects (3d) or an adherence to nonfunctional routines (3b). 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 [30]. Several studies have indeed shown less [31] or less complex [32] 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.

## VI. Conclusion

We have developed two Thinking in Pictures hypotheses about cognition in autism. At the minimum, cognitive and neuroimaging evidence suggests that Thinking in Pictures gives a cogent characterization of autistic cognition, alongside other theories. We posit further that Thinking in Pictures has significant potential as a causal description of autism, both in terms of its explanatory breadth regarding the behaviors listed in the *DSM-IV-TR* 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 a subset of the autistic population. 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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