Investigating Children's Eye-Movements: Cause or Effect of Reversing Ambiguous Figures?

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Abstract

We examined whether eye-movements play a significant role in perceiving both interpretations (reversing) of ambiguous figures such as the duck/rabbit (Jastrow, 1900). In an eye tracking study we investigated 3-, 4- and 5-year-old children's reversal abilities while their eye-movements were recorded. Children's eye-movement patterns were also compared to those of adults. No significant differences in eye-movement patterns between children who reversed and those who did not reverse were found. This means that looking at specific parts of the image is not sufficient to perceive both alternative interpretations. We conclude that eye movements are not a major cause of reversing ambiguous figures.

Keywords: ambiguous figures; preschool-children; eye movements.

Introduction

Ambiguous figures such as Jastrow's (1900) duck/rabbit (Figure 1) are figures for which multiple interpretations are possible although the figure itself remains unchanged. Viewers experience the two competing interpretations reverse from one to the other and only one interpretation can be perceived at a time. In this study we investigated the role of eye-movements in the ability to reverse ambiguous figures.

Studies with adults have been unable to determine whether fixation changes cause reversal, or reversal causes observers to alter their fixation points. For example it has been suggested that focusing on a particular part of the image (e.g. between the duck's beak and eye) may bias the image towards one interpretation (e.g. duck) (Tsal & Kolbet, 1985). Adopting appropriate search patterns may therefore induce shifts.

Studies have suggested that eye-movements precede reversals (Ellis & Stark, 1978; Kawabata, Yamagami, & Noaki, 1978; Ruggieri & Fernandez, 1994), that eye-movements follow rather than precede reversals (Einhäuser, Martin, & König, 2004; Gale and Findlay, 1983; Pheiffer, Eure, & Hamilton, 1956), or that eye-movements and reversals are unrelated (Flamm & Bergum, 1977; Ito, Nikolaev, Luman, Aukes, Nakatani, & van Leeuwen, 2003). It has also been suggested that there are considerable differences between scanning strategies across individuals (Holcomb, Holcomb, & De La Peña, 1977).

Only a few studies have looked at children's perceptions of ambiguous figures (e.g. Doherty & Wimmer, 2005; Gopnik & Rosati, 2001; Rock, Gopnik, & Hall, 1994). Rock et al. (1994) looked at spontaneous reversals in 3- to 4-year-old children. Children were given a Reversal task where they had to look at an ambiguous figure for 60 seconds and report any perceived change of interpretation. They found that preschool children who are not initially informed about the ambiguity of an ambiguous figure do not perceive changes in interpretation over a one minute viewing period. Even when informed about the ambiguity only a few children were able to reverse an ambiguous figure. Gopnik and Rosati (2001) found that children at the age of 5 but not younger are able to reverse an ambiguous figure during a 60 second viewing period when initially informed about the ambiguity. This was replicated by Doherty and Wimmer (2005), who nevertheless found that by the age of about 4 years children understood that these figures can have two interpretations. Although it appears that a conceptual deficit underlies the ability to reverse, this is overcome a year before children can reverse, leaving open the question of what additional ability is required to achieve reversal.

In this study we examine whether this additional ability relates to appropriate eye-movements. As discussed, research with adults has not been able to reach a consensus on whether eye-movements are the cause or effect of reversal. Developmental work can make a unique contribution to the debate by examining fixation patterns around the age children begin to reverse. If eye-movements are an important factor in perceiving reversal, we would expect a change in the pattern of fixation at or around the time children become able to reverse.

Method

Participants

Thirty-seven children (18 boys, 29 girls) from a predominantly middle class background in Stirling, Scotland took part. Children's age ranged from 3;2 (3 years, 2 month) to 5;9 (5 years, 9 months), Mean age = 4;4, SD = 8 months. The children were divided into three age groups: Eleven 3-year-olds, Mean age = 3;7; thirteen 4-year-olds, Mean age = 4;3; and thirteen 5-year-olds, Mean age = 5;2. In addition 12 adults between the ages of 24 and 50 from the University of Stirling took part.

Design

Each child received two conditions: uninformed and informed. The uninformed condition was always presented first and was the same for all children and adults. Afterwards 17 children received an ambiguous figures Reversal task requiring a pointing response (Reversal task Point) and 20 children a Reversal task requiring a verbal response (Reversal task Verbal). All twelve adults received the Reversal task Verbal.

Materials

For this study a Tobii 1750 eye tracking machine (accuracy 0.5°, drift < 1 degree, binocular tracking, data rate 50 Hz) was used, along with Clearview 2.1.0 analysis Software. The eye tracker, integrated in a 17" monitor, was non-intrusive and had a head-motion compensation mechanism. This means that the child was not required to wear any apparatus and could move freely in front of the eye tracker. The child sat approximately 60 cm from the screen. A pointer stick (19 cm) with a soft tip was used for pointing out features of the ambiguous figure. Before starting the task a 5 point calibration phase was conducted.

The ambiguous figure used was the duck/rabbit. This figure has been used in previous studies with children, who can reliably perceive both alternatives when disambiguated by an experimenter. For the disambiguation phase two disambiguating context drawings were used – the duck's body on a lake with other ducks in the background, and a rabbit's body, complete with a carrot. The bodies appeared around the duck's/rabbit's head on the eye tracking screen.

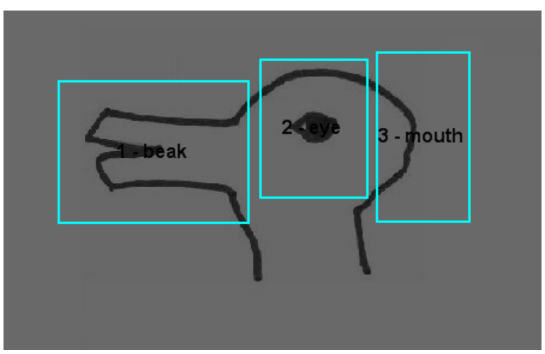

Figure 1: duck/rabbit (Jastrow, 1900) divided into areas of interest

Procedure

Uninformed condition This was the same for all participants. Children (or adults) were shown the ambiguous figure on the eye tracking monitor. They were asked, "What is this?" After the child's response, (e.g.) "Duck", they were asked, "What is it now?" 3 times: after 5, 30 and 60 seconds. Children and adults who reported any perceived change of interpretation during the 60 second viewing period were coded as reversers. The purpose of this condition was to investigate eye-movement patterns when unaware of the ambiguity of the image.

Disambiguation phase The disambiguation phase took place after the uninformed condition and before the test phase of the Reversal task verbal/point. The child (or adult) was shown the duck/rabbit on the monitor again and asked "What is this?" after the child's answer (e.g.) "duck" the body of the duck was added and the child was asked to point to the duck's eye. Then the experimenter said "But look it can be something else too. [puts on the body of the rabbit] What is it now? . . . Yes you are right, it's a rabbit!" Again the child was asked to point out the rabbit's ears to ensure that s/he was genuinely perceiving this alternative. The experimenter finally reminded the child of the two alternatives "Now this is very funny. This picture can change back and forth from a duck [the duck's body added briefly on the screen] to a rabbit [the rabbit's body added briefly on the screen]" and then with appropriate swapping of the disambiguating contexts on the screen and brief pauses to allow the child to look at the figure, "or from a rabbit to a duck". But it might just stay a duck or it might just stay a rabbit".

Reversal task verbal This task was adapted from Rock et al. (1994) and followed exactly the same procedure as the uninformed condition. The difference was that children had now been informed about the ambiguity.

Reversal task point The instructions were the same except that children were asked to point out features of the non-reported interpretation after 5, 30 and 60 seconds instead of giving verbal responses. For example if the child initially perceived the duck s/he was asked to point to the mouth of the rabbit after 5 seconds. If the child correctly pointed to the mouth of the rabbit s/he was asked to point to the beak of the duck after 30 seconds and to the ears of the rabbit after 60 seconds. If the child failed to point out features correctly after 5 seconds the same question was repeated after 30 seconds and so forth. Children who were able to point out features of each interpretation at least once during the 60 seconds period were deemed reversers.

This task had 2 purposes:

1) The Reversal task Point has been used in previous research (Wimmer, 2007) and is a methodologically more sensitive task for assessing reversal abilities, because children do not have to give verbal responses. Giving verbal responses about one's own perceptual experience is difficult for preschool children.

2) Asking children to point out features plausibly prompts them to scan the whole image in order to search for the required feature. This may induce active search.

Analysis

The eye movement analysis was based on the average fixations lengths and the average number of fixations. The analysis represents the time children were actively looking at the figure/screen rather than a timeline of 60 seconds taken for the tasks. Additionally we were interested in how long and how often children averted their gaze from the screen, thus whether they had problems maintaining fixation. Children's difficulty maintaining fixation in this task has been noted in previous studies (Wimmer, 2007) but eye tracking equipment was not available to measure it experimentally.

We were primarily interested in fixation patterns over the whole image and within specific areas of the image. For this the ambiguous figure was divided into areas of interest as follows: beak of the duck/ears of the rabbit; eye; mouth of the rabbit/back of the duck's head (Figure 1). The beak comprises the largest area of the ambiguous figure and the mouth (from the rabbit perspective) the smallest. Hence the beak is more likely to have longer and more frequent fixations. This should be taken into consideration and therefore we give more emphasis to the overall fixation pattern.

We also analyzed the order of fixations. In particular, we assessed the likelihood for a participant to fixate one specific area of interest (eye, beak, mouth) following fixation of another (e.g. mouth). For that we evaluated the *baseline likelihood to fixate one area of interest* [e.g. the probability of fixating the beak is the number of fixations of the beak divided by the total number of fixations]; and the *likelihood to fixate one area of interest after fixating another area of interest* [e.g. the probability of fixating the beak after fixating the mouth is the number of fixations of the beak after the mouth divided by the proportion of fixations that were of the mouth].

Results

Task performances

None of the thirty-seven children reversed in the uninformed condition. In the informed condition 4 out of 20 children who received the Verbal task reversed (20%), and 9 out of 17 who received the Pointing task (53%). There were no significant differences between the tasks or the age groups.

Eye movement data

Reverser vs. Non Reverser Reversers did not fixate longer or make more fixations than non-reversers in either Reversal task, nor did they avert their gaze more often or for longer. Figure 2a shows the proportional length of fixation to different parts of the figure; Figure 2b shows the proportional number of fixations to different parts of the figure. The bars for "Background" refer to fixations outside the defined areas of interest and the bars for "Averted" refer to gaze aversions from the screen.

There were no differences between reversers and non-reversers in the length of time different parts of the image were fixated for either task. Similarly, the number of fixations to different parts of the image did not differ for the Verbal task. In the Pointing task, reversers fixated the mouth more often than non-reversers (a mean of 8 times compared to 2 times) and this was marginally significant (t (11) = 1.95, p = 0.077).

Uninformed vs. Informed In the Verbal task, children did not fixate the image longer or more often once informed of the ambiguity. In the Pointing task children fixated longer once informed, and this was marginally significant, t (15) = 1.93, p = 0.072. In this task children also looked away less frequently (t (15) = - 2.18, p = 0.046) and for less time once informed (t (15) = -2.05, p = 0.058). The gaze aversions in the Point task were also fewer and shorter than in the Verbal task, (t (35) = 2.31, p = 0.027, and t (35) = 2.01, p = 0.051, respectively).

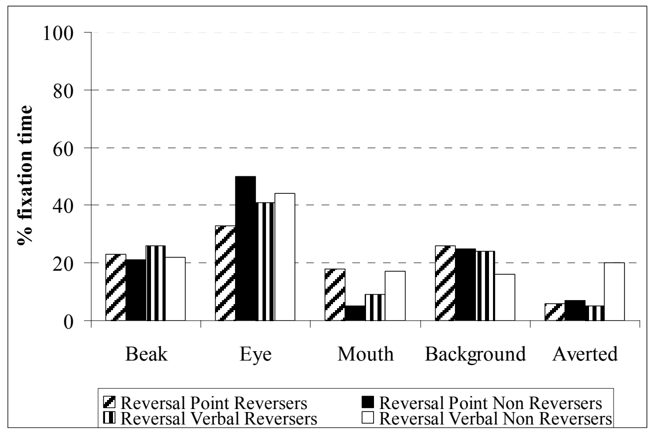

Figure 2a: Mean length of fixation of reversers and non reverses to different areas of interest in relation to the overall fixation time.

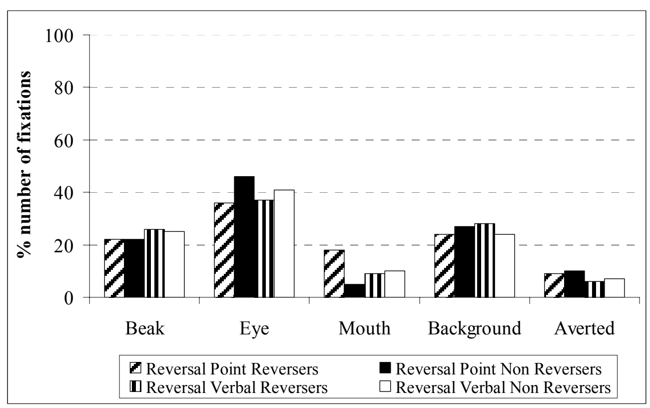

Figure 2b: Mean number of fixations of reversers and non reversers to different areas of interest in relation to the overall fixation time

Fixation Order In order to compare the fixation orders of reversers and non-reversers directly, performance on both Reversal tasks (verbal/point) was merged together, due to the small number of reversers in the Reversal task verbal (N = 4). We calculated the fixation order, disregarding successive fixations of the same area of interest: when fixation of one area of interest is finished, where do reversers and non-reversers fixate next? As can be seen

(Figure 3), the fixation order for the reversers is similar to the non-reversers. Both reversers and non-reversers were most likely to fixate the eye after the beak or the mouth. After reversers and non-reversers looked at the eye, then the beak was more likely to be fixated than the mouth. Both reversers and non-reversers rarely fixated the beak after the mouth or vice versa.

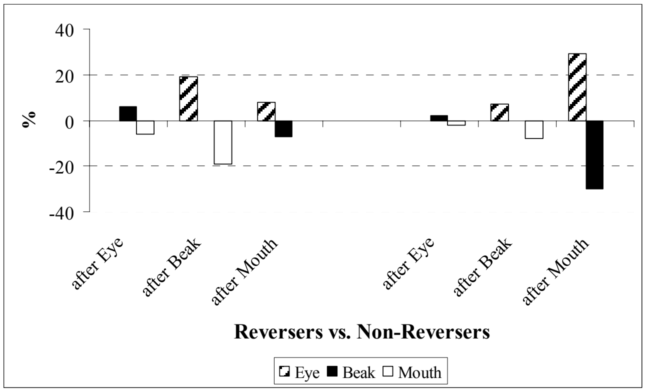

Figure 3: Likelihood of fixating one area of interest after fixation of another, relative to the baseline likelihood of fixating for reversers (left) and non-reversers (right)

Comparison of age groups

In the uninformed condition, 3-year-olds looked away more frequently and for longer than older children: F (2, 32) = 3.97, p = 0.029, F (2, 32) = 6.45, p = 0.004 respectively. In the Reversal task verbal 3-year-olds also looked away more frequently than older children: F (2, 17) = 3.24, p = 0.064. No other age effects were found. In the Reversal task point, 3-year-olds fixated the image significantly longer than older children: F (2, 14) = 4.29, p = 0.035.

Adults

Uninformed condition Only 2 of the 12 adults reported that they had never seen the ambiguous figure before, one of whom did not reverse in the uninformed condition. The eye movement pattern is very clear for this participant (Figure 4). She perceived the duck, and made no fixation to the mouth area (which plausibly favors the rabbit interpretation). This suggests that if reversal does not occur, adults tend to only fixate the parts of the figure consistent with their interpretation. However, from only one observer conclusions are not possible. Out of the 11 adults who reversed two did not fixate the mouth area and one did not fixate the beak area. This indicates that it is not necessary to fixate those areas for reversal if someone is aware of the figure's ambiguity.

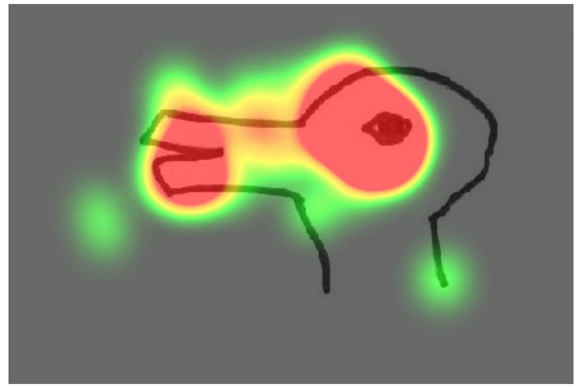

Figure 4: Fixation pattern of adult non reverser in the uninformed condition. The red fields indicate longer fixations

Informed condition In the informed condition all adults reversed but 3 out of 12 did not fixate the mouth area of interest and one additional adult did not fixate the beak area. This supports the findings from the uninformed condition and strongly suggests that fixations of specific areas are not necessary in order to reverse.

Fixation order Adult reversers showed the same pattern of successive fixations as children (Figure 5). Adults were most likely to fixate the eye after fixating the beak or the mouth. They were unlikely to fixate the beak after the mouth or vice versa. In this respect, adults' fixation sequence is similar to children's.

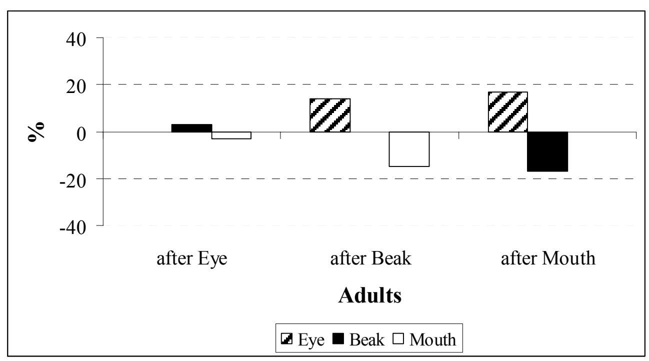

Figure 5: Likelihood of fixating one area of interest after fixation of another, relative to the baseline likelihood of fixating for adults

Comparison between children and adults

Adults fixated longer than children (adults: Mean = 29.2 seconds; children: Mean = 11.6 seconds), t (47) = -6.07, p < 0.001. Adults made more fixations than children (93 compared to 44, t (47) = -5.86, p < 0.001). Furthermore, none of the adults averted their gaze during the 60 seconds period, so children looked away significantly more often (t (47) = 2.72, p = 0.009) and for longer (t (47) = 1.95, p = 0.057).

Discussion

Overall there were no differences between the fixation patterns of those children who reversed an ambiguous figure and those who did not reverse. This suggests that eye-movements are not critical to the development of the ability to reverse. This was also confirmed by the fact that adults were able to reverse without focusing on all specific key areas (e.g. the mouth of the rabbit) of the ambiguous figure. For example adults were still able to reverse if they only focused between the beak and the eye area. However this does not mean that eye movements cannot facilitate reversal; appropriate scanning strategies may enhance the reversal process.

Our findings also revealed no differences in the eye movement patterns when children were uninformed versus informed about both relevant interpretations. This implies that being informed about the ambiguity does not trigger specific scanning strategies over the image. The same conclusion cannot be drawn from the sample of adults, since only two observers were naïve and had never seen this ambiguous figure before. The one adult who did not reverse in the uninformed condition did not fixate the mouth area and perseverated in the perception of a duck. However observers who had no problems reversing also did not necessarily fixate all areas. On the other hand those adults were aware of the ambiguity. It seems that once aware of the ambiguity it is not necessary to scan over the whole image to reverse. A larger sample of naïve adult observers would be needed in future research to clarify this issue.

Overall adults fixated longer and more frequently than children. However, this cannot explain why some children could not reverse since reversers looked as long and as often at the figure as non-reversers. In addition the fixation patterns of child reversers and non-reversers and adults were all similar: the eye was usually fixated between a fixation of the beak or of the mouth area.

Our findings also revealed that asking children to point out features did not induce more active search. There were no differences in the scanning patterns of children who participated in the Pointing and Verbal reversal tasks. There were also no significant performance differences between the Verbal and the Pointing tasks and no significant performance increases with age. This conflicts with previous findings of improvement in reversal ability between the ages of 3 and 5 (Doherty & Wimmer, 2005; Gopnik & Rosati, 2001). However, this is plausibly due to the small number of children per age group and the small number of children in the Reversal task verbal (N = 4) who reversed.

The lack of differences in eye-movement patterns between reversers and non-reversers suggests that adopting appropriate scanning strategies is neither necessary nor sufficient for reversal to occur. This leaves open the question of what causes the sudden development of reversal ability around five years. There is considerable evidence that children recognize that representations can have multiple interpretations between the ages of 3 and 4. This *meta-representational* understanding includes the conceptual understanding that an ambiguous figure can have two interpretations (Doherty & Wimmer, 2005), that people can have different mental representations of the same state of affairs (Doherty & Wimmer, 2005; Wimmer & Perner, 1983), and numerous related developments (e.g., Flavell, 1986; Flavell, Flavell, & Green, 1983; Gopnik and Astington, 1988). Even though children can recognize the possibility of multiple interpretations of an ambiguous figure, they nevertheless cannot perceive the reversal until one year later. This study examined the possibility that in addition children have to develop appropriate eye-movement patterns in order to reverse

Our results speak against this possibility for two reasons: 1) Most obviously, there were no differences in eye movement patterns between reversers and non reversers. 2) There were no differences in scanning strategies between observers who were uninformed and informed about the ambiguity. We conclude that eye-movements are not a major cause of reversal. It remains possible that eye-movements can facilitate reversal once the appropriate conceptual development has taken place. However, they do not appear to be necessary. This may be why previous studies with adults have produced consistently inconsistent results.

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