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The Beginnings of Deductive Reasoning Abilities in Infants

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Abstract

There is wide disagreement over when children begin to show deductive reasoning skills that adults use daily. Preschoolers have previously demonstrated deductive reasoning skills (Dias & Harris, 1988, 1990; Hawkins, Pea, Glick, & Scribner, 1984; Richards & Sanderson, 1999) through verbally presented hypothetical syllogisms. The present study employed a habituation paradigm with 18-, 22-, and 26-month-olds. Infants were presented visual stimuli with external parts and dynamic motions to assess when they begin to deduce the relation among static and dynamic features. The findings of the research were minimized by sample size and effect magnitude. However, results revealed an effect of sex of the infant, with females but not males being able to deduce such relations. Since this is a new area of research, future research needs to replicate the current findings to determine what other manipulations can help facilitate the demonstration of deductive reasoning abilities in infancy.

The Beginnings of Deductive Reasoning Abilities in Infants

Deductive reasoning involves taking a general principle and applying it to a specific situation or individual. As Markovits and Barrouillet (2002) point out, making logical inferences is a cognitive ability that distinguishes humans from other species. Conditional reasoning is an essential part of logical thinking, which is especially important within scientifically oriented societies such as ours (Hawkins, Pea, Glick, & Scribner, 1984). Deductive reasoning is often conceptualized in the form of a syllogism which includes three parts. First, a statement about a definitive characteristic of the general class: $A=B$. Second, a statement about an individual object belonging to the class: $C=A$. Third, a conclusion that the individual has the characteristic: $C=B$. A common example used to conceptualize deductive reasoning is: All men are mortal. Socrates is a man. Therefore, Socrates is mortal.

According to Piaget, deductive reasoning is not demonstrable until a child enters formal operations in adolescence (Inhelder & Piaget, 1958). At this stage, children develop the ability to think abstractly, formulate hypotheses, and analytically test them to derive answers to problems. A body of research shows that sophisticated deductive reasoning with an understanding of logical necessity does not develop before early adolescence (Galotti & Komatsu, 1989; Kuhn, 1989; Markovits, Schleifer, & Fortier 1989). A few developmental research studies have focused on demonstrating whether younger children can be shown to have deductive reasoning abilities. Some studies have demonstrated deductive reasoning abilities in children as young as preschoolers using verbally presented hypothetical syllogisms and visually presented conceptual information (Dias & Harris, 1988, 1990; Hawkins et al., 1984).

Hawkins et al. (1984) studied deductive reasoning as a contextually embedded ability. They examined the effects of problem content, problem complexity and task organization on preschoolers' performance on syllogisms. In particular, they simplified the reasoning problems,

provided children with context cues by varying the sequence of problems, and varied the truth value of the problem content. They devised a technique in which it would be impossible for preschoolers to use real-world knowledge. That is their questions involved “fantasy problems” concerning mythical creatures which by design are alien to practical knowledge. Inferences were compared for content which was congruent with practical knowledge to others that were incongruent with practical knowledge. The order of presentation of the different types of syllogisms was varied. The results indicate order of presentation effected the strategy 4- and 5-year-olds used to complete the task. The children who were presented with fantasy problems first correctly used deductive reasoning. In fact, they produced significantly more correct responses and made more theoretical justifications, using information presented in the problem to justify their responses, than any other group for all types of problems. Replicating Scribner (1977), responses that were theoretically justified were almost always correct. Both results indicate that these children were approaching the task differently. When incongruent problems were presented first, the preschoolers produced more incorrect responses overall due to perceived trickiness in the experiment. In summary, young children demonstrated verbal deductive reasoning under certain conditions with problem content and problem sequence affecting their performance. Optimal conditions included fantasy problems when practical knowledge could not be used to answer questions. These findings suggest that four- and five-year olds are beginning to logically think to answer the syllogisms correctly and give justifications in certain situations.

Richards and Sanderson (1999) demonstrated that two-, three-, and four-year-olds were equally able to reason deductively when given verbal syllogisms containing counterfactual material and cued to use their imagination. This cuing allowed preschoolers as young as two years of age to go successfully against their belief bias and reach a correct conclusion even

though it disagrees with their beliefs about the real world. Paralleling the findings of Hawkins et al. (1984), Richards and Sanderson (1999) also found that the group of children in the high imagination condition gave more theoretical justifications. Therefore, under certain circumstances children demonstrated deductive reasoning abilities, at a younger age than demonstrated by Dias and Harris (1988, 1990) who established similar skills for four-, five- and six-year-olds. Children, as young as two years olds, can assume a theoretical approach and reason correctly with counterfactual materials within certain contexts.

Dias, Roazzi, O'Brien and Harris (2005) extended the findings of Dias and Harris (1988, 1990) by showing that both unschooled and five-year-olds in school in two cultures improved their deductive reasoning abilities when the problems were presented in a fantasy context. In fact in the make-believe context, unschooled children did not differ from those in school on the number of correct responses.

The previous studies have utilized verbally presented materials to assess deductive abilities. However, an alternate method to facilitate the demonstration of young children's deductive abilities would be to use visually presented stimuli. It is possible, for example, that infants could solve deductive-like visual tasks by correlating features in visual events; if infants learn that things with legs are self-propelled and that things with legs have eyes, would they infer that things with eyes are self-propelled? It is feasible that infants could make such inferences by learning correlations among attributes; therefore, it is imperative to understand the literature regarding infants' ability to encode correlations among features of objects. In the first experiment on this issue, Younger and Cohen (1986) habituated infants of 4-, 7- and 10-months of age to static line drawings of imaginary animals that possessed a cluster of correlated attributes (i.e. body, tail, and feet). They found that by 7-months of age infants can extract correlations among features of static objects when all attributes were correlated, but not under

other circumstances. Ten-month-old infants responded to objects on the basis of correlations among attributes when the correlations occurred in a category context from the habituation studies.

Rakison and Poulin-Dubois (2002) took the next step and assessed infants' ability to extract correlations between dynamic and static cues embedded in a category context. They performed a series of experiments examining how infants, aged 10- to 18-months, process new information, utilizing geometric figures with distinctive bodies, parts and trajectories, instead of familiar objects. Infants were habituated to two events in which objects with distinctive parts and bodies moved along a computer screen in either curvilinear or rectilinear movements. The question was at what age infants would start correlating features with types of motion. Rakison and Poulin-Dubois (2002) found that 10-month-old infants process static features, the bodies of the objects, but not the dynamic features of an event. Fourteen-month-old infants were able to process the correlation between motion trajectory and parts only if the parts move. Eighteen-month-old infants processed correlations between individual features, whole objects, and movement properties even if only one of the features is dynamic. That is they learned that objects with particular parts and particular bodies moved in particular trajectories. Rakison and Poulin-Dubois (2002) postulated that infants by the age of 18 months expect that parts, most likely large and external parts, were connected to motion trajectory. The infants then attend to the parts as they watch the motion trajectories. Rakison and Poulin-Dubois (2002) proposed that infants develop conceptual knowledge of objects using their perceptual system that detects the individual features (both static and dynamic), whole objects, and motion trajectories and an associative learning mechanism that encodes individual features and relationships among features.

Rakison (2004) performed a series of experiments that assessed infants' ability to attend to correlations between static and dynamic features in a category context; that is, when infants were shown multiple exemplars from a category with the same feature correlations. In one experiment, utilizing the stimuli of Rakison and Poulin-Dubois (2002) infants were habituated on objects which had distinct bodies and moving parts consistently associated with certain motion trajectories. The finding was that 14-month-old infants could not process any of the features (i.e. parts, bodies, or motion trajectories), 18-month-old infants processed features but not relationships among features, while 22-month-old infants processed the relationships among the moving features that are embodied in multiple exemplars. Therefore, the sensitivity to correlations among dynamic features emerges between 18- and 22-months of age. In another experiment, 22-month old infants failed to encode the body-motion path correlation or parts-body correlations. Rakison (2004) interpreted these results as indicating that infants who are 22-months of age are more sensitive to the relations among dynamic cues than between static and dynamic cues. In a final experiment, 22-month old infants but not 18-month-old infants were able to generalize the learned feature motion relationship to a new situation. The associative learning mechanism that infants use to learn about relations among dynamic cues is the same that is used to learn about relations among static cues.

There is currently very little research showing deductive reasoning in preschoolers using visual stimuli. The one study identified is that of Rakison and Yermolayeva (2011) which explored the beginnings of deductive reasoning in 20- and 26-month old infants. Rakison and Yermolayeva (2011) proposed deductive reasoning abilities begin due to infants' ability to encode relationships among features, properties and events. That is, if infants learn that two features are associated and that one of them is associated with another, novel feature then it is possible that they might anticipate an association between the first and third feature. This

conceptualization is consistent with the findings of Rakison (2004) that 18-month olds associate parts with motion types and 22-month olds can generalize this understanding to objects that have parts with features correlated to the initial features. Rakison and Yermolayeva (2011) habituated 20- and 26-months-old infants to two events. One event showed the object's shape and internal details (e.g. a blue square has a yellow heart). Another event showed the object's shape and its motion trajectory (e.g. a blue square moves linearly). Their question was whether the infants would deduce a correlation between a static and dynamic feature that was not observed but was implied by two related correlations. In the test trials, the events have a novel shape that is either consistent (e.g. an object with a yellow heart moves linearly) or inconsistent with the relationship that might have been deduced from the habituation phase (e.g. an object with a yellow heart moves in a curvilinear path). A longer looking time at the inconsistent event relative to the consistent event would indicate that the infants deduced the unseen correlation from the habituation phase of the experiment. The results indicated that 26-month-olds but not 20-month-olds looked longer at the inconsistent event, suggesting that they deduced the relationship between a static and a dynamic feature that was not seen but implied by their association with other features.

Assessing deductive reasoning skills using perceptually presented information is a new area of research. The current study is a replication of Rakison and Yermolayeva (2011) except with external parts rather than internal parts. The rationale for this is based on the reasoning of Rakison and Poulin-Dubois (2002), who postulated that infants expect that large and external parts were connected to motion trajectory. Collectively the findings of Rakison and associates have the following implications for the current study: it is expected that 26-month-old infants will apply deductive reasoning skills to the dynamic motion experiment with external parts. Since external parts may be more salient than internal parts, infants of 22 or 18 months of age

may successfully demonstrate these deductive-like skills (Rakison and Poulin-Dubois, 2002). In particular, infants at 22 months of age may be sufficiently older than the 20-month olds who failed to deduce relationships in Rakison and Yermolayeva (2011). For example, if infants learn that blue square objects move in a curvilinear pattern and blue square objects have green triangle hats on them, will they deduce that other objects with green triangle hats move in curvilinear patterns? The present study addressed the following research question: at what age will infants use deductive-like reasoning when applied to dynamic motion with stimuli with external parts.

Methods

Participants

The participants in this study were infants recruited through birth lists obtained from a private company. The participants were fourteen 18-month-old (mean age=17.94 months, range=17.39-18.41 months), nine 22-month-old (mean age=22.1 months, range=21.63-22.68 months), and eight 26-month-old (mean age=26.05 months, range= 25.7-26.43 months) healthy full-term infants. There were 4 boys and 10 girls in the 18-month-old group and 4 boys and 5 girls in the 22-month-old group and 4 boys and 4 girls in the 26-month-old group. The majority of infants were white and of middle socioeconomic status. Data from 4 additional infants were excluded from the final sample: 1 due to failure to habituate and 1 due to fussiness, 1 due to parental influence and 1 for looking more than 2 SD beyond the condition mean. Participants were given a small gift of a book or a t-shirt for participating.

Design

Stimuli

The habituation and test events were computer-animated events modeled after Rakison (2004). The stimuli were created with Macromedia Director 5.0 for PCs. In each event, an object moved from left to right across the computer screen. In the experiment, 18-, 22- and 26-

month-old infants were habituated to two different static stimuli with external features, one a blue square with a green triangle hat on it, the other a red circle with a yellow elongated semi-circle hat on it. Infants were also habituated to two different dynamic stimuli. The first one was a blue square moving in a curvilinear motion trajectory. The second was a red circle moving in a linear pattern. In the curvilinear motion, the object moved up and down twice in each event, and in the linear path, the object moved up and down four times in each event. Each event lasted eight seconds for both motion paths, and each event could be repeated up to three times per trial. Each presentation of an event was separated by a blue screen that descended and ascended, taking one second. The pairing of objects (red square and blue circle) and external shapes (green triangle and yellow elongated semi-circle), as well as the pairing of objects and motion paths (linear and curvilinear) were counterbalanced across participants.

 Insert Figure 1 about here

Procedure

Infants at 18-, 22-, and 26- months of age were recruited, through a database and phone calls to their residence, to participate in this study at the Infant Cognition Laboratory at Carnegie Mellon University for one session which lasted approximately 45 minutes. All participants were brought to the lab by a parent or guardian, who signed an informed consent form assuring confidentiality, their rights, and their voluntary participation in the study. During the experiment, each infant sat on their parent's lap in front of a table with a computer screen in front of them.

In the experiment, 18-, 22-, and 26-month-olds were habituated to two different static stimuli, a blue square with a green triangle hat on it and a red circle with a yellow elongated

semi-circle hat on it. Infants were habituated to two different dynamic stimuli: a blue square moving in a curvilinear pattern or a red circle moving in a linear pattern (see Figure 1). The order of these two stimuli was counterbalanced across participants. After the habituation phase, the infant was presented with two test items, one consistent and one inconsistent with the correlation. One test trial consisted of a novel body part, a purple muffin-shaped object with a green triangle-shaped hat or a yellow semi-circle hat on it moving in a curvilinear pattern. The other test trial consisted of the same object moving in a linear pattern (See Figure 2.) The order of the two test trials and external parts was counterbalanced among participants. An example of a consistent test event would be the purple muffin-shaped object with a green triangle hat moving in a curvilinear path when the infant had been habituated on the blue square with a green triangle hat moving in a curvilinear path. At any time, the parent could choose to terminate the study for any reason.

During the habituation and test phase, each event was present until the infant looked away for 1 s or after 27 s of continuous gaze. The habituation phase was terminated when an infant's looking time for a block of three trials decreased to 50% of that recorded for the first three trials or until 18 trials were presented. To help focus the infant's attention, a green expanding and contracting circle against a black background was presented before the initial habituation trial and between each habituation and test trial.

Each infant's looking time (in seconds) was coded live during the actual experiment. All sessions were videotaped for later reliability coding by a second experimenter who coded 25% of each age group's looking behavior. Reliability for infants' looking time was $r > .98$, with an average difference between the coders of 0.017.

Results

The mean looking time of the three age groups during the two test trials are presented in Table 1. Infants' looking times to the test trials were analyzed with a 2 (test trial: consistent vs. inconsistent) x 3 (age: 18 months vs. 22 months vs. 26 months) mixed design analysis of variance (ANOVA). I was assessing if infants at any of the three age groups looked longer at the inconsistent event relative to the consistent event indicating the unseen correlation from the habituation phase. The analysis revealed no significant main effect of test trial, $F(2,29)=0.128$, $p>.72$, and no significant interaction between test trial and age, $F(2,29)=0.21$, $p>.82$. The analysis, however, indicated a significant interaction between test trial and sex, $F(2,29)= 7.43$, $p<.012$, but no significant interaction between test trial, sex, and age, $F(2,29)= 0.149$, $p>.86$.

Follow-up t-tests were used to examine separately each sex's looking times. Results revealed that females looked marginally longer at the inconsistent test trial ($M=14.63$, $SD=9.50$) than the consistent test trial ($M=10.21$, $SD=7.03$), $t(11)=2.08$, $p<.062$ while males looked longer at the consistent test trial ($M=14.28$, $SD=9.89$) than the inconsistent test trial ($M=7.14$, $SD=6.19$), $t(16)=2.00$, $p<.062$ (See Table 2 and Figure 3.)

Discussion

This experiment was designed to address when deductive-like reasoning develops in infants. Assessing deductive reasoning skills using perceptually presented information in infants is a new research area. The current study replicated the only other identified study, that of Rakison and Yermolayeva (2011), with the exception that infants saw objects with external instead of internal parts. Due to Rakison and Poulin-Dubois' (2002) claim that infants expect large and external parts to be connected to motion trajectory, it was hypothesized that 26-month-old infants would make deductive inferences to the dynamic motion experiment with external parts. Since external parts were thought to be more salient than internal parts, younger infants

of 22 or 18 months of age might have successfully demonstrated these deductive-like skills (Rakison and Poulin-Dubois, 2002). The research question addressed was: at what age will infants use deductive-like reasoning when applied to dynamic motion with stimuli with external parts. Since previous studies have not shown sex effects none were predicted. Unfortunately, the small sample sizes here made it impossible to assess if infants of these ages, especially the 26 month group, could demonstrate the beginning of deductive reasoning abilities given the magnitude of the effect.

The difference between this study and that of Rakison and Yermolayeva (2011) is whether the geometric figures had internal or external parts. Even though infants should associate external parts with motion trajectory (Rakison and Poulin-Dubois, 2002) there may be a bias toward internal features in infants' inferences about objects (Newman, Herrmann, Wynn and Keil, 2008). Newman et al. (2008) found that 14-month old infants associated an animated cat's self-generated motion with internal rather than external features. In one experiment, infants were familiarized to two animated cats which each exhibited a unique self-generated motion. Infants then saw a novel individual with an internal feature (stomach color) similar to one cat, but an external feature (hat color) similar to another cat. Infants looked reliably longer when the individual's motion was congruent with the external rather than the internal feature. In a subsequent study, the experimenters found that in the absence of self-generated motion there was no preference towards the internal features. The applicability of their findings to a geometric figure presented on a computer screen with ambiguously caused motion is unclear.

Rakison (2004) cites there is evidence that infants, like adults, detect an object's properties more easily when the object moves (Burnham & Day, 1979; Kellman & Spelke, 1983; Washburn, 1993; Werker et al, 1998). However, there is no literature comparing the relative salience of geometric figures with external versus internal parts when associated with motion

trajectory. From the available data, it appears that by the age of 26-months, infants deduce inferences based on correlated internal features, apparently earlier than they deduce relationships based on external features. Future studies should compare whether deductive-like inference abilities can be demonstrated utilizing geometric figures with distinctive bodies, parts and trajectories, comparing the efficacy of external versus internal parts with infants of the same age groups.

The methodology of this study and that of Rakison and Yermolayeva (2011) depends on the infant's abilities to process relationships of visual stimuli. As Westermann and Mareschal (2004) point out, the shift in infants' processing features to relationships between features depends on the complexity of the visual stimuli. Therefore, there is no particular age at which this shift occurs. Rather infants process simple visual stimuli with relational processing while processing more complex stimuli using feature-based processing. The geometric figures used as stimuli in this study are relatively simple stimuli. Therefore, the expectation is that infants should be able to process relationships with these stimuli somewhat earlier than more complex, real-world stimuli.

Galotti and Komatsu (1989) argued that studies (Dias & Harris, 1988, 1990; Hawkins et al., 1984) that demonstrate younger children's deductive reasoning abilities had procedures that "facilitate maximally children's abilities to draw inferences" (Galotti & Komatsu, 1989, p.71). Markovits, Schleifer, and Fortier (1989) argued that even if younger children demonstrate deductive abilities, they do not have a full understanding of the relationships between the premises and conclusions before 11 years of age. Similarly, Moshman and Franks (1986) argued that even when children draw deductively valid conclusions, they lack a full understanding of the idea of logical necessity, that is that the accuracy of their conclusions are due to rules of logic, not on real world verification.

The limited data about the beginnings of deductive reasoning in infants leaves an incomplete understanding. The hypothesis of Rakison and Yermolayeva (2011) that deductive reasoning emerges due to infants' ability to encode two features as associated and one feature as associated with a novel feature leading to their associating the first and third features, is promising for future research. The process that Rakison and Yermolayeva (2011) propose could lead to increasing efficiency and precision over time.

The main finding of this study - that there is a sex difference in deductive-like reasoning - was not predicted. This is because the research on young children's ability to solve verbal syllogisms has never found sex differences (Hawkins et al., 1984; Dias & Harris 1988, 1990; Dias, Roazzi, O'Brien & Harris, 2005). Why, then, did girls but not boys engage in deductive-like abilities in a visual task? It would have seemed more likely that if one sex developed such skills first it would perhaps have resulted from an evolved difference. However, the directionality should have been that males developed these skills due to their experiencing different adaptive problems than females. Their ability to deduce from correlated attributes to motion, if demonstrated, may have been related to a previous need to detect motion in potentially dangerous situations throughout human history (Rakison, 2005). The current finding is inconsistent with available educational literature which suggests that males are superior to deductive reasoning than females (Gurian & Ballew, 2003). However, one possibility suggested by Gurian (2001) is that girls are better at multi-task behavior and using both sides of the brain when processing information. Perhaps this visual task requires multi-tasking because infants have to process both the external part and the motion of the geometric shape. It is also unclear why a sex difference would not have occurred for internal features in the study of Rakison and Yermolayeva (2011). One explanation for this difference could be that infants perceive the external feature as a separate entity than the geometric figure, whereas the internal feature may

be perceived as a part of the whole. Future research will determine if the age findings of Rakison and Yermolayeva (2011) or the current findings will be replicated.

The limitation of the present experimental design and procedure is that it is unclear to what extent infants' reasoning about geometric figures will apply to deductive reasoning about real-world objects. The intent of this study was to assess deductive reasoning about new information instead of about objects on which infants could have had prior knowledge.

Current findings were minimized by sample size. In summary, the current study found that infants were unable to infer an unseen correlation between two features on the basis of two other learned correlations. I found no effect of age, in which one group looked longer at the inconsistent event relative to the consistent event, indicating the unseen correlation from the habituation phase. There was however a significant effect between test trial and sex. The results revealed that females looked marginally longer at the inconsistent test trials than at the consistent test trials, while males had the opposite trend. The sex difference, indicating that females tended to deduce inferences, despite the small sample sizes, needs to be followed up with further research. Since this is a new area of research there is still much to discover about the beginnings of deductive reasoning in infants.

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Table 1

Means and Standard Deviations of Looking Times (in Seconds) at 18-, 20-, and 26-months at Consistent and Inconsistent Test Trials.

	Consistent	Inconsistent
18 months	11.51 (8.76)	10.88 (8.09)
20 months	12.02 (9.03)	12.02 (9.30)
26 months	12.00 (7.88)	12.89 (11.31)

Table 2

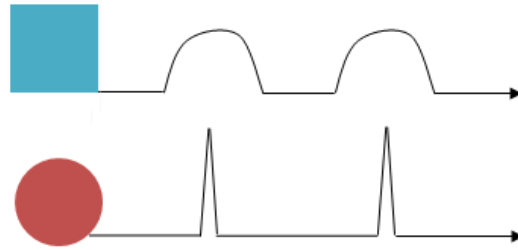
Means and Standard Deviations of Looking Times (in Seconds) by sex at Consistent and Inconsistent Test Trials.

	Consistent	Inconsistent
Males	14.28 (9.89)	7.14 (6.19)
Females	10.21 (7.03)	14.63 (9.50)

Habituated to:

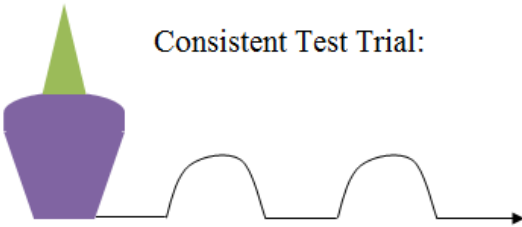


Static Stimuli with External Parts



Dynamic Stimuli

Consistent Test Trial:



Inconsistent Test Trial:

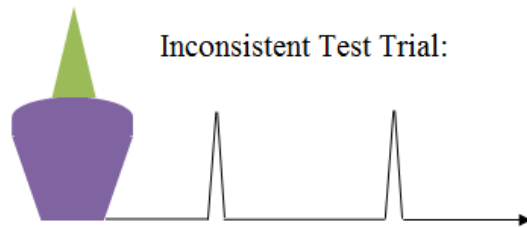


Figure 1. Stimuli for habituation and test trials.

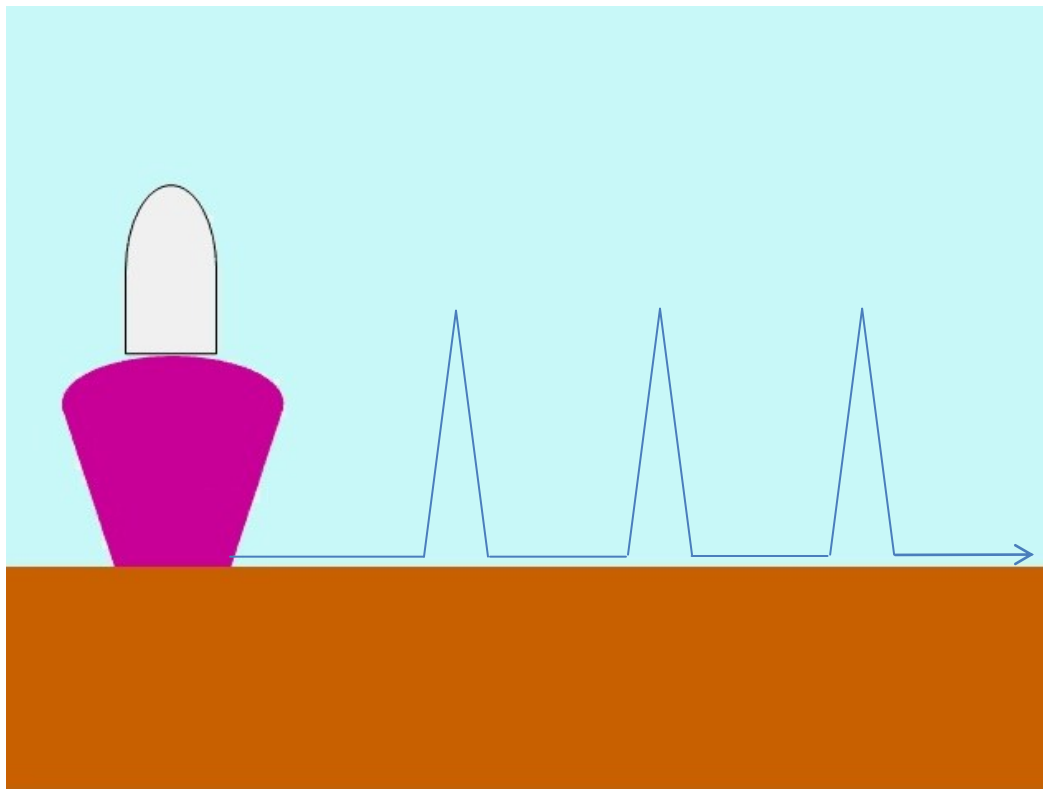


Figure 2. Screen Shot of test trial with added trajectory.

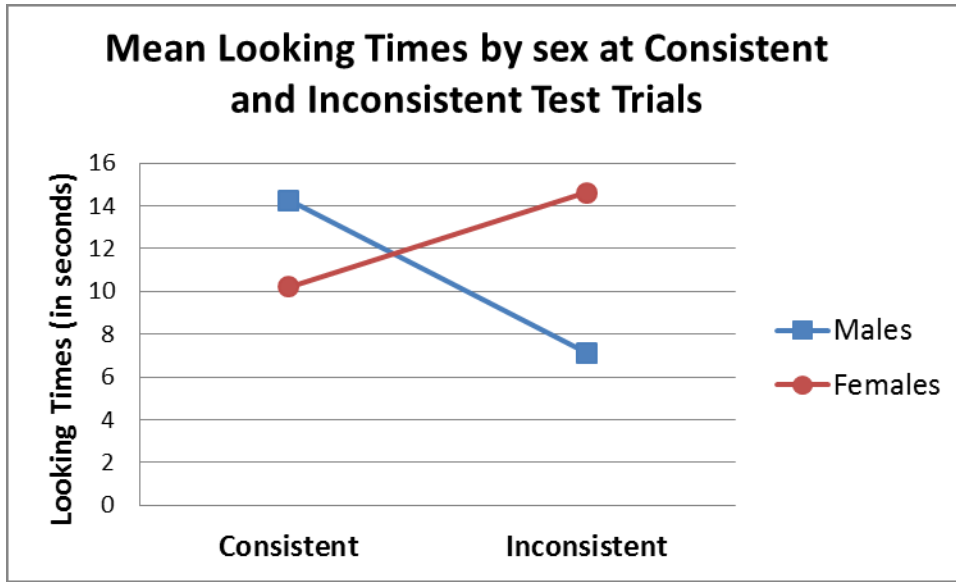


Figure 3. Mean Looking Times (in Seconds) by sex at Consistent and Inconsistent Test Trials.