Understanding responses of individuals with ASD in syllogistic and decision-making tasks: A formal study
(Short paper in the position paper category)

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Abstract. Recent studies have shown that in some reasoning tasks people with Autism Spectrum Disorder perform better than typically developing people. The present note gives a brief comparison of two such tasks, namely a syllogistic task and a decision-making task, identifying the common structure as well as differences. In the terminology of David Marr's three levels of cognitive systems, the tasks show commonalities on the computational level in terms of the effect of contextual stimuli, though an in-depth analysis of such contexts provides certain distinguishing features in the algorithmic level. We also make some general remarks on our approach.

1 Introduction

It is well-known from the vast psychological and psychiatric literature on Autism Spectrum Disorder[3] (ASD) that children with ASD have a limited or delayed capacity to respond correctly to certain psychological reasoning tests such as false-belief tasks. In other words, on such tests, children with ASD perform less well than children with a typical development (TD). However, it turns out that in some other reasoning tasks, people with ASD perform not *worse*, but *better*, than typicals, thus, showing that ASD is not in all respects a "disability", a view that was put forward by Simon Baron-Cohen [2] two decades ago. During the last few years, several new empirical studies have emerged where individuals with ASD perform better than typical individuals, thus supporting Baron-Cohen's view.

In [5], Farmer et al. investigate adult's performance in a decision task where the subject has to choose between pairs of consumer products that are presented with a third, less desirable decoy product. According to conventional economic theory, a consumer's choice of one product over another should be independent of whether there is a third option. To quote the paper, "If one prefers salmon to steak, this should not change just because frogs' legs are added to the menu". Farmer et al. demonstrate that the tendency to violate this norm is reduced among individuals with ASD, thus, in this sense, they are more rational than typical individuals. They found a similar difference between the two groups of people drawn from the general population, classified in accordance with their levels of autistic-like traits, measured in terms of the self-report questionnaire called the Autism-Spectrum Quotient (AQ).

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[3] Autism Spectrum Disorder is a psychiatric disorder with the following diagnostic criteria: 1. Persistent deficits in social communication and social interaction. 2. Restricted, repetitive patterns of behavior, interests, or activities. For details, see *Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (DSM-V)*, published by the American Psychiatric Association.

A similar example can be found in [9], where Lewton et al. compare the ability to do syllogistic reasoning in the general population with individuals showing autistic-like traits which are measured in terms of the AQ-score. Some syllogisms are consistent with reality: *All birds have feathers. Robins are birds. Therefore robins have feathers*, but others are not: *All mammals walk. Whales are mammals. Therefore whales walk.* Both of these syllogisms are valid, that is, the conclusion follows logically from the premises, in fact, they have exactly the same logical structure, but the validity is more difficult to detect in the second syllogism because the correct answer is inconsistent with reality. Thus, prior knowledge of reality can affect the judgement of validity, and the study in [9] shows that there is a negative correlation between this reasoning bias and the AQ-score, thus, the more autistic-like a person is, the better the person is to judge syllogisms without being affected by irrelevant prior knowledge of reality.

Now, to the best of our knowledge, there are no systematic and theoretical studies of the commonalities between the psychological tasks where individuals with ASD perform better than typical individuals, as reported in [5, 9]. It is the goal of the present paper to investigate this question–an interdisciplinary enterprise requiring insights from both logic and economic theory. Such an investigation will help us in providing a better understanding of the capabilities of the individuals with ASD, which in turn might help in accommodating a better work environment for them. A common feature of the above mentioned tasks seems to be that they require an ability to disregard irrelevant contextual information, but this is a very informal verbal description. We will aim at a more formal and precise analysis, identifying a common structure, inspired by other works aiming at identifying a common logical structure in superficially different reasoning tasks.[4] As a tool to analyze the tasks in question, we make use of David Marr's levels of analysis of cognitive systems [10]: Any task computed by a cognitive system must be analyzed at the following three levels of explanation (in order of decreasing abstraction):

Computational level: Identification of the goal and of the information-processing task as an input–output function;

Algorithmic level: Specification of an algorithm which computes the function;

Implementational level Physical or neural implementation of the algorithm.

Analogous levels of analysis can be found in several other works of cognitive science, e.g., see the overview in [14], pages 9–12. For this work, we shall focus on the computational and algorithmic levels.

2 The syllogistic task

In this section, we analyze the performances in the syllogistic tasks as investigated in [9] on both computational and algorithmic levels.

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[4] In particular, in [3] it is demonstrated that two seemingly dissimilar reasoning tasks, namely two different versions of a false-belief task called the Smarties task, have exactly the same underlying logical structure. Similarly, in [4] it is demonstrated that four second-order false-belief tasks share a certain logical structure, but they are also distinct in a systematic way. We remark that such a strategy was also pursued in the book [15], where it was shown that a false-belief task and what is called the box task have a logical structure similar to a third task called the suppression task.

2.1 Computational level analysis (syllogistic task)

Four different types of syllogisms are considered in [9]. The two syllogisms described in the introduction were of the respective types of valid-believable and valid-unbelievable (this terminology should be self-explanatory). But there are also the types invalid-believable and invalid-unbelievable. An example of an invalid but believable syllogism is: *All flowers need water. Roses need water. Therefore Roses are flowers*. An invalid and unbelievable syllogism with exactly the same structure is: *All insects need oxygen. Mice need oxygen. Therefore mice are insects*.

In [9] each subject has to judge four congruent syllogisms (valid-believable and invalid-unbelievable) as well as four incongruent ones (invalid-believable and valid-unbelievable). A subject scores 1 point for each correct judgement. So there is a 0-4 scale for congruent syllogisms and 0-4 for incongruent ones. A belief bias occurred when there is a decrease in accuracy for incongruent problems (valid-unbelievable and believable-invalid) relative to congruent problems (valid-believable, invalid-unbelievable). Such a bias is calculated by subtracting the score for incongruent syllogisms from that of congruent ones, resulting in a possible score from -4 to 4.

The study reports a number of correlation results, in particular, the correlation between AQ and belief bias was -0.39 (with p-value less than 0.001). The AQ-congruent correlation was -0.11 but not significant, whereas the AQ-incongruent correlation was 0.40 (also with p-value less than 0.001). Thus, the congruent and incongruent variables measure different underlying cognitive abilities, only the latter is associated with AQ.

What does it precisely mean that a subject is able to judge a syllogism without bias, that is, without involving irrelevant contextual information? We assume that the validity of syllogisms are defined in the usual manner as in first-order logic in terms of first-order models $\mathcal{M}$. This defines a function *valid* which maps syllogisms to truth-values. This function formalizes the normatively correct judgement of syllogisms.

Now, a subject's judgement of a syllogism takes place in a specific context, that is, in a specific state of affairs, namely the actual state of affairs, where for example *Robins have feathers* is true, but *Whales walk* is false. Such a state of affairs is formalized by a model. This means that a subject's judgement of syllogisms in a context can be modeled by a function *believable* similar to the function *valid*, but with an extra parameter, representing a context. Thus, the function *believable* maps a pair consisting of a syllogism and a model to a truth-value, and the requirement of context-independence can be formulated as

$$(1) \qquad believable(S, \mathcal{M}_1) = believable(S, \mathcal{M}_2)$$

for any syllogism S and any models $\mathcal{M}_1$ and $\mathcal{M}_2$. A stronger requirement than the independence of context is the notion of correctness, that is,

$$(2) \qquad believable(S, \mathcal{M}) = valid(\mathcal{M})$$

for any syllogism S and any model $\mathcal{M}$. Note that this is a strictly stronger requirement, for example, a *believable* function that always gives the incorrect answer would be independent of contexts. We note here that we would not find a similar requirement in case of the decision task we discuss later.

2.2 Algorithmic level analysis (syllogistic task)

In what follows we shall describe some theoretical explanations of belief bias in syllogistic reasoning, based on the work done in [8]. These explanations have the form of algorithms, where bias arises at one of the three different stages in the reasoning process: during input, processing, or output (cf. see [8], page 852). Given the algorithmic character of the explanations, we are situated at the second of Marr's three levels, where an algorithm computes the input-output function specified at the top level. We give particular attention to the reasoning process that takes place when incongruent syllogisms are judged, that is when logic and belief conflict.

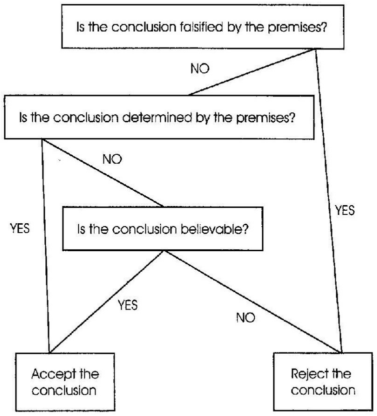

Fig. 1. The misinterpreted necessity model, taken from [8].

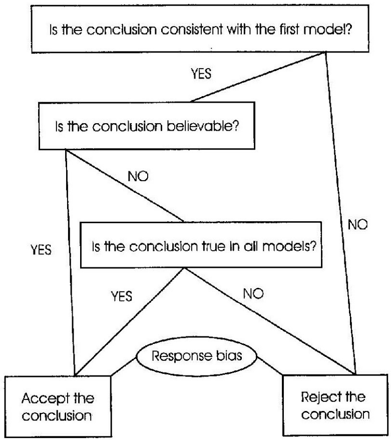

Fig. 2. An account by mental models, taken from [8].

One of the algorithms described in [8] is the *misinterpreted necessity model*, which is described by the flowchart-like diagram in Figure 1. A feature of this algorithm is that the logically correct answer is guaranteed if the conclusion follows from the premises or if the conclusion is falsified by the premises (called *determinately invalid*). If none of these two conditions are satisfied, that is, if some models of the premises falsify the conclusion and some models verify it (called *indeterminately invalid*), then the output of the algorithm is decided by the conclusion's believability. Thus, the logically correct answer is guaranteed for any syllogism that either is valid or determinately invalid. Note that the bias here takes effect *after* the logical reasoning process. According to Klauer et al. [8], the bias in this model is due to the subject's misunderstanding of what it means to say a conclusion not following from the premises, namely that it is sufficient that the conclusion is falsified by *some* models of the premises, not necessarily *all* such models.

Earlier we discussed the invalid "rose" and "mice" syllogisms, which have exactly the same logical structure. Since syllogisms with this structure have models of the premises that verify the conclusion (the "rose" case) as well as models that falsify it (the "mice" case), they are indeterminately invalid. Thus, in these syllogisms, the response of the misinterpreted necessity model is decided by the believability of the conclusion, so in the "rose" syllogism, the response would incorrectly be "valid", but in the "mice" syllogism, the response would correctly be "invalid" (but for the wrong reason).

In [8], Klauer et al. also give an account of the belief bias based on the "mental models" school in the psychology of reasoning, according to which the mechanism underlying human reasoning is the construction of models, [7]. An account by mental models is shown in Figure 2. The first step of this algorithm is to build an initial model of the premises of the syllogism under investigation, which is followed by an evaluation of the conclusion in the model in question. If the conclusion comes out as true, but it is not believable, this triggers the generation of further models of the premises, as indicated in the figure. Note that like in the misinterpreted necessity model, the logically correct answer is guaranteed for any syllogism that either is valid or determinately invalid. But if a syllogism is indeterminately invalid, then the answer becomes incorrect if and only if the conclusion is true in the initial model and also believable, hence, the selection of initial model matters. Note that the bias here takes effect *during* the reasoning process.

3 The decision task

We now analyze the performances in a decision task of choosing between pairs of consumer products in the presence of a third less desirable decoy product, investigated in [5]. We investigate the task on computational as well as algorithmic levels.

3.1 Computational level analysis (decision task)

In [5], Farmer et al. investigate whether individuals with ASD show reduced sensitivity to contextual stimuli when exposed to a decision-making situation where they had to make choices between pairs of consumer products that are presented with a third, less desirable decoy option. In a choice set, a decoy option is usually considered as an asymmetrically dominated alternative which is dominated by one of the choice alternatives but not by the other, i.e., based on the preference determining attributes, it is completely dominated by (i.e., inferior to) one option (target) and only partially dominated by the other (competitor). The choice task included participants to see 10 pairs of products (e.g., USB sticks); the products in each pair differed on two dimensions (in the case of USB sticks, storage capacity, and longevity). Each pair was presented twice, once with a decoy that targeted one product and once with a decoy that targeted the other. According to the conventional economic theory, any rational individual when exposed to such a situation should show a consistent preference behavior as the individual's preference between two items should be independent of the 'decoy' options on offer.

In theory, the rational decision-makers are expected not to show sensitivity to context stimuli and be more consistent in their choices when they had to make choices in the situation mentioned above in the presence of a decoy option. Choice consistency should be the norm in this case. More formally, we can consider a choice function which returns the chosen item from the finite tuple of possible choices and the requirement for context-independence is given by:

$$(3) \quad \mathit{Choice}(\mathit{Product}_1, \mathit{Product}_2, \mathit{Decoy}_1) = \mathit{Choice}(\mathit{Product}_1, \mathit{Product}_2, \mathit{Decoy}_2)$$

Note that this is analogous to the requirement on the judgements of syllogisms that we called context-independence (requirement (1) on a *believable* function). On the other hand, there is no requirement similar to the correctness of the *believable* function (requirement (2) on the function).

In contrast to the theoretical understanding, it was observed in [5] that the choices of the general participants (control group) were heavily influenced by the composition of the choice set. Rather than being based on an independent assessment, the attractiveness of a given option relied upon on how the individual compared it with the other values that were simultaneously present (attraction effect). But this tendency was quite reduced for individuals with ASD. Thus, they showed reduced sensitivity to contextual stimuli, indicating that their choices were more consistent and conventionally rational.

In general, the individuals with ASD made fewer context-induced preference reversals making them ‘rational decision-makers’. The reduced context effect in people with ASD might be a manifestation of their reduced understanding of, or concern for, the likely beliefs and appraisals of others. Thus, the choices of individuals with ASD have a better chance to satisfy the norm given by (3) than typical individuals [2].

3.2 Algorithmic level analysis (decision task)

We now provide an algorithmic explanation of the attraction effect bias that is visible in context-dependent decision tasks [5]. To this end, we consider dimensional weight models as discussed in [16, 1], where the authors mention how the difference in dimensional (attribute) weights are highly dependent on the similarity relationship among the items. The more similar a set of items is on one attribute the easier it is to notice discrepancies on their other attribute (for both target and decoy items) so that the observed discrepancies on a given dimension increase the corresponding weight. Thus, once the decision-maker (DM) is able to determine the important dimension it then goes on to compare the three items (target, decoy, and competitor) on that dimension. After the comparison, the DM gives more attention weight to the target and decoy as the distance between them is smaller compared to that between competitor and decoy, eventually selecting the target as the final choice.

Decision Structure Theory (DST) [12], which considers four phases of a decision process (cf. Figure 3) is used to describe the decision process discussed above. We analyze the dimensional weight theory using the flowchart-like diagram in Figure 3 and establish a line of argument as to how the decision task explained in [5] fits in this respect. The decision task in [5] considers a choice set with three items defined on two dimensions where the target strictly dominates the decoy. According to the DST, the DM follows the following four phases of the decision process:

1. Pre-editing Phase: In the first phase, the DM screens and evaluates the attributes and alternatives. Alternatives with a better chance of becoming dominant is selected.

2. Finding a promising alternative phase: The DM now moves on to detect an alternative with attractive attributes that can be considered as a promising alternative (see Figure 3). The attraction effect bias becomes evident in this phase as the target shows a higher potential of being a promising alternative because of its strict dominance over the decoy.

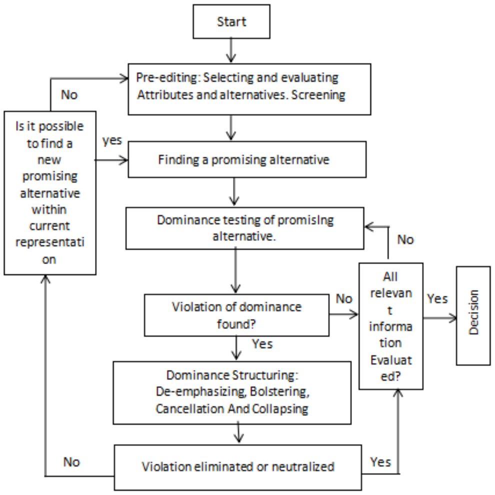

Fig. 3. The decision process, adapted from [12].

3. The dominance testing phase: Once the DM is able to find a potentially promising alternative, the dominance test is done in this phase. If there is any violation, the DM caters to it in the next phase. If no violation is found, the DM checks whether all the relevant information has been evaluated (Figure 3). Once this is done, the final decision is taken, otherwise, the DM moves on to test dominance once again.
4. The dominance structuring phase: After identifying a violation of dominance the DM tries to neutralize it in this phase using the ways mentioned in Figure 3. After possible removal of the violation, the DM moves on to make the final decision. Otherwise, the evaluation process starts again. We note that the decision process of Figure 3 is task-dependent and might vary accordingly.

For the example discussed in the previous section, it is seen that the target strictly dominates the decoy thus reducing its chance of getting selected, but both the target and the competitor are considered as options at this stage [Phase 1]. Now, the target is considered as the more promising alternative because of the attraction effect [Phase 2]. A strict dominance of the target over the decoy is established but the target and the competitor are found to be incomparable [Phase 3]. This leads to a violation that gets resolved in the next phase [Phase 4].

We note here that the syllogisms discussed in Section 2 are endowed with a notion of (in)correct reasoning and bias in the algorithmic models amounts to various ways of deviating from this norm. In the case of the decision task, one can also consider norms, but we leave it to future work to investigate how the algorithmic models can capture such deviations from the relevant norms, if any.

4 Discussion

For certain syllogistic tasks [9] and decision tasks [5], it was shown that individuals with ASD performed better than typical individuals. To analyze these results on a computational level, we took a functional approach (with a subject's reasoning being represented by a mathematical function) where the functions considered the respective tasks as arguments together with certain contextual information. For such functions, we have considered the following properties: *contextual independence* and *correctness*.

While the syllogistic task gave rise to certain functional expressions (as defined by mathematical functions) pertaining to both of the properties, those corresponding to the decision task paved the way for considering one of them, namely, context independence. These decision tasks were based on certain attributes, and no single choice was a dominant one (i.e. strictly better than the others), hence no notion of correctness. One might argue that such a correctness condition may be added to the decision task in case one of the choices is a strictly dominant one. But, more often than not, these tasks have rather complex choices. Moving on to contextual considerations, they can be further developed in the decision tasks by considering the following effect: *attraction effect* and *dominance effect*. These are absent in the syllogistic tasks.

To summarize, the commonalities in these two tasks on the computational level exist in terms of the effect of contextual stimuli, though the in-depth analyses of such contexts provide us with certain distinguishing features.

At the algorithmic level, the mental model corresponding to the syllogistic tasks provided in Figure 2 constitutes of building an initial model satisfying the premises of the syllogism under investigation. Then, an evaluation of the conclusion takes place in the model in question. Thus, the algorithm bases on the initial input of the model structure. In contrast, the algorithm given by DST for the decision tasks considers the entrance of possible promising alternatives within the process itself, and as such, we have an ongoing process of introduction of the alternatives at different phases.

In addition, for the syllogistic tasks, belief biases are considered both *during* the reasoning process and *after* the reasoning process, depending on the model. For the decision making task, the corresponding notion of attraction effect is considered throughout the four phases of the decision-making process considered according to DST.

We note here that in the computational level for the syllogistic and decision making tasks we were not able to make a deeper connection with respect to contextual independence. This was taken care of at the algorithmic level as we had a better grounding of the belief biases for the syllogistic tasks.

When the tasks are analyzed at the abstract computational level, the responses of ASDs in both tasks exhibit certain similarities, but when they are analyzed in the more concrete algorithmic level, the differences are made explicit with respect to the handling of biases. One might argue that our study should be relevant for typical individuals as well, but then we would digress from the initial analysis at the computational level. The functional expressions fit very well for the individuals with ASD.

5 Future work

In the present paper, we consider two studies with reasoning tasks where individuals with ASD perform better than typical individuals, namely, [9] and [5]. Below, we mention three more example studies that provide further validation towards better performance of individuals with ASD. We plan to subject these studies to similar analysis in the future, so as to provide a more detailed formal insight into the performances of the individuals with ASD. As we mentioned earlier, this would lead to a better understanding of the capabilities of such individuals.

In [6], Fujino et al. investigate adults' performance in the so-called sunk-cost task, which measures the tendency to include considerations on past costs while choosing between current alternatives. According to conventional economic theory, past expenses are irrelevant, rational decision-makers should only pay attention to future consequences of possible alternatives. It is shown in [6] that individuals with ASD are less prone to violate this norm than typical individuals. The study [11] investigates adult's performance on a financial task in which the monetary prospects were presented as either loss or gain, and it is shown that individuals with ASD demonstrate a larger consistency in decision making than typical individuals. The study [13] compares the performance of individuals with ASD and typical adolescents on tasks from the heuristics and biases literature, including the famous Linda task, involving the conjunction fallacy, which violates a fundamental law of probability theory. It is found that children with ASD are less susceptible to this fallacy.

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