# Eye tracking measure for inferential processes in adults.

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**Abstract**

Since Fodor's language of thought hypothesis, proposed decades ago, research on the primitives element of thinking has stalled. Here we try to make progress on this issue. We show that adults reason about non-linguistic scenes by showing behavioral signatures characterizing elementary logical inferences. We identify eye-tracking correlates of logical operations that have been previously found in infants. The continuity between infants and adults suggest that humans come equipped with logical resources that are available in a wide set of problem-solving situations regardless of the ability to master a natural language.

# 1 Introduction

Fodor's language of thought theory (LOT) (in Bonatti, 1994) proposes that reasoning is an operation of internal representations which are manipulated according to rules described in a formal system. According to LOT "many of higher cognitive processes are rule governed" (Fodor, 1975). LOT proposition stands in a strong opposition to the behaviorist psychology, which suggests that mind is much more procedural, i.e. each mind develops its own way of thinking based on experience (especially reinforced experience) (Skinner, 1986). Here we will focus on the origins of propositional logic, a formal rule governed system, in human cognition. Supporters of LOT theory argue that propositional logic and logical connectives (for example logical 'and' $\wedge$ or negation $\neg$ or 'or' $\vee$) are primitives of thought, the basic rules which are used to create more complex thoughts. LOT theory proposes that such structures for thinking exist in mind independently of experience. Alternative views suggest that such primitives are acquired in a pragmatic form when we become familiar with them during and thanks to language acquisition (Crain and Khlentzos, 2010, for discussion). This means that humans should not be capable of performing these mental operation had these operations not been previously reinforced during interaction with the environment (more specifically, humans would have low probability of performing such mental operations) (Skinner, 1986). In order to empirically distinguish between these two hypothesis Cesana-Arlotti (2015, unpublished doctoral thesis) have investigated the use of disjunctive syllogism $((A \vee B) \wedge \neg A) \implies B$ in prelinguistic infants. Their successful application of this formal rule prior to language acquisition would favor the LOT argument that humans come to the world already equipped with tools for rational thinking that provide fundamental blocks (or rather connectives) for more complex cognitive operations.

An interesting tendency infants show is the bias to map novel words to novel objects (Halberda, 2003). There are several theories which suggest what computational mechanism is responsible for such bias, some of them pointing to the inference by exclusion operation, in other words a disjunctive syllogism. This method of inference proceeds by eliminating all possible alternatives until a correct response is arrived at. Infants were shown to employ this type of inference in experiments on word acquisition. Typically in such experiments two objects are presented to the infants, a familiar and a novel object (Halberda, 2003, 2006). Then a word is uttered which either presents a known word naming the familiar object or a novel non-word ("Dax"). Infants tend to look significantly more to the novel object when a novel word is presented, and their gaze shifts comply with the underlying inference by exclusion process (Halberda, 2006).

These experiments show that such logical formalisms can operate in the linguistic domain, but it is unclear whether the ability to perform disjunctive syllogism (DS) develops together with language acquisition, or precedes it. A possibility exists that this logical formalism belongs outside linguistic domain, that is, that it does not develop specifically to assist word learning and is not acquired during linguistic development (Crain and Khlentzos, 2010). In this case, DS would constitute an elementary primitive of thinking supporting the LOT proposition about the ontology of human mind. Performing of the disjunctivye syllogism by infants who did not yet acquire language would support such 'logical nativism' view.

In order to investigate this question Cesana-Arlotti (2015) tested a group of prelinguistic infants on a 'The Partial Containment Task', a non-linguistic design involving logical reasoning (Figure 2). Cesana-Arlotti examined if infants can perform the disjunctive syllogism in a non linguistic domain. Infants success in the task would constitute and empirical evidence for operation of formal logical rules independent of understanding and production of their explicit linguistic manifestations. Such case would prove that propositional logic is available very early in human development (pre-linguistically) favoring the LOT proposition about innateness of formal systems in human psychology.

During the experiment infants are presented stories about two objects of different kind, that however share an identical top part (Figure 2). Two objects are hidden behind an occlusion and the infants see that one of them was put inside a container (a cup). The infants are then left to reason about which object is inside the cup and during this time one object that is not inside the cup is revealed. Infants who successfully infer what object is inside the cup by choosing the alternative one to the revealed object are plausibly employing disjunctive syllogism. The initial studies on infants analyzing their looking times and gaze dynamics indicated that they in fact are sensitive to violations of logical rules presented in animated stories (Cesana-Arlotti, 2015). The infant study found a correlation between gaze pattern, specifically number of gaze shifts, and infant's sensitivity to violation of the propositional logic rules implied in the story (Figure 1).

Here, we expand our investigations to adult sample in order to see if the gaze patterns, reporting underlying cognitive operations, are preserved during development. Adult study also allows us to record more types of responses and information. In order to identify specific gaze correlates of disjunctive syllogism we modified and improved an experimental protocol from an earlier infants

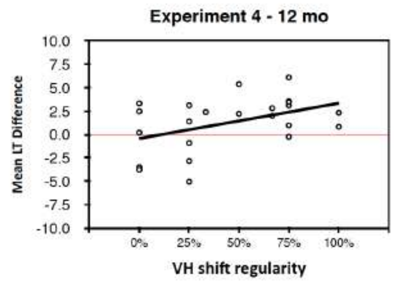


Figure 1: The 'The Partial Containment Task' presented a story to infants which could have a possible or impossible ending defined as accordance or violation of propositional logic rules. Infants who performed more gaze shifts showed higher sensitivity to violation of logical outcome shown as increase in looking time to the impossible outcome.

studies. This allowed us to expand the scope of the investigation by comparing what do organisms who have language do and to measure how stable are the observed gaze pattern across development?

## 2 Methods

The scenes, which we will call the 'Partial Information and Disjunction' protocol present to participants an animated story about two objects. The story contains all necessary elements to afford inference by exclusion. There are few variations between particular types of stories presented in Partial Information and Disjunction protocol but the main sequence of events always follows the following scheme (Figure 2):

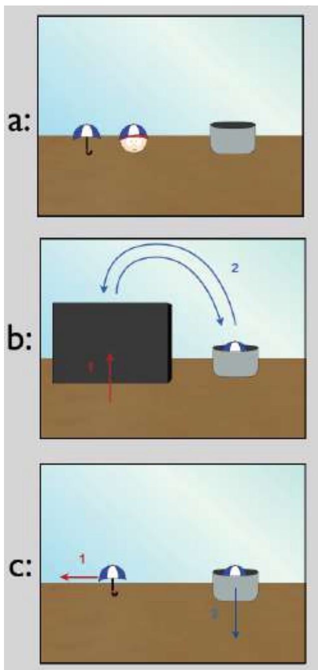


Figure 2: The 'Partial Information and Disjunction' protocol. During phase a two objects are introduced, object A and object B. The third element on the screen is a cup which will grab one of the objects. A and B are visually different objects but they have exactly identical top parts. In phase b an occluder appears in front of the objects, after which one of them is grabbed by a cup. In phase c the identity of object A is revealed. This allows a participant to infer what object is inside the cup by the process of inference by exclusion.

After the phase c (Figue 2) the object previously grabbed by the cup is revealed. This object can be either different from the one reveled in phase c, which is a true logical outcome of the inference by exclusion. However, sometimes the object revealed in phase c and in the end have the same identity, which is a logically impossible outcome. This violation can be detected if inference by exclusion was successfully performed in the phase c of the story. Increased looking times to the story endings indicate that infants may have performed inference by exclusion and that they found that their rational expectations had been violated.

During the experiment participants completed two main types of trials: Classification and Interruption trials. In one type, a full story was played and at the end a question was asked whether participants believed it was a possible or impossible story (classification trials). In the second type, the story paused in one of the phases of the video and participants were asked what object currently

| Phase | Description | Time |
|---|---|---|
| a | objects appear | 0 ms |
| b | one is grabbed | 5000 ms |
| c | the non-grabbed object is revealed | 12000 ms |
| d | outcome is presented | 16000 ms |

Table 1: Time course of the different phases during a trial. The times of phases are approximate because they varied between trial types.

was inside the cup (interruption trials). The interruption trials were introduced to motivate participants to track the content of the cup at all time during the story and thus to perform inference in the desired time window.

## 2.1 Classification trials

There were 4 different sequences used in this group, 2 of the sequences afforded inference by exclusion (inference condition) and 2 did not (no inference condition). The difference between the inference and no inference conditions was that in the former the object was grabbed by the cup from behind the occluder, while in the latter both objects were visible when the cup grabbed one of them.

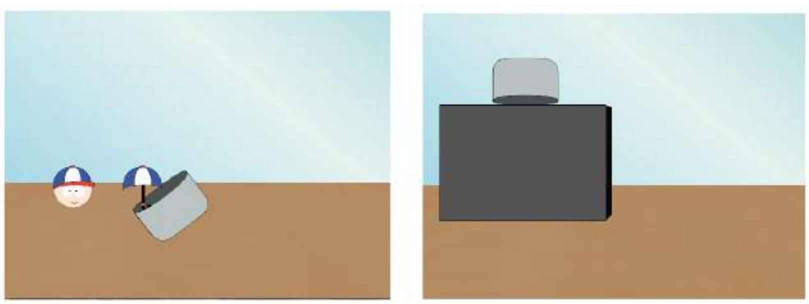

Figure 3: Left image presents the object being grabbed in a no inference condition. Both object are visible at the time of grabbing (phase b). Right hand side image presents the same situation in a inference condition. The occluder is about to move downwards behind the occluder, grab one of the objects and return to the right side of the screen. Because the only visible part of the object inside the cup is the top, it is impossible to know what object it is (the two objects have identical top parts)

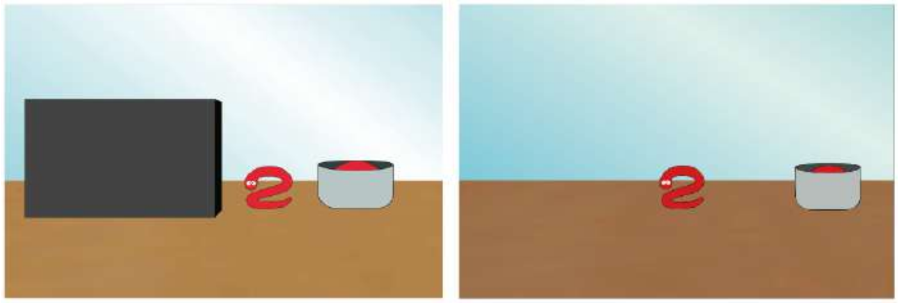

Figure 4: Left image presents the inference phase (phase c) in the first type of inference condition trials. The object appears from behind the occluder, stays visible for 2 seconds and returns behind the occluder. Right image presents the second trial type in the same condition. Instead of the object shifting from behind, the occluder is removed (slides down) and the object is revealed.

Within the condition half of the trials presented the visible object during phase c (Figure 3) by removing the occluder, while the other half did so by moving the object from behind a visible occluder.

At the end of all classification trials a question was asked to the participant, whether she believed it was a possible or impossible story. Two answers appeared on the screen and participants responded with a mouse click. This question is a homologue measure to the infants difference in looking times to the possible and impossible outcomes. By asking this question we wanted to measure whether participants could correctly identify logical and non-logical stories.

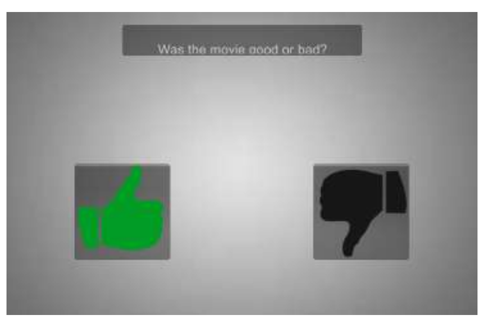


Figure 5: Screenshot of a screen appearing during the classification question at the end of the story. Participants clicked the selected response with a mouse indicating whether they believed the story was logical or not.

## 2.2 Interruption trials

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One third of the trials were interrupted at various points of the story, between phase a and b, after phase b and after phase c. participants were asked what object is currently inside the cup. This question was designed to accustom participants for tracking the object inside the cup at all times, since the story could pause at any moment and ask this question. We introduced this type of trials also to measure how well subjects are able to track the hidden content of the cup.

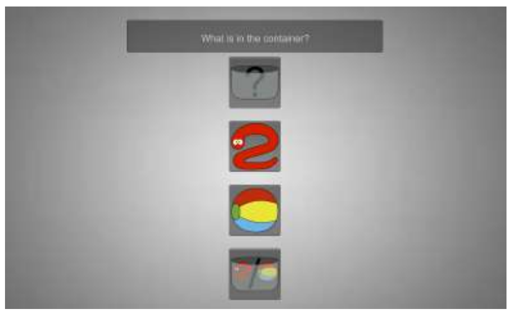


Figure 6: Screenshot of a screen appearing during interruption trial. participants were asked about the content of the cup and given 4 possible answers (from the top): I do not remember, object A, object B, Impossible question. Only the position of buttons for objects A and B (in respect to the left and right position on the screen) were randomized.

## 2.3 Experimental protocol

In the beginning of the experiment participants were given both written and spoken instructions about the experiment and promised a compensation of 5 euros for their participation. All participants submitted their written consent for participation. participants completed two blocks of pseudo-randomized classification and interruption trials. After the instruction phase and participants completed the eye tracker calibration. For the calibration we used psyscope (www.psy.ck.sissa.it) software presenting a 9-point calibration method. After the calibration participants completed two experimental blocks, each made of 12 classification and 6 interruption trials (36 trials in total). The whole two experimental blocks took on average 42 minutes to finish.

### 2.3.1 Participants

30 participants took part in the study, but only 16 were used for the presented analysis. The 14 participants had to be excluded to to eye tracking recording failure.

### 2.4 Materials

Eye tracking signal was recorded using a Tobii Pro 60 hz infra-red sensor. The experimental application was developed using Unity 3D and run at 60 frames per second on a 60 hz monitor (without vertical synchronization). Data analysis was done using python and accompanying packages (numpy, scipy and matplotlib).

## 3 Results

### 3.1 Explicit responses

Participants responded to two different questions on separate trial types, i.e. classification and interruption trials. Classification question (blue box plot) asked the participants whether they believe the presented story was possible or impossible. Interruption question (magenta box plot) asked about the hidden object inside the cup during the interrupted stage of the story.

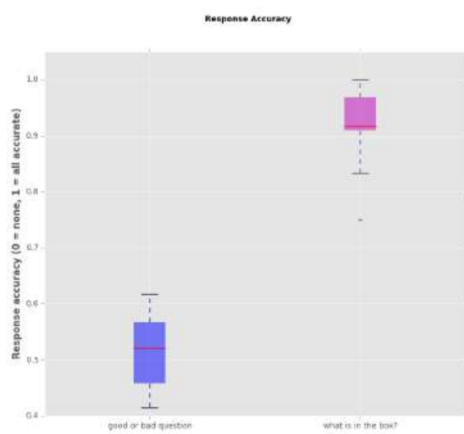


Figure 7: Response accuracy for two different questions. Participants responded around chance level for the question whether the story was logical or not. Participants responded very accurately to the question about the hidden content of the cup.

We performed a chi-square test (Table 2) to measure whether the participants could classify the story as logical or not above chance level. Test showed no significant relationship between the type of the story outcome and the participant response $\tilde{\chi}^2(2, \text{N} = 700) = 1.28$ , $p = 0.26$.

| | Possible Outcome | Impossible Outcome |
|---|---|---|
| Possible Answer | 180 / **188** | 173 / **165** |
| Impossible Answer | 178 / **169** | 170 / **178** |

Table 2: Contingency table for trial classification plotted in Figure 7. The distribution of participant responses is grouped by types of trial outcomes. The light font values represents the expected outcome, bold values represents the observed outcome (expected / **observed**).

We observe a small tendency favouring the correct responses. The ratio obtained by dividing the sum of correct responses by the sum of incorrect ones was 1.1. Such proportion varied from participant to participant and individual differences in classification accuracy might have disappeared in the global count which produced the contingency table (Table 2). Therefore the same ratio was calculated individually for each participant and used for later correlation with eye tracking measures (see Figure 15).

## 3.2 Eye tracking data

### 3.2.1 Preprocessing

Gaze data was restricted to samples recorded inside the display coordinates (1920 by 1080 px display). Missing data points (due to loss of tracking, for example during eye blink) was filled using linear interpolation (numpy.interp). The x and y coordinates of the gaze were constructed from the average position of left and right eye. In case when one eye was not detected only the valid eye data was used.

### 3.2.2 Regions of Interest Analysis

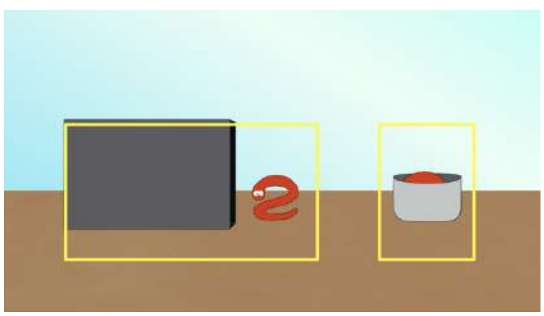

Figure 8: Two regions of interests (ROI) selected for the analysis are indicated by yellow squares. The left ROI represents the position of a visible object which appears from behind the occluder. The right ROI represents the hidden object whos identity participants are trying to infer.

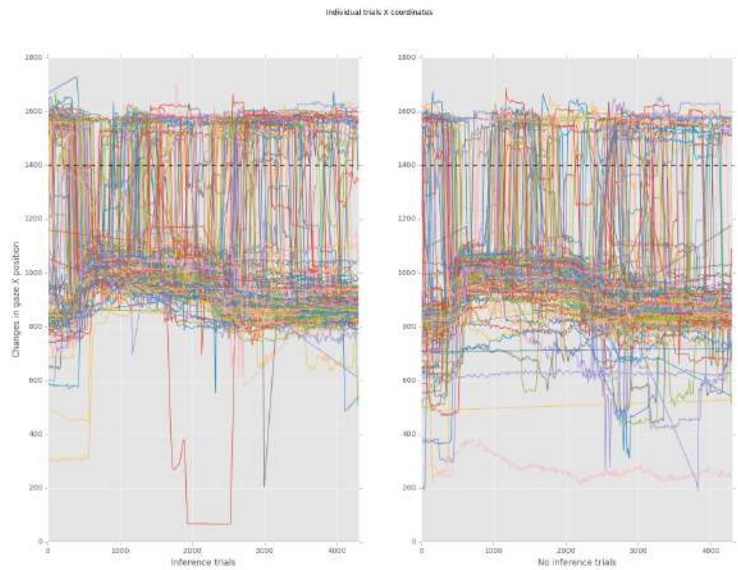


Figure 9: Time courses of gaze x position during the inference phase. Each colored line represents the x value of participant gaze during single trial. The black dotted line represents the boundary of the ROI, i.e. the hidden object position on the screen. The upward crossings (i.e. from visible to hidden object) were counted as gaze shifts.

Two Regions of Interest (ROI) were selected, left (i.e. below the black dotted line in Figure 9) representing the visible object appearing from behind an occluder and right (marked by yellow squares in Figure 8) representing the hidden object inside the cup. To identify when participants switched the gaze from visible to hidden ROI the x-component of gaze coordinates was isolated resulting in the collection of time series plotted in Figure 9. The average amount of times the x value of the gaze crossed the threshold value from below (i.e. from left to right or from visible to hidden object) was calculated per each participant per each condition. A paired t-test showed that the mean amount of gaze shifts towards the hidden object was significantly higher during the inference (m = 0.98 sd = 0.38) then no inference (m = 0.73 sd = 0.34) condition (t(15) = 2.206, $p =$ 0.05). This result suggest that participants moved the gaze between the hidden and visible object more frequently when the identity of the hidden object was unknown. This gaze pattern might be indicative of underlying computation of inference by exclusion.

The gaze shifts measure is nevertheless insensitive to the temporal dynamics of the DS. It is still unclear when the participants perform the inference, whether during the appearance of the visible object from behind the occluder or during the inference phase i.e. after the disappearance of the visible object. It is

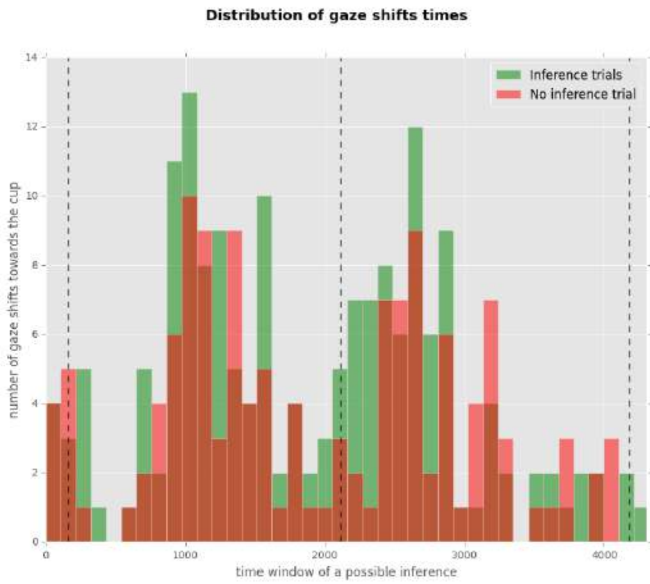


Figure 10: Gaze shifts latency distribution. The histogram values represent a total count of gaze shifts in 100 millisecond bins. Green bars represent this count in the inference trials, while the red bars represent no inference trials. The left black dotted line represents the appearing of an object from behind the occluder. The middle black line represents the disappearance of the visible object. The right hand-side dotted line represent the end of inference window.

important to find when exactly do participants perform the gaze shifts, which will allow us to understand the context (i.e. the history of on screen events) which allowed for the inference to take place. To investigate this temporal aspect we produced a histogram of gaze shifts latencies during inference and no inference conditions (Figure 10).

The histogram of gaze shift latencies shows two major concentrations of saccades in two different time windows. The first window spans over the time when the visible object appears from behind the occluder until it returns. The second window covers the time when no object is visible on the display.

In order to investigate when exactly the participants perform the DS we calculated for each participant the average amount of threshold crossing marked by black dotted line in Figure 9) and compared the collection of averages between inference and no inference conditions in an extending time window.

We incrementally increased the length of the full time window by adding one second to the beginning of the possible inference window. Each longer time window was used for a paired t-test comparing the amount of gaze shifts between inference and no inference conditions. The first window when statistically significant differences could be observed will mark the shortest amount of time

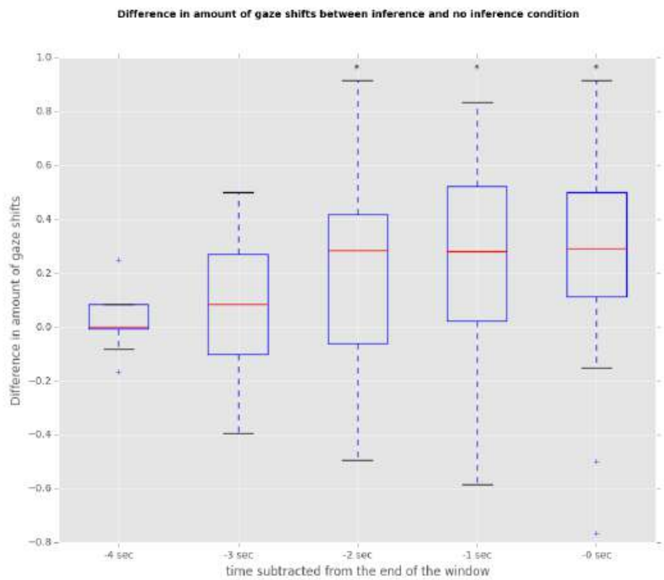


Figure 11: Repeated comparison of the amount of gaze shifts in an incrementally larger time window. We begin by extracting 4 seconds from the end of the time signal, and reduce this amount by 1 second until a full signal is analysed. We can observe statistically significant difference in amount of gaze shifts already in the first two seconds of the time window.

when the inference by exclusion is performed (Figure 11).

The first significant difference (t(15) = 2.16, $p < 0.05$) is observed when taking into the account the time window from the beginning until the end -2 seconds of the time window (i.e. first ˜ 2 seconds of the inference window) (Figure 11). This finding suggests that participants were performing the inference already during the appearance of the visible object, and not necessarily during the inference phase per se (i.e. when both objects were invisible). Here we did not use the Bonferronni correction for multiple comparisons. This tests were conducted on a dataset which was reduced from a bigger set, i.e. from all gaze shifts throughout the inference time window. The t-test comparing the total count of gaze shifts already yielded statistically significant results (see first paragraph of this section) and here we proceeded by reducing the amount of data points used for comparison. Using less data points already decreased the statistical power of the test between two populations known to be different, thus further corrections where deemed unnecessary. However, this is an exploratory method and the limitations and possible improvements will be addressed in the discussion.

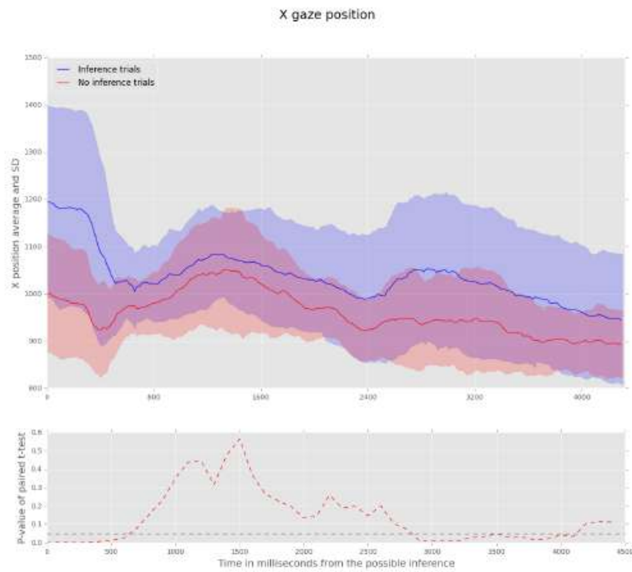


Figure 12: Top plot: The grand average of changes in X coordinate during the inference vs no inference condition. Bottom plot: The $p$-value of a moving paired t-test, an exploratory measure of time points when two signals significantly deviate. The t-test was performed on the data intervals sampled every 100 milliseconds..

#### 3.2.3 Time-series analysis

Following a similar approach to the ROI analysis we isolated the x-coordinate of the gaze to create a collection of signals in inference and no inference conditions. This approach enables identifying common time points when all participants' gaze differed between conditions. For each participant an average signal (representing changes in x coordinates ) time was calculated. The averages were aligned and the standard deviation at each corresponding time point was calculated (Figure 12). Figure 12 can be understood as a grand average of Figure 9 where the standard deviation represents between participants variability.

In order to identify the time points when two collections of signals differ we performed an paired t-test on a moving sample with a frequency of 100 milliseconds. This frequency was chosen to reflect the fastest possible reaction times for human saccades, i.e. 80 to 120 ms (Kingstone and Klein, 1993). Starting from the beginning of the signal every 100 milliseconds the values representing the amplitude of each participant average were compared between the inference and no inference conditions. The conservative Bonferroni correction yielded all but a first few samples insignificant which did not serve the exploratory purpose of this method. The presented $p$-value is not corrected for multiple comparisons.

Figure 12 shows two points when possible difference occurs, first between 0 and 500 milliseconds and second between 3000 and 4000 milliseconds Overall we can observe a greater tendency to look in the direction of the hidden object in the inference (blue signal) then in the no inference condition (red signal). The first difference cannot be easily attributed to inference-related gaze behavior because it was caused by the difference between conditions in the time of the arrival of the cup in its final position. In the inference condition the cup had arrived on the final position just before the inference window, whereas in the no inference condition the cup has been there earlier. In the no inference condition the the cup grabs the object and then the occluder moves up, in the inference condition this sequence is reversed. Thus it is possible that in the very begging of the inference window two subjects are looking to the last place something was moving which causes the early difference in the average x position. This results however differ from the ROI analysis which identified significant difference in gaze behavior already after the first 2 seconds of this time window (see discussion for further explanation).

#### 3.2.4 Spatial analysis

In addition to understanding when a correlates of DS can be observed it can also be of interest to answer where do participants look when they perform it. In order to analyse spatial markers of DS we constructed spatial frequency maps (i.e. heat maps) and contrasted them between inference and no inference conditions. The heat maps were constructed from a grand average of both x and y gaze position of all participants. The 2D histograms were then convolved with a gaussian kernel using scipy.ndimage.filters.gaussian filter with a sigma parameter set to 2 (responsible for the degree of spatial smoothing).

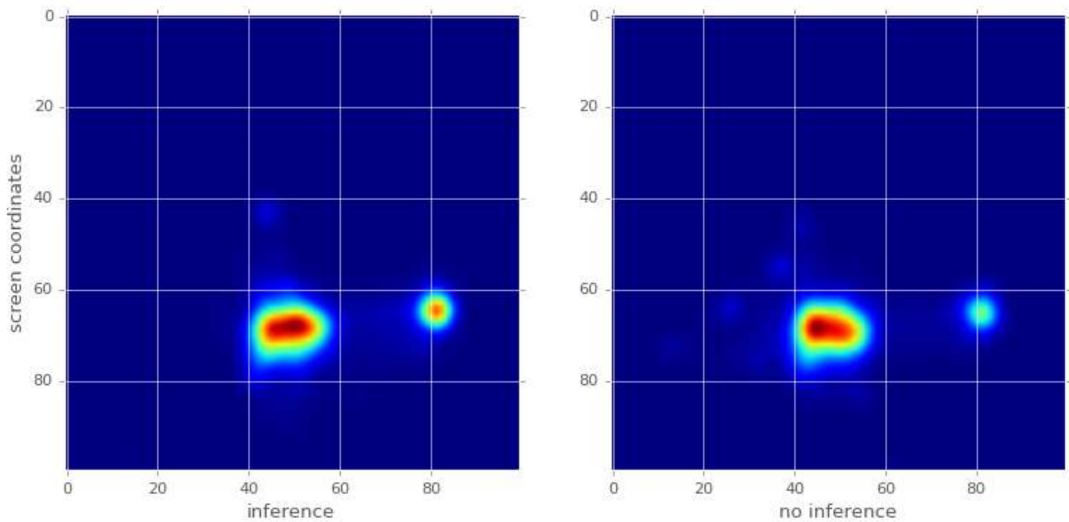


Figure 13: Spatial distribution of looking frequency, i.e. heat maps. The color code denotes the proportion of time participants spent looking at this location on average. The hotter the color the more frequently participants looked at the location.

Figure 13 shows different spatial distribution of the gaze between the inference and no inference conditions. From there we can see that in the inference participants looked more to the hidden object position (the hot spot on the right hand-side). In order to look at more detailed difference between the two heat maps we subtracted one from another creating a difference map (Figure 14).

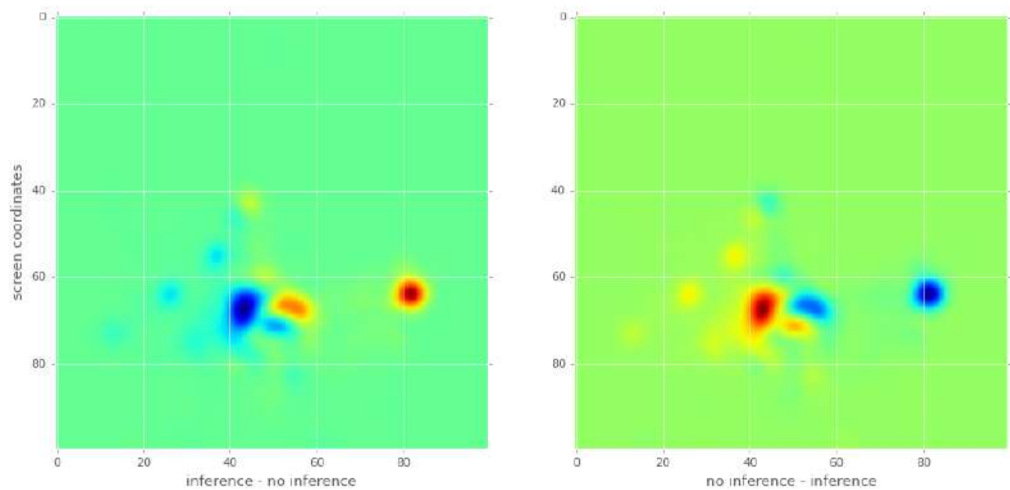


Figure 14: The difference between the inference and no inference conditions in the spatial distribution of the gaze. The left and right plots are each other opposites. The blue color code represents negative values, i.e. places where the subtracted condition had higher frequency. The red color represents the places where the base condition had higher frequency.

The difference plot (Figure 14) in addition to showing the difference at the hidden object location also suggests a more fine grained difference at the location of the visible object. During the no inference condition participants looked more frequently to the occluded location of the visible object, i.e. at the occluder. In fact the difference plot suggests participants spent more time looking at the occluder during the no inference condition then they did at the location of both objects during the inference condition.

## 3.3 Behavioral and Eye tracking results correlation

For the final analysis we looked at the relation between the identified gaze correlates of the DS and the behavioral results. Such relation would strengthen the claim that the correlates of the DS are actually reporting the participants preforming such inference. However, two limitations of our behavioral measures rendered such analysis difficult. One measure, the classification accuracy was the cup question, was performed at ceiling value, with 3 of the participants not making a single mistake. This might mean the task as well as performing the DS was extremely easy for adult participants.

Regardless of these limitations we looked at the correlation between the

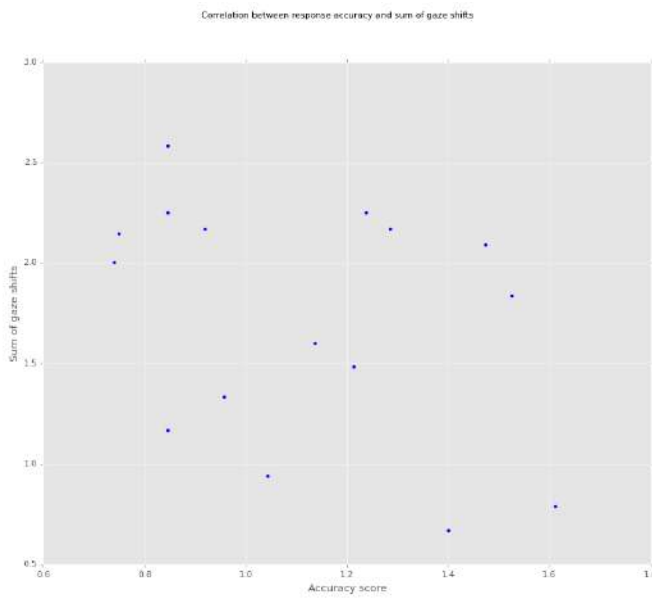


Figure 15: Relation between the total amount of gaze shifts and the classification accuracy score. The correlation is non significant but shows a surprising negative relation tendency.

ROI analysis results, i.e. the gaze shifts frequency (Figure 9) and the (Table 1) computed for each participant individually.

We calculated the correlation for the participant classification accuracy and the following measures:

Table 1: Correlation between ROI measures and behavioral results.

| | Correlation with classification accuracy proportion |
|---|---|
| Amount of gaze shifts during inference | r = -0.31, $p$ = 0.24 |
| Amount of gaze shifts during no inference | r = -0.27, $p$ = 0.31 |
| Difference in amount of gaze shifts | r = -0.06, $p$ = 0.82 |
| Sum of the amount of gaze shifts | r = -0.36, $p$ = 0.17 |

The sum of the gaze shifts during both inference and no inference conditions (i.e. overall gaze shift frequency) had surprisingly the strongest (although not statistically significant) relation with the classification accuracy (Figure 8).

# 4 Discussion

The presented experiment was developed to examine whether it is possible to find gaze patterns in adult participants correlating with operation of inference by exclusion. Such gaze patterns are especially important as they point to the specific computational strategy that was employed by participants to solve the experimental task. We have found several markers of inference by exclusion when contrasting the gaze behavior between inference and no inference conditions in a Partial Containment Task.

The first important marker was the pattern of gaze shifts, showing that during the inference condition participants tended to shift their gaze towards the hidden object more frequently than in the no inference conditions (Figure 11). This finding agrees with the infant studies results which show that infants tend to shift the gaze between familiar and unfamiliar object when finding a match for the novel label (Halberda, 2003). In his work, Halberda (2003) suggested that performing a gaze shifts from a novel to a familiar object upon hearing a novel label marks the underlying cognitive process of excluding the alternative (i.e. performing inference by exclusion). Our findings confirm gaze shifting between two alternative objects really is a behavioral marker of performing inference by exclusion and thus a) is not only driven by perceptual features of the scene and b) points to a particular computational strategy when observed both in infants and adults. Cesana-Arlotti, 2015 found a correlation in 12 months old infants between the amount of gaze shifts and difference in looking time to possible vs impossible outcomes of the story. This means 12 month old infants who shifted their gaze more formed stronger expectation about the hidden content of the cup. This correlation however disappeared in older infants, who were overall more successful in performing the task, as indicated by the difference in looking times to outcomes. A plausible reason for this correlation to disappear is that the task becomes easier as the infants inferential skills develop in time, and the numerous saccades become redundant for the performance of the task. This hypothesis finds a confirmation (although not statistically significant) in a negative correlation between total amount of gaze shifts during the experiment and classification accuracy scores of adult participants Figure 15. More frequent gaze shifts occurred when participants had more trouble performing the task (i.e. found it more difficult), which might also have been the case for the 12 months old. What will need to be tested to confirm that hypothesis is the total amount of gaze shifts between 12 month old infants and older, expecting that the younger infants perform more of the shifts since the task is more difficult for them.

We have also looked at the temporal course of the gaze shifts in order to identify when participants performed the inference. Our results (Figure 10) indicated that there were two plausible temporal windows for this operation. The first one begins when the visible stimulus appears from behind the occluder until it again disappears (between the first two black dotted lines on Figure

10). An interval t-test measure for this temporal course (Figure 11) indicated that it was already possible to distinguish between inference and no inference conditions looking only at this first window. However, the same results were not confirmed by our second measure (Figure 12) which focused on the average of the x coordinate of gaze between conditions. Here, we performed a moving t-test to identify individual time points at which participants,on average, looked more to the hidden than to the visible object (or currently behind the occluder, but visible in that time window). There we found that participants tended to look more at the cup only in the second plausible temporal windows for inference, i.e. only after the visible object has returned behind the occluder. A possible explanation for this divergence in findings is that the average measure was insensitive to the small contribution of very fast and short saccades performed already in the first temporal window. The gaze shift measure looked only at the frequency of shifts, which need not to be equal to the average looking time if the shifts are very short. In order to confirm that participants indeed perform this very fast and short saccades when performing inference a further analysis will be needed which decomposes signal in saccades and fixations.

The analysis of spatial distribution of the gaze between conditions (Figure 14) shows that the difference in gaze is caused by the participants looking more precisely at the top part of the object hidden in the cup. The increased visual salience of the top part of the hidden object cannot be explained as a purely perceptual effect (this part usually being containing the highest contrasts and most curvatures on the scene) since we observe a difference between conditions where these perceptual properties were identical. Thus a question arises, where were the participants looking when they weren't looking at the top part of the hidden object. It might appear they were simply looking more at the visible object or its supposed location behind he occluder 13. However a more detailed analysis 14 shows that there were two spatial peaks in the position where the visible object would emerge and disappear behind the occluder. It appears that during the no inference condition participants looked more directly at the occluder, while in the inference condition they looked more at the right edge of the occluder. This edge is where the object would appear thus, thus it follows that if participants were interested in performing the inference they should pay more attention to that region. In the no-inference condition participants did not need to track the visible object to infer which one is it, because the scene that they saw out seconds before left them with no doubt as to which object is where. In the inference condition, instead, participants were expecting the object to appear from behind the occluder and reveal its identity, and by inference the identity of the object inside the cup for the first time. The increased saliency of the point which provides information necessary for the inference by exclusion again supports that this was indeed the computational strategy employed to solve the required task.

Our results do suggest that the strategy used to solve our experimental task does not depend on language competence and therefore in this sense they support the LOT position. However, many questions are left unanswered and many possibly different theoretical approaches are possible. Our findings indicating that both prelinguistic infants and adults may use a computational strategy involving logical connectives and inference do not provide a definitive answer the debate between the proponents of LOT theory and behaviorists. Logical nativism assumes that rules are really in the genes, as if the alternative were only either nature or nurture, however such dichotomies tend to be over-simplistic. There are certain contingencies that occur in the world and thus need not be stored anywhere, because they will always be accessible to an organism present in the world (Chalmers and Clark, 1998). Logical representations seem to qualify for being embedded in the world, rather than natively stored in the mind. It is very likely that every organism will have a similar experience in the logical domain regardless of their genetic differences. Regularities that can be formulated in formal logic occur in nature, for example: if it's dry *and* hot there will be no water, I get full when I eat a berry *or* when I eat a nut. Logic perhaps need not to be neither stored in genetic code, nor does it have to be embedded in language to be a universally accessible tool for thinking.

## 5 Conclusions

A big question that emerges from the history of nature vs nurture debate is about the ontology of logic. Is it a man-made formal system explicitly taught to infants during language acquisition or is it a cognitive gestalt, a grammar of the of language of thought? Our result that both prelinguistic infants and adults use the same computational strategy for the inference task seems to tilt the scale in favor of LOT theories. Many other questions are still unanswered. What if the operation of disjunctive syllogism is based on history of reinforcement in non-linguistic domain? Even if this operation is proven to be innate, why does it have to be a formal system of rules, rather then a heuristic one? For the future work this experimental design should also be conducted in an imaging experiment to identify the neural correlates of disjunctive syllogism.

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