Children’s Perception and Understanding of Ambiguous Figures

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Contents

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Declaration

This thesis is submitted in fulfilment of the requirements for the degree of Doctor of Philosophy at the University of Stirling, United Kingdom. I declare that this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that this thesis has not been previously or concurrently submitted, either in whole or in part, for any other qualification at the University of Stirling or other institutions.

Publication and Conference Presentations

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Abstract

Background

Research has shown that people need to be pre-informed about the ambiguity in order to perceive both interpretations (reverse) of an ambiguous figure. Children younger than 4 years mostly do not experience reversal even when informed. This suggests that the processes involved in reversal develop at this age.

Aim

The aim of the studies reported here was to disentangle the cognitive processes (metarepresentation, executive function, mental imagery) and the role of eye-movements involved in reversal.

Method

Four studies (7 experiments), each involving around sixty 3-, 4- and 5-year-old children, using multiple tasks, were conducted. The primary tasks used were the Ambiguous Figures Production and Reversal tasks. The secondary tasks used were metacognitive, executive function and mental imagery tasks. New tasks were also implemented in order to assess reversal abilities.

Results

Between the ages of 3 and 4 children develop the basic conceptual understanding for reversal (Study 1), that an ambiguous figure can have two interpretations. This is associated with the understanding of false belief, synonymy and homonymy. Between the ages of 4 and 5 children develop inhibitory (Study 3) and image generation abilities (Study 4). These are key cognitive processes necessary for reversal. Contrary to previous research, when task demands were changed (Reversal Task Revised) children’s reversal is at ceiling by the age

of 5 (Studies 3 and 4). Eye-tracking data suggests that appropriate eye-movements, focusing on particular parts of the ambiguous figure, are not a primary causal factor in the development of reversal abilities (Study 4).

Conclusion

The ability to reverse develops in two stages. During stage 1 (between 3 and 4 years) children develop the necessary conceptual understanding that an ambiguous figure can have two interpretations (top-down knowledge). During stage 2 (between 4 and 5 years) children develop the necessary cognitive processes for reversal to occur (inhibition and image generation).

1 Introduction

Ambiguous figures, such as Jastrow’s (1900) well-known duck-rabbit, hold a fascination for psychologists; the physical properties of the figure remain unchanged, yet multiple interpretations can be perceived. This becomes apparent when ambiguous figures reverse (switch) from one interpretation to the other. How is this possible? When looking at the phenomenon of ambiguous figures first a distinction needs to be made between “seeing” and “seeing as”. The Austrian philosopher Wittgenstein (1958) convincingly stated that once we see an image as one thing and then as another thing we interpret it and see it according to how we have interpreted it. That is, if one is looking at an object one does not need to think of it, one just perceives something (e.g., a duck). In order to reinterpret it one must be thinking about what one sees. Taking this philosophical viewpoint into account Wittgenstein had already perfectly disentangled two important aspects involved in the phenomenon of ambiguous figures: the visual perceptual component and the cognitive component.

Researchers have tried to gain insight into the phenomenon of ambiguous figures for more than 100 years and have reached the conclusion stated by Wittgenstein. Reversing ambiguous figures involves both pure automatic passive perceptual processes (bottom-up processes) and active cognitive processes (top-down processes). Overall this is a conclusion too broad to be indicative.

If we want to get a more detailed view on the topic it needs to be investigated how the ability to reverse ambiguous figures develops. If we think of pure bottom-up perceptual processes there is no reason why children should not be able to perceive both interpretations of an ambiguous figure. The perceptual system mostly develops during infancy (e.g., Slater, 1998). Immaturities in the visual system have mostly disappeared by the end of the first year of life (Hainline, 1998). For example spatial vision and accommodation (adjusting the focus) develop rapidly over the first year of life; colour vision is present even in early infancy; binocular vision is near adult level in the second half of the first year; some oculomotor developments, (i.e.) fixations and saccades, are adult-like already in early infancy (Hainline, 1998). There is also evidence that no significant developmental changes occur from 3 years into adulthood for the susceptibility to geometrical illusions (Grieve, Hogben, & Williams, 1983) and that 4-year-old children are already susceptible to the Ebbinghaus Illusion (Káldy & Kovács, 2003). However, the Ebbinghaus Illusion effect is significantly smaller in 4-year-old children than in adults (Káldy & Kovács, 2003) and Kovács (2000) in contrast suggests that integrating illusory contours develops until the age of about 14 years - this is due to late maturation in parts of the occipital perceptual system (ventral visual stream).

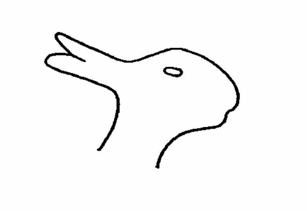
The literature about children's ability to perceive ambiguous figures tells a different story. That is, most children younger than 5 years old are unable to reverse ambiguous figures. Taking Kovács claim and a bottom-up explanation into consideration it may be that parts of the perceptual system are still maturing during childhood. These maturations, however, appear gradually and thus do not readily explain any sudden change in reversal abilities between the ages of 4 and 5. Furthermore, the Ebbinghaus Illusion and illusory contour integration are present in young children although they are weaker than in adults. Moreover, 3-year-old children are already able to perceive both interpretations of an ambiguous figure when reversal is induced externally by adding the contextual information of each interpretation (e.g., Doherty & Wimmer, 2005). Hence, these late developing aspects of the visual system cannot account for the lack of reversal in young children.

Why is it then that children below the age of 5 do not reverse ambiguous figures? This can only be explained in terms of additional cognitive abilities being involved in the reversal process. So far it is known that it is around the age of 5 that the interplay between bottom-up and top-down (cognitive) processes begins. Little is known about what are the particular cognitive processes leading to the ability to reverse. By using the developmental approach, where a timeline between non-reversers and reversers exists, it becomes possible to identify which cognitive processes are involved. Only a handful of studies have systematically dealt with development of reversals so far (e.g., Doherty & Wimmer, 2005; Gopnik & Rosati, 2001; Rock, Gopnik, & Hall, 1994) and rather similar methods have been used to investigate children's reversal abilities.

The main aim of this research, therefore, is to establish the cognitive development of the reversal process. By using a developmental approach it explores when those necessary abilities develop and it is attempted to disentangle the particular cognitive processes involved. At the end of the thesis a theoretically complete account of how children reverse will be provided. It will be argued that the development of reversal takes place in two stages. At stage 1, between the ages of 3 and 4, children develop a particular conceptual understanding of ambiguous figures (top-down knowledge). At stage 2, between the ages of 4 and 5, children develop the ability to reverse (cognitive processes). By using new methods it will be demonstrated that children develop the ability to reverse around 6 months earlier than previous research has suggested. It will also be shown how this relates to adult research on the topic. The developmental approach, by allowing us to identify the cognitive processes as they develop, provides unique and new insights into a long-studied phenomenon.

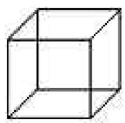
1.1 Review of Research with Adults on Ambiguous Figures

There are several common examples of ambiguous figures. These can be divided into three categories: 1) content ambiguous figures, such as the duck-rabbit (Jastrow, 1900) (Figure 1.1) man-mouse (Bugelski & Alampay, 1961) (Figure 1.2), wife-mother-in-law (Boring, 1930) (Figure 1.3); 2) perspective ambiguous figures, such as the Necker Cube (Necker, 1832) (Figure 1.4), Schröder Staircase (Schröder, 1858) (Figure 1.5), ambiguous triangles (Attneave, 1968) (Figure 1.6), overlapping squares (used in Long & Olszweski, 1999) (Figure 1.7); and 3) figure-ground ambiguous figures, such as the vase-faces (Rubin, 1958) (Figure 1.8), and the Maltese Cross (Köhler, 1940) (Figure 1.9). The phenomenon of ambiguous figures has been described for more than 100 years and there have been several explanations why ambiguous figures reverse (see Long and Toppino (2004) for an excellent review).


1.1 Duck/Rabbit


1.2 Man/Mouse


1.3 Wife/Mother-in-law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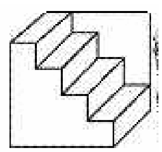
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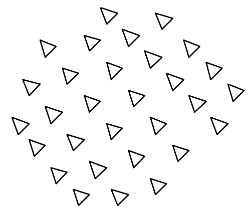
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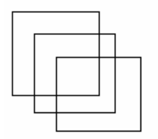
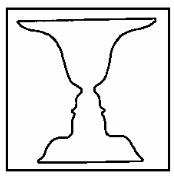
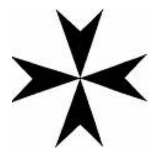

1.7 Overlapping Squares


1.8 Vase/Faces


1.9 Maltese Cross

"Bottom-up" versus "Top-down" theories have tried to explain the phenomenon of reversal over the past decades. Bottom-up means that processing is driven by lower order information. This process is controlled by incoming data, stimulus driven, and is a passive (automatic) process. According to this, reversing ambiguous figures happens to the viewer automatically by looking at the figure. Empirical support for the bottom-up theory comes from research which comprises three major topics: 1) Increased number of reversals over time, 2) Stimulus characteristics, and 3) Adaptation effects. Top-down means that processing is driven by higher order information. This process is controlled by previous experience, and is an active (cognitive) process. In this case, reversing ambiguous figures requires cognitive efforts from the observer. Evidence for the top-down theory of reversal can also be subsumed under three major topics: 1) Context Effects/Adaptation, 2) Awareness, Knowledge, Intention, and 3) Voluntary Control/Dual task load.

Each theory has its weaknesses and neither can explain the reversal phenomenon fully. A hybrid model of reversal (Long & Toppino, 2004), taking both processes into consideration, may therefore be plausible.

1.1.1 Bottom-Up Theory of Reversal

According to the bottom-up theory increased fatigue/satiation and decreased recovery in neural processes causes the ambiguous figure to change more frequently back and forth from one interpretation to the other over time. A good example of a fatigue process is the formation of afterimages. For example, when one's eyes are exposed to a hue (e.g., green) for a few seconds and then one looks away at a white background, one often sees the inverse colour (e.g., red). This happens because staring at one colour for an extended period fatigues photoreceptor cells in the retina and the opposite colour becomes prevalent. In the case of ambiguous figures cortical regions underlying one interpretation of an ambiguous figure satiate (interpretation A), which leads to a reversal to the second interpretation (interpretation B). This second interpretation (B) can be perceived until the cortical areas representing this interpretation are also satiated. Then the first interpretation (A) will be perceived again. However, the brain areas underlying this interpretation (A) have only partly recovered from their original satiation during this period. Therefore, the brain regions underlying interpretation A satiate more quickly than before. It follows that the perception of each interpretation becomes shorter (i.e., more reversals occur) because each interpretation satiates/fatigues more and more over time. This was originally proposed by Köhler and Wallach (1944).

Increased frequency of reversals over time

Increased frequency of reversals over time was taken as evidence for the bottom-up theory. This suggests that those cortical areas underlying each interpretation on the one hand fatigue/satiate more and on the other hand recover more slowly the longer the ambiguous figure is observed. This leads to an increased frequency of reversals when viewing an ambiguous figure (the Maltese Cross) over a few minutes (Köhler, 1940). However, when for example rotating the Maltese Cross so that the sectors of the cross fall on different retinal regions or for example moving the Necker cube to a different location in the visual field after a few minutes of viewing, the reversal rate falls back to its baseline (Howard, 1961; Köhler, 1940). Furthermore, when given rest the reversal rate drops (Spitz & Lipman, 1962). It is therefore concluded that the reversal rate is influenced by fatigue in cortical structures receiving retinal information, thus involving low-level processes.

The increased number of reversals could also be taken as evidence for the top-down theory, thus more reversals occur due to learning (i.e., increased experience with the stimulus) (Long, Toppino, & Kostenbauder, 1983). However, the top-down theory cannot explain the fact that the reversal rate drops after rest or when rearranging the stimulus presentation (e.g., through rotation).

Stimulus characteristics

Low-level stimulus characteristics such as intensity and illumination influence the reversal rate, suggesting a considerable involvement of sensory processes, which are early (low-level) cortical processes. The basic idea is that incomplete or less illuminated figures produce less physical stimulation and therefore sensory satiation takes longer, leading to fewer reversals. For example it has been demonstrated that incomplete ambiguous figures lead to a reduced reversal rate in comparison to complete figures (Babich & Standing, 1981; Cornwell, 1976). Furthermore, it has been found that the degree of illumination influences the reversal rate. That is, more reversals occur for a more strongly illuminated ambiguous figure than for a weaker illuminated one (Cipywnyk, 1959; Lynn, 1961).

It is difficult to see how the top-down theory can explain these findings.

Adaptation effects

Both theories bottom-up and top-down make opposite predictions about adaptation effects, both of which have received empirical support. Pre-exposure to an unambiguous interpretation of an ambiguous figure leads to adaptation on the part of the perceiver. This affects the initial perception of the ambiguous figure after the adaptation and the subsequent reversal rate.

According to the bottom-up theory, when showing the ambiguous figure after presenting one alternative interpretation, the other interpretation which has not been triggered is more likely to be perceived (Hochberg, 1950; Virsu, 1975; Von Grünau, Wiggin, & Reed, 1984). This implies that the adaptation to one interpretation leads to a fatigue/satiation in cortical areas underlying this interpretation. After the adaptation, when presenting the ambiguous figure, the other interpretation will be perceived initially because the cortical areas underlying this interpretation have not yet been fatigued/satiated.

The adaptation effect has an additional impact on the subsequent reversal rate when viewing the ambiguous figure. It has been demonstrated that the reversal rate (after adaptation) increases when a previously presented ambiguous adaptation figure and the subsequent presented ambiguous figure appear in the same retinal location. The reversal rate falls back on a baseline level when a previously presented adaptation figure and the subsequent presented figure appear at a different retinal location (Babich & Standing, 1981; Toppino & Long, 1987; Von Grünau et al., 1984). Again, as it is the case for the increased frequency of reversals, the fatigue of cortical structures depends on the retinal input.

The top-down theory of reversal (see section 1.1.2) predicts exactly the opposite. That is, after presentation of an unambiguous interpretation, the observer will perceive the corresponding interpretation initially when viewing the ambiguous figure. According to the top-down theory the presentation of one interpretation creates an expectancy- or priming effect towards the later presented ambiguous figure. This has been shown in research where context was manipulated before the ambiguous figure was presented (e.g., Bugelski & Alampay, 1961; Bruner & Minturn, 1955; Chastain & Burnham, 1975; Goolkasian, 1987).

For example it was demonstrated that the presentation of a biased version of an ambiguous figure before presenting the ambiguous figure leads to a perception of the interpretation in the same configuration (Goolkasian, 1987). It has been shown that presenting a segment of the man/mouse ambiguous figure which favours for example the man interpretation leads to a perception of the man interpretation when the full figure is visible (Chastain & Burnham, 1975). Context was also manipulated for example through presenting a series of aspects favouring one interpretation of an ambiguous figure, such as numbers for the ambiguous broken–B figure (which is either a B or a 13) (Bruner & Minturn, 1955) or a series of people for the man/mouse ambiguous figure (Bugelski & Alampay, 1961). In case of the former example the number 13, and in the latter one a man, is more likely to be perceived initially when presented with the ambiguous figure.

Manipulating the context is however different to unambiguous adaptation as investigated in favour for the bottom-up account. That is, for context manipulation there is no adaptation to an unambiguous interpretation of an ambiguous figure.

Two studies clarify this paradox of opposite evidence and account for a Hybrid Theory of Reversal (see section 1.1.4). It has been shown that the duration of adaptation influences which interpretation would be perceived initially after adaptation (Long & Olszweski, 1999; Long, Toppino, & Mondin, 1992). Short adaptation is “priming” the perceiver and leads to a “same configuration effect”, which supports the top-down theory. Long adaptation plausibly fatigues/satiates cortical areas underlying this unambiguous interpretation and leads to a “different configuration effect”, which supports the bottom-up theory. Furthermore, few reversals follow long adaptation periods because the brain areas representing the adaptation interpretation are fatigued. Hence, this interpretation is not “available” until the brain areas have partly recovered. On the other hand frequent reversals follow short adaptation periods (Long et al., 1992) because there has been no such long fatigue of either interpretation. Thus, either interpretation is equally “available”.

Long and Olszweski (1999) found different adaptation effects for different kinds of ambiguous figures. In particular, it has been revealed that viewers adapted well to unambiguous interpretations of perspective ambiguous figures (e.g., overlapping squares; Figure 1.10) and content ambiguous figures (e.g., wife/mother-in-law). When the ambiguous figures were presented viewers more likely perceived the other (non-presented) interpretation. However, viewers did not adapt to unambiguous interpretations of figure-ground ambiguous patterns used in a study by Horlitz & O'Leary (Figure 1.11). When the ambiguous figure was presented viewers were no more likely to perceive the same interpretation shown in the adaptation or the different interpretation. This suggests that some figures (e.g., overlapping squares) when presented unambiguously create a stronger adaptation effect than others (e.g., figure-ground patterns used by Horlitz & O'Leary, 1993) and therefore have different effects on which interpretation will be perceived afterwards. This is plausibly due to the fact that some ambiguous figures cannot be presented entirely unambiguously (i.e., figure-ground ambiguous figures), and this in turn may decrease the adaptability to an unambiguous interpretation, and hence may not effect the subsequent perception. That is, figure-ground ambiguous figures can never be presented in a fully unambiguous version and are always ambiguous to a certain degree, since neither figure nor ground can be entirely eliminated. For example for the vase/faces ambiguous figure, which is the most famous figure-ground pattern, imagine if the faces' outline was removed and only the vase presented (Figure 1.10). Through the outline of the vase someone can still perceive the two faces flanked on both sides, since the two noses and mouths are still present. Uninformed viewers may be still more likely to perceive the unambiguous interpretation of the adaptation figure but this interpretation is causing less strong adaptation. In order to be unambiguous, figure-ground ambiguous figures would have to be altered considerably (unlike the other types of ambiguous figures). This suggests that some ambiguous figures are better than others for certain types of studies and hence may influence the results considerably.

Figure 1.10: Vase outline, vase/faces ambiguous figure vs. unambiguous overlapping squares

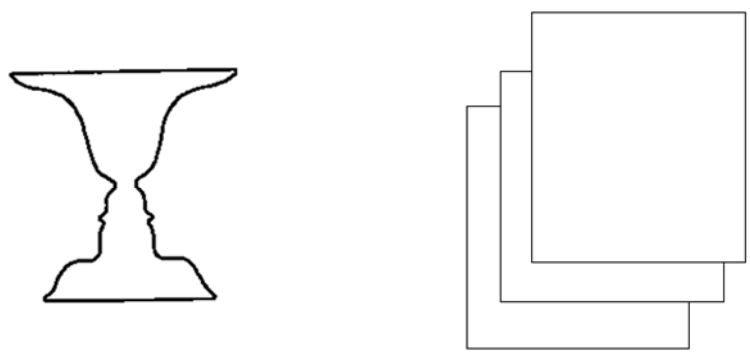


Figure 1.11: Figure-ground patterns used in Horlitz & O'Leary (1993) and unambiguous adaptation figure

1.1.2 Top-Down Theory of Reversal

1.1.2.1 Metarepresentation

Awareness, knowledge, intention

Research supporting the top-down theory suggests that three conditions are necessary for adults to experience reversal of ambiguous figures:

They must know that the figure is ambiguous (Girgus, Rock, & Egatz, 1977; Rock, Hall, & Davis, 1994; Rock & Mitchener, 1992), they have to be explicitly informed of the two different possible interpretations of the figures (Girgus et al., 1977; Rock et al., 1994; Rock & Mitchener, 1992), and must also have an intention to experience the alternative interpretation (Rock et al., 1994).

That is, in order to reverse, Rock and colleagues partly claim that people must know that the figure is ambiguous. In this case ambiguity means that a figure has two interpretations. Knowing that something has two interpretations implies knowing that it can represent two different things. The knowledge that something can represent two different things is ***metarepresentation***. Metarepresentation is defined as the ability to represent the representing relation itself (Pylyshyn, 1978), or representing a representation ***as a representation*** (Perner, 1991). Hence, Rock and colleagues' claim partly suggests that observers must be capable of metarepresentation in order to reverse ambiguous figures. This means that it is necessary to understand the relationship between the figure and its interpretations in order to experience reversal. The ability to metarepresent is taken for granted by adults, and therefore has not been emphasized as a top-down factor in reversal.

However, recognition of its central role can give much needed theoretical unity to the top-down account.

However, Rock and colleagues' findings do not clearly support their top-down account. For example Girgus, Rock, and Egatz (1977) demonstrated that when uninformed of the ambiguity only half of the participants were able to reverse an ambiguous figure, in contrast, when informed about the ambiguity and the two possible interpretations all of the participants reversed. Only one third of the participants who were uninformed about the ambiguity reversed in a similar study by Rock and Mitchener's (1992).

Although this implies that being informed about the ambiguity and about the two alternative interpretations is important for the initial reversal experience, it does not explain why in Girgus et al.'s study still 50 percent, and in Rock and Mitchener's study still one third of the uninformed participants experienced reversal. One possible explanation is that the involvement of partly automatic processes in the reversal process, which is suggested by the bottom-up theory of reversal, cannot be ruled out. An alternative explanation for these findings is that the participants may not have been entirely naïve to ambiguous figures. That is, it is likely that they had previous experience with some ambiguous figure since they are a widely known phenomenon.

Rock et al. (1994) demonstrated that when the participants know that the ambiguous figure is reversible and what the two possible interpretations are, they reversed less often if the intention to reverse was distracted by a different intention (Experiment 2). In their experiment all participants had full and explicit knowledge of the reversibility but the experimental group was given a distractor task with ambiguous figures, in which they were told to report binocular rivalry and not explicitly told to report any experienced reversals. The participants in the experimental condition received two pictures presented simultaneously (rivalry pairs): On one side a picture with a random pattern and on the other side an ambiguous figure was presented. The participants in the experimental group were instructed to report which picture dominated their perception and what they were seeing. Since it was possible that the participants in this condition perceived reversals but did not report them, a thorough interview phase with unambiguous versions of the ambiguous figure was conducted at the end in which they were questioned about what they had really perceived. A second control group received exactly the same rivalry pairs but they were explicitly told that the rivalry pairs are a distractor condition and instructed to report what they saw in the ambiguous figures. The results of Experiment 2 revealed that only 20% of the experimental group reported reversals versus 93% in the control group. This again gives strong evidence that reversal is an active process. On the other hand, Rock and colleagues' results also demonstrated that distracting the intention to reverse did not entirely prevent "unintended" participants from experiencing reversal, which cannot rule out the involvement of partly automatic processes contrary to Rock et al.'s top-down claim.

In order to investigate the role of knowledge and awareness in ambiguous figure reversal it is necessary to find a participant group which is naïve to ambiguous figures and hence not aware of the two interpretations beforehand. Since ambiguous figures are a widely known phenomenon in our society it is difficult to find naïve adult participants who have never had any experiences with ambiguous figures before. Even with novel figures it is likely that adult viewers suspect the possibility of more than one interpretation when asked to look at a figure and to report what they see. Alternatively, young children are unlikely to have had prior experience with ambiguous figures, which has lead to the first systematically developmental study of reversal (Rock, Gopnik, & Hall, 1994). Rock et al. found that uninformed 3- to 5-year-old children never reverse the duck/rabbit, vase/faces, and man/mouse ambiguous figures. Moreover, even when informed about the two interpretations in a detailed interview phase, the younger children were unable to reverse. Thus, children under the age of about 4 years are unable to reverse whether informed or not.

The bottom-up theory in terms of reversals due to neural fatigue processes cannot explain these age differences. During the ages of 3 and 4 children undergo rapid improvements in metarepresentational abilities (e.g., Wimmer & Perner, 1983). Metarepresentation has been shown to play a major role in children's understanding of other people's mental states. The best elaborated task assessing children's mental states is the False Belief task (Wimmer & Perner, 1983). The role of metarepresentation in reversal will therefore be investigated (Study 1). If Rock and colleagues are correct it is hypothesised that metarepresentation is a prerequisite, top-down ability required to reverse ambiguous figures.

1.1.2.2 Executive Functions

Voluntary control

Several studies have demonstrated that the reversal rate can be brought under voluntary control, which primarily supports the top-down theory. Studies have shown that observers are able to voluntarily inhibit one interpretation of an ambiguous figure when instructed to do so (e.g., Hochberg & Peterson, 1987; Liebert & Burk, 1985; Meng & Tong, 2004; Peterson & Gibson, 1991; Peterson & Hochberg, 1983; Strüber & Stadler, 1999; Suzuki & Peterson, 2000; Toppino, 2003). However, in the studies mentioned, participants were not fully able to control their reversal rate. In particular, even when instructed to hold one possible interpretation, observers reversed. For example in Strüber and Stadler's study over a 3 minutes period participants who were instructed to inhibit one interpretation were reversing content ambiguous figures around 1/3 less and perspective ambiguous figures 1/2 less than those participants who were not instructed to hold one interpretation. This suggests the additional involvement of some automatic processes, as predicted by the bottom-up theory.

Henceforth the question occurs whether inhibitory abilities are linked to the development of reversal. Maintaining one interpretation of an ambiguous figure may involve inhibiting the alternative interpretation. This inhibitory capacity might also be turned on to the current interpretation, thus inhibiting it, in order to facilitate reversal. If inhibition can prevent observers reversing, can increased executive control facilitate reversal? This will be investigated in Study 3.

Dual task load

Evidence in support of working memory being involved in reversal comes from studies which have demonstrated that the reversal rate is influenced when an additional cognitive distractor task is introduced. The assumption is that if reversal was a passive process, the reversal rate should not be influenced by additional cognitive load.

It has been demonstrated that the initial reversal is delayed and the reversal rate drops if observers are required to count digits backwards and to reverse simultaneously (Reisberg, 1983; Reisberg, & O'Shaugnessy, 1984) or if they have to keep a digit sequence in memory while reversing (Reisberg, 1983). Thus, diverting working memory to the distracter task disrupts reversals. The conclusion is that overall the distracter task is competing with the reversal task in working memory (Reisberg, 1983; Reisberg, & O'Shaugnessy, 1984).

Since it has been shown that working memory influences the reversal rate, the question occurs whether working memory capacity is linked to the development of reversal. The role of working memory in reversal will therefore be investigated in Study 3.

1.1.2.3 Mental Imagery

Rock et al. (1994) suggested that the viewer has to impose a mental image onto the stimulus in order to get it to reverse. This necessarily requires mental imagery abilities, in particular it requires visualisation of the image. That is, the viewer may have to be able to call up the image of the alternative interpretation and map that onto what is currently being seen.

A distinction needs to be made between reversing a mental image and using a mental image to reverse. Studies have demonstrated that it is possible to reverse a mental image (Mast & Kosslyn's, 2002; Peterson, Kihlstrom, Rose, & Gilsky, 1992). The interest of this research lies in Rock and colleagues' hypothesis that a mental image of the opposite interpretation is imposed onto the real image in order to reverse. Mast and Kosslyn (2002) revealed increased reversals in those people who were superior in mental rotation. In their study, using the young/old woman upside-down ambiguous figure, in a learning phase, participants uninformed of the ambiguity, were required to draw either the young woman or the old woman several times until they could accurately draw the figure from memory. After that, visual cues (fragments of the figure) were presented to the participant and the participant's task was to form the mental image corresponding to the one they had drawn (either of the young or of the old woman). The cues were additionally rotated from 0 degrees until 180 degrees, so that they rotated from a young woman to an old woman interpretation or vice versa. Then participants were asked what the configuration looked like. Out of 44 participants 8 were able to reverse while memorising the figure in the learning phase and 16 after mentally rotating it with the cues. Participants who reversed were furthermore significantly better in an image rotation task than non-reversers. This suggests that people with increased mental imagery abilities, such as image rotation, are more successful in reversing upside-down ambiguous figures. However, this might not generalise to more common ambiguous figures that do not require rotation in order to reverse.

The question therefore occurs, which imagery abilities are directly linked to the development of reversal? This will be investigated in Study 4.

1.1.3 Eye-Movements, Fixation and Attention

Toppino (2003) subsumed the evidence for the role of eye-movements, fixation and attention under the "focal-feature hypothesis". According to this, specific focal regions of an ambiguous figure favour different interpretations of the ambiguous figure. Which interpretation of an ambiguous figure will be perceived is dependent on which focal area is selected for primary or enhanced processing. Hence, reversal occurs through shifts in primary processing from one focal area to another. The selection of a specific area of the ambiguous figure can be achieved through fixation ***or*** attention.

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 reversals. Alternatively, reversals may cause observers to focus on particular parts of the image.

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). That is, some people are more likely to scan over an image than others, which plausibly influences reversal.

Thus, no clear pattern of results whether eye-movements precede or follow reversals has been found.

The role of eye-movements in respect to the top-down and bottom-up theories is unclear. It is possible that eye-movements induce reversal through low-level processes. Fixating on specific parts may trigger reversal. Reversal may occur automatically by looking at a part of the image - the processing starts from the stimulus. Alternatively, it is possible that with the awareness of both interpretations, someone may fixate specific areas, or may scan over the image, with the intention to experience reversal. In this case eye-movements may be a result of high-level processes – the processing starts from the schema. Evidence for the latter hypothesis comes from a very complex study by Gale and Findlay (1983). In their study the role of eye-movements and different versions of the wife/mother-in-law figure was investigated when viewing the complete figure, and when certain key features were removed. For each interpretation a specific fixation pattern was found (e.g., fixating the nose from the wife perspective produced more wife perceptions; fixating the mouth from the mother-in-law produced more mother-in-law perceptions). This indicates that different key features favour one or the other interpretation. When these key features were removed (e.g., the mouth of the mother-in-law or the nose of the wife) observers still fixated the area of the missing key features and perceived the interpretation consistent with the area. This implies that the fixation locations are not entirely determined by stimulus characteristics since the same pattern of fixation occurred when these stimulus characteristics were missing (e.g., the mouth of the mother-in-law or the nose of the wife interpretation). Thus, the observer has according to Gale and Findley (1983) an “internal schema” of the image and this is driving his/her fixation position. This is consistent with Rock et al.’s (1994) theory that one has to impose a mental image of the alternative interpretation onto the stimulus in order to reverse. In addition, it suggests that eye-movements were guided through higher order cognitive structures, which supports the top-down theory.

It was also demonstrated that in some cases before a reversal an eye-movement occurred from one specific key feature to another favouring the other interpretation. In this case eye-movements preceded reversals. On the other hand, in 68% of cases, reversal was not preceded by specific eye-movement patterns. Thus, in some cases eye-movements preceded reversals and in some cases reversals occurred without a particular change in fixation. These results suggest that eye-movements can play a role in reversal but are not a necessary prerequisite for reversal to occur.

A further group of studies emphasized the importance of ***attention*** towards specific areas in an ambiguous figure which favour a specific interpretation (e.g., Georgiades & Harris, 1997; Goolkasian, 1991; Kawabata, 1986; Tsal & Kolbet, 1985). Attention is different to fixation in the sense that attention can be shifted independently of fixation (e.g., Posner, 1980). It is, for example possible, to attend to the left and right of a fixation cross while the eyes are fixating the cross. Attention implies that higher level cognitive processes are involved.

Attention to key features allows one to perceive a specific interpretation (Tsal & Kolbet, 1985). It has been demonstrated that detecting a letter on a screen following an ambiguous figure (e.g. duck/rabbit) was faster when the letter appeared in the area (e.g., beak) which favoured the perceived interpretation (e.g., duck) than in the area which favoured the other interpretation (Tsal & Kolbet, 19985; Experiment 1). Furthermore directing attention to a specific part of the ambiguous figure (e.g., the duck's beak) through the presentation of a letter in this area shortly before the presentation of the ambiguous figure, increased the likelihood of perceiving the corresponding interpretation (duck) rather than the alternative one (rabbit) (Experiment 2). These results suggest that maintaining an interpretation fixes attention in a particular area (Experiment 1) and fixing attention influences the perceived interpretation (Experiment 2).

Georgiades and Harris (1997) demonstrated that the removal of certain key features from an ambiguous wife/mother-in-law figure affected which alternative interpretation would be perceived initially (Experiment 1) and led to fewer reversals in comparison to the wife/mother in law figure with no features removed. In a second experiment they showed that placing a fixation point near a critical feature increased the perception of the corresponding interpretation. As a result viewers tended to reverse less and perseverated in this corresponding interpretation. Also, reversals occurred significantly more often for a small than for a large ambiguous figure. This can be explained by the fact that in a large ambiguous figure key features biasing either interpretation are spatially more separated. The processing of the key features requires shifting attention or eye-movements between key features (see García-Pérez 1989; 1992, for a discussion), whereas a small ambiguous figure can be processed as a whole.

Similarly, Goolkasian (1991) revealed different effects on different sized ambiguous figures. The pre-exposure of a critical feature or a biased version of an ambiguous figure had a significant influence on the interpretation of a large ambiguous figure but not of a small one. Thus, for the large ambiguous figures the same interpretation was more likely to be perceived as favoured through the pre-exposure information. This can be explained because in larger figures distinct features of the image are more obvious and thus the pre-exposure to these features has a stronger effect. With larger figures it is not possible to fixate the entire image at once so selective processing of different parts is required.

García-Pérez (1989; 1992) addressed the issue of the difference and interaction between attention, fixation and eye-movements. García-Pérez (1989; 1992) reported that when a large ambiguous figure is viewed only the specific area which is fixated can be perceived in fine detail and the area around is blurred (this is the case only for large figures, because the distance between specific key features favouring different interpretations is greater). Hence, in order to perceive one specific interpretation of an ambiguous figure a specific key feature needs to be fixated, while the other key features favouring the alternative interpretation are more likely to fall into the blurred area. Here eye-movements are sometimes necessary to produce a reversal towards the alternative interpretation through moving the eyes towards another key feature in order to receive a fine detailed, non-blurred perception. However, this does not apply to small ambiguous figures, where all key features can be perceived in one fixation and no blur occurs. For small ambiguous figures attention can be shifted from one key feature to the other without the involvement of eye-movements.

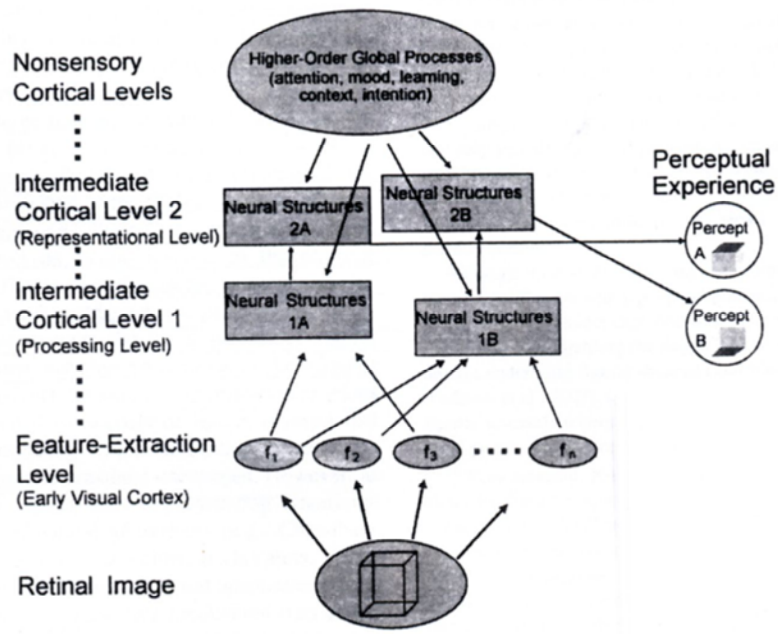
As discussed, the cause-effect relationship of eye-movements and ambiguous figure reversals cannot be determined on present evidence. There is also evidence which excludes the possibility of fixation or attention to certain key features being the sole cause of reversal. For example reversals occur together for two simultaneously presented ambiguous figures (Babich & Standing, 1981; Howard, 1961; Toppino & Long, 1987). It is impossible to look simultaneously at two presented ambiguous figures. Reversals also occur for afterimages and retinally-stabilised images (Gregory, 1970). A retinally-stabilised image is achieved through an experimental technique where the eye moves normally, but the movements do not produce corresponding shifts of the retinal image across the retina. Reversals also occur for remembered visual images (Mast & Kosslyn, 2002). Furthermore, people reverse after creating a mental image of an ambiguous figure (Peterson, Kihlstrom, Rose, & Glisky. 1992).

Developmental work can make a unique contribution to this debate examining fixation patterns around the age children begin to reverse. If eye-movements are an important factor in experiencing reversal, a change in the pattern of fixation would be expected at or around the time children become able to reverse. In this research therefore the question whether eye-movements play a significant role in reversal is investigated. This is explored in Study 4 below.

1.1.4 Hybrid Model of Reversal

To summarise the ambiguous figures literature, neither kind of theory - “bottom-up” or “top-down” - can fully explain the reversal of ambiguous figures. Therefore Long and Toppino (2004) suggested a “Hybrid-Model of reversal” which includes several levels of information processing that involve both bottom-up and top-down processes. Their model suggests that competing perceptual experiences are mediated at a higher representational level which is associated with structures which are located relatively high in the visual system (Toppino & Long, 2005). In Long and Toppino’s hybrid model (Figure 1.12) at an early feature-extraction level stimulus features (e.g. orientation, depth, size, motion …) are localized to specific retinal areas. Intermediate cortical areas on the processing level receive input from this feature-extraction level. Intermediate cortical areas on the representational level receive input from the processing level and from higher nonsensory cortical levels in the system, thus, from higher order global processes (e.g. attention, mood, learning, context, intention). Both input from processing level and higher order processes can differentially affect these intermediate neural structures on the representational level and thus, the reversibility of an ambiguous figure.

Figure 1.12: Hybrid Model of Reversal (Long & Toppino, 2004)



Evidence for a Hybrid theory comes from studies that demonstrated that the perception of one interpretation of an ambiguous figure can be brought under voluntary control, but the degree of control is dependent on specific stimulus characteristics. In this line of evidence, experiments were conducted with a manipulated Necker cube, or with manipulating ambiguous motion, so that one interpretation (direction) was more prevalent than the other.

For example one direction of the Necker cube appeared more forward than the other direction or one direction of the ambiguous motion stimulus was stronger favoured. In addition, participants were asked to hold the perception of a particular interpretation (direction). The results revealed that it was easier to hold one interpretation (direction) which was favoured by the manipulation and more prevalent than to hold the other less favoured interpretation/direction (Hochberg & Peterson, 1987; Peterson & Hochberg, 1983; Suzuki & Peterson, 2000; Toppino, 2003). Thus, it is possible to control the reversal rate but this is dependent on stimulus characteristics.

Furthermore, it has been demonstrated that the reversal rate increased significantly over a two minute viewing period, suggesting increased fatigue/satiation, which supports the bottom-up explanation. On the other hand the number of reversals in a weekly session increased steadily across four weeks, suggesting that learning took place, which supports the top-down explanation (Long, Toppino, & Kostenbauder, 1983).

1.2 One Problem of the Ambiguous Figures Literature

1.2.1 Distinction between Initial Reversal and Subsequent Reversal

A distinction has to be made between two different kinds of ability being involved in reversal:

a) The ability to perceive both alternative interpretations (to reverse at all).
b) The ability to subsequently and voluntarily reverse back and forth in a given time period.

The ability to perceive both alternative interpretations cannot be taken for granted even for adults. As Rock and colleagues have demonstrated, some naïve adults, who are unaware of the ambiguity, were not able to reverse an ambiguous figure. Long and Toppino (2004) differentiated between the terms ambiguity and reversibility. Ambiguity refers to the fact that one stimulus can produce more than one interpretation. Reversibility on the other hand involves the question of "why the system essentially abandons the perceptual interpretation (Percept A or Percept B) first reached after it has solved the ambiguity problem … and then subsequently alternates between the interpretations" (pp. 761). Both do not necessarily involve the same processes or the processes in the same manner (see Hybrid model, section 1.1.4) (Long & Toppino, 2004).

1.2.1.1 Distinction made in the Current Research

It is important to make this distinction because the ability to initially perceive both interpretations (ambiguity) is a prerequisite for reversing back and forth between the two interpretations (reversibility). As mentioned above, ambiguity reflects the fact that one stimulus can have two different interpretations. Understanding this may require metarepresentation. Metarepresentation then in turn may be a prerequisite for the reversibility. Once the understanding of ambiguity is resolved it is then necessary to address what directly causes the reversibility between two interpretations.

1.2.1.2 Type of Stimuli used in the Current Research

In the current research two different types of ambiguous figure were used: three content- (duck/rabbit; man/mouse; seal/donkey) and one figure-ground (vase/faces) ambiguous figures (see Appendix). There are three reasons why these figures were chosen:

1) Extended piloting revealed that these figures are of equal difficulty and perceivable for children aged between 3 and 5 years. Furthermore, the duck/rabbit, man/mouse and vase/faces ambiguous figures have been used in previous studies carried out with children between 3 and 5 years.
2) Since content is a major factor for top-down processes and it was of interest which cognitive processes are involved in reversal, it makes sense to use predominantly content ambiguous figures.
3) Perspective ambiguous figures were not used because the competing interpretations are hard to describe. The disambiguation process is therefore limited. On top of this, even if children reverse, how would they verbalise their reversal? Children within the investigated age range are not able to verbally express the perceptual experience about the 3-dimensionality of a (e.g.) Necker cube. Without being instructed which label to use for either perceived interpretation even adults would have difficulty to verbalise their perception.

1.3 Children's Understanding of Dual Representation and Referential Ambiguity

Since younger children do not reverse ambiguous figures, it is plausible that children may need to develop an understanding of ambiguity in order to reverse. Before investigating this experimentally it is necessary to address the different forms of children's understanding of ambiguity which have been explored in the literature so far, and furthermore to provide reasons why some may be more relevant for reversing ambiguous figures than others. In order to do this it is necessary to distinguish between the developments of an understanding of ***dual representations*** and the understanding of ***referential ambiguity***. Each develops at different times throughout childhood and involves different forms of ambiguity.

Ambiguous figures are examples that require an ***understanding of dual representation***. That is, in order to understand ambiguous figures children need to understand that one stimulus can have two distinct interpretations. For example the duck/rabbit figure can represent a duck or a rabbit. Both the duck and the rabbit are equally valid interpretations - either interpretation is possible and appropriate. The crucial argument here is that for ambiguous figures there are two equally valid and correct interpretations of one stimulus.

On the other hand, ***referential ambiguity*** occurs when only one interpretation is correct but it is not obvious which one (see Robinson & Whittaker, 1987 for an overview). That is, for example ambiguous utterances, where there is more than one valid interpretation but the speaker has one in mind and the listener does not have enough information to determine which one it is. For example if someone refers to "the red one" in an array of red objects, it is impossible to infer which object is referred to, but only one object is referred to which is the "correct" one. Furthermore, an example of the understanding of the effect of ambiguity on another person is to ask "will the person know to which object I am referring to, when I say the red one?" [Correct answer: "No"]. This requires inferences about the knowledge state of another person based on ambiguous information. Making inferences about the knowledge of another person involves an additional understanding of another person's mental state.

Moreover, not only people's utterances can be ambiguous, visual input can be also ambiguous (uninformative). If someone sees only a small part of an object one might not exactly know what it is. This has been investigated with the "Droodle task" which will be described in more detail below. The crucial aspect here is that in this case there is only one valid interpretation (the identity of the object) and the viewer does not have enough information to determine what the object really is.

Thus, when referring to the term ambiguous it is necessary to distinguish between ambiguous figures (two equally valid interpretations), ambiguous utterances (more than one valid interpretation, the speaker has one in mind but the listener does not have enough information to determine which one it is), and ambiguous/uninformative visual information (one valid interpretation that cannot be determined on present evidence). The latter two cases pose similar problems - ambiguous utterances depend on the speaker's intention whereas uninformative visual information depends on objective identity.

1.3.1 Understanding of Dual Representations

There are several lines of evidence demonstrating the development of preschool children's understanding of multiple representations/interpretations/perspectives being applicable to a single stimulus. Children's understanding of multiple representations was examined in the context of mental representations (e.g., Gopnik & Astington, 1988; Wimmer & Perner, 1983), models as representations (e.g., Blades & Cooke, 1994; DeLoache, 1987; DeLoache, 2000), objects as representations (e.g., Flavell, Flavell, & Green, 1983; Flavell, 1986), linguistic representations (e.g., Collins & Robinson, 2005; Doherty, 2000; Doherty & Perner, 1998; Perner, Stummer, Sprung, & Doherty, 2002), spatial representations (e.g., Flavell, Everett, Croft, & Flavell, 1981; Masangkay, McCluskey, McIntyre, Sims-Knight, Vaughn, Flavell, 1974), and pictorial representations (e.g., Liben, 2003; Robinson, Nye, & Thomas, 1994; Slaughter, 1998; Zaitchick, 1990).

Children as young as 3 years are able to find the true identity of dual identity objects. This was investigated by the "appearance-reality distinction" (Flavell, 1986; Flavell, Flavell, & Green, 1983). For example 3-year-olds understand that a dual identity object which looks like a rock, can be a sponge after having touched it. However, after having experienced both perspectives, only 4-year-olds correctly state that the object's identity is a piece of sponge and not a rock although it looks like a rock. Children around the age of 3 also perfectly understand that when the picture of a turtle is placed in front of them, with the feet closer to the child, that the turtle is standing on its feet from the perspective of the child (Flavell, Everett, Croft, & Flavell, 1981; Masangkay, et al., 1974). When the picture is turned upside down, so that the back is closer to the child, the child also understands that the turtle is now lying on its back from the perspective of the child. However, when 3-year-old children need to integrate two different perspectives in one situation, problems occur. Difficulties occur for example when the child is asked from which perspective the experimenter sees the turtle (who is sitting opposite the child), whether on its feet or back. The understanding that the same object can represent two perspectives arises around the age of 4. Both appearance-reality and perspective-taking require metarepresentation. That is, children need to understand the relationship between the object and the two interpretations (perspectives) referred to.

Related to the development of children’s perspective-taking skills and the appearance-reality distinction is the understanding of false beliefs (Gopnik & Astington, 1988; Moore, Pure, & Furrow, 1990), which develops at the same age (Wimmer & Perner, 1983). The False Belief task requires the child to accurately represent a person’s false belief, which contrasts to that of the child’s. For example the child needs to understand that a person thinks that a piece of chocolate is in the cupboard where the person last saw it, rather than in the actual new location which is only known to the child. In order to solve the False Belief task the child needs to correctly infer the person’s mental state, which Perner (1991) referred to as metarepresentation (forming a representation of a representation). At about the same age that children become able to ascribe false belief to others they also become able to attribute false beliefs to themselves (Gopnik & Astington, 1988).

Related to children’s false belief understanding is the understanding of synonymy (Doherty & Perner, 1998) and homonymy (Doherty, 2000), which require metalinguistic awareness (Doherty, 2000; Doherty & Perner, 1998; but see Perner, 2000). For example, children at the age of 4 understand that “bunny” and “rabbit” (synonyms) refer to the same object/situation, or that the word bat (homonym) can refer to a flying mammal or to a piece of sports equipment depending on the context. In order to understand synonymy and homonymy it is necessary to understand the representational relationship between the word and its referent. Similarly, there is evidence that children between the ages of 4 and 5 are able to apply a one-to-one mapping between words and their referents (Collins & Robinson, 2005; Experiment 2).

Research also focused on the relationship between children's understanding of mental representations and pictorial representations (Charman & Baron-Cohen, 1992; Leekam & Perner, 1991; Leslie & Thaiss, 1992; Zaitchik, 1990). In a "false-photo" task (Zaitchik, 1990), a photo was taken of a scene (e.g., Bert lying on the mat) and while the photo developed the scene was changed (e.g. Bert goes inside and Big Bird lies on the mat). Three-year-old but not 4-year-old children wrongly predicted that the photograph depicts the changed scene (Big Bird lying on the mat). In addition, this performance was of similar difficulty to false belief performance. Therefore Zaitchik (1990) argued that understanding pictorial representations are part of a general problem with understanding of representations developing around the age of 4. However, there is evidence that understanding the false-photo and the false belief task do not share a common underlying mechanism (Charman & Baron-Cohen, 1992; Leekam & Perner, 1991; Leslie & Thaiss, 1992; Slaughter, 1998). Slaughter (1998) found that there is no significant association between an understanding of false beliefs and false photos. Moreover, it was demonstrated that in the false photo task, directing attention to the picture when the test question was asked improved performance, and the photograph task was easier than the false belief task. It is therefore concluded that children experience "referential confusion" over whether the test question refers to the reality or to the situation in the photograph (Slaughter, 1998). It was also shown that children with autism who have a deficit in understanding false beliefs do not show this deficit in understanding false photos (Leekam & Perner, 1991; Leslie & Thaiss, 1992) or false drawings (Charman & Baron-Cohen, 1992). This suggests that they do not rely on a common understanding of representations. It is therefore crucial to distinguish between understanding of mental representations or other forms of metarepresentation and pictorial representations in the case of false photos. Mental representations such as false beliefs require an understanding that two distinct representations of current reality exist, the false belief (e.g., the chocolate is in drawer A) misrepresents reality (e.g., the chocolate is in drawer B). However, in the case of false photos the photo is not a misrepresentation of reality but a representation of ***former*** reality (e.g., Bert lying on the mat). Thus, in the case of false photos no misrepresentation of reality, which has to be evaluated against the reality, occurs. In the False Photo task it is therefore plausible that children may require an accurate memory of past representations rather than metarepresentation as such. Similarly, Robinson, Nye, and Thomas (1994) demonstrated that 4-year-old children perfectly understand picture-referent relationships (e.g., they understand that an object can be represented by a picture). However, children assume that features of pictures change when their referents are changed or vice versa. Robinson et al. (1994) suggest that although preschool children understand picture-referent relationships, they still have difficulties holding in mind distinct properties of a picture and its referent.

Despite this impressive competence at using pictorial representations, it remains unclear when children are able to properly understand the representational nature of pictures. This current research therefore aims to shed more light into the development of children’s pictorial representations by using ambiguous figures. Ambiguous figures are ideal for exploring children’s understanding of pictorial representations since two distinct interpretations that are equally valid refer to one stimulus. In order to understand this one must represent the representational relationship between the stimulus and its two interpretations.

Liben (2003) also looked at children's understanding of photographs as representations. Three-, 5- and 7-year-old children were shown pairs of photographs that differed in vantage point (different viewing distance, viewing angle, and viewing azimuth). The children's task was to state if and why there was a difference in the photograph pairs. It was found that most of the 3-year-olds stated that there was no difference between the photograph pairs, half of the 5-year-olds and most of the 7-year-olds correctly stated the difference. Moreover, most of the younger children attributed the difference to something in the referent (e.g., something that changed its place) rather than in the vantage point (e.g., the photographer moved further away with the camera). This suggests that 3-year-olds have difficulty when the same scene is depicted from different vantage points and they further justify their answers on referential content. However, one limitation of this study is that it might have been difficult for 3-year-olds to verbally express the differences in vantage points and therefore the study may underestimate children's understanding.

Further to the use of pictures as representations, children as young as 3 years are able to use models as representations in order to find an object hidden in a corresponding room (e.g., DeLoache, 1987; DeLoache, 2000). However, DeLoache (2000) demonstrated that when the physical salience of the model is decreased (by placing it behind a window) even 21/2-year-old children can accurately use the model to infer the hiding location in the real setting. On the other hand, when the physical salience of the model is increased (by allowing the child to play with it) even 3-year-old children have problems using the model in order to infer the hiding location (DeLoache, 2000). This implies that 3-year-old children still have problems in understanding dual representations, when the model's salience as a representation of something is increased.

Moreover, Blades and Cooke (1994) demonstrated that children understand element-to-element correspondences by the age of 3 but this is dependent on the uniqueness of the hiding location. For example when an object was hidden in a unique hiding location (wardrobe, bed), 3-year-old children had no problems using these correspondences. However, when there was no unique hiding location (two identical chairs) and the object was hidden underneath one of the two, only 4- to 5-year-olds understood the correspondence. This suggests that it is not until at least 4-years that children can use geometric correspondences between two spaces.

Using geometric correspondences is however not necessarily evidence for children's understanding of pictorial representation. That is, understanding correspondences does not require children to understand that one represents another (Perner, 1991). For example Perner (1991) states that British houses built next to each other often have identical layouts. If you visit your neighbour it will be easy for you to find the bathroom because it will be at the same location as in your house since the two houses correspond in their room arrangements. If you have knowledge about these correspondences you can use this knowledge for example to find the bathroom. However, this does not imply that your house represents the neighbour's house.

These examples show that there is broad evidence that children at the age of 4 develop the understanding that multiple representations are applicable to a situation, to a word, or to an object. On present evidence it is however not clear when children have a representational understanding of pictures. Children at the age of 4 understand picture-object relationships but still think that the picture changes when the object changes or vice versa (Robinson et al., 1994). Children at the age of 4 understand false-photos (Zaitchik, 1990). However, when an attention-directing method is used already 3-year-old children pass the False-Photo task (Slaughter, 1998) and it is concluded that false photos cause referential confusion rather than measuring pictorial representation (Slaughter, 1998). Furthermore, in Liben's (2003) Photograph task it might have been difficult for the younger children to verbally express differences in vantage points shown on pictures. Moreover, being able to use correspondences does not imply that children understand that one represents the other (Perner, 1991).

In this research it is therefore anticipated to gain more insight into children's understanding of pictorial representation with the use of ambiguous figures.

1.3.2 Understanding of Referential Ambiguity

The understanding of referential ambiguity develops later. There are several lines of evidence demonstrating children's difficulty with evaluating ambiguous information. Five- and 6-year-old children, when ambiguous information is given, tend to overestimate their knowledge of which object is referred to (e.g., Beck & Robinson, 2001; Robinson, Thomas, Parton, & Nye, 1997). However, when their knowledge is contradicted by adding unambiguous information in favour of a different object, 5- and 6-year-old children have no problems in reconstructing their knowledge, and correctly identify the object referred to (Beck & Robinson, 2001; Experiment 1). In addition, 5- and 6-year-old children are able to integrate information over two successive ambiguous messages in order to correctly identify an object (Beck & Robinson, 2001; Experiment 2). However, 5- and 6-year old children are less likely than 7- and 8-year-olds to actively search for further information in order to disambiguate a situation (Beck & Robinson, 2001; Experiment 3). This suggests that children from the ages of 5-6 onwards have an understanding of ambiguity. Yet they still overestimate their knowledge based on ambiguity, and they do not actively try to disambiguate a situation. Disambiguation develops later.

Robinson and Whittaker (1985) reported that correct response to ambiguous messages is based on an understanding of uncertainty. They demonstrated a relation between correct responses to ambiguous messages and correct judgements about the uncertainty about these messages. In particular, awareness of uncertainty preceded giving the correct response to an ambiguous utterance. It is suggested that before children understand that ambiguous messages require further evaluation, they try to make the best interpretation possible out of the ambiguous input (Robinson & Robinson, 1982).

Shultz and Pilton (1973) reported that children detect phonological, lexical, surface, and deep-structure ambiguities at different times. The former develops between the ages of 6 and 9, lexical ambiguity increases linearly between 6 and 15, and surface and deep-structure ambiguities do not occur before the age of 12 (cited from Shultz, 1974). Shultz (1974) found that 6-year-olds, but not 8-year-olds, have, for example, difficulties in detecting the hidden meaning of ambiguities in riddles (e.g. "Why did the farmer name his hog Ink?" … because he kept running out of the pen).

To summarize, from around the age of 6 onwards children become able to understand the nature of ambiguity, in particular ambiguous messages. They understand that it is impossible to identify a referent based on ambiguous information. More complex forms of ambiguity, such as, for example, active disambiguation of a scene (Beck & Robinson, 2005) and identifying ambiguities in riddles (Shultz, 1974) still continue to develop afterwards.

Around the same time that children can understand ambiguous utterances children develop the understanding of uninformative (ambiguous) visual input. However, there is inconsistent evidence when children begin to understand the effect of uninformative input on the knowledge state of another person (Chandler & Helm, 1984; Perner & Davies, 1991; Ruffman, Olson, & Astington, 1991; Taylor, 1988). In a typical "Droodle task" children are shown a non-descriptive, ambiguous portion of a picture and are asked if someone who only sees this portion will be able to infer the picture's identity [correct answer: "No"]. Overall, children from the ages of around 5 onwards are able to understand that, based on uninformative (ambiguous) information, it is impossible to judge the identity of a picture. It has been argued that an understanding of the effect of ambiguity requires false belief understanding, a mentalistic understanding of the knowledge state of another person, (Perner & Davies, 1991; Ruffman, Olson, & Astington; 1991) and, on the other hand, that children as young as 4 still think that "seeing leads to knowing" (Taylor, 1988) and they have not yet acquired a proper understanding of the effect of ambiguity.

Understanding ambiguous utterances and the understanding that an uninformative portion does not lead to knowledge of the identity of an object are important examples of children's understanding of mental representation which develop around the ages of 5 and 6. Thus, children's understanding of referential ambiguity develops one to two years later than children's understanding of dual representation. These findings suggest that children by the age of 4 acknowledge that a word, scene, or an object etc … can have two interpretations but that it is more difficult to judge the effect of ambiguous utterances on the mental state of the listener or of uninformative information on a viewer. The latter two cases require a more sophisticated understanding of the knowledge state of another person based on ambiguous or uninformative input, whereas the former case requires “only” an understanding that a stimulus, scene, object, situation, etc… can have two interpretations. This may explain the gap of 2 years. This phenomenon, although interesting, is beyond the scope of this work.

1.4 Children’s Understanding and Perception of Ambiguous Figures

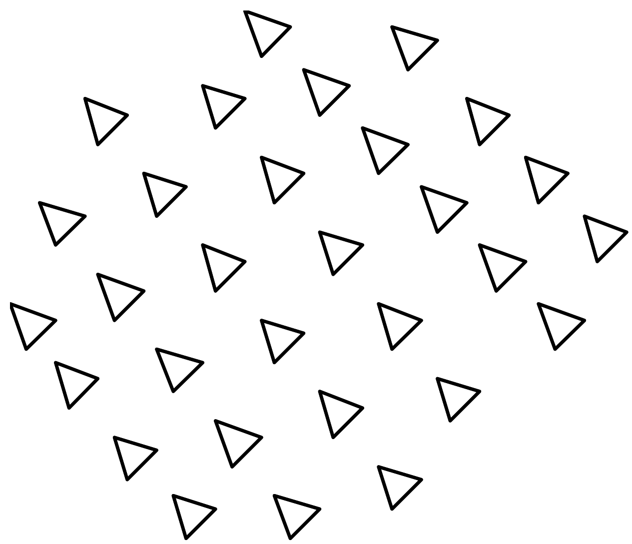
Only a few studies have systematically looked at children’s understanding and perception of ambiguous figures (Bialystok & Shapero, 2005; Carpendale & Chandler, 1996; Doherty & Wimmer, 2005; Gopnik & Rosati, 2001; Mitroff, Sobel, & Gopnik, 2006; Ropar, Mitchell, & Ackroyd, 2003; Rock, Gopnik, & Hall, 1994; Sobel, Capps, & Gopnik, 2005).

Rock, Gopnik and Hall (1994) examined spontaneous reversals in 3- to 4-year-old children. Children of this age are unlikely to have had previous experiences with ambiguous figures and hence are completely naïve participants. If knowledge of reversibility and of the two interpretations is necessary for reversal, we would expect children to be unable to reverse when uninformed. In their study children were given a Reversal task where they had to look at an ambiguous figure for 60 second and report any perceived change of interpretations. In particular, while viewing the ambiguous figure, children were asked “what do you see?” after 5, 30 and 60 seconds. Those children who reported both interpretations during the 60 seconds (e.g., “duck/rabbit”) were deemed reversers. Their results revealed that preschool children who were not initially informed about the ambiguity of an ambiguous figure do not perceive changes in interpretation over a one minute viewing period. When informed about the ambiguity beforehand, 25% of 3-year-olds and 62% of 4-year-olds were able to reverse an ambiguous figure.

In the context of bottom-up and top-down explanations, the bottom-up theory based on neuronal fatigue/satiation cannot account for these findings. That is, if reversal is purely due to neuronal fatigue/satiation processes then even young children should experience reversal. The evidence that children before the age of around 4 are unable to reverse and only informed 4-year-olds reverse favours the top-down account. This suggests that additional active cognitive processes are necessary for reversal to occur. The finding that children younger than about 4 years do not reverse thus suggests that a conceptual deficit may underlie reversal. That is, it is possible that younger children may not be able to understand the ambiguous nature of the stimulus itself even when it is clearly demonstrated to them. Children may need to develop the understanding that an ambiguous figure can represent two different things. Gopnik and Rosati (2001) therefore investigated what conceptual understanding children from 3- to 5-years may lack. They repeated the Reversal task (Rock, Gopnik, & Hall, 1994), adding a False Belief task (Experiment 1) and a “Droodle” task (Experiment 2). Gopnik & Rosati (2001) found no correlation between performances on the False Belief task and the Reversal task. The Reversal task was considerably harder (Experiment 1). In Experiment 2 they gave children a Droodle task and compared it to reversal. In this version of the Droodle task the child was initially informed about the identity of the stimulus. After that s/he needed to correctly judge that an uninformed person will not know what is depicted when only uninformative (ambiguous) information was available. Typically children up until the age of 5 years wrongly judge that a viewer would know what the full picture was. In their experiment performance on the Droodle task correlated well with performance on the Reversal task ($\phi = 0.86$, $p < 0.001$) and performances hardly differed. Gopnik & Rosati (2001) therefore suggest that reversal "may depend on a broader understanding of ambiguity" (p.182).

The strong association between the two tasks is surprising because the Droodle task and Reversal task involve two different abilities. Both require to deal with visual ambiguous (uninformative) information, however, each has additional different requirements. The Droodle task requires children to make inferences about the information of another person, the Reversal task does not. That is, the Droodle task requires a judgement of how another person deals with visual ambiguous (uninformative) information. Alternatively, the Reversal task requires mental action in order to perceive the two interpretations, the Droodle task does not. For example if one looks at these ambiguous triangles below (Figure 1.13) it becomes apparent that the observer him/herself can decide in which direction the arrows are facing. Hence, active mental action creates the reversal of the arrows. This implies that the reversal process itself is a skill on the part of the perceiver and not a conceptual understanding. It is therefore suggested that a conceptual understanding of ambiguous figures is a necessary prerequisite but that the immediate cause for reversal is an additional process that allows reversal.

Figure 1.13: Ambiguous triangles (Attneave, 1968)



Doherty and Wimmer (2005) therefore examined the claim that the ability to reverse ambiguous figures is dependent on a broader understanding of ambiguity. In an unpublished study we compared performance on the Reversal, False Belief and Droodle tasks in a sample of sixty-two 3- to 5-year-olds. The results revealed that the Reversal and Droodle tasks were of equal difficulty, but were only weakly related ($\phi = 0.26$, $p < 0.05$).

In Experiment 1 in Doherty and Wimmer's study a novel Production task for ambiguous figures was designed. This Ambiguous Figures Production task assesses the ability to acknowledge that there are two interpretations of an ambiguous figure. This task was adapted from Doherty and Perner's (1998) "Say Something Different Task" used to examine children's understanding of synonymy. In our novel Production task children were first informed about the ambiguity of the figure and its two interpretations. Then the experimenter showed an ambiguous figure and provided one interpretation, e.g. "duck", ["I say it's a duck, what else can it be?"]. The child's task was to name the alternative interpretation ["rabbit"]. After some intervening trials, the experimenter showed the same figure but provided the other interpretation, for example "rabbit", ["I say it's a rabbit, what else can it be?"]. Again the child had to name the alternative interpretation ["duck"]. Children were scored as successful on that item if they could supply the alternative interpretation on both occasions. This criterion was necessary since children would be successful half the time by providing their favoured interpretation regardless of what the experimenter said. The findings from our Ambiguous Figures Production task revealed that around 40% of 3-year-olds, 80% of 4-year-olds and 90% of 5-year-olds were able to produce both interpretations of an ambiguous figure. This suggests that children are able to acknowledge both interpretations of an ambiguous figure at around the age of 4.

This task bears similarities to a task used by Carpendale & Chandler (1996), one of the few other studies to have exposed children to ambiguous figures. In their procedure of their Experiment 1 children were shown an ambiguous figure and witnessed one doll calling it (e.g.) a duck, and another doll calling it a rabbit. They were then asked if this was "okay", and why. In order to pass children had to say it was okay, and justify this "as due to the ambiguous nature of the … object" (p.1696). Five- and 6-year olds may have difficulty articulating their understanding, and unsurprisingly, only 2 out of 10 children passed this composite measure. Carpendale & Chandler do not report how many agreed that the different judgements were okay. Their task perfectly fits into the research on referential ambiguity in the sense that children need to understand that people may make different interpretations of an ambiguous stimulus.

In Experiment 2 Doherty and Wimmer (2005) compared children's performance on the False Belief and Ambiguous Figures Production tasks to the Reversal of ambiguous figures and performance on the Droodle task. Experiment 2 had two main findings. First, it was found that the Droodle and the Reversal tasks were of equal difficulty, which fits into Gopnik and Rosati's results. On the other hand the two tasks were only weakly associated ($\phi = 0.31$, $p < 0.05$) and did not remain significantly associated after partialling out age. Second, it was found that reversal does not occur until about a year after children pass the False Belief and Production tasks, suggesting that these tasks mark a prerequisite. Because reversal did not correlate with either of these tasks, Doherty and Wimmer suggested that the prerequisite is not required for reversal as such, but for a quite different process that will result in reversal.

It has been concluded that the understanding of the ambiguous nature of the stimuli is necessary but is not sufficient to achieve reversal. Some additional cognitive process is required. The lag of one year between the ability to understand ambiguous figures and the ability to reverse can be explained by the difficulty of this additional process.

A recent study by Mitroff, Sobel, and Gopnik (2006) investigating 5- to 9-year-old children's spontaneous and informed reversals, suggests that one third of the children within this age range are able to spontaneously reverse when uninformed about the two possible interpretations. According to their results, out of 34 children 12 children spontaneously reversed, 20 reversed when informed about the two interpretations and 2 did not reverse at all. No significant improvement with age was found. It was also found that children's spontaneous reversal abilities were significantly associated with the second order ice cream False Belief task (Perner & Wimmer, 1985). In a typical second order false belief question children need to infer the mental state about what another person had thought (i.e., "he believes that she thinks…"). Mitroff et al. suggest that higher level metarepresentational abilities are required for spontaneous reversals. However, overall the results of this study are not very clear.

Bialystok and Shapero (2005) investigated monolingual and bilingual children's abilities to identify the other, alternative interpretation of an ambiguous figure and the association of their abilities with aspects of executive function. Bilingual children generally perform better on executive functions tasks (Bialystok, 1999; Bialystok & Martin, 2004). It was found that bilingual children were significantly better than monolingual children in finding the other, alternative interpretation of an ambiguous figure. Bilingual children were also better in mental set-shifting abilities as measured by the Dimensional Change Card Sort task (DCCS) (Frye, Zelazo, & Palfai, 1995). In an overall regression analysis it was revealed that performance on the DCCS significantly predicted the ability to find the alternative interpretation of an ambiguous figure when performances of both language groups were merged together (Experiment 2). This suggests that mental-set shifting abilities as measured by the DCCS may be involved in the ability to identify the other, alternative interpretation. This finding will be investigated in further detail in Study 3 in this research.

Two studies have investigated children with autism's perception of ambiguous figures. It is known in literature that autistic children have difficulties with False Belief tasks (Baron-Cohen, Leslie, & Frith, 1985) and hence, are impaired in their metarepresentational abilities. Therefore, if there was an association between metarepresentation and ambiguous figures reversal, children with autism should also have problems with reversal. Ropar, Mitchell and Ackroyd (2003) found that children with autism were able to reverse ambiguous figures but failed in a False Belief and Droodle tasks, in contrast to children with moderate learning disabilities who had no problems in all tasks. In their ambiguous figures task children were shown the ambiguous figure and initially asked whether there was anything else they could perceive. Then they were informed about the other (non-perceived) interpretation and asked to point to the head of the other interpretation. Those children who were able to point to the head of the alternative interpretation were deemed as reversers. Out of 22 children with autism 16 reversed both figures.

These findings may at first glance suggest that metarepresentation is not underlying ambiguous figures reversal. However, because autism is a special case the link between AF reversal and metarepresentation may still exist in typically developing children. It is further possible that the children with autism were able to indicate the head of the figure without reversing the whole ambiguous figure. There is evidence that children with autism process visual information in a detailed manner rather than in a global sense (see Happé & Frith, 2006 for a recent overview). Uta Frith suggested in her “weak central coherence theory” (Frith, 1989) that children with autism have weak central coherence and hence have a bias for local and featural information. If we consider the nature of ambiguous figures, they are specially constructed to be unstable. If children with autism have weak central coherence, they may have difficulty maintaining a stable interpretation of the figures ***per se***. This may have been exactly the case for those children participating in Ropar et al.’s study and may explain why children with autism were unimpaired in reversals.

Alternatively, Sobel, Capps, and Gopnik (2005) found that children with autism had fewer reversals (spontaneous and informed) of the duck/rabbit, vase/faces, and man/mouse figures than typically developing children. Similar to Ropar et al.'s (2003) results, no relationship between spontaneous or informed reversals and success on the Ice Cream task (Perner & Wimmer, 1985) was found in children with autism. Furthermore, all of the children with autism who failed the Ice Cream task reversed in the Ambiguous Figures task. Children were also given a Strange Stories task (Happé, 1994) which measures children's understanding of non-literal communication (i.e., jokes, lies, irony and sarcasm). Only children who passed the Ice Cream task were subsequently given the Strange Stories task. Performance on the Strange Stories task was significantly related to spontaneous reversal but not with informed reversals, in children with autism, in contrast to the other children where no association was found. Therefore Sobel et al. suggested that there is a relationship between reversal and higher-level representational abilities in children with autism. However, overall the results of this study are not very clear.

The findings from the two studies that children with autism are on the one hand unimpaired in reversal but on the other hand impaired in False Belief tasks (Ropar et al., 2003) and the lack of association between reversal and higher-order false belief understanding (Sobel et al., 2005) may speak at first glance against the assumption that the development of metarepresentation is a conceptual prerequisite for reversal. However, it is possible that children with autism do not have a stable perception of one interpretation of an ambiguous figure ***per se***. Frith's Weak Central Coherence theory suggests that children with autism are impaired in extracting global information from a visual scene. That is, if children with autism have weak central coherence it is possible that their perception of figures is a priori unstable. This gives rise to future work on children with autism's perception of ambiguous figures.

1.5 Implications on Adult Literature and on Developmental Literature

From research with adults (sections 1.1.1 and 1.1.2) we know that top-down and bottom-up processes are involved in the reversal process. From research with children we know that children before the age of about 5 are mostly unable to reverse. However it is one year earlier that children understand that ambiguous figures can have two interpretations. We also know that children and adults do mostly not reverse if they are not informed about the ambiguity of an ambiguous figure. This suggests that top-down processes are required for reversal, and that pure bottom-up processes are not sufficient for reversal to occur.

This raises several questions:

1. Does the understanding of ambiguous figures derive from false belief understanding or does it require metarepresentation in the pictorial domain? (This will be addressed in more detail in Study 1).
2. How does the conceptual understanding of ambiguous figures relate to other forms of metarepresentation developing around the same time around the age of 4 (e.g., understanding of homonymy, synonymy)?
3. What are the particular cognitive processes involved in reversal (i.e., executive functions, mental imagery abilities) that develop between the timeline when children understand that an ambiguous figure has two interpretations at the age of 4 and when children reverse ambiguous figures at the age of 5?

4. What is the role of appropriate eye-movements over the image? Is there an association between “appropriate” scanning strategies over the ambiguous figure and the ability to reverse?
5. How does this relate to adult research on ambiguous figures?

1.5.1 The role of different methods of assessing reversal abilities

Due to the small number of studies of children’s understanding and perception of ambiguous figures only one Reversal task has been used so far – the task implemented by Rock and colleagues. A variety of new tasks are implemented in this research and existing tasks are methodologically improved. This is necessary, and a crucial prerequisite, in order to investigate actual reversal abilities.

1.6 The current Studies

The current research reports 4 studies (7 experiments) with 3- to 5-year-old children; each experiment presents about sixty children with multiple tasks.

Study 1 examines the necessary conceptual development (top-down knowledge) for reversing ambiguous figures, and attempts to replicate previous findings (Doherty & Wimmer, 2005). It is also investigated whether children’s understanding of ambiguous figures derives from false belief understanding or whether it is an example of metarepresentation in the pictorial domain. The results of Study 1 reveal that children between the ages of 3 and 4 develop the understanding that an ambiguous figure can have two interpretations (Ambiguous Figures Production task). This development is related to the understanding of synonymy, homonymy and false beliefs. It is suggested that an understanding of ambiguous figures requires pictorial metarepresentation. The conclusion is that the conceptual development for understanding the dual nature of ambiguous figures is part of a broader development of metarepresentation and does not derive from false belief understanding.

Study 2 is designed to methodologically improve the Ambiguous Figures Production task, to implement a new, simplified method of assessing reversal abilities, and to compare those new measures to tasks used in previous research. A new Feature Identification question is implemented, which investigates children's ability to initially identify both interpretations of an ambiguous figure. This is compared to young children's reversal abilities (Reversal task). The claim that reversal is dependent on a broader understanding of ambiguity (Droodle task) (Gopnik and Rosati, 2001) is also examined. Study 2 shows that between the ages of 4 and 5 children develop the ability to indicate features of an ambiguous figure (Feature Identification). To actively ask children to indicate features (Feature Identification) improves performance of the 5-year-olds significantly. This is in contrast to the performance on the Reversal task where no rapid increase occurs and where children are required to passively stare at the ambiguous figure and to report any changes in perception over a 1 minute viewing period. In addition, Study 2 reveals no association between reversal abilities and performance on the Droodle task, as was suggested by previous research (Gopnik & Rosati, 2001).

In Study 3 a new task is implemented (revised Reversal Task) and the role of executive function in the reversal process is explored. The revised Reversal Task is a combination of the Feature Identification question and the original Reversal task. In the revised Reversal task children are required to view the ambiguous figure for 60 seconds but instead of passively staring at the figure (Rock et al., 1994), children are asked to indicate features after 5, 30 and 60 seconds. To ask children to indicate features plus extended viewing (revised Reversal Task) improves performance between the ages of 4 and 5 in comparison to the original Reversal task. The finding from Study 3 is that when task demands are minimised, children are able to reverse around 6 months earlier than previous research has suggested. In addition, Study 3 investigates the immediate cognitive process involved in reversing ambiguous figures. In two experiments children are given an executive functions battery (planning, set-shifting, working memory, inhibition) and performance is compared to their reversal abilities. The results from Study 3 reveal that children's ability to reverse (revised Reversal Task) is particularly associated with inhibitory abilities, even when chronological and verbal mental age is partialled out. The ability to reverse is not particularly associated with any other executive function. It is therefore concluded that the ability to inhibit each interpretation of an ambiguous figure is crucial in order to reverse an ambiguous figure, and is a key process allowing the reversal experience.

Study 4 investigates the effect of mental imagery abilities on reversal. Children's reversal abilities are compared to their ability to retain an image over time (Image Maintenance) and to mentally form an image and impose it onto a shape (Image Generation). Although reversal abilities and image maintenance abilities are associated with each other, when controlling for age and verbal abilities this association is not robust. On the other hand the ability to mentally form and impose an image onto a shape is significantly associated with the ability to reverse ambiguous figures. This implies that for reversing ambiguous figures children require image generation abilities which are independent of memory abilities.

The role of eye-movements in reversal is also explored. In an eye-tracking study eye-movement patterns of reversers and non-reversers are compared (Study 4, Experiment 7b). No differences in eye-movement patterns are found. It is therefore concluded that appropriate eye-movements are not a necessary prerequisite in the ability to reverse ***per se***.

Overall from the 4 studies it is concluded that the top-down knowledge required for reversal is that different interpretations of the same stimulus are possible. In particular, the conceptual understanding that an ambiguous figure can have two interpretations is the understanding of the relationship between a figure and what it represents; that is, pictorial metarepresentation. The key cognitive processes involved in reversal are additional inhibitory abilities and mental imagery abilities, which allow reversal around six months later. This is around half a year earlier than previous research has suggested. Appropriate eye-movements are not playing a causal role in this development. It is between the ages of 4 and 5 that the interplay between bottom-up and top-down processes begins.

1.7 Statistical Note

The main feature of interest was to identify associations between task performances. In order to do this correlations and partial correlations controlling for age and verbal mental age effects were calculated. Of main interest was the size of associations. Correlations were calculated as Pearson Product Moment correlations including interval and dichotomous variables. The point biserial and phi correlations, which are special cases of Pearson’s r, are used when one or both variables are dichotomous, respectively (Hinkle, Wiersma, & Jurs, 1979). Study 1 further relies on Linear Regression analysis using the Forward Stepwise method in order to determine the influence of false belief, homonyms, and synonyms performance on the performance on the Ambiguous Figures Production. Linear Regression was used because the Ambiguous Figures Production task produces interval data. Studies 3 and 4 rely on Binary Logistic Regression in order to identify the most influential variables predicting children’s reversal abilities. Binary Logistic Regression was used because the Reversal task produces dichotomous data. The analysis of the False Belief task (the amount of children who passed/failed the test question), used throughout the thesis, included all children, even those who failed the control questions. The low failure rate on the control questions across the different experiments provided reassurance that the task was understood by the majority of participants. The descriptive data reported in tables are rounded up to the nearest full number if the decimal was 0.5 or higher or rounded down to the nearest number if the decimal was below 0.5.

The significance levels were labelled accordingly:

$P < 0.10$ is labelled with †

$P < 0.05$ is labelled with *

$P < 0.01$ is labelled with **

$P < 0.001$ is labelled with ***

2 Study 1 - Ambiguous Figures and Meta-representation

Introduction

Study 1 focuses on the conceptual prerequisite for reversing ambiguous figures. In particular, the role of ***metarepresentation*** as a conceptual prerequisite for reversal is explored. Children's understanding of ambiguous figures is compared to the understanding of false beliefs, synonymy and homonymy.

There is evidence from Rock and colleagues that in order to experience reversal, adults must know that the figure is ambiguous and what the two interpretations are ***(***this can be subsumed as: ***knowledge and awareness)*** (Girgus, Rock, & Egatz, 1977; Rock & Mitchener, 1992; Rock, Hall, & Davis, 1994, Expt. 1), and must also intend to experience the alternative interpretation (Rock, Hall, & Davis, 1994, Expt. 2). Knowing that an ambiguous figure has two interpretations implies knowing it can represent two different things. Understanding that an ambiguous figure can represent two different things (***knowledge*** and ***awareness***) is an example of ***metarepresentation***. Metarepresentation is required to understand that an ambiguous figure can represent for example a duck and a rabbit. If Rock and colleagues' claim is correct that viewers need the ***knowledge*** and the ***awareness*** in order to experience reversal, then being able to ***metarepresent*** may be a crucial prerequisite in order to reverse.

The standard task to assess children's metarepresentational abilities in the mental domain is the False Belief task. The False Belief task demonstrates that children are able to represent the relationship between beliefs and the state of the world that the beliefs are about. Understanding that an ambiguous figure can represent two distinct objects also requires children to be able to represent the representational relationship between the figure and the two interpretations. One therefore might expect an association between the False Belief task and reversal abilities. Gopnik and Rosati (2001) found no correlation between the tasks, and the Reversal task was more difficult (Experiment 1). Instead, they found a significant association between reversal abilities and performance on the Droodle task (Experiment 2). As noted previously, the Droodle task requires children to represent the effect of uninformative (ambiguous) visual information on the knowledge state of another person (Perner & Davies, 1991; Ruffman et al., 1991) and the understanding that seeing is not always knowing (Taylor, 1988). For this task a far more complex understanding than for the False Belief task is required. That is, the Droodle task not only requires children to represent the knowledge state of another person but also to base this on the impact of uninformative (ambiguous) visual information. Gopnik and Rosati concluded that children's reversal abilities are dependent on a complex understanding of ambiguity which is, according to them, indexed by the Droodle task.

This finding would indicate that the critical development for reversal is in the conceptual prerequisites of reversal, rather than the ability to bring it about. It would also indicate what the conceptual prerequisites are: whatever gives rise to success on the Droodle task. However, it is argued here that the process of reversal is a skill, not a conceptual understanding, and requires mental action on part on the perceiver. Before performing this mental action someone must understand or be aware that an ambiguous can have two distinct interpretations.

Doherty and Wimmer (2005) investigated when children develop the understanding that ambiguous figures can have two interpretations. In an Ambiguous Figures (AF)

Production task we showed that children from the age of 4 can understand that a figure can be for example a duck and a rabbit. This develops one year earlier than when children are able to reverse around the age of 5, and is, furthermore, significantly easier than the Droodle task. Moreover, it was found that performance on the AF Production task was significantly associated with the False Belief task. We therefore suggested that children are able to conceive of a stimulus as having more than one interpretation from the age of roughly four, and this understanding has a common basis with the understanding of belief, that is metarepresentation.

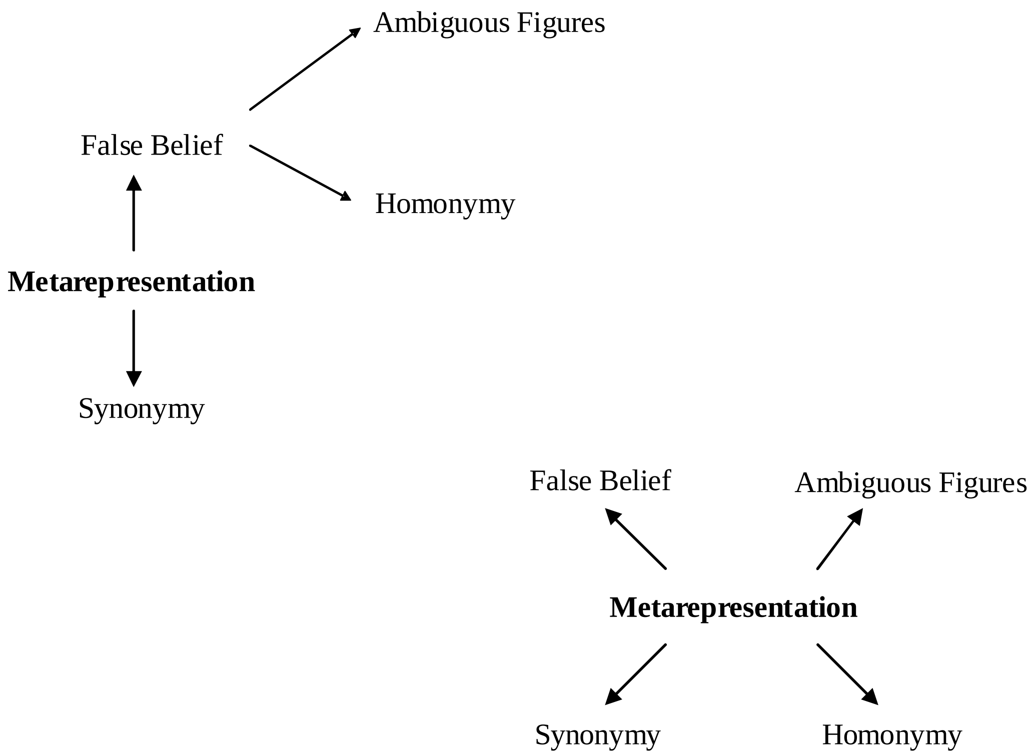
The aim of this study is to replicate and extend these findings and to investigate the specificity of the relationship between the AF Production task and the False Belief task.

There is a counter explanation for Doherty and Wimmer’s claim that children’s understanding of ambiguous figures is part of a general understanding of representations arising at the age of 4. One possibility is that the ability to pass the AF Production task derives from false belief understanding (Figure 2.1). It is possible that children notice that ambiguous figures can be seen in two different ways, and without necessarily understanding why, interpret that as meaning that ambiguous figures can produce two different beliefs in people. For example the duck/rabbit figure produces a “duck belief” and a “rabbit belief” in different people. The same argument applies to homonyms. When hearing a homonym (i.e., “bat”), someone might think the speaker is talking about flying mammals when in fact s/he is talking about sports equipment. That is, children may understand that for example the homonym “bat” creates different beliefs in people: “a flying mammal belief” and “a sports equipment belief”. Ambiguous figures are analogous to homonyms in that one stimulus can represent more than one type of object (e.g., an ambiguous figure can represent a duck or a rabbit; the word ***bat*** can represent two different things). The counter explanation then for Doherty and Wimmer’s findings is that children understand non-mental representations (ambiguous figures, homonyms) by considering their effects on belief rather than understanding ambiguous figures because of pictorial-, and homonyms because of linguistic-metarepresentation. Doherty (2000) found that children’s understanding of homonymy develops between the ages of 3 and 4 and is significantly associated with children’s understanding of synonymy and false beliefs.

Another non-mental representational puzzle is synonymy. In a Synonym Production task (Doherty & Perner, 1998) children have to produce both synonyms for naming the same item (e.g., truck/lorry, lady/woman, coat/jacket etc.). For example the experimenter provides one synonym [e.g., “I say this is a truck, what else can it be?”… Child’s correct answer: “lorry”. Then after intervening trials the experimenter says: “I say this is a lorry, what else can it be?” Child’s correct answer: “truck”]. Children understand synonymy from the age of about 4 years and the development of this understanding is strongly associated with the development of false belief understanding (Doherty & Perner, 1998; Perner et al., 2002). According to Doherty and Perner synonyms and false beliefs are associated because both rest on a common insight that things can be represented in a particular way (Perner, 1991).

Children’s understanding of synonymy is not subject to the counter explanation that it may derive from false belief understanding. For example the synonyms “bunny” and “rabbit” do not create different beliefs in people because both refer to the same meaning. That is, the difference in meaning between “bunny” and “rabbit” is very subtle and even adults would have problems to explain how they differ. Alternatively, the “duck” and "rabbit" in the case of ambiguous figures or "a flying mammal bat" and "cricket bat" create different meanings.

Figure 2.1: Children's understanding of Ambiguous figures (AF) and Homonymy derives from False Belief understanding (top left) versus Children's understanding of AF, Homonymy, Synonymy, and False Beliefs are different forms of metarepresentation (bottom right)



The AF Production task was originally adopted from the Synonym Production task. In addition, performance on the AF Production task develops in a very similar way to performance on the Synonym Production task and shows a similar association with false belief understanding. As a result a direct comparison between the understanding of ambiguous figures with the understanding of synonymy and homonymy might be more appropriate than with false belief. That is:

First, Homonyms and ambiguous figures are analogous in the sense that depending on the context either interpretation is possible. For example, in the case of ambiguous figures the duck/rabbit can be a duck or a rabbit, depending on the context. In the case of homonyms a bat can be a flying mammal in one context and a piece of cricket equipment in another context.

Second, the AF Production and the Synonym Production tasks are analogous in form and performances on both tasks show a similar relation to false belief.

Third, children's understanding of synonymy is not subject to the counter explanation that it derives from false belief understanding. Hence, if there was an association between children's understanding of ambiguous figures and synonymy it would strengthen the claim that metarepresentation is required for an understanding of ambiguous figures.

Fourth, only the False Belief task involves misrepresentation of current reality (i.e., the protagonist thinks that the marble is in the box while it is really in the jar).

The aim of Study 1 then is to investigate this counter explanation and to strengthen Doherty and Wimmer's claim that children pass the AF Production task because it is another example of metarepresentation but in the pictorial domain. There are two possible outcomes:

1) If the counter explanation is correct and children's understanding of ambiguous figures and homonymy derives from false belief

understanding, then they should both relate more strongly to false belief than they relate to each other, and develop slightly later.

2) On the other hand it would be expected that the understandings of ambiguous figures, synonymy and homonymy are more strongly related because they pose more closely related representational problems.

In Experiment 1 children's understanding of ambiguous figures was compared to children's understanding of synonymy and false beliefs. The surface form of the Synonym Production task is most comparable to the AF Production task, because both require the child to say something different in the experiment about a given stimulus. Moreover, synonymy is not subject to the counter explanation. On the other hand the deep structure of homonymy is most comparable to that of figure ambiguity, despite surface differences in the task (which involves pointing to different pictures). In Experiment 2, therefore, children's understanding of ambiguous figures was compared to the understanding of homonymy and false beliefs.

2.1 Experiment 1

Method

Participants

Fifty-seven children (28 boys and 29 girls) from two nursery and two primary schools with a working class intake in Stirling, Scotland took part. Children were divided into three age groups as shown in Table 2.1. Verbal mental age (VMA), measured using the BPVS-II, is shown in parentheses.

Table 2.1: Details of children participating in Experiment 1 (VMA)

Age group	N	Mean (y;m)	SD (months)	Range (y;m)
3-year-olds	15	3;6 (3;10)	3 (11)	3;2-3;10 (2;10-6;5)
4-year-olds	24	4;4 (4;9)	3 (10)	4;0-4;9 (3;2-7;1)
5-year-olds	18	5;4 (5;4)	4 (13)	5;0-6;0 (3;7-8;0)

Design

Each child completed five tasks: the Ambiguous figures (AF) Production task, Synonym Production task, False Belief task and the Droodle task in two sessions. Task order was counterbalanced within and between the sessions. The BPVS-II was administered at the end of the session.

Materials and Procedure

Each child was seen in a quiet and familiar room adjacent to the nursery and primary area. The experiment took approximately 15 minutes per session.

Ambiguous figures (AF) Production task

The ambiguous figures were three line drawings depicting a duck/rabbit (7.7 cm x 5 cm), vase/faces (10cm x 10 cm), and a man/mouse (5cm x 4cm). Each was drawn in pencil on A4 (29.5 x 21 cm) paper. For each ambiguous figure there were two disambiguating context drawings (Figures 2.2a and 2.2b). For example for the duck/rabbit the two drawings were of a duck's body on a lake with other ducks in the background, and a rabbit's body, complete with a carrot. These were also on A4 sheets with holes cut to accommodate the ambiguous stimuli, in this case the duck's/rabbit's head.

Figure 2.2a: duck/rabbit

Figure 2.2b: disambiguating drawings

Disambiguation Phase

In this phase children were introduced to the alternative interpretations of each figure. First the child was shown the ambiguous figure (duck/rabbit) and asked: “What is this?” [Child answers, e.g. rabbit] “Yes, you are right, it’s a rabbit.” The experimenter put on the body of a rabbit and asked the child to point to a specific features, the rabbit’s ears (see table 2.2). Then the body of the rabbit was removed and the experimenter said: “Look it can be something else too . . . [puts on the body of the duck]. What is it now? … Yes, you are right, it’s a duck!” Again the child had to point out a specific feature, the beak of the duck[1]. If the child failed to point to the appropriate feature, the experimenter would explain the other unambiguous figure by pointing out specific features of the other interpretation, and the child had to point out features again. This was necessary to make sure that children perceived the alternative interpretation while disambiguated, which is a necessary prerequisite to pass the Ambiguous Figures Production task. Then the disambiguating drawing was removed and the experimenter said: “So this picture can be two different things, it can be (e.g.) a rabbit and a duck!” This was repeated for the two remaining stimuli.

[1] Strictly speaking, ducks have bills, but it was felt that this is unlikely to be in children’s vocabularies.

Table 2.2: features of an ambiguous figure to be pointed out in the disambiguation phase of the Ambiguous Figures Production task

Stimuli	Disambiguation phase	
Duck/Rabbit	Beak	Ears
Vase/Faces	Top of vase	Noses
Man/Mouse	Eyes	Tail

Test-phase

First the experimenter said: “Remember all these pictures can be two different things. Now I am going to say one thing and I want you to say the other thing, ok?” Then the child was shown the duck/rabbit figure and the experimenter said, “I say this is a rabbit, what else can it be?” If the child provided the correct answer the next ambiguous figure was presented. If the child repeated the experimenter’s version she said: “Well I’ve already said that it’s a (e.g.) rabbit…….what else can it be?” If the child still didn’t provide the answer after a reasonable pause, the experimenter said something like: “I know! It can be (e.g.) a duck, can’t it?” This was repeated for the remaining two ambiguous figures.

The three ambiguous figures were then presented a second time with the experimenter providing the alternative interpretation (e.g. duck, see table 2.3). Children were deemed successful on a figure if they provided the alternative interpretations on both trials. Children scored from 0 to 3 pairs produced.

Table 2.3: Order of the stimuli/interpretations presented by the experimenter in the Production Task

Trial	Experimenter	Correct response
1	Rabbit	Duck
2	Vase	Faces
3	Man	Mouse
4	Duck	Rabbit
5	Faces	Vase
6	Mouse	Man

Synonym Production task

Four A4 sheets were used in the vocabulary check. Each sheet contained four coloured line drawings. Two synonym items (truck/lorry, lady/woman, coat/jacket and TV/television) later used in the experimental condition and two items chosen from a bin, a church, a key and a cake appeared on each sheet. For the modelling phase coloured line drawings on individual A4 sheets were used. For the modelling phase these were of a rabbit/bunny and a cup/mug, and for the test phase each of the synonyms (truck/lorry, lady/woman, coat/jacket and TV/television) was again depicted in colour on a separate A4 sheet.

Vocabulary check

The purpose was to check children's knowledge of the synonyms used later in the actual test. Children were asked to point to - first sheet: truck and lady; second sheet: jacket and

TV; third sheet: lorry and television; fourth sheet: woman and coat. Thus, children had to identify objects under each synonym to be used in the test phase.

Modelling Phase

The objective of this phase was to model the test procedure. The child was shown the picture of a rabbit and the experimenter said: “Look, here are some more pictures. We’re going to play a game now. I say the one thing and you say the other thing, ok? Now I say it’s a rabbit. What‘s another way of saying rabbit? [Pause] I know, you can also say bunny, because it is a rabbit, and it is a bunny. There are different ways of saying the same thing.” This was repeated for the other modelling item, cup/mug. If children gave an answer they were praised or gently corrected, and the justification was given.

Experimental Phase

The modelling phase was continued with four new pictures, but the experimenter no longer provided the answers. Pictures were presented one at a time, the experimenter named them and then the Test Question was asked:

Test Question: “What’s another way of saying truck?”

If children gave no answer they were prompted with: “Can you think of a different way of saying truck?” If children repeated the word used by the experimenter they were told “But I say it is a truck. You are supposed to say something different” and the test question was repeated. If children still didn't give an answer they were reassured by some phrase such as "Never mind" or "That's a hard one, isn't it?" and the next item was presented. All four experimental items were presented twice, with the experimenter using different synonyms on the two occasions. Half the children had Lorry, Television, Woman and Coat presented first and half had Truck, TV, Lady and Jacket. Children had to produce the other synonym on both occasions. Children scored from 0 to 4 pairs produced.

Some plausible variants were accepted as synonyms so long as children provided a target synonym on the other occasion. These were mummy or girl (8 cases), and telly (8 cases). Tractor (2 cases), cardigan, adult and person (3 cases) were not accepted. A strict (all those items above incorrect) and a lenient statistical analysis (according to our criteria) was conducted which showed that these scoring criteria made no difference to the results.

False Belief task

For this test a short story was acted out with two Playpeople dolls (5cm), a marble, an opaque jar (5 cm high x 2.5 cm wide) and a box (3 cm high x 4 cm wide). In the story Sally placed a marble in the box and exited. In her absence Tony moved the marble to the jar and left. Sally returned and children were asked the following questions:

Belief question: "Where will Sally look first for her marble?"

Reality question: "Where is the marble really?"

Memory question: "Where did Sally put the marble in the beginning?"

Droodle task

The Droodle task involved two A4 pencil drawings of a flower and an elephant (Figures 2.3a and 2.4a). A second piece of paper with a 3 cm square hole could be overlaid over these drawings, so that only a small unidentifiable portion of the picture would be visible ("Droodle") (Figures 2.3b and 2.4b). A hand puppet served as research assistant.

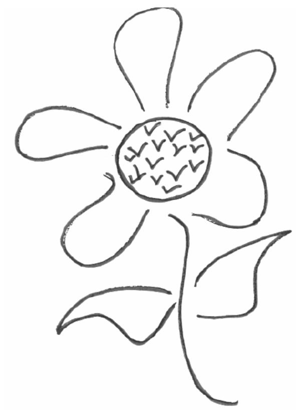


Figure 2.3a

Figure 2.3b

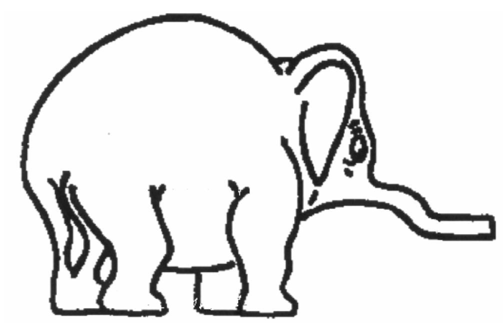


Figure 2.4a

Figure 2.4b

The child was first shown the unidentifiable portion of a picture (Droodle), and asked what it was. After the child's incorrect guess [e.g. "fish"], the full drawing was revealed. Then the overlay was replaced. Puppet appeared and the child was asked the test question:

"Puppet has never seen this picture before. If he comes in and sees just this bit, will he know that this is a flower/elephant?" Children had to state that Puppet would not know that the full drawing was a flower/elephant. In a control condition, the other drawing was fully visible from the start and the child was asked the same test question. Children had to state that Puppet would know that the full drawing was an elephant/flower. Children who passed both questions were scored as passing the task.

Results

A summary of performance on all tasks is shown in Table 2.4. Performance on the False Belief (false belief test question) and Droodle tasks are reported as percentages of children who passed whereas performance on the AF Production and Synonym Production tasks is reported as Mean percentage of successful trials (e.g., 0 out of 3 pairs produced, 1 out of 3 pairs produced, etc …). Mean percentage of successful trials allows a more detailed insight into children's performances on the AF Production and Synonym Production tasks which would otherwise be masked by passed/failed criteria.

Table 2.4: Summary of performance on each task (with the AF Production and the Synonym Production tasks scored as Mean percentage of successful trials[2])

	Age groups			Total
	3y6m(N=15)	4y4m(N=24)	5y4m(N=18)	N=57
AF Production	51%	83%	87%	76%
Synonym Production	35%	60%	81%	60%
False Belief	53%	63%	100%	72%
Droodle	13%	17%	44%	25%

<u>AF Production task.</u>

Performance on the AF Production task was good; roughly half of 3-year-olds produced 0 or only 1 ambiguous figure pair, and roughly half produced 2 or all 3 pairs. Most 4-and 5-year-olds produced all 3 pairs (Table 2.5). A One-Way ANOVA with the number of pairs produced by each child as the dependent variable indicated a significant age improvement, $F(2, 54) = 7.05$, $p = 0.002$. Post Hoc Bonferroni multiple comparisons revealed a significant difference between the 3- and 4-year-olds, $p = 0.006$. Non-parametric Friedman-test for related samples showed no difference in performance on the 3 ambiguous figures.

[2] Mean % of trials success was calculated as: the mean of percentage of pairs correct (e.g. 0 out of 3 = 0%, 1 out of 3 = 33%, 2 out of 3 = 67%; 1 out of 4 = 25%, 2 out of 4 = 50%, 4 out of 4 = 100%....)

Table 2.5: Produced pairs of the AF Production task within and between the different age groups and overall. The mean number of produced pairs produced by each age group and overall is shown at the bottom.

Produced AF Pairs	Age group			Total
	3y6m(N=15)	4y4m(N=24)	5y4m(N=18)	N = 57
0	40%	0%	0%	10%
1	7%	8%	6%	7%
2	13%	33%	28%	26%
3	40%	58%	67%	56%
Mean	1.53	2.50	2.61	2.28

<u>Synonym Production task</u>

Most 3-year-olds produced 0 or 1 synonym pair; most of the older children produced 3 or 4 pairs (Table 2.6). A One-Way ANOVA with the number of pairs produced by each child as the dependent variable indicated a significant age improvement, $F(2, 54) = 8.68$, $p = 0.001$. Post Hoc Bonferroni multiple comparisons revealed a significant difference between 3-year-olds and 4 year-olds, $p = 0.050$.

Table 2.6: Produced synonym pairs of the synonym production task within and between the different age groups and overall. The mean number of pairs produced by each age group and overall is shown at the bottom.

Produced Synonym Pairs	Age group			Total
	3y6m (N=15)	4y4m (N=24)	5y4m (N=18)	N = 57
0	40%	4%	6%	14%
1	13%	29%	0%	16%
2	20%	17%	6%	14%
3	20%	21%	44%	28%
4	7%	29%	44%	28%
Mean	1.40	2.42	3.22	2.40

<u>False Belief task</u>

Just over half of the younger children and most of the older children correctly predicted where Sally would look first (Table 2.4). This age improvement is significant: Kruskall-Wallis $\chi 2 = 10.46$, df = 2, p = 0.005. There was a significant difference between 4-year-olds and 5-year-olds, Fisher's Exact, p = 0.005 (two-tailed). Four children failed the memory control question ("can you remember where Sally put the marble in the beginning?"), one of whom also failed the reality control question ("where is the marble really?").

<u>Droodle task</u>

Performance on the Droodle task was poor, with even most 5-year-olds failing (Table 2.4). The age improvement approached significance, Kruskall-Wallis $\chi 2 = 5.57$, df = 2, $p = 0.062$.

Comparison of tasks

Table 2.7 shows correlations between all tasks, age and VMA (verbal mental age). Partial correlations, controlling for age and VMA are shown below the diagonal. Performance on the AF Production, Synonym Production, and False Belief tasks are all substantially correlated and remain significantly correlated once age and VMA are partialled out. Performance on the Droodle task is at best weakly correlated with the other tasks, and none of these correlations remain significant after age and VMA are partialled out.

Table 2.7: correlations and (partial correlations in parenthesis - after controlling for age, VMA) between the tasks

	AF Production	Synonym Production	False Belief	Droodle	BPVS-II
Age	.43***	.50***	.44***	.36**	.58***
AF Production	----	.53***	.53***	.29*	.45***
Synonym Production	(.33*)	----	.49***	.33*	.49***
False Belief	(.37**)	(.29*)	----	.18	.40**
Droodle	(.13)	(.17)	(-.01)	----	.26†

In order to predict performance on the AF Production task (pairs produced) a hierarchical linear Regression using the Stepwise Method, with all the remaining tasks, age and VMA performance as independent variables, was calculated. False Belief performance the most influential predictor and predicted a significant amount of variance in children's abilities to produce both alternatives of ambiguous figures over and above age and verbal age, $R^2 = 0.29$, $F(1, 55) = 21.91$, $p < 0.001$. In addition, performance on the Synonym Production task predicted a significant amount of variance in children's Production of ambiguous figures beyond the effect of False Belief, $R^2 = 0.09$, $F(1, 54) = 8.17$, $p = 0.006$.

In order to compare all tasks, performances on the AF Production and Synonym Production tasks were scored as pass or fail. A score of 2 or more trials correct was considered a pass. Although somewhat arbitrary, this strikes a balance between excessively strict (all trials correct) which would punish minor lapses in attention, and excessively lenient (1 trial correct) which might allow some success through random factors. Table 2.8 compares all four tasks (using Binomial analysis). The number pairs represent: number of children passing the row task but not the column task – number of children passing the column task but not the row task. For example, 10 children passed the AF Production task and failed the Synonyms task, and 3 children showed the opposite pattern. The pattern of results is clear: The Droodle task was more difficult than all the other tasks. The Synonyms, and False Belief tasks are of comparable difficulty and - although statistically not significant – more difficult than the AF Production task.

Table 2.8: Task comparisons in difficulty using Binomial analysis

	AF Production	Synonym Production	Droodle
False Belief	***2***-8	***7***-6	***29***-2***
AF Production	----	***10***-3†	***33***-0***
Synonym Production		----	***27***-1***

<u>Discussion Experiment 1</u>

Experiment 1 confirmed that children between the ages of 3 and 4 develop the understanding that ambiguous figures can have two interpretations (AF Production task). This understanding is significantly associated with the understanding of false beliefs over and above age and verbal abilities. Moreover, the understanding that ambiguous figures can have two interpretations develops earlier than children’s complex understanding of ambiguity (Droodle task). These findings are consistent with Doherty and Wimmer’s (2005) results. Similarly, children between the ages of 3 and 4 develop the understanding for synonymy. Most importantly children’s understanding of synonymy was significantly associated with the AF Production and False Belief tasks – even after controlling for age and VMA. The association between children’s false belief and synonym understanding replicated previous findings (Doherty & Perner, 1998; Perner et al., 2002). The regression analysis revealed that False Belief performance was a significant predictor for performance on the AF Production task. Moreover, performance on the Synonym task was a significant predictor over and above false belief performance. This supports the hypothesis that children require metarepresentation in order to understand ambiguous figures, since an understanding of synonymy requires metarepresentation and is not subject to the counter explanation that it derives from false belief understanding. This suggests that a common mechanism is underlying all three tasks. That common mechanism is metarepresentation.

2.2 Experiment 2

Experiment 2 investigates the association between the understanding of ambiguous figures, homonymy and false beliefs in order to investigate the counter-explanation that ambiguous figures and homonymy understanding derive from false belief understanding. If the counter-explanation were correct then homonymy and ambiguous figures understanding should both relate more strongly to false belief than they relate to each other, and develop slightly later.

Moreover, the comparison between ambiguous figures and homonyms may be more appropriate than with false belief since homonyms are the pictorial equivalent of ambiguous figures in the sense that one stimulus can have two distinct interpretations (i.e., the word bat can refer to a flying mammal or a piece of sports equipment; an ambiguous figure can be a duck or a rabbit).

Method

Participants

Thirty-two children (14 boys, 18 girls) from two nursery schools, one with a predominantly working class intake, and one with a predominantly middle-upper class intake, in central Scotland took part (see Table 2.9; two children did not complete the BPVS). Seven additional children were excluded for non-compliance.

Table 2.9: Details of children participating in Experiment 2 (verbal mental age, indexed by the BPVS-II in parenthesis)

Age group	N	Mean (y;m)	SD (months)	Range (y;m)
3-year-olds	17 (15)	3;3 (3;10)	3 (10)	2;11-3;9 (2;11-5;7)
4-year-olds	15	4;3 (4;1)	3 (7)	4;0-4;10 (3;4-5;5)

Design

Each child participated in the: Homonym Production, AF Production, and False Belief tasks, counterbalanced in a sequence-balanced Latin-Square design. The BPVS-II was administered at the end of the session.

Materials and Procedure

Homonyms task (from Doherty, 2000)

Five homonyms were used, 2 for the modelling and 3 for the test phase: knight/night, nail (finger nail/metal nail), letter (grapheme/envelope), bat (flying mammal/cricket bat), and glasses (spectacle glasses/drink glasses).

Vocabulary Check

For the vocabulary check 5 A4 sheets, each with a picture of two alternatives of a homonym, and 2 distracters were used. The homonym judged to be most familiar to children was covered with a white piece of card (finger nail, night, envelope, flying bat, spectacles glasses) and children were asked: “Which one of these three is the nail?” After the child had pointed out the metal nail, this was covered with the card and the child was asked again: “Which one of these three is the nail?” The child had to point to the finger nail this time. All children were able to identify the homonyms under each interpretation in the vocabulary check.

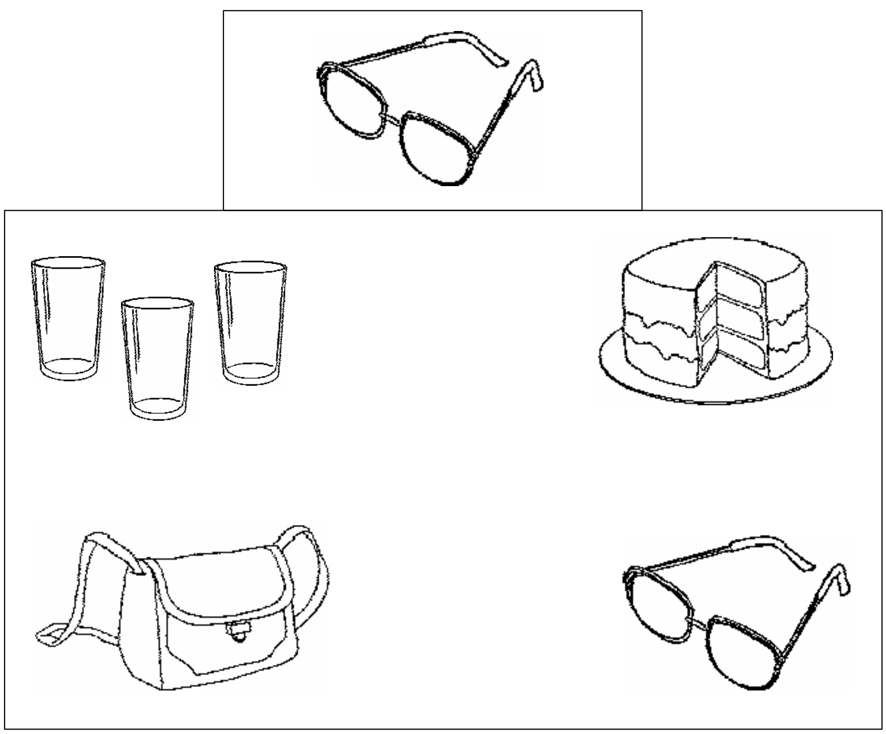
Modelling Phase

The child was shown an A4 sheet with four pictures: both items from a homonym pair (e.g., finger nail and metal nail) and two distracters. Above the A4 sheet a 10x15 cm card was placed with a picture identical to one of the homonym pictures on the sheet (e.g. finger nail). Which of the two items that was on the card was counterbalanced between children. The card was pointed out and the child was told: “Look, here is a nail. But, can you show me a different kind of nail?” If the child pointed correctly: “Yes, look, this is a nail and this is a nail but they’re different aren’t they?” If the child pointed to the identical picture, the experimenter pointed out that it was the same kind of nail, and stressed they were looking for a different kind of nail. If the child still did not point to the other half of the homonym pair, the experimenter indicated it herself and then gave feedback (“yes, look, this is a nail and this is a nail, but they’re different aren’t they?”). This procedure was repeated for the next modelling item: knight/night.

Test phase

For the test phase the procedure continued without feedback or prompting. There were 6 trials in total. Each experimental homonym pair appeared once in each sheet, in the order: letter, bat and glasses. Above each sheet a card was placed with a picture identical to one of the homonym pictures on the sheet (e.g. spectacles) (Figure 2.5). Half of the children received grapheme (letter), flying mammal (bat), and spectacles (glasses) first; the other half envelope, cricket bat, drinking glasses first. Children needed to identify each item of a homonym on both sheets. Children scored from 0 to 3 homonym pairs produced.

Figure 2.5: Example of Homonyms Task layout. In this case the child was asked “look, here are glasses (pointing to the card above), can you show me different glasses?”



AF Production and False belief tasks

The materials and procedures were the same as in the previous experiment (see page 72).

Results

Task performance

A summary of performance on all tasks is shown in Table 2.10. Performance on the False Belief task (false belief test question) is reported as the percentage of children who passed whereas performance on the AF Production and Homonym Production tasks is reported as Mean percentage of successful trials (e.g., 0 out of 3 pairs produced, 1 out of 3 pairs produced, etc …).

Table 2.10: Summary of performance on each task (performance on the AF Production and the Homonym Production tasks scored as Mean percentage of successful trials)

	Age groups		Total
	3y3m(N=17)	4y3m(N=15)	N=32
AF Production	41%	89%	64%
Homonym Production	53%	89%	70%
False Belief	18%	53%	34%

Homonyms Production task

Children's performance on the Homonyms task is shown in table 2.11. Three-year-olds mostly produced 0 or all 3 homonym pairs; most 4-year-olds produced all 3 homonym pairs. An independent samples t-test, with the homonym pairs produced as dependent variable, indicates a significant age improvement, t (30) = -2.73, p = 0.011.

Table 2.11: Produced homonym pairs within and between the different age groups and overall. The mean number of homonym pairs produced by each age group, and overall is shown at the bottom

Produced Homonym Pairs	Age group		Total
	3y3m (N=17)	4y3m (N=15)	N = 32
0	29%	7%	19%
1	18%	7%	13%
2	18%	0%	9%
3	35%	87%	59%
Mean	1.59	2.67	2.09

Ambiguous Figures Production task

Most 3-year-olds produced 0 or 1 pairs (Mean = 1.24); most 4-year-olds produced 2 or all 3 pairs (Mean = 2.67) (Table 2.10). This age improvement is significant, t (30) = -3.89, p = 0.001.

False Belief task

Most 3-year-olds failed (14 out of 17 children) and most 4-year-olds passed (8 out of 15 children) (Table 2.10). This age improvement is not significant (Mann-Whitney U = 82, z = -2.09, p = 0.089). Five children failed the memory question and 1 additional child failed the reality question.

Comparison of tasks

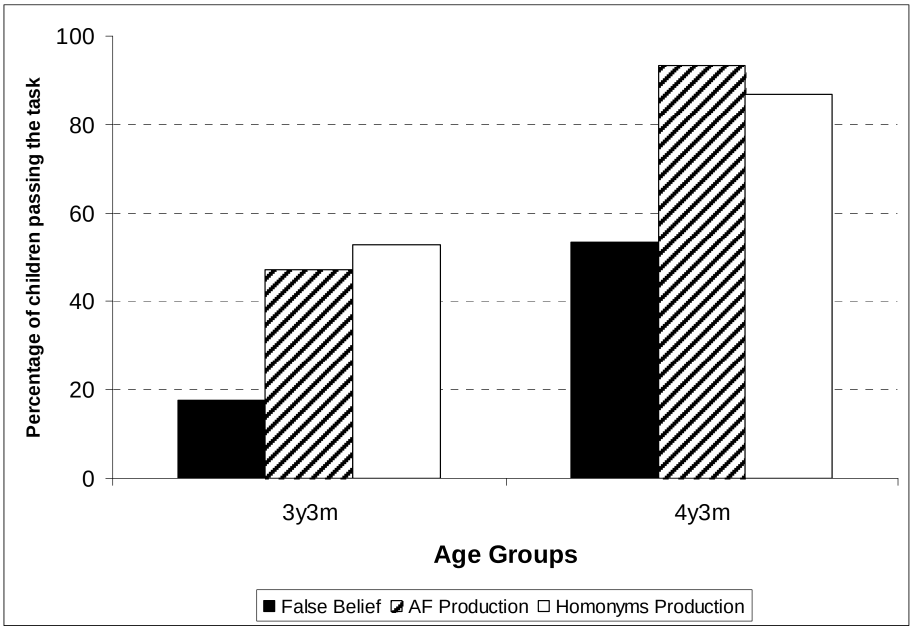
Table 2.12 shows correlations between age, verbal mental age (VMA), and the three experimental tasks. Partial correlations after controlling for age and VMA are shown below the diagonal in parenthesis. Performances on the ambiguous figures, homonyms and false belief task were all substantially correlated, r = .48 or greater. After partialling out age and verbal age, a highly significant association between Ambiguous Figures Production and Homonyms Production remained. A linear stepwise Regression with the ambiguous figure pairs produced as dependent variable, indicated performance on the Homonyms Production task was the most influential factor predicting Ambiguous Figures Production task performance, $R^2 = 0.481$, $F(1, 28) = 25.98$, $p < 0.001$. Furthermore age was a significant predictor, step 2, $R^2 = 0.100$, $F(1, 27) = 6.47$, $p = 0.017$. False Belief performance was not a significant predictor.

Table 2.12: Correlations and partial correlations (in parentheses) between age, verbal mental age (VMA) and all the other tasks

	AF Production	Homonym Production	False Belief	BPVS-II
Age	0.59***	0.43*	0.32†	0.20
AF Production	---	0.70***	0.48**	0.40*
Homonym Production	(0.56**)	---	0.49**	0.36†
False Belief	(0.28)	(0.34†)	---	0.35†

In order to compare performances on the Production tasks with the False Belief task, children were scored as passing each production task if they produced two or three pairs. The False Belief task was significantly more difficult than either of the Production tasks, binomial, $\chi^2 = 7.62$, $p = 0.001$, which did not differ from each other, binomial, $\chi^2 = 16.01$, n.s. A comparison between performance on the tasks is shown in Figure 2.6 which represents the percentage of children passing each task.

Figure 2.6: Age groups' performance on the Homonyms, Ambiguous Figures and False Belief tasks (AF and Homonym Production performances were scored as passed if two or three pairs were produced)



Discussion Experiment 2

The results of Experiment 2 revealed that children's ability to understand homonyms develops between the ages of 3 and 4. This is consistent with previous findings (Doherty, 2000). A very similar developmental trend was found for the AF Production task which is consistent with the findings of Experiment 1. Overall performances between the AF Production task and the Homonyms task hardly differed and they were significantly associated with each other even after partialling out age and verbal mental age. Both tasks were associated with false belief understanding but this association lost significance after partialling out age and verbal mental age. Furthermore, the False Belief task was more difficult, which was also found in the previous experiment (although not statistically significant).

The results of Experiment 2 revealed that the association between children's understandings of homonymy and children's understanding of ambiguous figure is stronger than between children's understandings of false beliefs and ambiguous figures. This rules out the counter-explanation that children's understanding of ambiguous figures and homonymy derives from false belief understanding.

The strong association between ambiguous figures and homonyms is plausible because in addition to requiring metarepresentational abilities homonyms and ambiguous figures are analogous in that one stimulus can represent two distinct kinds of object.

General Conclusion Study 1

The ability to acknowledge both interpretations of an ambiguous figure does not arise in isolation. In two experiments it has been demonstrated that this understanding is significantly associated with the understanding of synonymy, false beliefs and homonymy. This shows the general development of metarepresentational ability, pictorial, mental, and linguistic representation, applicable in ambiguous figures, false beliefs, homonyms and synonyms, respectively.

Results from Experiment 1 replicated the association between an understanding of ambiguous figures and false beliefs that was found in previous research (Doherty & Wimmer, 2005). Furthermore, the additional relation between ambiguous figures and synonyms showed the generality of metarepresentation. Results from Experiment 2 showed that children's understanding of ambiguous figures significantly related to that of homonymy. This is because homonyms and ambiguous figures are analogous. The strong association between homonyms and ambiguous figures over and above false belief rules out the counter explanation that children's understanding of ambiguous figures derives from false belief understanding. Instead, it suggests that children's understanding of ambiguous figures is due to pictorial metarepresentation.

However, there is another counter explanation for the findings of Study 1. That is, in the AF Production task children are unable to produce the alternative interpretation because they cannot inhibit their prevalent interpretation and therefore have difficulties in recalling the other alternative interpretation. This would imply that executive function deficits underlie poor performance on the AF Production task. On the other hand given that the AF Production task is associated with a range of metarepresentational tasks this explanation is unlikely. The surface forms of the False Belief, Synonyms, and Homonyms tasks are different, which makes it unlikely that they all have exactly the same executive demands. Moreover, the AF Production task is analogous in form to the Synonym Production task. The Synonym Production task has also been administered in the judgement version where children are required to judge the production attempts of a Hand Puppet (Doherty & Perner, 1998). The judgement version of the Synonyms task does not involve additional inhibitory and recall demands because both alternatives are provided almost simultaneously by the experimenter. Despite posing different executive difficulties the Synonym Production version and the Judgement version are of similar difficulty and correlated with false belief performance (Doherty, 2000; Doherty & Perner, 1998; Perner et al., 2002). The AF Production task was significantly associated with the Synonym Production, Homonyms and the False Belief tasks. It therefore seems reasonable to conclude that they measure a similar competence (metarepresentation), and is unlikely to be substantially affected by poor executive functioning.

Overall from the results of Study 1 it is claimed that the conceptual understanding for ambiguous figures (top-down knowledge) requires an understanding of pictorial representation which develops between the ages of 3 and 4. This is suggested by the significant associations with false belief, synonymy, and homonymy understanding, demonstrating the generality of metarepresentation. Moreover, ambiguous figures are the pictorial equivalent of homonyms. Ambiguous figures and homonyms are tokens in a representational medium – pictorial and linguistic – which can represent different things depending on context. Understanding this requires children to represent the relationship between the representational medium and the situation referred to. False belief and synonymy also require children to do this: synonymy, because one situation can be referred to by two different words, and false belief because one situation can be represented by different beliefs.

3 Study 2 – Reversing Ambiguous Figures

In Study 1 it has been established that the conceptual prerequisite for reversal is pictorial metarepresentation and that develops roughly at the age of 4.

Study 2 tries to carry on from that finding and investigates the additional ability to reverse ambiguous figures. It has been found that children are able to reverse around the age of 5 (Doherty & Wimmer, 2005; Gopnik & Rosati, 2001), one year later than they are able to acknowledge that there are two interpretations (Doherty & Wimmer, 2005). The aim of this study was to implement methodologically improved methods in order to investigate reversal abilities. This was a necessary starting point because the only existing task to assess reversal abilities is methodologically problematic.

In the literature so far only one ambiguous figure Reversal task has been used – the task originally devised by Rock and colleagues (Rock et al., 1994). In Rock et al.'s Reversal task children stare at an ambiguous figure for 60 seconds and are asked "what do you see?" after 5, 30, and 60 seconds. Children who report any perceived change in interpretation are deemed as reversers. This task requires children to be attentive and motivated to look at an ambiguous figure for 60 seconds – within this period nothing is happening. This is an extremely passive method and pilot work has already suggested that it poses attention difficulties especially for the younger children. The danger, then, is that these additional task demands, such as motivation and attention, mask the onset of the ability to reverse. That is, it is possible that children are able to reverse earlier than previous research has suggested but this has not become apparent because of these additional task demands. It is therefore necessary to find a more robust measure for assessing reversal abilities. To this end, a new Feature Identification question within the AF Production task that assesses initial reversal is implemented.

The Feature Identification question has two objectives. First, this new Feature Identification question investigates children's ability to initially identify both alternative interpretations without these task demands. In this new Feature Identification question the viewing time is minimised and no verbal response is required. Second, the possibility is investigated that the AF Production task is a Reversal task. That is, it is possible that children can acknowledge that there are two interpretations of ambiguous figures because they actually perceive both interpretations. If that is the case, then it would be expected that there are no significant differences between the AF Production and the Feature Identification questions.

In the new Feature Identification question within the AF Production task children were required to indicate features of the interpretation of an ambiguous figure which was contrary to the child's initial perception. After the AF Production question ("what else can it be?") the child was asked to indicate features of the ambiguous figure (Feature Identification question). For example, if the child initially perceived a duck s/he was asked to indicate features of the rabbit (e.g. the mouth, the ears of the rabbit). If the child is able to perceive this interpretation s/he will be able to indicate features of it.

In this study the AF Production task was also modified. In the modified task children needed to produce the opposite interpretation of an ambiguous figure immediately after the disambiguation of each figure. By disambiguating each stimulus directly before the test question, then disambiguating the next one, and finally the third one, children do not have to hold all three pairs in mind before the test question is asked ("what else can it be?"). If the child for example initially perceived a duck s/he has to produce "rabbit" immediately after the disambiguation. This modification is necessary in order to reduce the memory demands in the AF Production task. One concern is that children might be able to acknowledge both interpretations of an ambiguous figure but are unable to remember what the other alternative is and therefore fail the task. If the younger children still fail this modified AF Production task it can only be explained due to the difficulty of acknowledging both interpretations of an ambiguous figure.

A Production Memory Control task is also implemented. This task is analogous to the AF Production task – instead of ambiguous figures, cards with different pictures on each side, are used. The child is shown pictures on each side and asked immediately afterwards what is on the other side. This task has minimised memory demands - analogous to the modified AF Production task. The difference to the AF Production task is that it does not require an understanding of metarepresentation. If it can be shown that children have no memory problems, it can be excluded as a factor in the AF Production task.

A further objective of this study is to investigate the high correlation found between the Droodle task and the Reversal task in Gopnik and Rosati's (2001) study. As noted previously, Doherty and Wimmer's (2005) findings and the results of Study 1 suggest that children understand something critical about reversal a year earlier than they reverse. That specifically is that an ambiguous figure can have two possible interpretations. It is therefore difficult to see how making inferences about the effect of uninformative/ambiguous information on the knowledge state of another person (Droodle task), a far more complex understanding, is the direct prerequisite for reversing ambiguous figures. Doherty and Wimmer (2005) found that the Droodle and Reversal tasks were only weakly related and lacked significance after controlling for age and verbal mental age. In order to investigate Gopnik and Rosati's findings further, children's performance on the Reversal and Droodle tasks were compared directly.

3.1 Experiment 3

Method

Participants

Sixty-three children (28 girls, 35 boys) from two nursery and two primary schools with a predominantly working class intake in Stirling, Scotland took part (see Table 3.1). Two additional children were excluded: one child did not give any responses and one child did not want to complete the tasks.

Table 3.1: Details of children participating in Experiment 3 (VMA for each age group in parenthesis)

Age group	N	Mean (y;m)	SD (months)	Range (y;m)
3-year-olds	20	3;5 (3;10)	5 (7)	2;3-3;11 (3;0-4;10)
4-year-olds	20	4;4 (4;10)	3 (12)	4;0-4;11 (3;3-7;3)
5-year-olds	23	5;6 (5;10)	4 (15)	5;0-6;0 (3;2 -8;2)

Design

Each child participated in the: False Belief, AF Production, Production Memory Control, Droodle, AF Reversal tasks. The order of task presentation was counterbalanced. The BPVS-II was administered at the end.

Materials and Procedure

The False Belief, Droodle and AF Production tasks used the same materials as in Study 1. An additional seal/donkey ambiguous figure (Fig 3.1.) was used either in the AF Production task or in the AF Reversal task. This was necessary in order that children were naïve to each stimulus in each task.

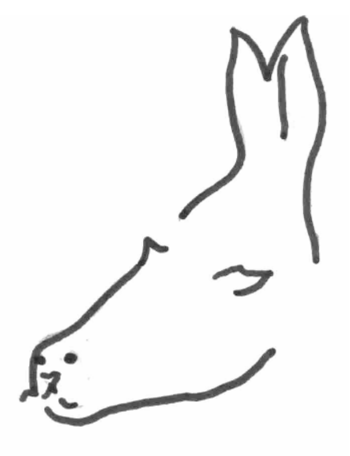


Fig 3.1: Seal/donkey ambiguous figures

Each child was seen in a quiet familiar room close to the nursery and primary area. Each session took approximately 15 minutes.

AF Production plus Feature Identification

Children received three of the four ambiguous figures (duck/rabbit, man/mouse, vase/faces and seal/donkey). The remaining figure was used in the Reversal task.

The task consisted of 3 phases: Disambiguation, Production question, Feature Identification question. Each ambiguous figure was used in a separate Disambiguation, Production and Feature Identification phase.

Disambiguation

First the (e.g.) duck/rabbit ambiguous figure was shown and the child was asked what it is [child's answer: (e.g.) "it's a duck!"]. Then the figure was disambiguated following the procedure as in Study 1.

Production question

The (e.g.) duck/rabbit figure was presented and the child was again asked: "What's this?" [child's answer: (e.g.) "it's a duck!"], in order to see whether the child has switched interpretation. Then the experimenter asked the Production test question: "I say it's a duck, what else can it be?" The child had to answer: (e.g.) "rabbit". The experimenter always used the child's label and the child had to produce the other interpretation contrary to the child's perception.

Feature Identification question

Immediately after producing the alternative interpretation of a figure the Feature Identification question followed: “Can you point to (e.g.) the mouth of the rabbit?” The child had to point to specific features (see table 3.2). Those features were distinct from the features which had to be pointed out in the Disambiguation phase. If the child failed to produce the alternative interpretation, the experimenter would provide the answer [e.g. “I know it can be a rabbit!”] and then ask the Feature Identification question.

This was repeated for the remaining two ambiguous figures. Overall children scored from 0 to 3 on the Production question and on the Feature Identification question.

Table 3.2: features of an ambiguous figure to be indicated in the two phases of the Ambiguous Figures Production plus Feature Identification task

Stimulus	Disambiguation phase		Test phase	
Duck/Rabbit	Eye	Ears	Beak	Mouth
Vase/Faces	Top of vase	Noses	Bottom of vase	Mouths
Man/Mouse	Nose	Ears	Ear	Tail
Seal/Donkey	Tail	Ears	Eyes	Eyes

Production Memory Control task

For this task three cards (10 x 15 cm) which had coloured line drawings on each side were used. Each card depicted: pig (side A)/dog (side B), tea pot/children, lady/sheep. The two pictures on each card were analogous to the ambiguous figures: two animals (dog/pig) analogous to the duck/rabbit ambiguous figure; container and two people (tea pot/children) analogous to the vase/faces; and a person and an animal (lady/sheep) analogous to the man/mouse.

The experimenter showed the child the cards and said: “Here are cards which have a picture on each side, and I want you to remember what’s on the other side, ok?” The child was shown the first card and asked: “What’s that?” After the child’s answer (e.g. “Dog”) this side (side A) was faced down, the picture on the other side (side B) was faced up and the experimenter asked: “And what’s that?” … child’s answer: (e.g.) “Pig”. Then side B was faced down, the picture on side A was faced up again, and the experimenter asked the Production Memory control question: “So on this side is (e.g.) dog, what’s on the other side?” [Child’s correct answer: “Pig”]. This was continued with the other two cards. Half of the children received side A facing up first and the other half side B facing up first. Children scored from 0 to 3.

<u>AF Reversal task</u>

In this task the child received the ambiguous figure not used in the Production task. The disambiguation phase was the same as in the Production task. Before the test phase the experimenter used the disambiguating context drawings in order to emphasize the reversibility: “Now this is very funny, this picture changes back and forth from a (e.g.) rabbit (briefly adds rabbit’s body) to a duck (adds the duck’s body)” and then with appropriate swapping of the disambiguating context drawings and brief pauses to allow the child to look at the figure, “or from a duck to a rabbit. Or it might just stay a rabbit or it might just stay a duck.”

Test phase

The experimenter removed the disambiguating drawings and said: “Now I want you to keep looking at the picture and tell me what it is, because it might change or it might not change.” Children were then asked “what is it now?” after 5, 30 and 60 seconds. This replaced “what do you see” used in the original version (Rock et al., 1994) in order to emphasise the possibility of the stimulus changing. Children who reported a change in interpretation of the ambiguous figure at any point in the 60 second period were coded as reversers. In order to assess false positives (children reporting a change without perceiving it), children who reported a change were asked to indicate features of the reported changed interpretation (see Table 3.2). In order to exclude false negatives (children who had a change in perception but failed to report it), children were asked to indicate specific features of the alternative (not reported) interpretation at the end of the 60 second viewing period (see Table 3.2).

Results

A summary of performance on all tasks is shown in Table 3.3. Performance on the AF Reversal, False Belief, and Droodle tasks is reported as percentage of children who passed whereas performance on the AF Production and Feature Identification, and Production Memory Control tasks scored as Mean percentage of successful trials.

Table 3.3: Summary of performance on each task (AF Reversal, False Belief, and Droodle tasks percentage passed - AF Production, Feature Identification, and Production Memory Control tasks scored as Mean percentage of successful trials)

	Age group			Total
	3y5m (N=20)	4y4m (N=20)	5y6m (N=23)	N = 63
AF Production	67%	85%	97%	84%
Production Memory C.	95%	98%	100%	98%
Feature Identification	23%	50%	73%	50%
AF Reversal	5%	50%	61%	40%
False belief	50%	60%	83%	65%
Droodle	0%	25%	39%	22%

Task performances

AF Production plus Feature Identification

Performance of the 3-year-olds on the AF Production question was already very good: most of the 3-year-olds produced 2 or 3 alternative interpretations of the three ambiguous figures; most of the 4- and almost all of the 5-year-olds produced three pairs (Table 3.4). A One-Way ANOVA with the number of alternatives produced by each child as the dependent variable indicated a significant age improvement, $F(2, 60) = 8.21$, $p = 0.001$.

When asked to indicate features of the alternative interpretation (Feature Identification), most 3- and 4-year-olds indicated 0 or only 1 feature. Most 5-year-olds indicated features of all three ambiguous figures (Table 3.4). This age improvement is significant, $F (2, 60) = 14.37$, $p < 0.001$. Post hoc Bonferroni analysis showed a significant difference between 3- and 4-year-olds, $p = 0.020$ and a marginal significant difference between 4- and 5-year-olds ($p = 0.051$). Performance in the Feature Identification question did not differ for the 4 ambiguous figures, although the man/mouse figure was slightly, non-significantly harder (duck/rabbit = 60% correct; vase/faces = 53%; man/mouse = 38%; seal/donkey = 50% correct).

Table 3.4: number of produced alternative interpretations of ambiguous figures (Production - PROD); number of ambiguous figures' features indicated correctly (Feature Identification question - FIQ) within and between the different age groups.

Number of ambiguous figures correct	Age Groups 3y5m (N=20)		4y4m (N=20)		5y6m (N=23)		Total N = 63	
	PROD	**FIQ**	**PROD**	**FIQ**	**PROD**	**FIQ**	**PROD**	**FIQ**
0	10%	45%	5%	10%	0%	9%	5%	21%
1	20%	40%	0%	50%	0%	13%	6%	33%
2	30%	15%	30%	20%	9%	30%	22%	22%
3	40%	0%	65%	20%	91%	48%	67%	24%
Mean	**2.00**	**0.70**	**2.55**	**1.50**	**2.91**	**2.17**	**2.51**	**1.49**

As can be seen in table 3.4 overall children performed better on the AF Production question than on the Feature Identification question. Only 3 children indicated features of 1 ambiguous figure without producing the alternative interpretation beforehand.

Production Memory Control task

Performance on this task was almost perfect (overall Mean = 2.94). Out of 63 children, only three 3-year-olds (Mean = 2.89) and one 4-year-old (Mean = 2.95), did not correctly remember all 3 pictures on the other side. These 4 children all remembered 2 out of 3 pictures correctly.

AF Reversal task

One 3-year-old, half of the 4-year-olds and a slight majority of the 5-year-olds reversed (table 3.3). This age improvement was significant, Kruskall-Wallis $\chi 2 = 15.01$, df = 2, $p = 0.001$. This was due to the improvement between 3- and 4-year-olds, Fisher's Exact, $p = 0.003$ (two-tailed). Two children reported a reversal but were not able to indicate the features of the reported changed interpretation. They were coded as non-reversers. An additional 7 children did not report any reversal but indicated features of the non reported interpretation after the 60 seconds. Those 7 were deemed as non-reversers because asking them to indicate features plausibly cued them and facilitated reversal.

In this task, the man/mouse figure proved harder than all other stimuli (duck/rabbit = 50% reversers; vase/faces = 44%; man/mouse = 7%; seal/donkey = 56% reversers).

<u>False Belief task</u>

Performance on the false belief task was good, with half of the 3-year-olds passing (Table 3.3). The age improvement was marginally significant, Kruskall-Wallis $\chi^2 = 5.25$, df = 2, p = 0.072. Four children failed the false belief reality question; 1 child failed the memory question.

<u>Droodle task</u>

None of the 3-year-olds and less than half of the older children passed (Table 3.3). This age improvement is significant: Kruskall-Wallis $\chi2 = 9.45$, df = 2, p = 0.009.

Comparison of tasks

Table 3.5 shows the correlations between the tasks. Partial correlations (partialling out age and verbal mental age) are shown below the diagonal in parenthesis. Performance on the Production Memory control task was at ceiling and therefore not included in the correlational analysis. Performance on the AF Production question was already at ceiling at the age of 4 and very good at the age of 3 which makes correlations difficult to interpret. After partialling out age and verbal mental age only the AF Production and the Feature Identification questions remained associated. This is not surprising because they are part of the same task. The Droodle task did not remain associated with the Reversal task over and above age and verbal mental age.

Table 3.5: Correlations and partial correlations below the diagonal (in parenthesis) between the tasks

	AF Production	Feature Identification	AF Reversal	False Belief	Droodle	BPVS-II
Age	0.50***	0.59***	0.41***	0.25*	0.37**	0.63***
AF Production	----	0.50***	0.39**	0.05	0.23†	0.41***
Feature Identification	(0.28*)	----	0.39**	0.09	0.11	0.39**
AF Reversal	(0.12)	(0.19)	----	0.05	0.35**	0.29*
False Belief	(-0.04)	(-0.06)	(-0.05)	----	0.15	0.21
Droodle	(0.02)	(-0.16)	(0.23)	(0.06)	----	0.41***

Performances on the AF Production and Production Memory Control tasks were compared directly. A repeated measures ANOVA was conducted on the performance scores with task (AF Production vs. Production Memory Control) as a within-subject factor and age group as a between subjects factor. There was a main effect for task, $F(1, 60) = 29.69$, $p < 0.001$, showing that the AF Production question is significantly harder. There was a main effect for age group, $F(2, 60) = 7.45$, $p = 0.001$, and a significant interaction between age group and task performances, $F(2, 60) = 7.45$, $p = 0.001$. The interaction is due to the 5-year-olds in the AF Production task approaching ceiling performance.

In order to compare all tasks directly, children were scored as passing the AF Production question if they produced 2 or more out of 3 alternatives as in the previous study. The same criterion was applied to performance on the Feature Identification question (see Table 3.6) and to the Production Memory Control task. According to these criteria (score of 2 or 3 = passed), all children passed the Production Memory Control task. Therefore no crosstabulations with other tasks was calculated.

The pattern of result is clear. The Droodle task is significantly harder than all other tasks (Table 3.6). Most interestingly, the Droodle task is more difficult than the Reversal task and indicating features (Feature Identification) is more difficult than producing ambiguous figures (AF Production). The first number in a pair represents the number of children passing the row task and failing the column task (e.g., 30 children passed the False Belief and failed the Droodle tasks); the second number represents the number of children failing the row task and passing the column task (e.g., 3 children passed the Droodle and failed the False Belief tasks).

Table 3.6: Task comparisons in difficulty using Binomial analysis (all tasks are scored according to pass/fail criteria)

	AF Production	Feature Identification	AF Reversal	Droodle
False Belief	***5***-20**	***21***-9*	***24***-8**	***30***-3***
AF Production	----	***27***-0***	***32***-1***	***42***-0***
Feature Identification		----	***12***-8	***21***-6**
AF Reversal			----	***15***-4*

Discussion and Conclusion Study 2

The results of Study 2 showed that in the modified AF Production question the performance increased already at the age of 3 and is at ceiling at the age of 4. Compared to Study 1, the association between this modified task and the False Belief task did not remain robust and the AF Production task was easier. However, because performance was very high, correlations were difficult to interpret. Altogether the 3-year-olds performance on the False Belief task was also already very good with half of them passing. This suggests that the sample of 3-year-olds was overall performing very well on both tasks – False Belief and AF Production. This is also indicated by their verbal mental age which was 5 months above their chronological age.

In the modified AF Production question children were asked immediately after the disambiguation of the figure to produce the alternative interpretation. Even when children have seen both interpretations seconds before, thirty percent of the 3-year-olds were still unable to produce at least two ambiguous figures pairs correctly. This is similar to the False

Belief Content task (Gopnik & Astington, 1988) where 3-year-old children have stated their wrong belief that there were Smarties in the box and had been unable to recall their own false belief a few seconds later.

In comparison, children had no problems in the Production Memory Control task to remember what was depicted on the other side of the card. In this task children had the same minimal memory demands as in the AF Production question. However, the AF Production question was more difficult. The performance difference can only be explained due to conceptual requirements for the AF Production question. In particular, it is argued that the additional difficulty is the understanding that an ambiguous figure can have two interpretations. Understanding this requires the child to understand the representational relationship between a stimulus and its interpretations - metarepresentation. This is independent of the ability to remember both alternative interpretations.

The association between the AF Production and Feature Identification questions was interesting. Being able to acknowledge both interpretations of an ambiguous figure (AF Production) is significantly easier than to indicate features (AF Feature Identification). This rules out the counter explanation that children succeed in the AF Production task due to perceiving both interpretations and shows that understanding that there are two interpretations is different to the ability to perceive them.

Study 2 also suggests that the Feature Identification question is a methodologically more sensitive way of assessing reversal abilities than the original Reversal task, which plausibly encourages passive behaviour. This has been shown by the significant performance increase in the Feature Identification question at 5-years in comparison to the original Reversal task where no such increase occurred. In the original Reversal task, when presented with the ambiguous figure for 60 seconds there is no apparent reason for the child to perform any mental action. On the other hand, the Feature Identification question neither requires prolonged viewing nor verbal response. Plausibly asking children to indicate features may reduce working memory load, inhibition and may prompt mental imagery. Working memory load may be reduced in the sense that children do not have to hold both interpretations in mind. Inhibition of the prepotent interpretation may be facilitated and mental imagery may be prompted due to being asked to indicate features of the non-prevalent interpretation. Moreover, it may prompt children to search for the alternative interpretation, which enables them to initially reverse. This might explain the seven children which were deemed as false negatives (not reporting a change in perception when actually perceiving it) in the Reversal task. Asking them to indicate features after the 60 seconds period plausibly reduced their working memory load, inhibition, prompted mental imagery and a search strategy was applied which helped them to identify the features of the previously non reported interpretation. One limitation of the Feature Identification question is that it may be prone to false positives. That is, children may by default indicate the correct feature. However, the performance pattern found for the Feature Identification question fits into the findings from previous studies that at approximately 5 years children are able to perceive the two interpretations. If it was prone to false positives an overall performance increase would be expected, and not only for the 5-year-olds, which was not the case.

Finally, the results of Study 2 revealed that the Droodle task was more difficult than all the other tasks and not specifically associated with either the Feature Identification question or the Reversal task after controlling for age and verbal mental age. Hence Study

2, consistent with Doherty and Wimmer (2005), did not replicate the strong association between the Reversal and Droodle tasks as found in Gopnik & Rosati's (2001) study. The Droodle task will therefore not be included in further experiments.

4 Study 3 – Reversing Ambiguous Figures and Executive Functions

In Study 2 it has been demonstrated in a new Feature Identification question, which involves children perceiving the alternative interpretation of an ambiguous figure, that reversal can be induced through asking children to indicate features. This improves performance at the age of 5 in comparison to the original Reversal task. It is plausible that the Feature Identification question may reduce working memory and inhibition load, may prompt mental imagery and active search for the features of the alternative interpretations, whereas the original Reversal task plausibly encourages passive behaviour.

One limitation is that the Feature Identification question only assesses initial reversal and it is not clear what happens within a 60 seconds viewing period. Taking a 60 seconds period for assessing reversal abilities allows a comparison with the adults' phenomenology of reversal: does an ambiguous figure reverse back and forth as it does for adults or do children reverse once and then perseverate in their changed interpretation? To this end, in order to compare children's performance on the original Reversal task directly, a new Reversal task is implemented (revised Reversal task). The revised Reversal task is a combination of the Feature Identification question and the original Reversal task. The original Reversal task requires children to give a verbal response about their perceptual experience after 5, 30 and 60 seconds whereas in the revised Reversal task children have to indicate features of each interpretation after 5, 30, and 60 seconds. Thus, the revised Reversal task requires no verbal response. If children are able to reverse they will be able to indicate features of each interpretation. It is assumed that prompting children to indicate features plus extended viewing (60 seconds) increases their ability to reverse ambiguous figures. This modification of the Reversal task is required in order to achieve a methodologically sensitive measure of children's reversal abilities.

In addition to a revision of the Reversal task Study 3 focuses on the processes involved in reversing ambiguous figures. There is a lag of one year between when children ***understand*** that an ambiguous figure has two interpretations and when children ***perceive*** both interpretations. It is therefore crucial to identify the developments of the necessary processes that enable children to reverse around the age of 5. Because reversal is an active process on the part of the perceiver it is assumed that this requires a high degree of executive function. When considering what mental action is required for the Reversal task it becomes apparent that it may require several forms of executive function. Children may have to inhibit their prevalent interpretation, hold both interpretations on line in working memory and may require to shift attention from one interpretation to the other in order to reverse. Grounds for the belief of executive functions involvement in reversing ambiguous figures comes also from three sources.

First, ambiguous figures reversal and executive function abilities are still developing in the preschool period (e.g., Carlson & Moses, 2001; Gerstadt, Hong, & Diamond, 1994; Kochanska, Murray, Jacques, Koenig, Vandegeest, 1996; Slade & Ruffman, 2005; Welsh, Pennington, & Groisser, 1991; Zelazo et al., 1995; Russell, Mauthner, Sharpe, & Tidswell, 1991).

Second, there is evidence that frontal brain structures are involved while reversing ambiguous figures and in executive functions. Several studies from research with adults (e.g., Ricci & Blundo, 1990; Meenan & Miller, 1994; Klemm, Li, & Hernandez, 2000; Kornmeier & Bach, 2005) have demonstrated considerable frontal lobe involvement while reversing ambiguous figures. Two studies from Ricci and Blundo (1990) and Meenan and Miller (1994) revealed the strongest evidence for considerable and specific frontal lobe involvement while reversing ambiguous figures. Ricci and Blundo (1990) assessed reversal abilities of patients with unilateral frontal or posterior cortical lesions. Patients with frontal lobe lesions were severely impaired in their ability to reverse ambiguous figures. Patients with posterior lesions only, where the visual system itself was damaged, did not show this impairment and performed as well as a control group. Furthermore, Meenan and Miller (1994) found that the difficulty in reversing ambiguous figures is restricted to patients with lesions in the right frontal region. The right frontal lobe has a dominant role in shifting visuospatial perspective (Miller, 1990).

Studies of patients with frontal lobe damage have also demonstrated several impairments in executive functions tasks. Luria (1966) described a series of impairments of patients with frontal lobe damage such as motor perseveration (e.g., unable to tap rhythms in succession), perseveration in one action (e.g., continuing to draw a cross when asked to draw a triangle afterwards), impulsive verbal reactions to a single perceived sign (e.g., selecting pictures by just looking at details only before the overall meaning of a picture becomes clear). This can be subsumed as impairments in selective, goal-directed actions. Moreover, frontal lobe patients show impairments in mental set-shifting abilities (e.g., Barceló & Knight, 2002; Keele & Rafal, 2000; Rogers, Sahakian, Hodges, Polkey, Kennard, & Robbins, 1998; Rowe, Bullock, Polkey, & Morris, 2001), working memory (e.g., Baldo & Dronkers, 2006; Rowe, et al., 2001; Soto, Humphreys, & Heinke, 2006), inhibitory abilities (e.g., McDonald, Bauer, Filoteo, Grande, Roper, & Gilmore, 2005; McDonald, Delis, Norman, Wetter, Tecoma, & Iragui, 2005; Rowe, et al., 2001) and planning abilities (e.g., Goel & Grafman, 1995; Levin, Fletcher, Kufera, Harward, Lilly, Mendelsohn, Bruce, & Eisenberg, 1996).

In addition, thirdly, there is a link between the development of executive function (EF) abilities and theory of mind (TOM) development (e.g., Carlson & Moses, 2001; Davis & Pratt, 1995; Frye et al., 1995; Hughes, 1998; Hughes & Russell, 1993; Kloo & Perner, 2003; Mutter, Alcorn, & Welsh, 2006; Perner, Lang, & Kloo, 2002; Russell et al., 1991). For example, several studies found an association between TOM and inhibitory abilities (e.g., Carlson & Moses, 2001; Russell et al., 1991), working memory (e.g., Davis & Pratt, 1995; Gordon & Olson, 1998), and mental set-shifting (e.g., Carlson & Moses, 2001; Frye et al., 1995; Kloo & Perner, 2003; Perner et al., 2002). Studies also found that there is a specific relationship between inhibitory abilities and theory of mind but not planning or working memory abilities (Carlson, Moses, & Claxton, 2004; Hughes, 1998). In contrast it was found that both inhibitory and working memory abilities are related to TOM (Carlson, Moses, & Breton, 2002; Mutter et al., 2006). However, the functional dependence between theory of mind and executive functions development is debated, and beyond the scope of the present work – that is, whether theory of mind is a prerequisite for executive function or whether executive function development is necessary for TOM.

Thus, there are three lines of evidence which suggest an involvement of executive functions in the ability to reverse ambiguous figures. First, executive function abilities develop considerably in the preschool period, as does the ability to reverse ambiguous figures. Second, there is evidence that executive function abilities and reversal abilities are both associated with frontal brain regions. Third, there is a link between the development of executive functions and theory of mind. Theory of mind development such as metarepresentation, is also a necessary prerequisite for reversing ambiguous figures. Hence, it is plausible that there is a direct link between executive function development and reversing ambiguous figures. The aim of Study 3, therefore, is to identify whether the development of executive function can explain the lag of one year between when children understand that ambiguous figures can have two interpretations and when they are able to perceive both interpretations.

4.1 Experiment 4

In Experiment 4 first children's performance on the original Reversal task (Rock et al., 1994) and on the revised Reversal task is compared. It is hypothesised that children would perform better on the revised Reversal task than on the original Reversal task since task demands and executive load are minimised and mental imagery may be prompted.

There is no direct evidence for an association between executive functions and reversing ambiguous figures. The only hint for a common underlying mechanism comes from a study carried out by Bialystok and Shapero (2005). They compared 6-year-old bilingual and monolingual children's ability to identify the alternative interpretation of an ambiguous figure when uninformed about the two possible interpretations. They also compared performance on their Ambiguous Figures task with performance on executive functions such as working memory, inhibition, and mental set-shifting, indexed by the Dimensional Change Card Sort task (DCCS).

The DCCS (Frye et al., 1995) is originally adapted from the Wisconsin Card Sort Test used in adult research. It requires children to sort a series of cards (e.g., blue apples and red bananas) to target cards (e.g., blue bananas and red apples) first according to one dimension, for example colour. After several trials, the same cards have to be sorted according to the other dimension, for example shape. The difficulty lies here in that two different pairs of rules are put into conflict - the same cards which first had to be sorted according to one dimension have to be sorted according to the other dimension. Importantly, they must be sorted to the opposite location – that is, the two rules have different outcomes. Studies using the DCCS (e.g. Frye et al., 1995; Kloo & Perner, 2003; Perner et al., 2002; Zelazo, Frye, & Rapus, 1996) found that children younger than around 4 years have difficulties in switching rules. They have no problems sorting the cards according to one dimension (e.g., colour) but fail to sort the cards correctly when the sorting dimension changes (e.g., shape), and continue with the old sorting procedure.

In Bialystok and Shapero's study also a new Ambiguous Figures task was implemented. In their Ambiguous Figures task children were informed that there was another interpretation but not what the other interpretation was. First, children were presented with an ambiguous figure and asked whether they could see the other alternative interpretation. If they failed to perceive the other interpretation a feature from the alternative interpretation was pointed out to them and they were told that the feature might be something else in the new picture. If the child was unable to perceive the other interpretation, this procedure would be continued with more features pointed out by the experimenter. If the child still did not perceive the other alternative interpretation a disambiguating context would be added. There were four prompting stages in total. If the child still failed to perceive the other alternative s/he would be deemed as non reverser. It was found that bilingual children performed significantly better than the monolingual children in this Ambiguous Figures task, in an Inhibition task and in the DCCS

(Experiment 2). This fits into previous evidence that bilingual children perform better on the DCCS than monolingual children (Bialystok, 1999; Bialystok & Martin, 2004). An overall analysis indicated that performance on the DCCS significantly predicted performance on their Ambiguous Figures task when data of both groups were merged together. It is not clear how the task performances were related within each group (i.e., bilingual vs. non-bilingual).

It was therefore argued that in order to sort correctly according to both dimensions (e.g., shape and colour) in the DCCS the target cards need to be reinterpreted from once being for example the red one to once being for example the banana. According to Bialystok and Shapero this is similar to ambiguous figure reversal. Reversing ambiguous figures requires a reinterpretation of the meaning in order to find the alternative interpretation. That is, when beginning to reverse one needs to reinterpret the ambiguous figure and reversal is a result of the reinterpretation – that is, reinterpretation causes reversal. If reinterpretation causes reversal one needs to first know ***what*** needs to be reinterpreted (i.e., what the two interpretations are). Therefore, Bialystok and Shapero’s argument can only be applied when the participant is informed about the two interpretations beforehand. However, in their study children were uninformed about the two interpretations. Children were told that there was something else but not what the other interpretation was. Hence, it is difficult to see how the meaning of an ambiguous figure can be reinterpreted without the awareness of what the alternative interpretation, thus, the other meaning is. The causal relationship between reversal as a result of reinterpretation and reinterpretation as a result of reversal is confused in their argument. In order to clarify this issue in the following experiment performance on the DCCS was compared to the ability to reverse ambiguous figures, where children were initially ***informed*** about the two possible interpretations. If Bialystok and Shapero's (2005) argument is correct, an association between set-shifting and reversing ambiguous figures is expected. If so, the development of mental set-shifting abilities may be relevant for reversal.

Several studies have demonstrated an association between mental set-shifting, indexed by the DCCS and Theory of Mind abilities (e.g., Frye et al., 1995; Kloo & Perner, 2003; Perner et al., 2002). The functional relationship between the two is debated. For example Zelazo and Jaques (1996) and Zelazo and Frye (1997) explain this association with the CCC Theory (cognitive complexity and control theory). There are systematic, age-related changes in the complexity of the rule systems that children can represent. For example ***if*** we play the colour game (setting 1) and ***if*** you give me a red banana (antecedent 1), ***then*** you place it with the red apple target (consequent 1), but ***if*** I give you a blue apple (antecedent 2), ***then*** you place it with the blue banana target (consequent 2). The same pattern continues with the shape game except that antecedent 1 applies to consequence 2 and antecedent 2 applies to consequence 1. Increases in complexity correspond to increases in metacognition and self awareness. This results in increased conscious control over thought and action (Zelazo & Frye, 1997; Zelazo & Jaques, 1996). On the other hand it is argued that children's difficulty with the DCCS and TOM is due to the inability to understand re-description (Kloo & Perner, 2003; Perner et al., 2002). In particular, Kloo and Perner (2003) suggest that "to understand false belief one has to understand that someone else can have a description of the real world that differs from one's own description" (pp. 1835). For the DCCS one has to understand that the same object can be re-described for example as being an apple and as being the blue one. This is in line with Bialystok and Shapero's (2005) claim.

It is difficult to see how the CCC Theory would be applied to ambiguous figure reversal because there is no rule children can follow. Moreover, ambiguous figure reversal is not embedded in if-then structures. On the other hand, if the re-description account is correct an association between the Reversal task and Card Sorting is plausible. As Bialystok and Shapero have suggested, being able to reverse requires a re-description of the meaning in order to find the alternative interpretation. This is investigated in Experiment 4.

Method

Participants

Seventy-five children (29 girls, 46 boys) from two predominantly middle class nursery and three primary schools in Stirling/Scotland took part. Table 4.1 shows children's age ranges and children's verbal mental ages (VMA).

Table 4.1: Details of children participating in experiment 4 (VMA in parenthesis)

Age group	N	Mean (y;m)	SD (months)	Range (y;m)
3-year-olds	21	3;5 (3;9)	6 (11)	2;9-4;2 (2;8-6;5)
4-year-olds	28	4;8 (4;11)	3 (12)	4;3-5;0 (3;6-6;8)
5-year-olds	26	5;6 (6;2)	3 (15)	5;1-6;0 (3;10 -8;10)

Design

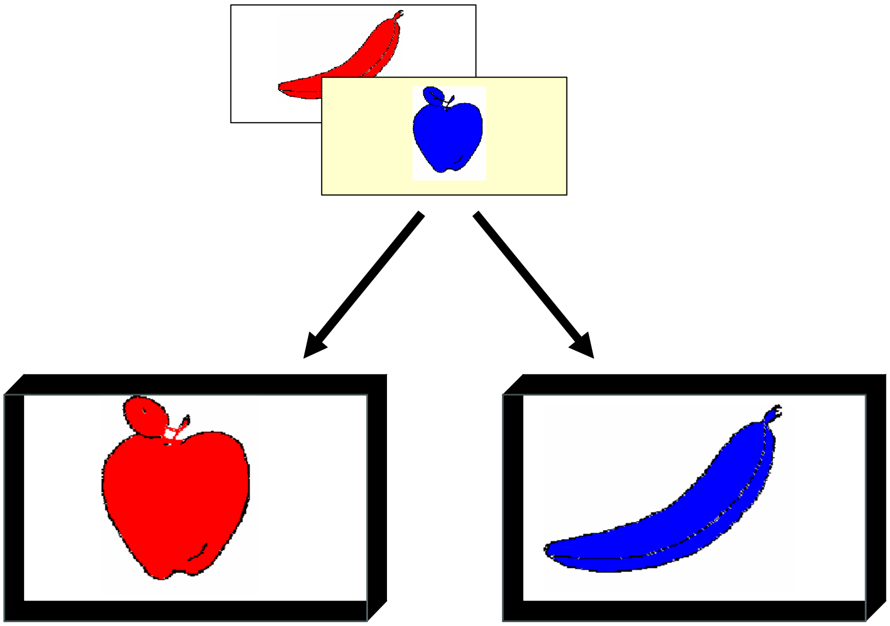
Each child received: False Belief, AF Production plus Feature Identification, and the Dimensional Change Card Sort (DCCS) tasks. Half of the children (37) also received the original AF Reversal task; the other half (38 children) received the revised AF Reversal task with the other tasks. Children were seen in two sessions. The order of task presentation was counterbalanced within and between the sessions. The BPVS-II was administered at the end.

Materials

Dimensional Change Card Sort (DCCS)

For this task two sorting boxes, 2 target cards and 12 test cards (15cm x 10cm) (colour/shape cards) were used (Figure 4.1). Each target card was affixed to a target box (26.5 x 19.5 x 9.5). The test cards had to be put in one of the two boxes through a slit. The target cards depicted a blue banana and a red apple; the test cards depicted red bananas and blue apples.

Figure 4.1: Dimensional Change Card Sort (DCCS)



False Belief, AF Production, original/revised AF Reversal tasks

The Materials for these tasks were exactly the same as those used in the previous study.

Procedure

Children were seen individually in a quiet part of the classroom or nursery. Each session took approximately 15 minutes.

Dimensional Change Card Sort (DCCS)

The procedure followed Frye et al. (1995, Experiment 2) and consisted of a preswitch and a postswitch phase. Half of the children had to sort in the preswitch phase according to shape and the other half according to colour.

Preswitch phase

Children were told to sort the card according to one dimension (e.g. shape): “We are going to play a game. This is the shape game. All the bananas go in this box and all the apples go in that box.” The experimenter then sorted the first two cards (blue apple and red banana) and labelled each according to both dimensions: “this is a red banana” [puts it in the correct box]; “this is a blue apple” [puts it in the correct box]. Then the child had to sort 5 cards on his/her own. In the preswitch phase the test cards were presented in a random order with the constraint that not more than two cards of the same type appeared in a row. Each time, the experimenter took the card, labelled that card according to both dimensions (e.g. “here is a red banana”) gave it to the child and asked: “where does this go?” Children were given feedback about the correctness of the sorting. Children had to sort five consecutive cards according to one dimension. Children scored from 0 to 5 in the preswitch phase.

Postswitch phase

Children had to sort the cards according to the other dimension (e.g. colour). For example children were told: “Now we are going to switch. We are not going to play the shape game anymore. We are going to play the colour game. Only red things go in here and only blue things go in there. This is the colour game.” The cards were again labelled according to both dimensions (e.g. “here is a red banana”) but no feedback about their correctness was given. Children scored from 0 to 5 in the postswitch phase. Children were deemed as having passed if they sorted at least 4 cards correctly in each phase (preswitch and postswitch).

Revised AF Reversal task

The disambiguation phase was the same as for the original Reversal task procedure. For the test phase the test question was changed. Instead of asking “what is it now”, the child was asked to indicate specific features of the ambiguous figure after 5, 30 and 60 seconds. The child was asked to indicate features of the interpretation opposite to the last one s/he reported.

First the child had to indicate features of the interpretation contrary to his/her initial perception. For example if the child initially perceived a duck s/he had to point to features of the rabbit after 5 seconds (e.g. the rabbit’s mouth); of the duck after 30 seconds; and of the rabbit after 60 seconds (see Table 4.2). If the child had failed to point out specific features at (e.g.) 5 seconds the question would have been repeated at 30 seconds and so forth. If the child was able to indicate features of the other alternative interpretation contrary to the initial perception s/he was deemed as reverser.

Table 4.2: features of an ambiguous figure to be indicated in the two phases in the Revised Reversal task

Stimuli	Disambiguation phase		Test phase	
			5/30/60 seconds	5/30/60 seconds
Duck/Rabbit	Eye	Ears	Beak/eyes/beak	Mouth/ears/mouth
Vase/Faces	Top of vase	Noses	Bottom/top/bottom	Mouths/noses/mouths
Man/Mouse	Nose	Ears	Ear/eyes/ear	Tail/feet/tail
Seal/Donkey	Tail	Ears	Eyes/tail/eyes	Eyes/ears/eyes

False Belief, AF Production plus Feature Identification, original AF Reversal tasks

The procedure of these tasks was exactly the same as in the previous experiment.

Results

A summary of performance on all tasks is shown in Table 4.3. Performance on the Reversal revised/original and False Belief (false belief test question) tasks is reported as percentage of children who passed each task whereas performance on the DCCS, AF Production, and Feature Identification tasks is reported as Mean percentage of successful trials (e.g., 1 out of 5 cards sorted correctly, 3 out of 5 cards sorted correctly etc …).

Table 4.3: Summary of performance on each task (Reversal original/revised and False Belief tasks are scored as percentage passed - DCCS, AF Production and Feature Identification tasks are scored as Mean percentage of successful trials)

	Age group			Total
	3y5m (N=21)	4y8m (N=28)	5y6m (N=26)	N=75
AF Production	38%	85%	94%	75%
Feature Identification	19%	45%	69%	46%
DCCS	21%	61%	88%	59%
Reversal revised	27% (N =11)	57% (N = 14)	92% (N = 13)	61% (N = 38)
Reversal original	20% (N =10)	36% (N = 14)	54 % (N = 13)	38% (N = 37)
False Belief	19%	75%	96%	67%

Task performances

AF Production plus Feature Identification

Most 3-year-olds produced 0 or 1 alternative interpretation whereas most 4- and 5-year-olds produced 2 and all 3 alternative interpretations of the ambiguous figures (Table 4.3). This age improvement was significant: $F(2, 72) = 28.52$, $p < 0.001$.

The majority of 3-year-olds were unable to indicate features of ambiguous figures or indicated features of only 1 ambiguous figure. The majority of 4-year-olds indicated features of at least 1 or 2 ambiguous figures and the majority of 5-year-olds correctly indicated features of 2 or 3 ambiguous figures (Table 4.3). This age improvement was significant: $F(2, 72) = 17.77$, $p < 0.001$.

Dimensional Change Card Sort task (DCCS)

Children's performance in the preswitch phase was perfect. All children managed to sort 5 consecutive cards correctly according to one rule. In the postswitch phase almost all children either sorted all cards or no cards correctly. Only one child sorted 4 cards (the criterion for success), one child sorted 1 card, and one child 2 cards correctly. Most of the 3-year-olds sorted no cards correctly, the majority of 4-year-olds passed and the 5-year-olds were almost perfect (Table 4.3). This age improvement is significant: $F(2, 72) = 15.59$, $p < 0.001$. There was a significant difference between 3- and 4-year-olds, Post hoc Bonferroni, $p = 0.004$ and between 4- and 5-year-olds, Post hoc Bonferroni, $p = 0.048$.

Revised AF Reversal task

Most 3-year-olds were not able to reverse, more than half of the 4-year-olds and most 5-year-olds reversed (Table 4.3). This age improvement was significant: Kruskall-Wallis $\chi 2 = 10.37$, $df = 2$, $p = 0.006$. There was a performance difference between 4- and 5-year-olds approaching significance, Fisher's Exact, $p = 0.077$ (two-tailed). Out of the 23 children who reversed, 22 reversed immediately and 3 times back and forth (mean number of reversals = 2.96). There were no differences in difficulty between the ambiguous figures.

Original AF Reversal task

In comparison to the revised Reversal task children performed worse. Most of the 3- and 4-year-olds were not able to reverse and around half of the 5-year-olds reversed (Table 4.3). This age improvement was not significant: Kruskall-Wallis $\chi 2 = 2.72$, $df = 2$, $p = 0.26$. Out of the 14 children who reversed, most reversed once or twice after 30 or 60 seconds and no child reversed 3 times (mean number of reversals = 1.57). This is different to the revised Reversal task where children reversed immediately and 3 times back and forth. Overall the figures were of equal difficulty.

False Belief task

Most 3-year-olds failed and most of the older children passed (Table 4.3). This age improvement is significant: Kruskall-Wallis $\chi 2 = 32.04$, $df = 2$, $p < 0.001$.

Comparison of tasks

Table 4.4 shows the correlations and partial correlations in parenthesis below the diagonal after controlling for age and verbal mental age (VMA).

The revised Reversal task was significantly associated with all the other tasks. These associations did not remain robust after partialling out age and VMA. The original Reversal task was not associated with any of the other tasks. All the other tasks correlated with each other. After partialling out age and VMA the correlation between the AF Production question and the False Belief task remained highly significant.

Because only half of the children received the revised Reversal task and the other half the original Reversal task a separate correlational analysis was conducted for both subgroups. In the subset of children that received the revised Reversal task an association between AF Production and DCCS was found after partialling out age and VMA ($r = 0.42$, $p = 0.011$) and the partial correlation between AF Production and False belief approached significance ($r = 0.30$, $p = 0.075$). In the subset of children that received the original Reversal task the association between AF Production and False Belief remained highly significant after controlling for age and VMA ($r = 0.62$, $p < 0.001$) . However, since each correlation only involved half of the participants and no significant partial correlation occurred between the two Reversal tasks and the other tasks, more emphasis should be given on the overall analysis with the remaining tasks, since this has more statistical power.

Table 4.4: Correlations and partial correlations (in parenthesis) between the tasks - note that only half of the children received the original Reversal task and the other half the revised Reversal task.

	DCCS	Reversal Revised	Reversal Original	AF Production	Feature Identification	False Belief	BPVS-II
Age	0.61***	0.52***	0.37*	0.66***	0.56***	0.66***	0.77***
DCCS	----	0.33*	0.20	0.48***	0.34**	0.44***	0.53***
Reversal Revised	(-0.06)	----	----	0.39*	0.42**	0.33*	0.62***
Reversal Original	(-0.04)	----	----	0.28†	0.29†	0.18	0.34*
AF Production	(0.10)	(0.06)	(-0.01)	----	0.51***	0.65***	0.60***
Feature Identification	(-0.05)	(0.13)	(0.04)	(0.17)	----	0.38***	0.61***
False Belief	(0.05)	(0.08)	(-0.18)	(0.37***)	(-0.02)	----	0.54***

In order to compare the Production and the Feature Identification questions with the other tasks children were coded as passers and failers according to the criteria in the previous studies (a score of 2 or 3 = passed). Table 4.5 shows the comparison between the tasks. The first number of a pair represents the amount of children passing the row and failing the column task. The second number of a pair represents the amount of children failing the row and passing the column task. The Feature Identification and Reversal tasks were of equal difficulty and significantly more difficult than the AF Production and False Belief tasks. The AF Production task was significantly easier than the DCCS.

The original Reversal task was almost significantly more difficult than the revised Reversal task, Mann-Whitney U = 543.5, z = -1.95, p = 0.051.

Table 4.5: Task comparisons in difficulty using Binomial analysis (all tasks are scored according to pass/fail criteria) - note that only half of the children received the revised Reversal task and the other half the original Reversal task

	AF Production	Feature Identification	DCCS	Reversal Revised	Reversal Original
False Belief	***2***-9†	***21***-6**	***13***-7	***7***-5	***14***-3*
AF Production	----	***23***-1***	***16***-3**	***9***-2†	***15***-2**
Feature Identification		----	***10***-19	***4***-9	***8***-5
DCCS			----	***7***-5	***10***-5

Discussion Experiment 4

Experiment 4 has two main findings. First, when changing the task demands children were able to reverse around 6 months earlier than in the original Reversal task. In the revised

Reversal task it was demonstrated that when task demands such as concentration and fatigue factors were removed and children were asked to indicate features instead, performance increased rapidly between the ages of 4 and 5. Asking children to indicate features plausibly reduces the working memory load, since the other alternative interpretation does not need to be held on-line. It may also reduce inhibitory demands in the sense that the prevalent interpretation may be easier to overcome by the prompt to indicate features of the alternative interpretation. In addition, asking to indicate features may prompt mental imagery since it may be easier to imagine the other interpretation by the mention of its features. It is also possible that it prompts children to search for the features, which in turn facilitates reversal. The revised Reversal task is a method with which reversal can be induced externally. On the other hand the original Reversal task encourages passive behaviour. In addition, the original Reversal task, although it is not longer than revised Reversal task, requires additional factors such as motivation and concentration to stare at a figure for 60 seconds. Perner and Lang (1999) have estimated in a meta-analysis of the relation between Theory of Mind and Executive Functions tasks that the length of testing session correlated with the size of correlation between the two tasks. They concluded that a longer testing session introduces performance factors such as tiredness and this can reduce correlations. This might explain the lack of significant associations between the original Reversal task and the other tasks because it requires an additional motivation and concentration load which the revised Reversal task does not. It is therefore suggested that the revised Reversal task demonstrates that reversal can be induced externally through prompting children to indicate features, which facilitates reversal. The revised Reversal task seems henceforth to be a methodologically more sensitive task for assessing reversal abilities.

First, it demonstrates that reversal can be externally induced and may reduce inhibitory-, working memory load and may prompt mental imagery. Moreover, it avoids these additional performance factors. An interesting difference between these two tasks was also the number of reversals. In the original Reversal task children were reversing once, and usually towards the end of the viewing period. In the revised Reversal task children had no problems to reverse back and forth from one interpretation to the other and reversed immediately after 5 seconds. This implies that prompting children to indicate features not only improved the ability to reverse but also the ability to reverse back and forth from one interpretation to the other in a given time.

It was also found that children performed better on the revised Reversal task than on the Feature Identification question, although it was not statistically significant. One concern is that the revised Reversal task and the Feature Identification question lacked a significant association after partialling out age and VMA. This needs to be investigated further.

The second main finding was that the ability to reverse was not particularly related or dependent on mental set-shifting abilities. The lack of association between the revised Reversal task and performance on the DCCS over and above age and verbal mental age speaks against the assumption that mental set-shifting is a key process allowing reversing ambiguous figures. This speaks further against Bialystok and Shapero’s (2005) argument. They suggested that finding the alternative interpretation of an ambiguous figure (when uninformed about what the other interpretation is) requires to reinterpret an image and to see it in a different way. As mentioned in the introduction, there are grounds to believe that the reinterpretation is only possible with the awareness of the two possible interpretations of an ambiguous figure. This was not the case in Bialystok and Shapero's study and only children who failed to indicate features after 4 prompts were shown both disambiguating contexts of an ambiguous figure. It was, however, the case for the revised Reversal task, where children were informed about the two possible interpretations beforehand. The lack of an association with the revised Reversal and Card Sorting tasks speaks against the assumption that mental-set shifting abilities are an important requirement for reversing ambiguous figures.

Moreover, Experiment 4 revealed no association between performance on the False Belief task and the DCCS after partialling out age and verbal mental age. This is consistent with previous studies (Carlson & Moses, 2001; Perner et al., 2002, Experiment 2) but does not replicate the findings of an association between TOM and DCCS (e.g., Frye et al., 1995; Kloo & Perner, 2003; Perner et al., 2002) and does not fit into both the cognitive complexity and control theory and the re-description theory. However, more research would be needed in order to replicate this lack of association between False Belief understanding and performance on the DCCS.

A further important finding was the association between the AF Production and False Belief tasks, which remained significant even when age and verbal mental age were partialled out. This replicates previous findings (Doherty & Wimmer, 2005) and fits into the findings from Study 1. This study confirms that the revised AF Production task is not easier than the original task.

4.2 Experiment 5

In Experiment 5 the role of inhibition, planning, and working memory in reversal is investigated. Experiment 4 did not reveal a particular association between mental set-shifting abilities and reversal. Additionally, Experiment 5 contains a wide range of tasks. The role of mental set-shifting was therefore not further explored.

Inhibition

It is assumed that in order to reverse ambiguous figures children have to inhibit their prepotent percept of one interpretation. Inhibitory control improves significantly over the preschool period (e.g., Carlson & Moses, 2001; Diamond, Kirkham, & Amso, 2002; Gerstadt et al., 1994; Simpson and Riggs, 2005). Gerstadt et al. (1994) gave 31/2 – to 7-year-old children a simplified version of the Stroop task (Stroop, 1935). The Stroop task demonstrates that if a word is displayed in a colour different from the colour it actually names, that is, if the word blue is written in red ink, one will say the word “blue” more readily than one can name the colour in which it is displayed (in this case “red”). In order to pass the Stroop task the prepotent response - reading the word (“blue”) - has to be inhibited in order to be able to name the colour (“red”).

In Gerstadt’s et al.’s (1994) version children were given a picture of a night scenario where children were required to say “day” and a day scenario, where children were required to say “night”. Hence, in their task children were required to say the opposite. Rapid improvements in inhibitory ability between 31/2- and 5-year-olds were found; but performance on the Day-Night Stroop task continued to develop, until 7-years. Simpson and Riggs (2005) investigated 31/2 to 11 year-old children’s performance on the Day-Night

Stroop task (Experiment 2). It was found that inhibitory abilities developed throughout childhood, but with rapid improvements between 31/2 and 5 years, and moderate improvements afterwards. This developmental trend is similar to the age range in which children improve significantly in reversing ambiguous figures. So far we do not know about children's reversal abilities after the age of 5 when 61% (Study 2, Experiment 3), 54% (Study 3, Experiment 4), 57% (Doherty & Wimmer, 2005) of the children are able to reverse ambiguous figures (original Reversal task). When children are not actively asked to indicate features, their performance at the age of 5 is not even close to ceiling (original Reversal task). It therefore seems likely to conclude that improvements still occur after the age of 5. Only one study (Mitroff et al., 2005) has assessed children's ability to reverse between the ages 5 and 9 but unfortunately it did not report age differences or developmental trends. Therefore no conclusion about improvements with age can be drawn from this study. Overall performance Mitroff et al.'s study was at ceiling – out of 34 children 32 reversed but the age distribution has not been reported (i.e., how many 5-year-olds participated and reversed?).

The current experiment uses the Day-Night Stroop devised by Gerstadt et al. (1994). The procedure is similar to their original study. A control task is also implemented in order to exclude the possibility that working memory demands can explain performance on the Day-Night Stroop. This control task follows Diamond et al. (2002) where children were required to say (e.g.) "pig" to the night scenario and (e.g.) "dog" to the day scenario. The control task consisted of the same memory demands as in the Day-Night but of no inhibitory demands because the correct responses ("dog" and "pig") were not semantically related as the ones to be inhibited ("day" and "night") (Diamond et al. 2002). However, in order to compare the reaction times of “day” and “night” (Day-Night Stroop) accurately with the control task (“pig” and “dog”), the word “pig” is replaced with the word “mouse”. The word pairs "day and night” and “dog and mouse” each start with the same phonetic sound class, which allows identical criteria for the determination of acoustic word onset. In the current experiment children’s correct/incorrect responses and reaction times on the Day-Night Stroop and on the Day-Night Memory Control are assessed.

Planning/problem-solving

A common task used to assess the efficiency of planning/problem-solving abilities is the Tower of Hanoi (TOH) (Simon, 1975). In the TOH disks of different sizes have to be transferred in a line of three pegs in order to achieve an end goal pattern. The disks have to be moved following specific rules. Before moving a number of disks the moves have to be planned mentally (fictive) in order to generate the correct sequence. This implies that acting on your own thoughts rather than on reality is required in order to achieve the end goal pattern. Hence, the TOH requires acting on your own mental representation of the problem space.

This is similar to ambiguous figure reversal. When reversing ambiguous figures you have to act on your mental representation independent of reality, since the stimulus configuration itself does not change. The drawn lines depicting the ambiguous figure remain unchanged on the piece of paper. What changes is the pictorial representation of the two possible interpretations where only one at a time can be true - this has to be done mentally. That is, when viewing ambiguous figures you have to mentally generate the other alternative interpretation in order to get it to reverse, when at the same time the physical reality of the figure remains constant. Therefore, in the current experiment, a possible association between planning abilities and reversing ambiguous figures is examined.

The TOH used in the current study follows Welsh (1991) originally adapted from Klahr and Robinson (1981) which has been used previously with children in this age range, with slight modifications. This simplified version of the TOH contains problems presented in an ascending difficulty level – from 2-move problems up to 7-move-problems. For the current study in total three disks are used which are the appropriate number for the age range of children participating in this study. In Welsh's study children were given a maximum of 6 attempts per problem and feedback about their correctness of response was given. Feedback had no effect on task performance. Therefore, in the current study, no feedback is given and children have only 2 attempts per problem. This is in order to avoid learning through trial and error.

Working memory

In the revised Reversal task of ambiguous figures children are asked to indicate features of the opposite alternative interpretation after 5, 30 and 60 seconds. By actively asking children to indicate specific features, they may not have to hold both interpretations in mind on-line in order to succeed. It is possible that through asking children to indicate features of the other alternative interpretation their working memory load is reduced. As a result the reduced working memory load may facilitate reversal. There is also a direct link between working memory and false belief performance (Davis & Pratt, 1995; Gordon & Olson, 1998). Since false belief performance is a prerequisite for ambiguous figure reversal and related to working memory abilities it is plausible that working memory abilities play a relevant role in reversal.

In order to assess the working memory involvement in both Reversal tasks, original and revised, a Backwards Word Span task (Slade & Ruffman, 2005) is used for the current study. The Backwards Word Span task (BWS) requires participants to suppress the natural tendency to repeat the words in a forward order, which makes this task an executive task in comparison to a Forward digit span (Perner & Lang, 1999) since it also contains inhibitory elements.

For the current study nine of the words used by Slade and Ruffman (2005) are replaced because their words had different numbers of syllables. Only words with one syllable are used in the current study throughout all trials.

Previous research suggested that preschool children found the backwards digit/word span working memory task difficult (Davis & Pratt, 1995; Slade & Ruffman, 2005) but working memory abilities increased rapidly between 3 and 4 years (Slade & Ruffman, 2005). However, it is not clear how the improvement will continue with older children. Davis and Pratt's (1995) study involved children between 3- and 5-years but their results did not reveal whether there were any significant age improvements or not. By also including older children, thus 5 year-olds, this question can now be addressed.

Method

Participants

Fifty-six children (34 girls, 22 boys) from 3 primary schools in working and middle class areas in Stirling (Scotland) participated. One additional child was excluded because of attention problems. Table 4.6 shows children's age ranges and their verbal mental age in parenthesis. For this Experiment only 4- and 5-year-old children participated because it was of specific interest which of the processes that develop between the ages of 4 and 5, enable children to reverse.

Table 4.6: Details of children participating in Experiment 5 (VMA)

Age group	N	Mean (y;m)	SD (months)	Range (y;m)
4-year-olds	26	4;6 (4;9)	3 (12)	4;0-4;10 (2;10-4;9)
5-year-olds	30	5;3 (5;0)	4 (14)	4;11-6;0 (3;2-7;2)

Design

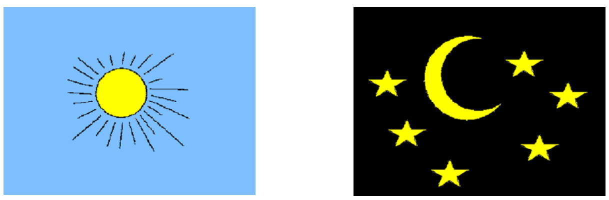
Each child received the: Day-Night Stroop, Day-Night Memory Control, AF Reversal original, AF Reversal revised, AF Production and Feature Identification, Tower of Hanoi (TOH), and the Backwards Word Span (BWS) tasks. In total there were three sessions. The order of task presentation was counterbalanced. The BPVS-II was administered at the end.

Materials and Procedure

Day-Night Stroop and Day-Night Memory Control

For these tasks a picture of a day and a night scenario (Figure 4.2) was used. The pictures (26.5 x 20 cm) were presented on a paper sheet for the training and on a laptop PC (39 cm screen) running with the program E-prime (www.pstnet.com; Psychology Software) for the pre-test and test phase. Each picture was coupled with a beep tone simultaneously when it appeared on the screen. A portable storage device attached to a microphone recorded children's verbal responses. A speech analysis tool called "Praat" (http://www.fon.hum.uva.nl/praat/) was used in order to assess reaction times. Visual and audio inspection of the speech signal allowed identification of the pause between stimulus onset and the child's answer. This gave an accurate measure of reaction time.

Figure 4.2: Pictures used for the Day-Night Stroop and Day-Night Memory Control task



The procedure consisted of three phases, training, pre-test and test-phase. In the training phase the child was first presented with an A4 picture of the day scenario: "When you see this I want you to say "night" ("mouse" – for the control condition)." "What do we say for this one?" [The child had to repeat the word "Night (mouse)"]. Then the night scenario was presented: "When you see this I want you to say "day" ("dog "– control condition)". "What do we say for this one?" [The child again had to repeat the word "Day (dog)"]

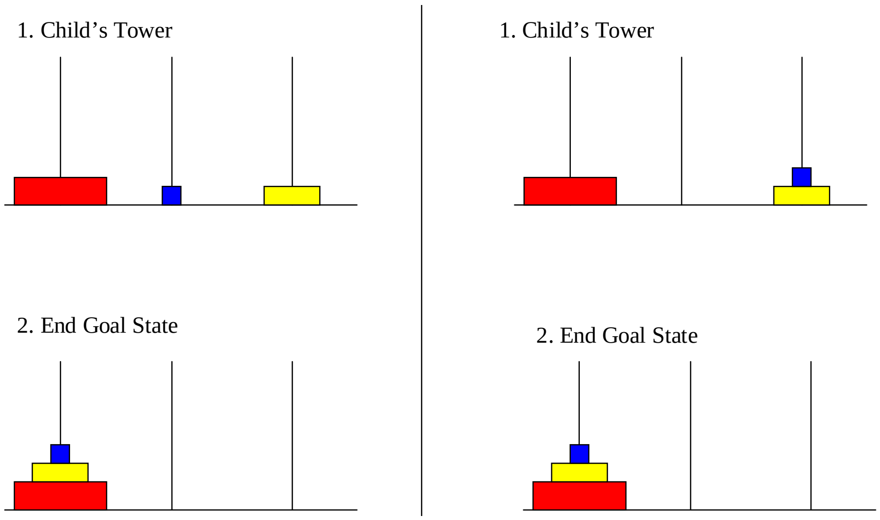
In the pre-test phase the child was first shown the day scenario but this time on a laptop PC. If the child gave no answer initially s/he would be asked: "What do you say for this one?" If the child responded correctly the other picture was presented (night scenario). The child again had to respond accordingly ["day"]. If no response was given the child was prompted: "What do you say for this one?" In the pre-test phase the experimenter never used the words "day" ("dog") or "night" ("mouse"). Children needed to be correct on both pictures (day-night/dog-mouse) in order to start the test-phase. If children failed to give correct responses after 6 pre-test trials they did not continue the task. All children gave correct responses after 6 pre-test trials.

In the test phase the pictures were presented on a laptop PC each for a maximum of 8 seconds but could be immediately terminated per mouse click once the child had responded. The pictures were presented in a pseudo random order – DNNDNDDNNDNDDNDN (8 day and 8 night pictures) - with 2 seconds inter-trial interval following Simpson and Riggs (2005). Children scored from 0-16 in the Day-Night Stroop and from 0-16 in the Day-Night Memory Control.

Tower of Hanoi (TOH)

The whole testing included two sets of Towers of Hanoi: one for the child and for the experimenter (end goal state). Each set consisted of three pegs attached to a wooden board (19.5 x 7.5cm) and three different sized and coloured rings (disks) (Figure 4.3).

Figure 4.3: On the left: example for a two-move problem; on the right: example for a three move problem. The end goal state is the experimenter's tower.



In the introduction phase the child was given the instructions within a story which contained monkeys (disks), Daddy monkey (large disk), mommy monkey (medium disk) and baby monkey (small disk), jumping from tree (pegs) to tree (Klahr & Robinson, 1981). The child's monkeys are copycat-monkeys who want to look like the experimenters monkeys (all three disks on the rightmost peg sorted according to size). Disks (monkeys) could only be moved following three rules: 1. a larger disk could not be placed on a smaller disk (because otherwise the smaller monkey would be squashed) 2. only one disk could be moved at a time (only one monkey can jump to the next tree, never two at the same time) and 3. the disks had to be placed on a peg at all times (otherwise the monkeys would fall into the water).

In the test phase children first had to achieve the end-goal state with two moves (two-move problem). If the child succeeded it would be continued with a three-move problem, and so forth in ascending difficulty. For each problem the children got a maximum of 2 trials. If children were not able to succeed at the first trial per problem the relevant rules were repeated before their second trial. If children still failed the task was terminated. In total there were 6 problems ranging from to 2 moves to 7 moves. Children scored from 0 to 6.

Backwards Word Span (BWS)

The pictures (15.5 x 10cm) used consisted of a horse, sheep, fork, bed, cake, spade, book, car, ball, fish, house, shoe, tie. The items ring, foot, plane, dog, pear, knife, boat, sun, key, bird and hat were only verbally presented. The pictures were taken from Snodgrass and Vanderwart (1980) and from the BPVS (Dunn, Dunn, Whetton, & Burley, 1997).

In the training phase pictures were placed in a line in front of the child and named by the experimenter [“Here is a fork and a bed”]. The experimenter said: “Look, I say fork first then bed. But I want you to say the backwards order, so you say bed (point) fork (point).” After 4 training examples the test-phase started and the experimenter said: “Now I am not going to put pictures down, I am just going to say the words. You say what I say in a backwards way.” The test sequences consisted of three two-words- and three three-word-sequences. If the child was incorrect on the first two test trials, they were again shown how to say the words backwards with the pictures. If children correctly repeated backwards two-words-sequences they scored 1, if they correctly repeated backwards three-words-sequences they scored 2 (following Slade & Ruffman, 2005). If they repeated words which were not adjacent in the three-words-sequences they scored 0.5 (e.g. instead of the correct backwards sequence: “knife, boat, sun!” stating: “boat, sun, knife!”). In total children scored from 0 to 9 (three points for reversing 3 two-word-sequences, plus six points for reversing 3 three-word-sequences).

Ambiguous Figures tasks (AF Production, Reversal tasks original and revised)

The materials and procedures for the ambiguous figures tasks were the same as in the previous experiment. The vase/faces ambiguous figure was removed because it is difficult to indicate features of this stimulus (i.e., for the vase interpretation it is only possible to indicate the top or the bottom of the vase but there are no distinct features).

Results

A summary of performance on all tasks is shown in Table 4.7. Performance on the Reversal revised and original tasks is reported as percentage of children who passed each task whereas performance on all the other tasks is reported as Mean percentage of successful trials. Because children scored in a defined range of percentages (from 0 to 100% correct) for each task, children's mean performance is shown.

Table 4.7: Summary of performance on all tasks with the revised and original Reversal tasks as percentage passed and the remaining tasks as mean percentage of successful trials

	Age group		Total
	4y6m (N = 26)	5y3m (N = 30)	N = 56
AF Production	89%	97%	93%
Feature Identification	44%	54%	49%
Reversal Revised	46%	77%	63%
Reversal Original	39%	53%	46%
TOH	39%	45%	42%
BWS	32%	46%	38%
Stroop Day-Night	64%	81%	73%
Stroop Memory Control	95%	94%	95%

Task performances

Ambiguous Figures tasks

AF Production plus Feature Identification

Performance on the Production question was already at ceiling at 4-years of age (Table 4.7). Only one child was unable to produce any alternative interpretation and only 3 children produced one or two interpretations. The remaining children performed perfectly. An independent samples t-test did not reveal any performance difference between the two age groups (t (54) = -1.49, p = 0.143).

Performance on the Feature Identification question was just below 50% at 4 years and above at 5 years (Table 4.7). This difference between the two age groups was not significant, independent samples t-test, t (54) = -1.06, p = 0.92.

Revised Reversal task

Around half of the 4-year-olds and most 5-year-olds passed (Table 4.7). This age improvement was significant: Mann-Whitney U = 271, z = -2.33, p = 0.02. Out of 56 children 35 reversed. As in the previous experiment if children were able to reverse (N = 35) they were mostly able to reverse back and forth immediately and at any time during the 60 seconds viewing period (Mean number of reversals = 2.57).

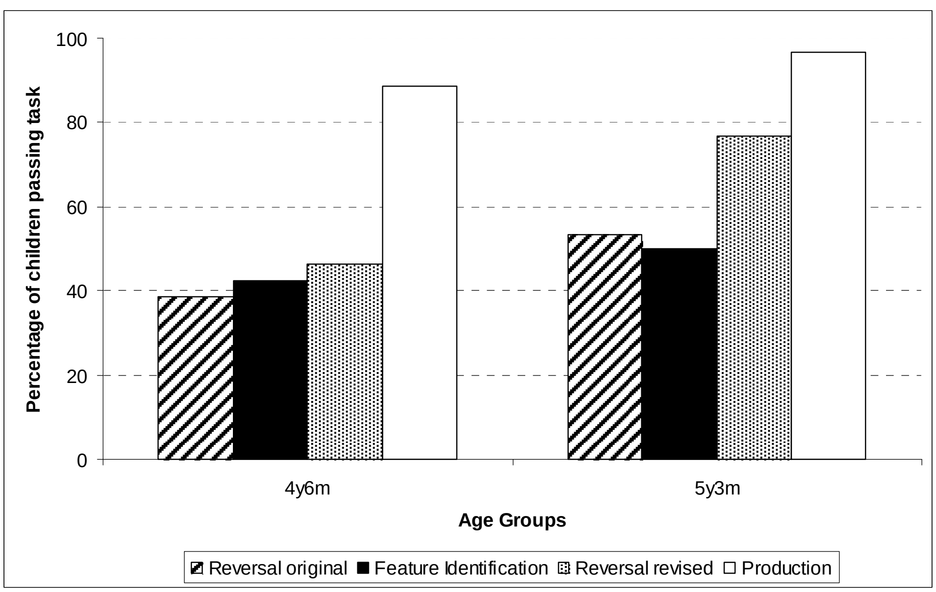
Original Reversal task

Most of the 4-year-olds failed and around half of the 5-year-olds reversed (Table 4.7). There was no significant performance difference between the two age-groups, Mann-

Whitney U = 332, z = -1.10, p = 0.27. Out of 56 children 26 reversed, most children reversed twice (Mean number of reversals = 2.08).

In order to compare the Ambiguous Figures tasks with each other, the Production and Feature Identification questions were scored as passed and failed according to the criteria in previous studies (passed = scores of 2,3). As can be seen in Figure 4.4, the 4-year-old children performed already almost at ceiling on the Production question. Children between 4- and 5 improved rapidly on the revised Reversal task but not on the original Reversal task and not on the Feature Identification question.

Figure 4.4: Performance on the ambiguous figures tasks (all tasks are scored according to pass/fail criteria)



Executive Functions tasks

Tower of Hanoi (TOH)

Children scored from 0-6. Children performed below 50% (Table 4.7). There was no significant difference between the age groups, t (54) = - 0.77, p = 0.45.

Backwards Word Span (BWS)

Children scored from 0-9. Children performed below 50% (Table 4.7). There was no significant difference between the two age groups, t (54) = - 1.53, p = 0.13.

Day-Night Stroop

Children scored from 0-16. Children were above 50% at 4-years and almost at ceiling at the age of 5 (Table 4.7). An independent samples t-test revealed a significant age improvement between 4- and 5 years, t (54) = - 2.39, p = 0.02.

Day-Night Memory Control task

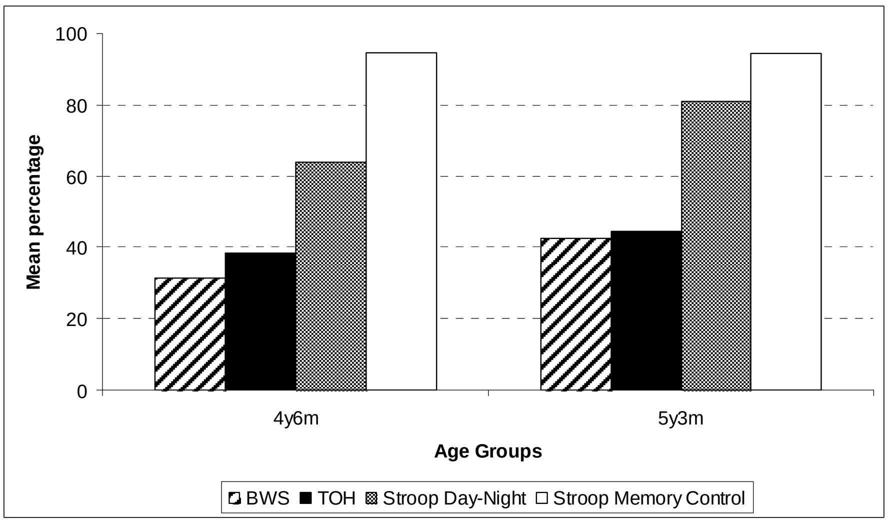
Children scored from 0-16. Overall performance was almost perfect already at the age of 4 (Table 3.5.1). There was no significant difference between the two age groups, t (54) = 0.09, p = 0.93.

Reaction times of 37 children (thirteen 4-year-olds; twenty-four 5-year-olds) of the Day-Night Stroop and Day-Night Memory Control task were assessed. The criteria for being included in the analysis were at least half of the trials correct in the Day-Night Stroop task (children who got a total of 8 or more) (following Simpson & Riggs, 2005). This was in order to get a reliable amount for measuring reaction times of correct responses. The analysis of the reaction times of correct responses revealed a significant difference between the Day-Night Stroop (Mean = 2.05, SD = 0.61) and the Day-Night Memory Control (Mean = 1.68, SD = 0.68) tasks, t (36) = -3.79, p = 0.001, showing that children took longer in the Day-Night Stroop. When comparing performances between the two age groups there was no significant difference in reaction times on the Day-Night Stroop task: 4-year-olds (Mean = 2.18) and 5-year-olds (Mean = 1.99); t (35) = 0.94, p = 0.352, but on the Day-Night Memory Control task, t (35) = 2.44, p = 0.02, indicating that the 4-year-olds (Mean = 2.02) were slower than the 5-year-olds (Mean = 1.51).

Overall this demonstrates that there is a significant difference between younger and older children in correct and incorrect responses in the Day-Night Stroop task. Once children are able to inhibit their prepotent response correctly, there is no difference between younger and older children in response times. For the further analysis, correct and incorrect responses rather than reaction time are used, because that is a more sensitive measure of children’s performance. This is consistent with Diamond et al. (2002) who stated that when children take their time they make overall fewer mistakes.

An overview of children’s mean performances on the Executive Functions tasks gives Figure 4.5. In order to compare them directly, performances on the tasks were rescaled in mean percentages of trials success. Because children scored in a defined range of percentages (from 0 to 100% correct) for each task, children's mean performances are shown. As can be seen, except for the Day-Night Stroop task children between 4 and 5 did not improve significantly on the other tasks.

Figure 4.5: Mean performances on Executive Functions tasks



Comparison of all tasks

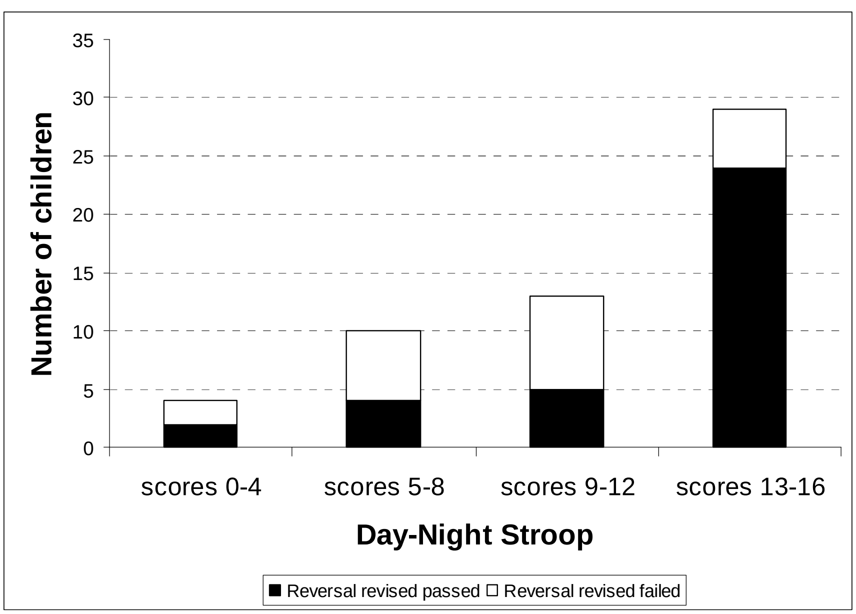
Table 4.8 shows the correlations and the partial correlations below the diagonal in parenthesis after controlling for age and verbal mental age. Performances of the Production task and Stroop Memory control task were at ceiling and therefore the correlations are not reported. None of the Executive Functions tasks were associated with the original Reversal task and the Feature Identification question. The Stroop Day-Night task was significantly correlated with the revised Reversal task and this association remained robust even after controlling for age and verbal mental age. Furthermore this association remained robust when isolating the inhibition aspect and controlling for the memory demand through partialling out performance on the Day-Night Memory Control task, $r = 0.28$, $p < 0.05$.

Table 4.8: Correlations and partial correlations (in parenthesis) between the tasks

	Reversal Original	Reversal Revised	Feature Identification	TOH	BWS	Day-Night Stroop
Age	0.24†	0.19	0.23†	0.37**	0.40**	0.35**
BPVS-II	029*	0.21	0.36**	0.33*	0.51***	0.19
Reversal Original	---	0.28*	0.39**	0.25†	0.09	0.22
Reversal Revised	(0.22)	---	0.56***	0.16	0.09	0.32*
Feature Identification	(0.31*)	(0.52***)	---	0.24†	0.14	0.19
TOH	(0.13)	(0.07)	(0.11)	---	0.36**	0.30*
BWS	(-0.13)	(-0.06)	(-0.10)	(0.17)	---	0.16
Day-Night Stroop	(0.13)	(0.27*)	(0.10)	(0.18)	(-0.01)	---

Figure 4.6 gives an overview about the relation between the Day-Night Stroop task and the revised Reversal task. The higher children scored on the Day-Night Stroop task (note that children scored between 0-16) the higher is the chance of passing the revised Reversal task. This association was confirmed in a Regression analysis. A Binary Logistic Regression analysis with the revised Reversal task as dependent variable and age, verbal mental age and all the other tasks as independent variables was calculated. Stroop Day-Night and Feature Identification performances significantly predicted the revised Reversal task performance over and above age and VMA; Feature Identification: Wald-Statistic = 13.00, $p < 0.001$; Stroop Day-Night: Wald-Statistic = 4.41, $p = 0.036$. The effect of Feature Identification is not surprising since it measures a similar competence. However, the effect of Stroop Day-Night performance on the revised Reversal task performance suggests that inhibitory abilities are significantly involved in ambiguous figures reversal.

Figure 4.6: Relationship between the Day-Night Stroop and the revised Reversal task



Discussion Experiment 5

The performance on the ambiguous figures tasks replicated the findings of Experiment 4 - especially the finding that children's reversal ability increases rapidly between the ages of 4 and 5 when asked to indicate features (Reversal revised) rather than to passively stare at the figure (Reversal original). The low performance increase between the ages 4 and 5 on the original Reversal task can be explained as an artefact of the unnatural task procedure. Making children stare at an image for a given time is not necessarily triggering specific cognitive competences it is rather adding additional cognitive and motivational factors in order to succeed in the task. Moreover, performances on the Feature Identification and the revised Reversal task were significantly associated even after partialling out age and VMA. This is what would be expected since they measure a similar competence.

The significant association between performance on the Day-Night Stroop task and on the revised Reversal task suggests that children need to actively inhibit their prepotent response in order to reverse an ambiguous figure. This was further strengthened by a regression analysis revealing inhibitory abilities as a significant predictor for reversal abilities. None of the other executive functions were particularly associated with reversal abilities.

Overall children's performance on the executive functions tasks did not show significant increases between the ages of 4 and 5 except on the Day-Night Stroop, where performance was almost at ceiling at the age of 5. Performances on the Tower of Hanoi and on the Backwards Word Span were still below average by the age of 5. Several studies have shown that children's executive function abilities are certainly not perfect by the age of 5 (e.g., Passler, Isaac, & Hynd, 1985; Welsh et al, 1991). Several executive function abilities are developing throughout childhood, which is associated with the late maturation of frontal brain structures. Welsh et al. (1991) demonstrated that there are different stages when children reach adult-like performance on executive function abilities. Abilities such as visual search efficiency and simple planning were already mastered by the age of 6; recognition memory even earlier, by the age of 4. Complex set shifting abilities were gained by the age of 10. On the other hand, abilities such as motor sequencing, verbal fluency efficiency and complex planning continued to develop into adolescence. Passler, Isaac and Hynd (1985) demonstrated that children's inhibitory abilities significantly increase between the ages of 6 and 12. Importantly this has to be seen as an increase in several stages within this age range. They concluded that most executive functions, associated with the frontal lobe, are fully developed by the age of 12. In their review article Welsh and Pennington (1988) furthermore emphasized that executive functions abilities, associated with frontal brain structures, continue to develop from the first year of life until adolescence. They also emphasized that it is important to use developmentally appropriate measures to assess executive functions abilities. This has been exactly the problem so far with tasks trying to assess children's reversal abilities. If we only considered children's performance on the original Reversal task we would conclude that even 5-year-old children are far from ceiling performance in reversing ambiguous figures, when only around 50% reverse. If we took only the performances on the original Reversal task into consideration we would be unable to draw a conclusion at which age most of the children are able to reverse. Moreover, performance on the original Reversal task was not associated with any of the other tasks. However, when the task demands change, most children by the age of 5 are able to reverse. This discrepancy can only be due to different task demands.

From Experiment 5 it is concluded that children, when asked to indicate features and view the figure for 60 seconds, are able to reverse between the ages of 4 and 5. Children’s understanding that ambiguous figures have two interpretations develops one year earlier (AF Production). Inhibitory ability is a major process allowing children to reverse around half a year later. However, since the correlation between inhibitory abilities and reversal was not that high, it is suggested that there are further processes involved in reversal. This is investigated in Study 4.

Study 3 General Conclusion

When children are not required to stare at an ambiguous figure passively for 60 seconds and when no verbal response is required, children are able to reverse almost perfectly by the age of 5. This has been demonstrated in a newly created Reversal task (revised Reversal task). It can be concluded that the original Reversal task which has been used in literature so far introduces additional performance factors such as concentration, motivation to stare at an image for a given time. Performance on this task was not significantly associated with any of the executive functions tasks in this study, nor to any other measures in previous studies, after controlling for age and verbal mental age. On the other hand, when these performance factors were eliminated, and reversal is induced externally, children’s ability to reverse was significantly associated with other executive functions such as mental set-shifting and inhibition. Importantly, when age and verbal mental age were controlled, children’s reversal abilities remained significantly dependent on inhibitory abilities but not mental set-shifting. This suggests that inhibitory abilities are a necessary process for reversal to occur. In particular, it is suggested that children have to be aware that an ambiguous figure can have two different interpretations, and in addition, they have to internally inhibit their prepotent interpretation in order to perceive the other alternative interpretation.

5 Study 4 – Reversing Ambiguous Figures and Mental Imagery

Rock et al. (1994) suggested that adults reverse by means of a process involving imagination; “one has to impose one’s imagined structure onto the stimulus and this is not necessarily easy to do (p.57).” This plausibly requires imagery abilities.

There is no clear line of evidence what imagery abilities are exactly and when children develop certain imagery abilities. There are two lines of evidence which give a more detailed view on the topic (Kosslyn, Margolis, Barrett, Goldknopf, & Daly, 1990; Piaget & Inhelder, 1971). Piaget and Inhelder (1971) gave children numerous mental imagery tasks. It was found that overall children from around the age of 7 onwards have complex spatial and geometric imagery abilities. However, lots of their experiments required children for example to make representational drawings of transformed images, which presupposes being able to draw representatively in the first place and might have been a problem for the younger children (e.g. the 4-year-olds).

Kosslyn et al. (1990) investigated 5-, 8-, and 14-year olds’ imagery abilities compared to adults’ imagery abilities. They distinguished between several imagery sub-abilities such as image generation (forming an image), image maintenance (storing an image in short-term memory), image scanning (shifting the attention over an imaged object or scene) and image rotation (transforming objects by mental simulation). Overall 5- and the 8-year-olds performed significantly worse than 14-year olds and adults, which suggests that imagery abilities are developing into adolescence. For example Image Generation, Image Maintenance, Image Scanning and Image Rotation abilities increased significantly between 5- and 8-year-olds as well as between 8- and 14-year-olds, who performed equally well as adults. Courbois (1996) using similar tasks and comparing typically developing 5- and 8-year-olds with mentally retarded participants (matched with mental age) found that the 8-year-olds performed significantly better than all the other groups. This confirms Kosslyn et al.'s (1990) results that imagery abilities are still developing over childhood. Interestingly, in Kosslyn's et al.'s (1990) study performances on the sub-abilities were not associated with each other. This implies that these imagery abilities are acting independently from each other. Kosslyn, Brunn, Cave and Wallach (1984) had already claimed that mental imagery abilities are not a general ability but comprise sub-abilities which are acting independently. They found adults' performances on several imagery tasks were overall not correlated with each other. They concluded that imagery abilities are not a coherent set of abilities.

Several other lines of research investigated children's mental rotation ability (which is according to Kosslyn and colleagues a sub-ability). There is inconsistent evidence from which age onwards children have mental rotation abilities. Children from around 8 years onwards are able to mentally track the rotation of a pointer and to indicate the pointer's imagined position (Dean, Duhe, & Green, 1983), which would be in line with Piaget and Inhelder (1971). On the other hand Marmor (1975) found that children at the age of 5 already use mental rotations in order to anticipate images. For example children were shown pairs of stimuli (e.g., ice-cream cones with a bit taken out on one side) that were rotated differently. The child's task was to judge whether they are the same. 5-year-old children were already able to mentally rotate the stimuli. One further study suggests that there is a link between mental imagery and the development of theory of mind abilities. Estes (1998) gave children a task which adults solve by using mental rotation. On a computer screen children were presented with two monkeys which were holding up either the same arm or the opposite arm. One of the monkeys was always in an upright position whereas the other one was rotated clockwise between 0° and 180°. The child's task was to judge whether they were the same or different from each other. In addition, children were asked to explain how they had made their judgements (i.e., "How can you tell if those monkeys are holding up the same arm or not?"). The results revealed that children's mental rotation abilities increased significantly between the ages of 4 and 6. In addition, 6-year-olds gave significantly more mental explanations than 4-year-olds (i.e., "Pretend your mind put them right side up. I turn this one around in my mind."), and did not differ significantly from adults. Overall children who performed well at the task described their behaviour in terms of mental activity; children who performed poorly did not. Estes therefore suggests that increased awareness of one's own mental states may allow more use of mental imagery. This would provide an additional reason why theory of mind abilities are a prerequisite for reversal. That is, since a representation of ones mental activity allows visual imagery it is possible that this in turn allows reversal. In particular, it is plausible that one needs to understand the nature of one's mental image in order to use or to manipulate it. If this is the case then the insight into one's own mental state may give oneself a better use of mental images. There is inconsistent evidence about when mental imagery abilities are developing but the studies by Estes (1998) and Marmor (1975) suggest that they are already developing in the preschool period.

So far no study has investigated the involvement of mental imagery in reversing ambiguous figures. This is the first attempt to explore this issue. Due to the sparse number of studies systematically investigating children's mental imagery abilities and due to the finding that mental imagery abilities comprise a set of sub-abilities which are unrelated, it is necessary to create new tasks that can show an imagery and reversal association. Thus, the aim of the current study is to devise new measures of mental imagery (Image Maintenance, Image Generation) that are comparable to children's reversal abilities, and to explore when certain imagery abilities develop.

As noted above there is evidence that mental imagery abilities comprise independently acting sub-abilities (Kosslyn et al., 1984; Kosslyn et al., 1990) such as image generation, image maintenance and image rotation and image scanning.

In Kosslyn et al.'s ***Image Maintenance task*** particpants were required to study grids presented on a computer screen that contained a pattern. The pattern was displayed by randomly filling in one fifth of the cells in the grid. Then only an empty grid was displayed. Two X marks appeared on the screen and the participants were required to judge whether or not both X's fell in cells that had been filled by the pattern. The 5-year-olds were responding significantly slower and were less accurate than the 8-year-olds and 14-year-olds who were not different to the adults. In addition the 5-year-olds and 8-year-olds did not show quicker reaction times in a light-load condition (with less to remember) than in a heavy-load condition, nor did the error rate differ. This finding is counterintuitive because it would be assumed that heavier load leads to longer reaction times and more errors if cognitive processing is involved. Since 5-year-olds already showed difficulties in this task and also because cognitive load did not influence performance it is unclear whether this task is appropriate for the younger age group. Moreover, this task involves abstract patterns whereas for ambiguous figures a stimulus interpretation with a specific content has to be maintained. It was therefore necessary to create a new Image Maintenance task.

In the newly devised Image Maintenance task children were required to maintain an image over a brief time and then to recognise this image out of 4 other images. The Image Maintenance task contained two different conditions: a simple cognitive load condition and a complex one. In the Image Maintenance simple condition children are shown pictures of 4 different, for example, giraffes. A further target stimulus which is the same as one of the 4 giraffes needs to be remembered and then after a brief pause recognised as the correct one out of the four. In the Image Maintenance complex condition children have to do exactly the same but this time different stimuli were used. The stimuli were more abstract but all contained the same specific content. For example a set of 4 different skewed swans were used. The difference between the complex and the simple conditions is that the stimuli in the complex task are more abstract, less familiar to children and have only an overall shape rather than specific features – hence they should be more difficult to remember and more visual imagery is needed. In both tasks the pictures cannot be remembered through labelling (e.g., “a giraffe”) because they comprise sets of the same animal. They can only be remembered through creating a mental image of each stimulus.

It was assumed that in order to impose an imagined structure of one interpretation of an ambiguous figure for reversal it has to be remembered to do so accordingly. In Study 4 it was assumed that this requires working memory. However, it is possible that the working memory task (Backwards Word Span) used in Study 3 was not the most appropriate comparison to the reversal problem of ambiguous figures. In particular, devising a task which involves children holding an image in the mind is probably closer to the reversal problem, than for them to hold words on line in working memory. If remembering an image is necessary for reversal an association between this newly created Image Maintenance task and the Reversal task would be expected.

In Kosslyn et al.'s (1990) ***Image Generation task*** a lowercase letter was displayed beneath an empty grid on a computer screen. One second later two x marks appeared in the grid. The participants' task was to judge whether both x marks would have fallen on the uppercase version of the letter if it had been displayed by filling in the appropriate cells of the grid. The participants were familiarized with the appearance of the uppercase letters in the grid before the experiment began. According to Kosslyn et al., one second is enough to recognize a cue but not to form an image completely. Thus, the response times reflect the relative time required to form the image. The results revealed that this was difficult for the 5-year-olds and that it took them overall around 5 seconds to respond, and there was no difference in reaction times between simple and complex stimuli. This is somehow unexpected because one would assume that the generation of a complex stimulus takes longer than that of a simple one. It is therefore not clear whether the results of the 5-year-olds reflect the time to generate images. Another problem with this task is that it presupposes children being able to read, which is not the case for the younger children participating in this research. It was therefore necessary to devise a task which is more appropriate for the age range of these children. One possibility would have been to display patterns instead of letters. However, since the task is already difficult for the 5-year-olds and ambiguous figures contain a specific content instead of abstract patterns, this possibility was ruled out.

If imposing one's imagined structure onto the ambiguous figure is necessary for reversal (Rock et al., 1994) it is necessary to create a task in which children have to impose a structure onto a stimulus. Therefore, a new Image Generation task was devised. The new Image Generation task contained the same stimuli as the Image Maintenance task except that the target stimulus (template) this time was a cut out hole of one of the four (e.g., swan) stimuli. The child's task was to judge which one of the four goes in the cut out hole (template). Thus, in this Image Generation task the child has to form an image of the stimulus from the cut out hole, compare that with the four stimuli, and select the stimulus which fits into the shape of the hole. Furthermore, there are no memory demands because all stimuli are presented simultaneously. Thus, the newly created Image Generation task involves forming an image and imposing an imagined structure onto a stimulus, which according to Rock and colleagues is necessary for reversal. It therefore seems an appropriate task to explore this issue.

The two other sub-abilities, image scanning and image rotation were not investigated in this study. Image scanning was directly investigated in Experiment 7b with the use of eye-tracking technique. In particular children's eye-movements when viewing ambiguous figures were recorded. This will be reported in more detail in Experiment 7b. Image rotation was not investigated because in the typical rotation tasks one of the stimuli is rotated and the participant's task is to judge whether they are the same or different. This requires someone to make a judgement about an externally induced transformation of the stimulus (i.e., rotation). In order to make this judgment mental rotation is required. This is different to reversing ambiguous figures. Exactly the opposite "action sequence" applies to ambiguous figures. Mental action is required ***in order to*** reverse an ambiguous figure and not a result of the reversal process (transformation). Thus, in order to “transform” the ambiguous figure mental action is required, rather than to use mental action in order to judge the already happened “transformation”. A direct comparison between a Rotation task and the Reversal task therefore seems inappropriate.

To summarize, Study 4 aims to identify the association between mental imagery abilities and the ability to reverse ambiguous figures. Since this is the first attempt to investigate this issue, a set of new tasks have been implemented. The few existing tasks were not appropriate for comparison to ambiguous figures reversal. In two experiments children were given an Image Maintenance task and an Image Generation task.

5.1 Experiment 6

In order to keep an analogy to children’s problems with reversing ambiguous figures a new Image Maintenance task (Image Maintenance Complex and Simple) was created. In the new Image Maintenance task the child was required to compare a shape with four other shapes and correctly select the one which looks the same (pre-test). This shape needed to be retained over time in memory for later recognition (test-phase). The shapes in the complex task comprised a set of 4 differently skewed swans, camels and horses. This was in order to keep shapes with contents rather than using completely abstract shapes, because the ambiguous figures used have specific contents such as, for example, a duck and a rabbit.

A second Image Maintenance task (Image Maintenance Simple) was implemented where children needed to fulfil exactly the same requirements but where different stimuli were used. The stimuli used in the Simple task were normal, non-skewed pictures of animals comprising a set of 4 camels, cows and horses. It was assumed that children have no problems with remembering specific pictures in the Simple task, because the pictures can be remembered according to specific features and were not abstracted. In particular, one image will feel much more familiar than the others.

The newly created Image Maintenance tasks are forms of simple and complex recognition tasks where verbal labelling (i.e., "a giraffe") does not aid the maintenance process. A mental image of the original target stimulus is plausibly much more useful in the complex task. Hence, because the complex task contains stronger mental imagery demands than the simple task, it is expected to be more difficult. If children do use mental imagery there should be age related changes in performances in the complex and simple tasks. Moreover, if image maintenance abilities are necessary for reversal to occur then the complex task should be more strongly associated with the Reversal task because more use of imagery is required.

Method

Participants

Fifty-two children (27 girls, 25 boys) from 2 predominantly working class nursery schools and 1 primary school in the surroundings of Stirling/Scotland took part (see Table 5.1). Two out of the remaining 52 children did not want to complete the BPVS-II and one additional child did not want to complete the Ambiguous Figures Production task and the BPVS-II, hence these data are missing.

Table 5.1: Details of children participating in Experiment 6 (VMA)

Age Group	N	Mean (y;m)	SD (months)	Range (y;m)
3-year-olds	17 (15)	3;6 (3;6)	5 (7)	2;11-4;0 (2;9-4;10)
4-year-olds	15 (14)	4;6 (4;1)	3 (14)	4;2-5;0 (2;4-6;5)
5-year-olds	20	5;7 (5;11)	3 (9)	5;2-6;0 (4;5-7;9)

Design

Each child received the: AF Production task plus Feature Identification, Image Maintenance Complex, Image Maintenance Simple, revised AF Reversal, and False Belief tasks. Children were seen on two different sessions. The order of task presentation was counterbalanced within and between the sessions. The BPVS-II was administered at the end.

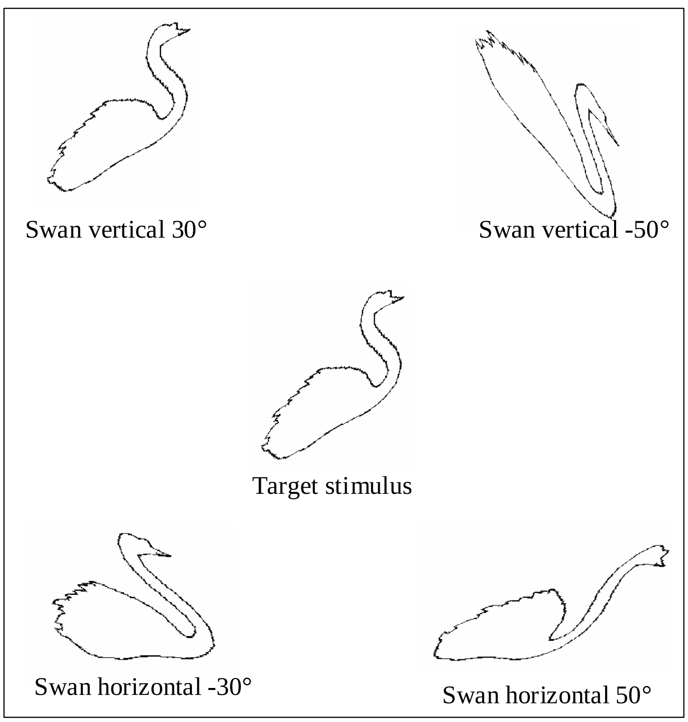
Materials and Procedure

Image Maintenance Complex task (IMC)

For this task outline pictures (15.5 cm x 14.5 cm) of four different skewed swans, camels and horses were used (Figure 4.6.1). They were all made skewed either vertically or horizontally towards 30/-30 50/-50 degrees. This was in order to make them more distinct from each other. Extensive piloting revealed that younger children had difficulties in distinguishing between skewed animals towards only 30 and 40 degrees. The swans were skewed vertical/30° and -50°; horizontal/-30° and 50°. The camels were skewed vertical/-

30°/50°; horizontal/30°/-50°. The horses were skewed vertical/30°/-50°; horizontal/-30°/50°. The four skewed pictures of each animal were affixed to each corner of a 20 cm x 48 cm cardboard surface. The target stimulus, which was the same as one of the affixed pictures, was placed in the middle of the cardboard surface (Figure 5.1). The target stimuli for the three animal groups were a swan vertical/30°, a camel horizontal/-50°, and a horse vertical/-50°. A second cardboard surface comprised the same pictures in a different order - none of the pictures was on the same position as on the cardboard surface before.

Figure 5.1: Swan stimuli used in the Image Maintenance Complex task in Experiment 6



The Image Maintenance Complex task (IMC) consisted of a pre-test phase and a test phase. In the pre-test phase the child was shown the first cardboard surface with the affixed 4 swans. A target stimulus (e.g. swan vertical/30°) was placed in the middle of the cardboard and the pre-test question was asked: “Which one of these four pictures looks exactly the same as this one in the middle here (pointing to the target stimulus)?”, “this one (point), this one (point), this one (point) or this one (point)?” (starting pointing from the top left clockwise). The child had to select the one which looked the same. Then the experimenter said: “Now I want you to remember this one here (pointing on the target stimulus), ok?” The target stimulus was turned faced down on the table and the first cardboard surface was removed. Immediately after that the second cardboard surface was presented and the test-question was asked (note that the stimuli were rearranged on the second surface): “Which one of these looks exactly the same as this one here (pointing to the faced down target stimulus)? This one (point), this one (point), this one (point) or this one (point)?” (starting from the top left clockwise). The child’s task was to correctly select the same stimulus on the cardboard surface which lay faced down on the table.

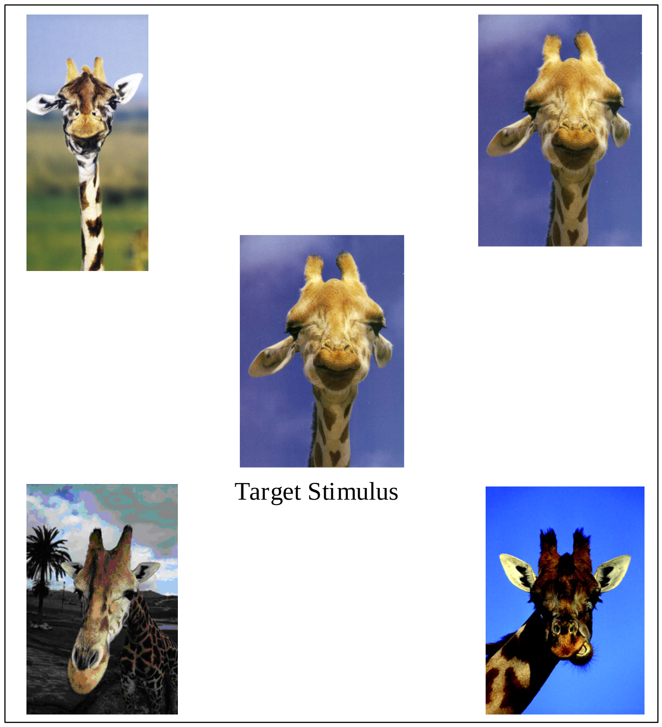
This was continued with the camel and the horse stimuli. One child received the first cardboard surface first and another child the second cardboard surface first in the pre-test and vice versa in the test-phase. Children were deemed successful if they answered the pre-test and the test-question of each animal correctly. Children scored from 0 to 3.

Image Maintenance Simple task (IMS)

For the Image Maintenance Simple task (IMS) the material set up with the cardboard surfaces was exactly the same, except that different pictures were used: giraffes, horses and cows in black and white and non-skewed (Figure 5.2).

The procedure of the Image Maintenance Simple task followed the one of the Image Maintenance Complex task.

Figure 5.2: Stimuli used in the Image Maintenance Simple task (IMS)



Revised AF Reversal, AF Production plus Feature Identification, False Belief tasks

The materials and procedures for these tasks were the same used in the previous experiment.

Results

A summary of performance on all tasks is shown in Table 5.2. Performance on the False Belief (false belief test question) and revised Reversal tasks is reported as percentage of children who passed whereas performance on the Image Maintenance Simple and Complex, Production and Feature Identification tasks is reported as Mean percentage of successful trials (e.g., 0 out of 3 images maintained, 1 out of 3 images maintained, etc …).

Table 5.2: Summary of performance on each task (False Belief and revised Reversal task scored as % passed - Image Maintenance Simple and Complex, Production and Feature Identification scored as Mean percentage of successful trials)

	Age Group			Total
	3y6m (N=17)	4y6m (N=15)	5y7m (N=20)	N=52
IMComplex	31%	67%	77%	59%
IMSimple	63%	87%	93%	82%
AF Production	44% (N=16)	73%	95%	73% (N=51)
Feature Identification	17% (N=16)	27%	57%	35% (N=51)
Reversal Revised	6%	47%	80%	46%
False Belief	29%	67%	90%	64%

Image Maintenance Complex task (IMC)

Children had no problems in the pre-test phase comparing the shape of the target stimulus to the other shapes. All children correctly identified the shape which matched target stimulus, except three 3-year-olds who selected 0 or 1 out of 3 stimuli correctly. Performance of the 4- and 5-year-olds was almost perfect. This age improvement was significant, $F(2, 51) = 6.64$, $p = 0.003$. Post hoc Bonferroni analysis indicated a significant difference between the adjacent age groups of 3- and 4-year-olds, $p = 0.009$.

In the test-phase most 3-year-olds maintained 0 or only 1 image over time correctly (Table 5.3). More than half of the 4-year-olds and the majority of 5-year-olds were able to maintain at least 2 images correctly. This age improvement was significant, $F (2, 51) = 13.37$, $p < 0.001$. Post hoc Bonferroni analysis indicated a significant difference between adjacent ages of 3 and 4, $p = 0.002$.

In order to investigate whether the 3- and 4-year-olds' performance is due to guessing, a one-sample t-test was calculated. The test statistic is 0.75 when comparing children's performance for all 3 trials against chance (3 x ¼). The results revealed that the 4-year-olds but not 3-year-olds significantly performed above chance, $t (14) = 5.73$, $p < 0.001$; $t (16) = 0.88$, $p = 0.39$, respectively.

Table 5.3: Image Maintenance Complex (IMC): number of stimuli maintained correctly within the different age groups after they had correctly selected them in the pre-test phase

Stimuli retained correctly	Age group			Total
	3y6m (N = 17)	4y6m (N = 15)	5y7m (N = 20)	N = 52
0	35%	7%	5%	15%
1	41%	13%	0%	17%
2	18%	53%	55%	42%
3	6%	27%	40%	25%
Mean	**.94**	**2.00**	**2.30**	**1.77**

Image Maintenance Simple task (IMS)

Children's performance in the pre-test phase was almost perfect with only 2 children selecting just 2 out of 3 images correctly. The remaining 50 children selected all images correctly.

More than half of the 3-year-olds and the majority of 4- and 5-year-olds were able to remember at least 2 or all images correctly (Table 5.2). This age improvement was significant, $F(2, 51) = 8.97$, $p < 0.001$. Post hoc Bonferroni analysis indicated a significant difference between 3- and 4-year-olds, $p = 0.013$.

In order to compare performances on the two Image Maintenance tasks – simple and complex – a repeated measures ANOVA was conducted on the performance scores with task (Image Maintenance Simple vs. Image Maintenance Complex) as a within-subject factor and age group as a between subjects factor. There was a significant effect for task $F(1, 49) = 30.99$, $p < 0.001$, showing that the complex was significantly more difficult; and for age group $F(2, 49) = 12.70$, $p < 0.001$, and no significant interaction between age group and task performances.

AF Production plus Feature Identification

Performance on the Production question was typical: more than half of the 3-year-olds failed, and the majority of the older children passed (Table 5.2). This age improvement was significant, $F(2, 50) = 10.88$, $p < 0.001$.

Performance on the Feature Identification question was also typical: the majority of 3- and 4-year-olds was able to indicate features of 0 or 1 ambiguous figure; the majority of 5-year-olds was able to indicate features of 2 or 3 ambiguous figures (Table 5.2). This age improvement was significant, $F(2, 50) = 8.41$, $p = 0.001$.

Revised Reversal task

Most 3-year-olds failed, around half of the 4-year-olds passed and the majority of 5-year-olds passed (Table 5.2). This age improvement was significant, Kruskall-Wallis $\chi 2 = 19.92$, df = 2, $p < 0.001$.

Out of 52 children 24 reversed. As previous experiments have shown, most children were able to reverse immediately and three times back and forth throughout the 60 seconds viewing period (mean number of reversals = 2.63, N = 24).

There was no significant difference in performance if children have seen the ambiguous figure before in the Production task new (50% correct) or were naïve to the stimulus (42.3% correct), Mann-Whitney U = 312, z = -0.551, p = 0.58.

False Belief

Most 3-year-olds failed and most of the older children passed (Table 5.2): Kruskall-Wallis $\chi 2 = 14.36$, df = 2, $p = 0.001$.

Comparisons of tasks

Table 5.4 gives an overview about correlations and partial correlations below the diagonal after controlling for age and verbal mental age (VMA). Performance on the Image Maintenance Simple task was almost at ceiling and is therefore difficult to interpret. After partialling out age and verbal mental age the revised Reversal task and Feature Identification question remained significant. This is not surprising because both tasks measure a similar ability. Most surprisingly, False Belief and AF Production performance were negatively associated, although not significantly, after partialling out age and VMA.

Table 5.4: Correlations and Partial correlations (in parenthesis) Experiment 6

	Reversal Revised	Production	Feature Identification	False Belief	IMComplex	IMSimple
Age	0.56***	0.57***	0.48***	0.57***	0.50***	0.46***
BPVS	0.59***	0.59***	0.58***	0.62***	0.59***	0.47***
Reversal Revised	----	0.47***	0.67***	0.46***	0.45***	0.42**
Production	(0.11)	----	0.45***	0.36**	0.45***	0.63***
Feature Identification	(0.50***)	(0.14)	----	0.32*	0.40**	0.39**
False Belief	(0.11)	(-0.04)	(-0.04)	----	0.43**	0.38**
IMComplex	(0.15)	(0.16)	(0.08)	(0.11)	----	0.54***
IMSimple	(0.13)	(0.47***)	(0.16)	(0.07)	(0.34*)	----

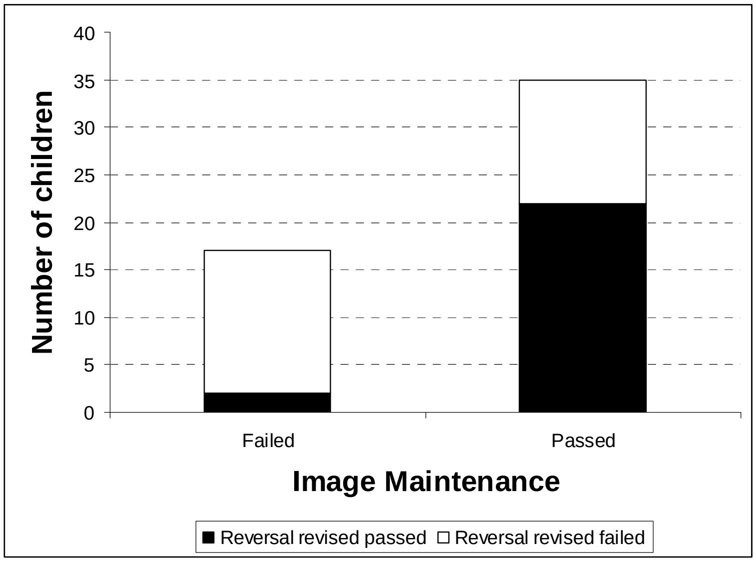
In order to illustrate the relationship between the revised Reversal task and the other tasks, performance on the Production and Feature Identification questions, and Image Maintenance Complex task (IMC) was coded into passers and failers. Children were coded as passers if they were able to maintain at least 2 images, or all 3 images correctly. This followed the scoring criteria for the Production and Feature Identification questions. Table 5.5 gives an overview about differences in difficulty between the tasks. The Feature Identification question was more difficult than all the other tasks. The revised Reversal task was more difficult than the Image Maintenance Complex, False Belief and AF Production tasks which were of even difficulty.

Table 5.5: Task comparisons in difficulty using Binomial analysis (all tasks are scored according to pass/fail criteria)

	Reversal Revised	Production	Feature Identification	IMC
False Belief	***12***-3*	***5***-9	***19***-3***	5-7
Reversal Revised	---	***1***-14***	***8***-1*	2-13**
Production		---	***21***-1***	7-5
Feature Identification			---	1-19***

As can be seen in Figure 5.3 most children who failed the Image Maintenance Complex task also failed the revised Reversal task (15 children), only 2 children failed the former and passed the latter task. Out of 35 children who passed the Image Maintenance Complex task 22 also passed the revised Reversal task. Thus, the revised Reversal task is harder.

Figure 5.3: Comparison of performances on the revised Reversal and Image Maintenance Complex tasks (according to pass/fail criteria)



<u>Discussion Experiment 6</u>

As hypothesised, overall it was easier for children to retain an image over time which has specific features (Image Maintenance Simple) than to retain an image over time which has a rather abstract pattern (Image Maintenance Complex). This suggests that recognition memory is involved more in the simple than in the complex task. Thus, image maintenance abilities are strongly dependent on the stimulus complexity and this is consistent with previous research (e.g. Kosslyn et al., 1990). However, Kosslyn et al., 1990 did not find performance differences in complexity levels in their Image Maintenance task in their sample of 5-year-olds. Moreover, their task was difficult for the 5-year-olds. In contrast in the newly devised Image Maintenance task it is shown that age related changes in children's image maintenance abilities occur and that children between the ages of 3 and 5 improve significantly. Moreover, children's performance was increased when the stimulus complexity was decreased. Overall, children's performance in the pre-test phase, where they had to correctly select the stimulus which matches the target stimulus, was perfect in both tasks, complex and simple. From that we can infer that even the 3-year-old children have no problems comparing two shapes with each other and matching the correct ones and this is independent of the level of complexity.

Overall the results clearly show that children as young as 4-years are already able to retain and recognize an imaged pattern over time even when the stimulus comprises an abstract pattern (Mental Imagery complex). This is inconsistent with Piaget and Inhelder's (1971) findings that children gain complex imagery abilities around the age of 7. However, image maintenance was not specifically required for reversing ambiguous figures which has been shown to be due to the lack of association between the Reversal and Image Maintenance tasks after partialling out age and verbal mental age.

Study 4 also revealed that the association between the AF Production and the False Belief tasks disappeared after partialling out age and VMA. This is contrary to the previous findings and needs to be investigated further.

5.2 Experiment 7a

In Experiment 6 there was a lack of evidence that simple or complex image maintenance abilities are particularly required for reversing ambiguous figures. The purpose of Experiment 7a was to further investigate whether image generation plays a role in children's reversal abilities. In Kosslyn et al.'s (1990) Image Generation task 5-year-old children had very long reaction times in contrast to the older children. Moreover, they did not show performance differences in generating complex and simple images. The accuracy of the 5-year-olds decreased significantly with stimulus complexity but in the complex condition they were almost at chance level. It is therefore plausible that this task was too difficult for the 5-year-olds and did not reflect their image generation abilities at all.

If Rock et al.'s (1994) hypothesis is correct, that in order to reverse someone needs to impose the imagined structure onto the stimulus, it is necessary to use a task which investigates this and is comparable to the reversal process of ambiguous figures. Since no standardised tasks exist to date, except Kosslyn and colleagues' Image Generation task, which is inappropriate for the reasons mentioned above and in the introduction, it was necessary to devise a new task. Children's performance on the new Image Generation task was compared to their reversal abilities.

In addition, children's reversal abilities were assessed on an eye-tracking machine, recording children's eye movements. The results of the eye tracking data will be stated separately in Experiment 7b. Thus, Experiment 7 had two aims: first investigating the question whether other mental imagery abilities such as image generation play a role in reversal (Experiment 7a) and second, on the perceptual side, exploring the role of eye-movements in reversal (Experiment 7b).

Method

Participants

Fourty-seven children (18 boys, 29 girls) from two predominantly middle class nursery and primary schools in Stirling (Scotland) took part (Table 5.6). Three additional children were excluded because of inattention.

Table 5.6: Details of children participating in Experiment 7a

Age group	N	Mean (y;m)	SD (months)	Range (y;m)
3-year-olds	13	3;7	2.5	3;2-3;10
4-year-olds	15	4;3	2.5	4;0-4;7
5-year-olds	19	5;1	3.0	4;10-5;9

Design

Each child received the: Production plus Feature Identification, False Belief, Mental Imagery Generation and Mental Imagery Control tasks. Additionally around half of the children (21) received the revised Reversal task and the other half the original Reversal task (26). This imbalance is due to 6 children who were allocated to the revised Reversal task group who were absent at the second occasion. Children were seen on two sessions. The order of task presentation was counterbalanced between and within the sessions.

Materials and Procedure

Mental Imagery Generation and Mental Imagery Control

The stimuli for the Mental Imagery (MI) Generation task were based on the stimuli in the previous experiment: differently skewed swans, camels and horses. The target stimulus was different. The target stimulus was a cut out hole of a swan, camel or horse (in the skewed shape as the target stimuli in experiment 6). On the four corners of the cardboard surface were cut out shapes affixed. On one surface the pictures were in an upright position and on a second cardboard surface the pictures were affixed rotated 90º anti clockwise. In total there were 6 cardboard surfaces, 2 for each animal (once upright and once rotated). The target stimulus was always in the middle in a normal/upright position on each cardboard surface.

The children's task was to match one of the four affixed pictures on the corners to the target stimulus. Children were shown the first cardboard surface and asked: "Which one of these four goes in here, this one (point), this one (point), this one (point) or this one (point) (starting from the top left clockwise)?" This was continued with the remaining five cardboard surfaces. Children were always shown the swans first and the horses last. Half of the children received the cardboard surface with the pictures in an upright position first and half with the rotated pictures first. Children scored from 0 to 3 in the upright condition and from 0 to 3 in the rotated condition. An overall Mental Imagery score was calculated including overall performance on both conditions; children scored from 0-6. This task required children to impose an imagined shape onto a cut out hole when both are visible simultaneously. In the rotated condition it was additionally required to rotate the stimulus mentally before imposing it into the cut out hole. This was assumed to be harder. No additional image maintenance abilities were involved since all the relevant shapes were visible throughout the task.

The stimuli of the Mental Imagery Control task (MIC) comprised four pictures: a frog, a sheep, a rooster and a rabbit which were not skewed. The target stimulus was the cut out hole of a sheep. For the Imagery Control task two cardboard surfaces were needed; one with the pictures in an upright position and one with the pictures in a rotated position (90º anti clockwise). The target stimulus was again always in an upright position in the middle of the cardboard surface on both surfaces. The procedure was the same as in the Mental Imagery (MI) Generation task. Children were deemed to have passed the upright condition and the rotated condition when they correctly selected the target stimulus. This task did not necessarily involve mental imagery abilities since children could succeed by simply labelling the items (e.g., “the sheep goes in the cut out hole of the sheep and not the frog”).

Reversal tasks (original and revised)

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. 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.

Each child received two conditions: uninformed and informed. The uninformed condition was always presented first and was the same for all children. Children were not informed about the ambiguity of the figure and were asked what they perceived after 5, 30, 60 seconds. Children who stated any change in perception were deemed as reversers. The purpose of this condition was to investigate eye-movement patterns when unaware of the ambiguity of the image. After that children either received the revised (21 children) or the original Reversal task (26 children). The procedures of the Reversal tasks were exactly the same as in previous experiments except that this time the figure, disambiguation and test phase were displayed on the eye tracking monitor. Additionally and importantly, children's eye-movements were recorded.

False Belief and Production plus Feature Identification

The materials and procedures were the same as in the previous experiment. For the Production plus Feature Identification the ambiguous figures vase/faces, man/mouse and seal/donkey were used.

Results

A summary of performance on all tasks is shown in Table 5.7. Performance on the revised/original Reversal and False Belief (false belief test question) tasks is reported as percentage of children who passed whereas performances on the AF Production and

Feature Identification, and Mental Imagery tasks is reported as Mean percentage of successful trials.

Table 5.7: Summary of performance on each task (False Belief and Reversal tasks scored as percentage passed - Mental Imagery (MI) upright and rotated, Production and Feature Identification questions scored as Mean percentage of successful trials; MIC = Mental Imagery Control

Tasks	Age group			Total
	3y7m(N=13)	4y3m(N=15)	5y1m(N=19)	N = 47
MI upright	64%	71%	90%	77%
MI rotated	44%	58%	84%	65%%
MIC upright	85%	100%	100%	96%
MIC rotated	92%	93%	100%	96%
Production	59%	87%	83%	77%
Feature Identification	31%	45%	51%	43%
Reversal Revised	17% (N=6)	50% (N=6)	78% (N=9)	52% (N=21)
Reversal Original	0% (N=7)	33% (N=9)	30% (N=10)	23% (N=26)
False Belief	62%	80%	84%	77%

Mental Imagery Generation

The majority of 3- and 4-year-olds correctly selected 3 shapes in the upright condition and 2 shapes in the rotated condition (Table 5.8). Most 5-year-olds selected all 3 shapes correctly in both conditions. This age improvement is significant, Mental Imagery upright condition: F (2, 44) = 3.63, p = 0.035; Mental Imagery rotation condition: F (2, 44) = 10.29, p < 0.001. Post hoc Bonferroni analysis indicated a significant difference between adjacent ages of 4 and 5 in the rotated condition only, p = 0.015.

In order to compare performance on the upright and rotated condition a repeated measures ANOVA was conducted on the performance scores with task (Mental Imagery upright vs. Mental Imagery rotated) as a within-subject factor and age group as a between subjects factor. The comparison revealed a main effect for task, F (1, 44) = 3.51, p = 0.007, showing that the upright condition is easier; a main effect for age group, F (2, 44) = 8.31, p < 0.001, and no significant interaction between task performances and age groups.

Table 5.8: Number of shapes selected correctly in the upright and in the rotated condition within and between the different age groups. The mean number of shapes selected correctly by each age group and overall is shown at the bottom

Shapes selected correctly	Age Groups						Total	
	3y7m (N=13)		4y3m (N=15)		5y1m (N=19)		N = 47	
	upright	rotated	upright	rotated	upright	rotated	upright	rotated
0	8%	15%	0%	13%	0%	0%	2%	9%
1	31%	39%	33%	20%	5%	5%	21%	19%
2	23%	46%	20%	47%	21%	37%	21%	43%
3	39%	0%	47%	20%	74%	58%	55%	30%
Mean	**1.92**	**1.31**	**2.13**	**1.73**	**2.68**	**2.53**	**2.30**	**1.94**

Mental Imagery Control (MIC)

Performances on the Mental Imagery Control upright and rotation conditions were at ceiling already at the age of 3 (Table 5.7). Out of 47 children only 3 children failed, two out of these were 3-year-olds. One 3-year-old failed both conditions, and one 3-year-old failed the upright control question. Additionally, one 4-year-old failed the rotation condition. This revealed a marginal significant performance increase with age for the Mental Imagery control upright condition: Kruskal-Wallis $\chi 2 = 5.35$, df = 2, p = 0.069 and no significant performance increase for the Mental Imagery control rotation condition: $\chi 2 = 1.41$, df = 2, p = 0.50. Post Hoc Bonferroni analysis indicated no significant performance difference between adjacent age groups in both conditions.

AF Production plus Feature Identification

Performance on the Production question was very good with the 3-year-olds already performing above 50% and the 4- and 5-year-olds performing at ceiling (Table 5.7). This age improvement was significant, $F(2, 44) = 4.0$, $p = 0.025$.

Performance on the Feature Identification question revealed that most 3-year-olds were not able to indicate features of an ambiguous figure or they indicated features of only one ambiguous figure correctly. The 4- and the 5-year-olds performed around 50% (Table 5.7). This age improvement is not significant: $F(2, 44) = 1.11$, $p = 0.339$.

Reversal tasks

Uninformed condition

One 5-year-old out of 47 children reversed when uninformed about the ambiguity and about the two possible interpretations

Revised Reversal task

Performance on the revised Reversal task was typical: only one 3-year-old reversed, half of the 4-year-olds and most 5-year-olds reversed (Table 5.7). This performance increase with age is not significant: Kruskal-Wallis $\chi2 = 5.15$, df = 2, p = 0.076.

Original Reversal task

None of the 3-year-olds reversed, less than half of the 4- and of the 5-year-olds reversed (Table 5.7). There was no significant performance increase with age: Kruskal-Wallis $\chi2 = 2.79$, df = 2, p = 0.248, and no significant difference between adjacent age groups' performances.

False Belief task

Performance was very good with already more than half of the 3-year-olds and most of the 4-year-olds passing (Table 5.7). There was no significant age improvement: Kruskal-Wallis $\chi2 = 2.31$, df = 2, p = 0.32. All children passed the memory or reality questions.

Comparison of tasks

Table 5.9 shows the correlations and partial correlations after controlling for age below the diagonal.

Because performance was at floor for the Reversal uninformed condition (1 child passed) and at ceiling for the Mental Imagery Control task (3 children failed) they were not included in the correlation. The Production task was significantly associated with the Imagery Rotated task and approached significance with the Imagery Upright task even after partialling out age. However, the Production task and the False Belief task were not associated after partialling out age and only approaching significance before the partial correlation. The revised Reversal task was significantly associated with both the Mental Imagery Upright and Rotated condition and overall with mental imagery abilities. Even after partialling out age, the revised Reversal task remained significantly associated with overall mental imagery abilities and in particular with the Mental Imagery Upright condition.

A Binary Logistic Regression using the Forward Stepwise Likelihood Ratio Method revealed Mental Imagery performance as the primary component significantly predicting performance on the revised Reversal task, Wald-statistic = 4.68, $p = 0.030$. When looking at the individual contributions of each Mental Imagery condition, the Mental Imagery Upright condition was the primary and most influential factor predicting revised Reversal performance, Wald-statistic = 4.10, $p = 0.043$ over and above age and the other tasks.

The original Reversal task was not specifically associated with any of the tasks.

Table 5.9: Correlations and partial correlations in parenthesis between the tasks (MI = Mental Imagery)

	MI Upright	MI Rotated	MI Overall	Production	Feature Identification	Reversal Revised	Reversal Original	False Belief
Age	0.38**	0.45***	0.49***	0.20	0.16	0.39†	0.68***	0.17
MI Upright	----	0.45***	0.85***	0.15	0.13	0.57**	0.11	-0.10
MI Rotated	(0.34*)	----	0.86***	0.37*	0.23	0.51*	0.09	0.18
MI Overall	(0.82***)	(0.82)	----	0.31*	0.21	0.60**	0.12	0.05
Production	(0.09)	(0.32*)	(0.25†)	----	0.43**	0.39†	0.24	0.26†
Feature Identification	(0.08)	(0.18)	(0.16)	(0.41**)	----	0.15	0.22	0.15
Reversal Revised	(0.50*)	(0.35)	(0.49*)	(0.25)	(0.03)	----	----	0.14
Reversal Original	(-0.01)	(-0.03)	(-0.02)	(0.25)	(0.21)	----	----	0.08
False Belief	(-0.18)	(0.12)	(-0.04)	(0.23)	(0.12)	(0.11)	(0.03)	----

In order to compare all the tasks performance on the Mental Imagery tasks and on the Production and Feature Identification question, performance was coded as passed or failed according to the criteria in the previous experiments (2, 3 = passed/ 0, 1 = failed) (table 5.10).

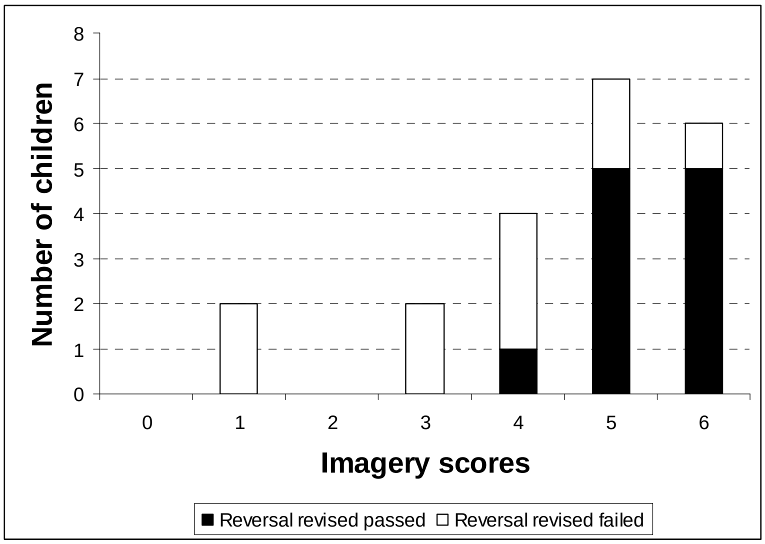
The first number in a pair represents the number of children passing the row task and failing the column task; the second number represents the number of children failing the row task and passing the column task. The Feature Identification question and the original Reversal task were more difficult than any other task. The revised Reversal task was more difficult than Image Generation.

Table 5.10: Task comparisons in difficulty using Binomial analysis (all tasks are scored according to pass/fail criteria); MI = Mental Imagery

	MI Upright	MI Rotated	Production	Feature Identification	Reversal Revised	Reversal Original
False Belief	***9***-9	***8***-6	***4***-8	***20***-1***	***7***-2	***15***-1***
MI Upright	----	***5***-7	***5***-9	***23***-4***	***6***-0*	***15***-2**
MI Rotated		----	***3***-9	***20***-3***	***7***-0*	***12***-2*
Production			----	***23***-0***	***6***-1	***18***-0***
Feature Identification				----	***1***-8*	***9***-2†

Of particular interest is the association between the revised Reversal task with Mental Imagery performance (upright/rotated) (Figure 5.4). All children who scored low on the Mental Imagery tasks (note that children scored from 0-6) also failed the revised Reversal task. Most of the children who scored high on the Mental Imagery conditions also passed the revised Reversal task.

Figure 5.4: Comparison between performances on the revised Reversal and Mental Imagery scores



<u>Discussion Experiment 7</u>

The results of Experiment 7 revealed that children's image generation abilities develop significantly over the preschool period. In particular, the ability to impose an imagined structure onto a shape increases significantly between the ages of 3 and 5 and children were close to ceiling at the age of 5 in both conditions, upright and rotated. This is again earlier than suggested by Piaget and Inhelder (1971). As expected, it was harder to impose a mental image onto a shape when additional rotation was required. The rotated condition was significantly harder for children than the upright condition. This is perfectly plausible since additional mental imagery processes were involved in the rotated condition. On the other hand children had no problems in imposing an image onto a shape when it was possible to label the shape and when the shapes were more distinct from each other. This was shown by performance on the Mental Imagery Control task where children throughout all age groups had no problem to impose the correct animal onto the cut out hole.

Overall children's image generation abilities were significantly associated with children's reversal abilities. This became apparent in the strong correlations between the Mental Imagery overall scores and in particular the Mental Imagery upright performance with the revised Reversal performance. It is therefore concluded that for reversing ambiguous figures, children need to mentally create an image of the alternative interpretations and then impose the imagined structure onto the figure. Again the original Reversal task was not particularly associated with any of the tasks, suggesting that it involves additional task demands which influence correlations.

Moreover the AF Production task was significantly associated with the Mental Imagery rotated and almost significantly associated with the upright condition even after partialling out age. This suggests that children do use mental imagery for producing the other alternative interpretation. It is possible that with the awareness that two interpretations are possible on one stimulus, then visualising the other alternative interpretation facilitates the production of it. However, the AF Production and False Belief task were only weakly related and this relation was not significant. On the other hand performances on both tasks were very similar with almost the same number of children passing in each age group and overall. It is possible that the lack of correlation is due to ceiling effects because in both tasks False Belief and AF Production already at the age of 3 around 60% passed.

General Conclusion Study 4

It was demonstrated that complex Mental Imagery abilities such as image maintenance and image generation are developing over the preschool period. With devising new tasks it has been shown that children develop in their image maintenance and image generation abilities significantly between the ages of 3 and 5. Following Rock et al.'s (1994) suggestion that in order to reverse ambiguous figures someone needs to impose the imagined structure onto the figure, two new tasks were devised in order to investigate this issue. It was assumed that in order to impose an imagined structure onto the stimulus someone would need to maintain an image over time. In Experiment 6 therefore a new Image Maintenance task was devised. Image maintenance was not particularly associated with the ability to reverse ambiguous figures (Experiment 6). However, the Image Maintenance task might not have tapped into the right skills in order to investigate Rock and colleagues' suggestion.

In Experiment 7a a new Image Generation task was devised that required children to impose a shape onto a cut out hole. Children's performance on this newly created task was significantly associated with the ability to reverse ambiguous figures (Experiment 7a). Moreover, performance on this task was the most influential component predicting performance on the revised Reversal task, indicated via a regression analysis. It is therefore concluded that mental imagery abilities play a significant role in reversing ambiguous figures. In particular, image generation is a key process allowing reversal to occur.

Furthermore, it was found in both Experiments that the association between the AF Production task and the False Belief task did not remain robust. In order to investigate this further an overall correlational analysis, involving all children participating in the AF

Production and False Belief tasks (N = 327) was calculated. The results revealed overall a highly significant association between performances on the two tasks that remained significant even after partialling out age and verbal mental age (Table 5.11).

Table 5.11: Correlations between performances of all children who participated in the False Belief and AF Production tasks (N = 327); (partial correlations are in parenthesis)

	False Belief	AF Production	BPVS-II
Age	0.46***	0.51***	0.69***
False Belief	___	0.42***	0.45***
AF Production	(0.20***)	___	0.51***

6 Reversing Ambiguous Figures and Eye-Movements

6.1 Experiment 7b

In this experiment the long-standing question of whether appropriate eye-movements are the cause or the effect of reversal is addressed. As discussed, research with adults has not been able to reach a consensus whether appropriate fixation changes over the image cause reversal or reversal causes changes in fixation. Developmental work can make a unique contribution to the debate since there is a timeline between when children are unable and when they are able to reverse. The current research indicates that children are unable to reverse, even when informed of the ambiguity, until the ages of around 4 to 5 years. If eye-movements are an important factor in perceiving reversal, a change in the pattern of fixation at or around the time when children become able to reverse would be expected.

In particular, in this experiment the question was investigated whether children's eye-movements over the image change when they develop the ability to reverse. For example Tsal and Kolbet (1985) suggested that specific parts of the duck/rabbit figure correspond to a particular interpretation. That is, looking at the beak of the duck (which is also the ears of the rabbit) favours the duck interpretation whereas focusing on the mouth of the rabbit (which is also the back of the head of the duck) favours the rabbit interpretation. It is possible that children develop appropriate scanning strategies over the image (i.e., from the beak to the mouth and vice versa) in order to perceive both interpretations.

The question also occurs whether children's eye-movement patterns change once they have developed the conceptual understanding for ambiguous figures. In particular, do children's eye-movements change once they become aware that an ambiguous figure has two different interpretations (AF Production)? If appropriate scanning for reversal is necessary one would expect children to change their eye-movement patterns once they have developed the conceptual understanding. That is, less scanning would be expected for those children who are unable to acknowledge that there are two interpretations, since there is no reason to “search” for an alternative interpretation.

It is also of interest to compare children’s eye-movements to those of adults. The issue of whether eye-movement patterns differ after discovery of the ambiguity of the image has not yet been addressed, either with adults or children. To test this issue adults are also included. When adults experience reversal do they tend to be looking at characteristic parts of the image? Does their pattern of eye-movements alter when told that a stimulus is ambiguous? Is there a difference in the perception of these figures between adults and children?

Additionally, it is explored whether children and adults have different scanning patterns when they are uninformed versus informed about the ambiguity. Does the awareness of the ambiguity change the scanning pattern over the image? If eye-movements play a causal role in reversal it would be assumed that being informed about both interpretations induces active search over the image. In contrast less active search would be expected when unaware that there is an alternative interpretation, since there is “nothing” to search for. Moreover, in order to compare those children who have never seen any ambiguous figures before with those who had prior experience with the figures in the AF Production task, children’s eye-movements were compared between those who received the AF Production task before the Reversal task with those who had received it afterwards. It is possible that fully naïve children who have never seen ambiguous figures before may show less active search than those who had prior experience with different kind of ambiguous figures, since those children would not have any “reason” to find an alternative interpretation.

Moreover, it is examined whether there are differences in scanning patterns between the two Reversal tasks (original and revised). In particular, it is assumed that asking children to indicate features (Reversal revised) induces more active search over the figure than when asked to simply look at the figure and report changes in interpretation (Reversal original).

In order to address these questions children’s eye-movements were recorded and compared to their reversal abilities. To do this the ambiguous figure was presented on an eye-tracking screen that was non-intrusive and that looked like a monitor of a regular PC. The two Reversal tasks (original and revised) followed exactly the same procedures as in the previous studies with the exception that everything was computerised. In order to compare children’s eye-movements when uninformed versus informed about the ambiguity, an Uninformed Condition preceded the two Reversal tasks. In the Uninformed Condition children were only shown the ambiguous figure (duck/rabbit) without informing them about both alternative interpretations.

The perfect experiment to assess the causal relationship between eye-movements and reversal would be to investigate where children are looking exactly before, during, and after reversal. In order to do this the participant would be required to press a button whenever a reversal occurs and to verbally state the interpretation perceived. This is unlikely to be possible with 3- to 5-year-old children. Instead, the two Reversal tasks (original and revised) were used to assess children’s reversal abilities and it was investigated where (fixation location), how long (fixation time), how often (number of fixations) and in which sequence (fixation order) children and adults were looking at an ambiguous figures.

Method

Participants

The participants were the same as in Experiment 7a. Ten children's eye-tracking data could not be included in the analysis because their eye-movements could not be recorded. The remaining children for Experiment 7b comprised thirty-seven children (18 boys, 29 girls). Children's age ranged from 3;2 (3 years, 2 month) to 5;9 (5 years, 9 months), Mean age = 4;4 (4 years, 4 months), 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). Furthermore 12 adults between the ages of 24 and 50 took part. They were recruited from the University of Stirling.

Design

Each child and adult 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 revised Reversal task and 20 children a original Reversal task. All twelve adults received the original Reversal task. Furthermore 20 children received the AF Production task before the Reversal task, and 17 afterwards.

The Materials and Procedure were the same as in Experiment 7a.

Analysis

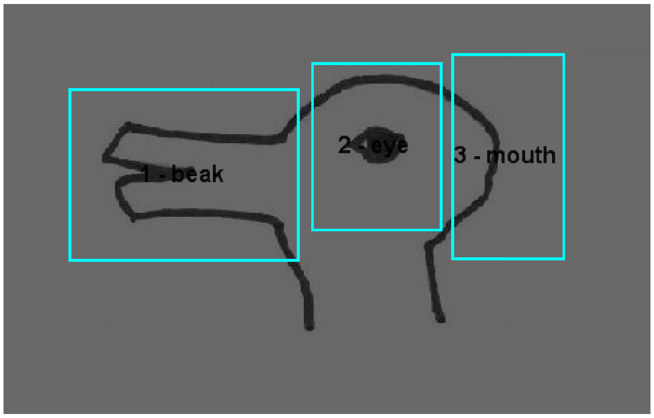
The eye-movement analysis was based on the average fixations lengths and the average number of fixations. For an eye-movement to be counted as a fixation, one has to stay within an area of a radius of 30 pixels for at least 100ms. Thus, the analysis represents the time children were actively fixating at the figure/screen rather than a timeline of 60 seconds taken for the tasks. Additionally it was of interest 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 the previous studies but eye-tracking equipment was not available to measure it experimentally.

It was of primary interested to investigate 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 6.1). 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 more emphasis is given to the overall fixation pattern.

The order of fixations was also analysed. In particular, the likelihood for a participant to fixate one specific area of interest (e.g., eye, beak) following fixation of another (e.g. mouth) was assessed. For that 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] was evaluated; 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].

Figure 6.1: duck/rabbit (Jastrow, 1900) divided into areas of interest



Results

Children

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 original Reversal task reversed (20%), and 9 out of 17 who received the revised Reversal task (53%). There were no significant differences between the tasks or the age groups.

Eye-movement data

Reversers vs. Non-Reversers

Reversers did not fixate longer or make more fixations than non-reversers in either Reversal tasks, or did they avert their gaze more often or for longer. Figure 6.2 shows the proportional length of fixation to different parts of the figure; Figure 6.3 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 original Reversal task. In the revised Reversal task, reversers fixated the mouth more often than non-reversers (a mean of 8 times compared to 2 times) and this was marginally significant ($t(11) = 1.95$, $p = 0.077$).

AF Production passed vs. AF Production failed (see Experiment 7a)

In either Reversal tasks, there were no differences in fixation lengths or in the number of fixations between those children who passed the AF Production task and those who failed, nor did failers avert their gaze more often or for longer than passers. There were also neither differences between those children who passed the AF Production task and those who failed it in the length of time the different areas of interest were fixated or in the number of fixations in areas of interest.

In the Uninformed Condition, the only significant difference was that children who passed the Production task were significantly fixating longer in the Uninformed condition than those who failed ($t\ (35) = -1.56$, $p = 0.034$). Furthermore, AF Production passers were significantly longer fixating the eye area of interest than failers ($t\ (35) = -1.61$, $p = 0.016$).

Uninformed vs. Informed

In the original Reversal task, children did not fixate the image longer or more often once informed of the ambiguity. In the revised Reversal 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 revised Reversal task were also fewer and shorter than in the original Reversal task, ($t\ (35) = 2.31$, $p = 0.027$, and $t\ (35) = 2.01$, $p = 0.051$, respectively).

AF Production before vs. after Reversal tasks

Children who have already seen ambiguous figures (AF Production before) overall in the Uninformed condition fixated the figure longer and more often: $t\ (33) = -0.94$, $p = 0.009$; $t\ (33) = -0.25$, $p = 0.023$, respectively. They fixated the eye longer, $t\ (33) = -0.50$, $p = 0.006$, but less often, $t\ (33) = 0.05$, $p = 0.037$ and also looked longer and more often to the background outside the defined areas of interest: $t\ (32) = -1.41$, $p = 0.001$; $t\ (32) = -1.20$, $p = 0.001$, respectively. Thus, overall those children who have had prior experience with ambiguous figures fixated the ambiguous figure longer and more often but the fixation pattern within the specific areas of interest is less consistent. There were no effects of eye-movement patterns in the two Reversal tasks. The only significant differences found were in the revised Reversal task, fewer eye fixations and longer mouth fixations when receiving the Production task before, t (15) = 0.035, p = 0.020; t (11) = -1.64, p = 0.011, respectively.

Figure 6.2: Mean length of fixation of reversers and non-reverses to different areas of interest in relation to the overall fixation time.

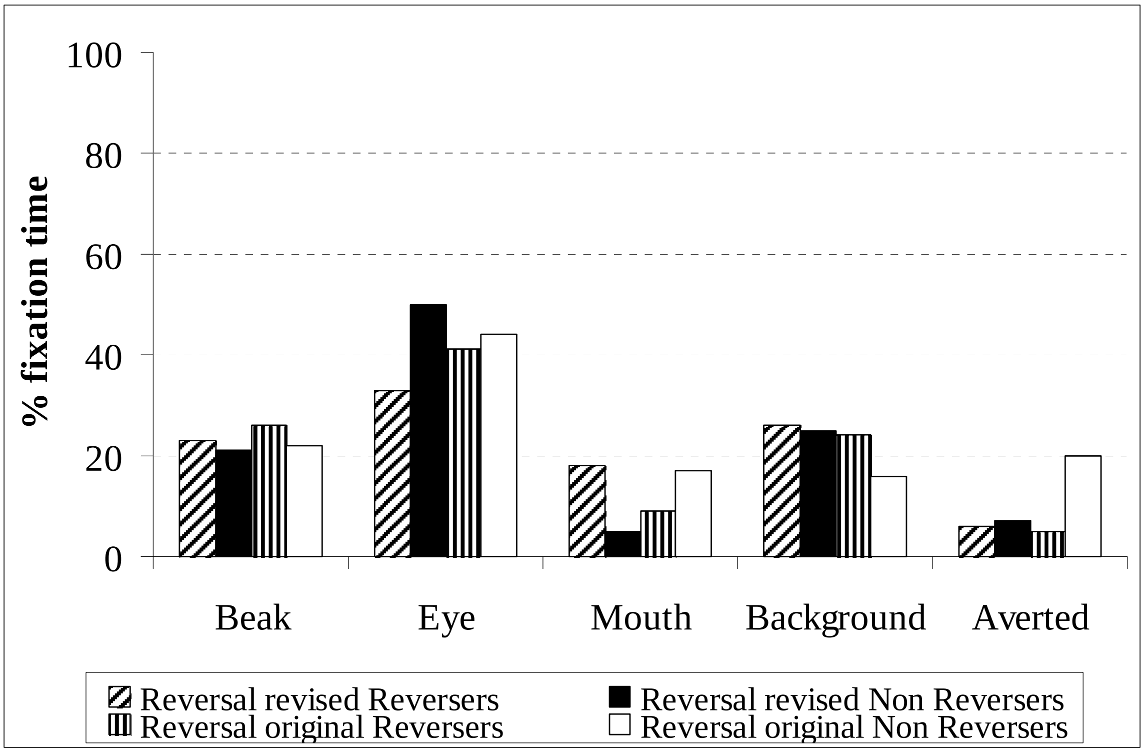
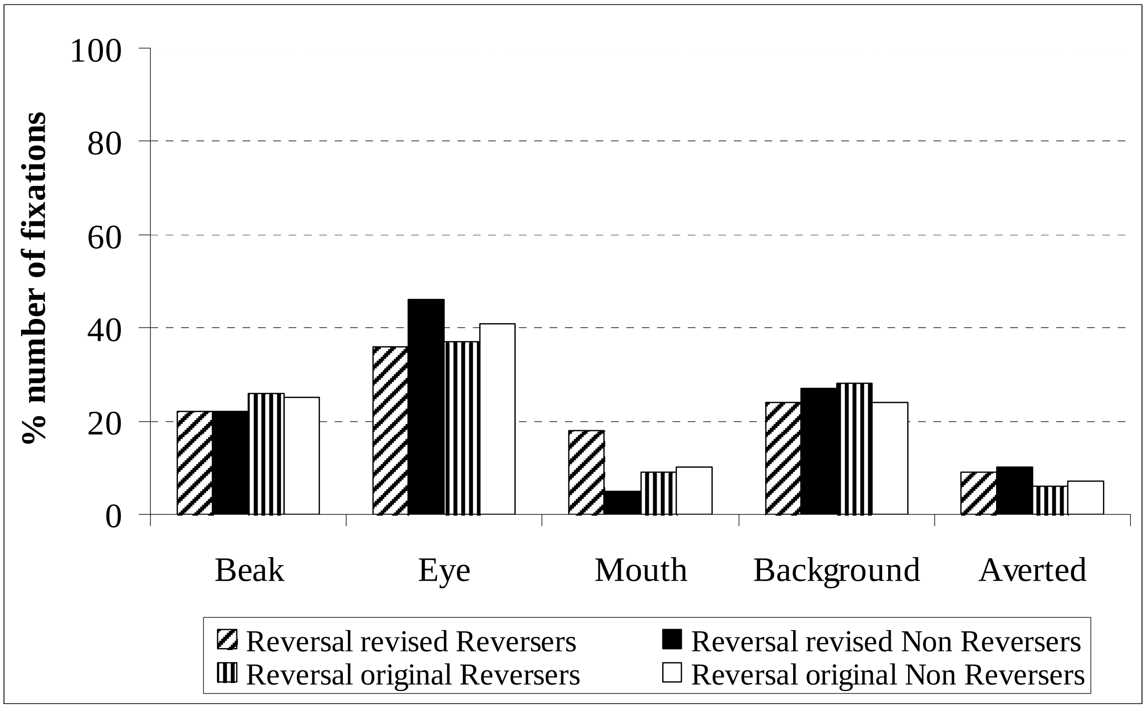


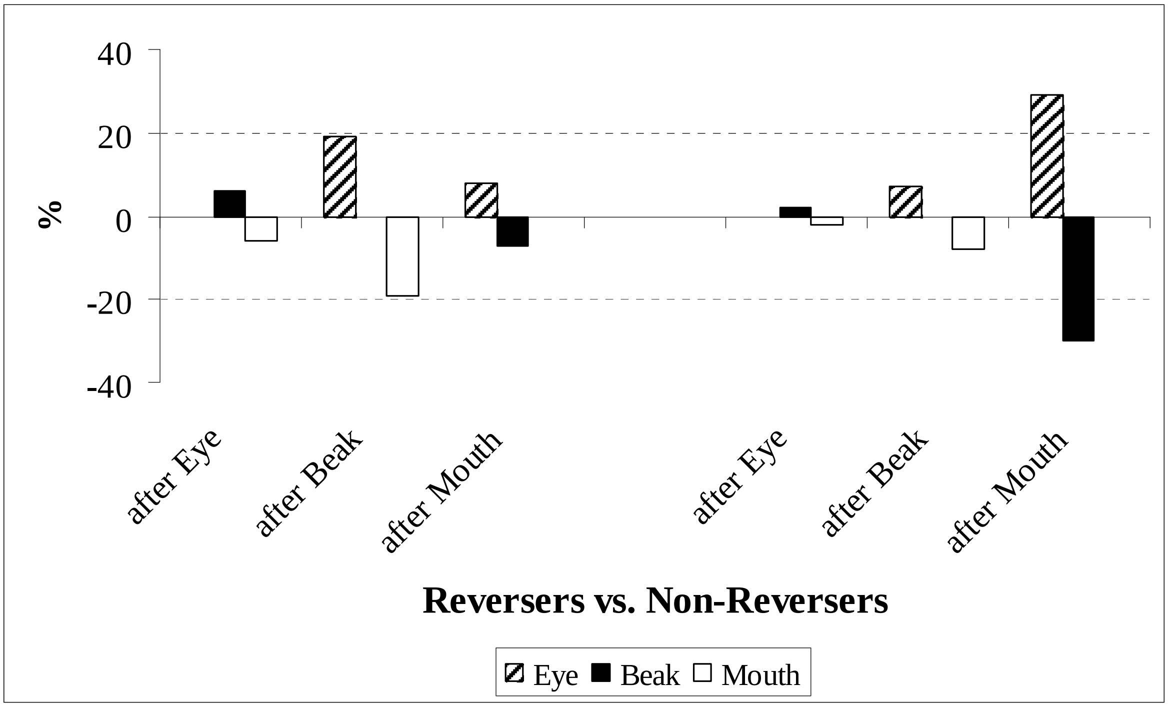
Figure 6.3: Mean number of fixations of reversers and non-reversers to different areas of interest in relation to the overall fixation time



Fixation Order

In order to compare the fixation orders of reversers and non-reversers directly, performance on both Reversal tasks was merged together, due to the small number of reversers in the original Reversal task (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 6.4), 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 6.4: 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)



<u>Comparison of age groups</u>

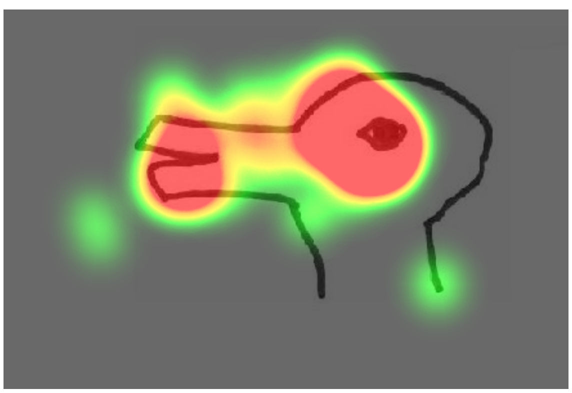
In the uninformed condition, 3-year-olds looked away more frequently and for longer than older children: $F(2, 32) = 3.97$, $p = 0.029$, $F(2, 32) = 6.45$, $p = 0.004$ respectively. In the Reversal task original 3-year-olds also looked away more frequently than older children: $F(2, 17) = 3.24$, $p = 0.064$. No other age effects were found. In the revised Reversal task, 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 6.5). She perceived the duck, and made no fixation to the mouth area (which plausibly favours 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 6.5: Fixation pattern of adult non-reversers in the uninformed condition. The red fields indicate longer fixations



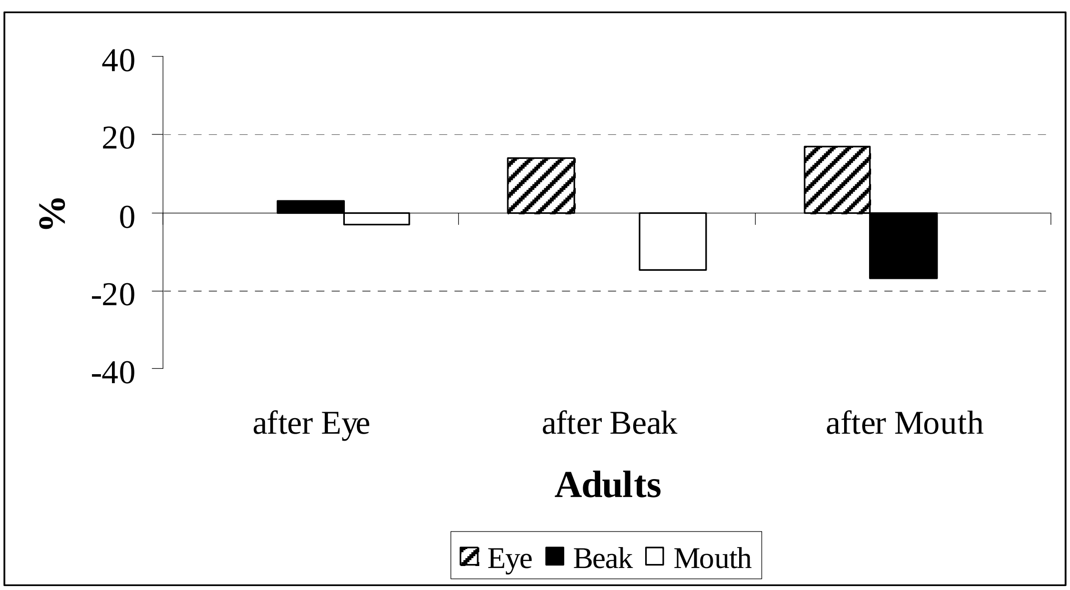
Informed condition

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 6.6). 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 6.6: 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 and Conclusion Experiment 7b

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.

It has also been demonstrated that children do not differ in their eye-movement patterns once they have developed the conceptual understanding for ambiguous figures (AF Production). That is, there were no different fixation patterns between those children who passed the AF Production task in comparison to those who failed. The only difference was that in the Uninformed condition children who passed the AF Production task fixated the figure and in particular the beak longer. Since there were no further differences this difference should not be given too much weight. Those children who received the

Production task before the Uninformed and Reversal tasks overall fixated the figure longer and more frequently in the Uninformed condition. However, the eye-movement patterns within the specific areas in respect to task order (AF Production before/after) was not clear. Furthermore, no differences in eye-movement patterns occurred in the two Reversal tasks. Thus, there was no association between eye-movement patterns and task order.

The 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 because 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.

The 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 revised and original Reversal tasks. There were also no significant performance differences between the original and the revised Reversal tasks and no significant performance increases with age. This conflicts with the findings from the previous studies. However, this is plausibly due to the small number of children per age group and the small number of children in the Reversal task original (N = 4) who reversed. Also in Experiment 7a before excluding the 10 children (those whose eye-movements could not be recorded) there was a significant performance difference between the Reversal tasks original and revised, indicating that the former is more difficult.

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.

The results speak against the possibility that, in addition, children have to develop appropriate eye-movement patterns in order to reverse 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. It is concluded 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 inconsistent results.

7 Summary and Conclusion

Rock et al. (1994) showed that adults need to know that a figure is ambiguous and what the two interpretations are in order to reverse. Knowing that an ambiguous figure can have two interpretations implies knowing that it can represent two different things. Thus, Rock and colleagues partly claim that ambiguous figure reversal requires metarepresentation. In this research therefore children's metarepresentational abilities in relation to the understanding of ambiguous figures was investigated. The principal experimental paradigm used was the Ambiguous Figure Production task (Doherty & Wimmer, 2005) which measures children's ability to report both interpretations of an ambiguous figure. Doherty and Wimmer (2005) demonstrated that children at the age of roughly 4 are able to acknowledge that an ambiguous figure has two interpretations and this is related to the understanding of false beliefs.

In Study 1 it was aimed to replicate and extend these findings. In Study 1 children's understanding that an ambiguous figure can have two interpretations was compared to the understanding of synonymy, homonymy and false beliefs. It was assumed that it is more appropriate to compare children's understanding of ambiguous figures with the understanding of homonymy and synonymy than with false belief since they pose more closely related representational problems. First, only in the False Belief task misrepresentation of current reality occurs (i.e., the protagonist thinks that the marble is in the box while it is really in the jar). Second, the AF Production task is structurally similar to the Synonym Production task (Doherty & Perner, 1998). Third, ambiguous figures are the pictorial equivalent of homonyms in the sense that one stimulus creates two different meanings. A further aim of Study 1 was to investigate the counter explanation for Doherty and Wimmer's (2005) findings that children's understanding of ambiguous figures derives from false belief understanding rather than arising directly through an understanding of (pictorial) representation. That is, it is possible that children notice that ambiguous figures can be seen in two different ways, and without necessarily understanding why interpret that as meaning that ambiguous figures can produce two different beliefs in people. For example the duck/rabbit figure produces a "duck belief" and a "rabbit belief" in different people. The same argument applies to homonyms. When hearing a homonym (i.e., "bat"), someone might think the speaker is talking about flying mammals when in fact s/he is talking about sports equipment. The counter explanation, however, does not apply to synonyms (e.g., bunny and rabbit) since they do not create different beliefs in people because they have the same meaning.

In Experiment 1 of Study 1 therefore children's understanding of ambiguous figures was compared to the understanding of synonymy and false belief. It was found that children's understanding of ambiguous figures was significantly associated with the understanding of false beliefs, replicating Doherty and Wimmer's findings. In addition, performance on the AF Production task was significantly associated with the Synonym Production task over and above False Belief performance. This rules out the counter explanation that ambiguous figures understanding, derives from false belief understanding. In Experiment 2 of Study 1 children's understanding of ambiguous figures was compared to those of homonymy and false belief. It was found that children's understanding of ambiguous figures is significantly associated with the understanding of homonymy and this relation is stronger than with false belief. This is plausible since ambiguous figures are the pictorial equivalent of homonyms. This is also further evidence against the counter explanation since both ambiguous figures and homonyms should be more closely related to false belief understanding than to each other if they derived from false belief understanding. Additionally, from the existing literature it is not clear when children develop a representational understanding of pictures. The Ambiguous Figures Production task is a clear test of children's understanding of pictorial representation.

From Study 1 it is concluded that children develop pictorial metarepresentation roughly at the age of 4 (AF Production task) and this is part of a broader development of metarepresentational abilities developing around this time

Having identified the critical prerequisites for ambiguous figure reversal it was necessary to investigate the actual processes directly involved in reversal. In order to do this it was first necessary to methodologically improve the Ambiguous Figures Production task.

To this end, in Study 2 all memory demands of the Ambiguous Figure Production task were reduced. One concern was that children might be able to acknowledge that there are interpretations of an ambiguous figure but are unable to remember what the one alternative was and therefore fail the task. The results of Study 2 showed that children fail this modified AF Production task because of the difficulty of acknowledging both interpretations of an ambiguous figure and not because of memory problems.

In Study 2 also a new method of assessing reversal abilities was implemented. This was necessary since only one Reversal task has been used in the literature so far – the one devised by Rock et al. (1994). This Reversal task is methodologically problematic because it requires specific attention and motivation to look at an ambiguous figure for 60 seconds. This may be difficult especially for younger children. Additionally, the possibility was investigated that the AF Production task is a Reversal task. That is, it might have been possible that children can acknowledge that there are two interpretations of ambiguous figures because they actually perceive both interpretations. In Study 2, therefore, a new Feature Identification question was implemented as part of the Production task. In the new Feature Identification question children were asked to indicate features of the initially non perceived interpretation. It was assumed that asking children to indicate features may facilitate reversal because working memory and inhibitory load may be reduced and mental imagery may be prompted. If that is the case, then it would be expected that there are no significant differences between the AF Production and the Feature Identification questions. However, this was not the case and the Feature Identification was significantly more difficult. This suggests that understanding that there are two interpretations is unlike the ability to perceive them. Moreover, children’s performance on the new Feature Identification question increased rapidly at the age of 5, in contrast to the original Reversal task in which no such rapid increase at the age of 5 occurred. It is therefore suggested that the new Feature Identification is a method whereby reversal can be induced by asking someone to indicate features, and this is a more sensitive method than the original Reversal task.

Gopnik and Rosati’s (2001) claim that reversal is dependent on performance on the Droodle task was also examined in Study 2. Consistent with Doherty and Wimmer (2005) no significant correlation between the tasks was found after partialling out age and verbal mental age. This is not surprising because, as discussed in the introduction, understanding the effect of uninformative (ambiguous) information on the knowledge state of another person (Droodle task) is not required for ambiguous figure reversal. Both tasks require children to understand that there can be more than one interpretation of a stimulus, but the Droodle task requires an additional complex theory of mind ability and the Reversal task requires mental action on the part of the perceiver. It is suggested that reversing ambiguous figures is a skill, a mental process on the part of the perceiver which is why a conceptual understanding (for example required for the Droodle task) cannot be the immediate underlying mechanism.

From Study 2 it can be concluded that young children fail the AF Production task because of difficulties in acknowledging that one stimulus can have two interpretations and not because of memory problems. Moreover, the AF Production task is not a covert Reversal task. Children's reversal abilities develop up to a year later. When reversal is scaffold externally through asking them to indicate features (AF Feature Identification) children's reversal abilities are at ceiling by the age of 5. On the other hand, in the original Reversal task no such performance increase between the ages of 4 and 5 occurred. It is suggested that the original Reversal task is not a sensitive measure for reversal abilities. Moreover, the high correlation between the Droodle and Reversal tasks in Gopnik and Rosati's study was not replicated and this is consistent with Doherty and Wimmer's findings.

In Studies 3 and 4 it was attempted to disentangle the particular processes involved that allow children to perform the mental action of reversing ambiguous figures. In Study 3 the role of executive function in reversing ambiguous figures was investigated. Study 3 revealed a strong association between children's reversal abilities and inhibitory abilities. This association remained robust even after controlling for age and verbal mental age. None of the other executive functions (planning, set-shifting, working memory) were significantly related to ambiguous figure reversal. It is therefore suggested that in order to reverse ambiguous figures children need to executively inhibit their prevalent interpretation in order to perceive the other interpretation.

The finding that inhibition is playing a role in reversal is implied from research with adults but has not been explicitly suggested. For example there is broad evidence from research with adults which has shown that the reversal rate can be brought under voluntary control (Hochberg & Peterson, 1987; Liebert & Burk, 1985; Meng & Tong, 2004; Peterson & Gibson, 1991; Peterson & Hochberg, 1983; Strüber & Stadler, 1999; Suzuki & Peterson, 2000; Toppino, 2003) and this was taken as evidence for the top-down account. Inhibitory abilities are taken for granted in adults. It has, however, been shown that patients with frontal lobe damages show impairments in ambiguous figures reversal (Meenan & Miller, 1994; Ricci and Blundo, 1990). Executive inhibition is guided through frontal lobe activity. Thus, frontal lobe patients have executive impairments as a result of frontal lobe damage, and these may have caused the inability to reverse.

The current research took these findings from studies with adults further, and found evidence that in particular people need inhibitory abilities to reverse an ambiguous figure. In this context it would be interesting to assess whether adults who are more successful at active inhibition are more likely to initially reverse an ambiguous figure.

In Study 4 the role of mental imagery in reversal was explored. Rock et al. (1994) suggested that someone has to impose a mental image onto the stimulus in order to get it to reverse. This requires a visualisation of the image. Rock's idea is however conceptually vague. The aim, therefore, was to investigate the particular role of two plausible imagery sub-abilities – image maintenance (holding an image in mind) and image generation (forming a mental image). Because there are no prior studies with suitable methods investigating children's mental imagery abilities, it was necessary to devise new tasks that allow a direct comparison with ambiguous figure reversal.

In Study 4 a significant association between reversing ambiguous figures and the newly devised Image Generation task was found. On the other hand, no association occurred between reversal and image maintenance abilities. Image generation was measured as the ability to impose an image onto a shape when both are visible at the same time. No additional memory abilities were involved. The findings from Study 4 suggest that for reversing ambiguous figures image generation allows someone to impose the imagined interpretation onto the figure in order to get it to reverse. This is independent of maintaining an image over time.

In this realm it would be interesting to investigate whether adults who have superior image generation skills are more likely to reverse initially. Also, the sparse and inconsistent evidence of children's development of mental imagery abilities gives rise to major further research possibilities in this area.

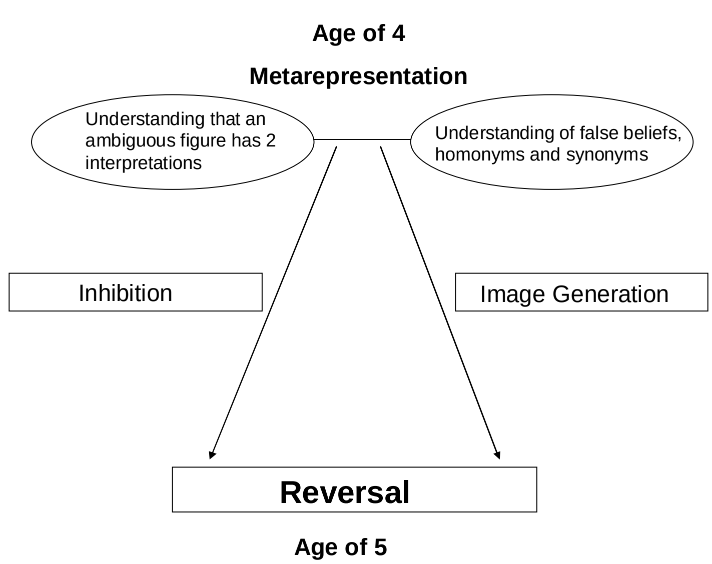
An additional part of Study 4 explored the role of eye-movements in reversing ambiguous figures using eye-tracking technology. The findings from the current research suggest that eye-movements are not a cause for reversal for two reasons. First, there were no differences between eye-movement patterns of those children who reversed and those who did not reverse. Second, there were no differences in scanning strategies between children who were uninformed and those who were informed about the ambiguity. It is therefore suggested that eye-movements are not a major cause for reversal. It remains possible that eye-movements can facilitate reversal once children have developed the ability to reverse. However, eye-movements are not a prerequisite ***per se*** for reversal to occur.

In addition to investigating the particular abilities involved in the reversal process it was also necessary to implement new tasks and methodologically improve existing tasks in order to assess reversal abilities. Over several studies it was demonstrated in a revised Reversal task that when children are asked to indicate features rather than being required to give verbal response about their reversal, performance increases dramatically. When task demands are minimised children are able to reverse by about 6 months earlier than previous research has suggested. It may be that in the revised Reversal task inhibitory load is reduced and mental imagery is prompted through asking children to indicate features. Moreover, once children have developed the ability to initially reverse an ambiguous figure they have no difficulty in reversing back and forth over a 1 minute viewing period.

From the current research it can be concluded that Rock et al.'s claim that metarepresentation is a necessary prerequisite for reversal to occur is correct. Their further claim that reversal requires someone to impose the imagined structure onto the ambiguous figure has been elaborated and tested. From this it seems that image generation is a key process underlying reversal. In addition, children require inhibitory abilities for reversal. It is suggested that inhibition and image generation have separate effects on reversal since the Image Generation task contained no obvious inhibitory elements. Thus, it can be concluded that the critical processes allowing the reversal experience all develop within a year between the ages of 4 and 5.

From this current research, a developmental cognitive Theory of Reversal can be proposed. I postulate that the development of reversal occurs in two stages (see Figure 7.1). At stage 1 between the ages of 3 and 4 children develop the conceptual understanding (top-down knowledge) of ambiguous figures. In particular, they understand that one stimulus can have two possible interpretations. This is part of a general metarepresentational ability developing at this age. At stage 2 one year later, between the ages of 4 and 5 children develop the ability to reverse ambiguous figures. The development of inhibitory and image generation abilities between stage 1 and stage 2 are the specific processes necessary to bring about reversal. Once children have developed the ability to initially reverse they have no difficulty in reversing an ambiguous figure back and forth. It is at this stage that the interplay between top-down and bottom-up processes begins.

Figure 7.1: Cognitive Model of Reversal



Almost 200 years of ambiguous figures research with adults concluded that both bottom-up and top-down processes are involved in reversal. The research conducted in this thesis, by using a developmental approach, sheds light on what the particular top-down cognitive processes are. For example, Rock and colleagues' (1994) claim that to reverse people need to be aware of the ambiguity and to know what the interpretations are suggests a role for metarepresentation. Long and Toppino (2004) highlight a need to distinguish between ***ambiguity*** and ***reversibility***. Ambiguity reflects the fact that an ambiguous figure can have two interpretations – and thus, directly concerns the dual nature of the figure itself. For this reason, understanding ambiguity requires metarepresentation. As the current research has shown, the recognition of the central role of metarepresentation as a conceptual prerequisite in reversal gives the top-down theory theoretical unity.

Developmental research on metarepresentation in the pictorial domain had so far been inconclusive. That is, it had been unclear when children develop a proper understanding of pictures as representations. With the use of ambiguous figures, in which one stimulus can refer to two equally valid and plausible interpretations it became possible to establish when children develop pictorial metarepresentational abilities. This develops around the age of 4 and is associated with other forms of metarepresentational abilities in the linguistic (synonyms, homonyms) and mental domain (false beliefs).

As a wider implication, this supports Perner's (1991) theory of children's cognitive representational development and in particular, the development of metarepresentation around the age of 4 years in different domains. Several competing theories cannot explain this association. For example, Simulation Theory suggests that mental representation is understood by putting yourself into the shoes of someone else or more scientifically stated, simulating the other person's mental state (Harris, 1992). This theory does not make any predictions about how metarepresentational abilities should develop in other domains and how they may be related. Similarly, Modularity theory (Leslie, 1987) of a biologically specified understanding of the mind does not account for the development of other types of metarepresentation. As has been demonstrated in the current research, an understanding of ambiguous figures is related to but does not derive from false belief understanding. A biological theory would have to postulate a separate mental module, affecting a pictorial understanding also activated in the 4^{th} year. It seems unlikely that these skills, with simultaneous onset, are unrelated. Indeed, the findings from this thesis suggest that understanding the representational nature of pictures is simply another form of metarepresentational ability all of which develop around the age of 4. In future research it may be interesting to extend these findings and to investigate whether an understanding of ambiguous figures transfers to other forms of understanding dual representations. For example we might expect this to be related to children's understanding of the appearance-reality distinction (Flavell, 1986) in which children need to acknowledge that something that looks like one thing (e.g., a rock) is in reality another thing (e.g., a sponge).

In regards to the reversibility of ambiguous figures adult research has shown that both bottom-up and top-down processes are involved in the reversal process. Research with adults has shown that adult viewers are able to voluntarily control the reversal rate and that it is possible to hold one interpretation to a certain extent. This implies a role for inhibition for reversal in the sense that if one is able to inhibit (voluntarily control) perception of a specific interpretation one also may be able to use this inhibitory capacity in the other direction, in order to reverse to the other interpretation. My developmental approach supports a crucial role for inhibition in reversal. However, research with adults so far has not investigated whether inhibitory strength is directly linked to reversal. That is, whether adults who are superior in executive control are also superior in reversal. There are individual differences in inhibitory abilities not only in children but also in adults. For example, some are more successful in controlling the daily chocolate intake than others. The inhibition day/night-Stroop task used in this thesis was originally adapted from the Stroop task used in research with adults. It would therefore be easily possible and interesting to extend these findings with children into research with adults and to investigate whether adults with more executive control are also more likely to experience reversal.

The role of inhibitory capacity in reversal also becomes apparent when using ambiguous figures that have different levels of difficulty. For example, the ambiguous triangles are much easier to reverse than the wife/mother-in-law ambiguous figure. Presumably, much more inhibitory capacity is required for the latter in order to reverse. This possibility may be interesting to address in future research.

In respect to top-down and bottom-up processing it is possible that there are two inhibitory processes involved in reversal: an automatic low-level and an active high-level inhibition process. For example, for ambiguous figures it seems necessary to know what needs to be inhibited in favour for an alternative interpretation. This obviously requires conscious inhibition and thus high-level processes. Further to that it is possible that stronger inhibition is required for more difficult ambiguous figures than for less complex ones. This may happen on a low-level and may therefore be a bottom-up process. In particular, this may directly link to neural fatigue/satiation processes. If a figure is more complex, and more difficult to reverse towards the other interpretation, the perceived interpretation is more dominant. Neural fatigue of this perceived interpretation may take longer and fewer reversals occur. Alternatively, with less complex figures, one interpretation may be less prevalent, leading to a shorter neural fatigue period and to more frequent reversals. In other words, there may be a top-down and bottom-up aspect involved in inhibition. This very much fits into the hybrid model of reversal. This can be tested directly in future research when using ambiguous figures that differ in complexity. Reversal performances of different figures can be compared with inhibitory abilities.

Another crucial aspect of reversal is mental imagery. The suggestion that one needs to mentally visualise the alternative interpretation and map this onto the figure in order to reverse an ambiguous figure is very plausible but difficult to operationalize. Research with children's development of mental imagery abilities is sparse and inconclusive. Research with adults suggests that mental imagery abilities such as image generation, rotation, image maintenance, and scanning are independent sub-abilities. As shown here using novel tasks, children's image generation and maintenance abilities develop significantly over the preschool period. It would be interesting to extend these findings and see how they relate to each other and how they relate to children's development of the two other sub-abilities, scanning and rotation. The lack of systematic research in mental imagery abilities gives scope for major follow up research in this area. Also it may be interesting to investigate the relation between imagery abilities and working memory. Holding an image in mind, for example, requires working memory and the role of working memory in mental imagery tasks is acknowledged in adult research. In the realm of ambiguous figures it may be interesting to investigate how performances on mental imagery and executive function tasks are both related to reversal and what the individual components' contributions to reversal are.

To summarize, this is the first extensive examination of the roles of metarepresentation, executive function, and mental imagery in reversal. The use of the developmental method in this fashion gives a more specific insight into the processes involved.

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Appendix