# Using a Robot to Reexamine Looking Time Experiments


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## Abstract

*We present new evidence to support criticisms of infant looking time experiments. One such experiment, in which Baillargeon concluded from looking times that infants understand object permanence, is examined in detail. An alternative model of infant cognition, using the idea that infants look longer at particular scenes based on visual processing at the pre-attentive level, rather than based on any understanding of the objects they are seeing, is suggested. The model is implemented on Nico, a humanoid robot currently being developed in the Yale Social Robotics Lab. The validity of the model is established by running Nico through a reenactment of Baillargeon's initial experiment and achieving comparable results. The argument is made that while these results do not prove the suggested model is correct, they do prove that the suggested model is sufficient for explaining Baillargeon's results. We conclude that the demonstrated validity of the model prevents Baillargeon from claiming that the initial experiment provides proof of an understanding of object permanence in infants. We suggest that the model could be further validated by running Nico through other looking time experiments.*


## 1. Introduction

In the past few years, the validity of infant cognition studies has been under debate. Because infants are unable to communicate their thoughts and, in the case of particularly young infants, unable even to control their bodies in meaningful ways, researchers desiring to determine what infants are thinking have been forced to rely exclusively on indirect cues such as looking times. In one popular looking time paradigm, the violation of expectation study, the infant watches a scene that is either physically possible or physically impossible. If the infant looks longer at the impossible scene, the researcher concludes that the infant was surprised by the scene because it is impossible, and that the infant must therefore possess some understanding of the principles which make the scene impossible. This paradigm was used famously by Karen Wynn to suggest that infants understand basic arithmetic [8]. A similar paradigm, in which infants habituate to a basic scene before being shown either an impossible or a possible variation of it, is also quite popular. It has been used in a number of studies to suggest infants understand various concepts about the laws of physics, such as object continuity [3]. The problem with these studies, critics such as Haith claim, is that they assume too much about the conceptual understanding of infants based on perceptual evidence [4]. According to Haith, infants may behave the way they do without any knowledge of such concepts as arithmetic, object continuity, or impossibility. Infants may follow much simpler rules for tracking objects and may respond to novel stimuli, stimuli that the rules did not predict, by looking longer at these stimuli, without giving any thought to what is possible or impossible.

Because of the difficulty of finding new ways to study infant cognition, the debate remains unresolved. However, the field of robotics may be key to determining whether a less generous model of infant cognition is sufficient to explain the results of infant cognition studies [1]. If robots, following basic rules without any knowledge of higher-level concepts, can replicate infant behavior, then it is possible that infant cognition follows similar basic rules. Schlesinger [6] created a very simple block animation based on Baillargeon's study [2] in which a cart moves down a track, briefly passing behind an occluder. Schlesinger evolved a neural network which received as input all the pixels in a given frame of the animation, as well as all the pixels in the foveal area, the part of the animation at which the agent was currently "looking." The neural network produced as output directives on where in the scene the agent should look next. After training the net with the basic animation, Schlesinger tested it on animations corresponding to the possible and impossible scenes used by Baillargeon.

Schlesinger was able to draw parallels between the performance of his neural network and the performance of infants in Baillargeon's study. However, because Schlesinger used a basic simulation with a simplified animation to represent what his agent was seeing, his interpretations are open to criticism. The agent did not have to deal with real world constraints such as noise in an image, nor could it benefit from real world cues such as depth. Furthermore, because the simulation involved evolving a net for a particular animation, using the same agent to mimic other infant cognition studies, or even other studies of object concepts, would be a nontrivial matter. At the very least, basic animations would have to be built for each study and a separate neural network might need to be evolved for interacting with each one. Even then, it is unclear whether the same types of results would be achieved. Thus, it is hard to justify generalizing his results to the performance of infants in the real world.

In the present paper, a new model of infant cognition is proposed as an alternative explanation for the results achieved in Baillargeon's looking time experiment. This alternative model is a pre-attentive model, meaning the model presupposes that the results in looking time experiments can be explained in terms of visual processing that goes on in the infant's brain before the infant is consciously aware of any visual stimuli. If the model is correct, then infants do not look longer at a particular stimulus because they make a conscious decision to look at what they find particularly surprising. Instead, they look longer at a stimulus because of basic, automatic mechanisms.

The model is implemented on the humanoid robot Nico and tested by running Nico through an experiment similar to Baillargeon's. The purpose of this experiment is not to determine whether the model accurately describes what is occurring within an infant's brain. The purpose is rather to demonstrate that the model could potentially result in infants behaving the way Baillargeon found them to behave.

## 2. Baillargeon's Experiment

In Baillargeon's object permanence experiment [2], 6-month-old and 8-month-old infants were first shown two randomly ordered familiarization trials. In both trials, a yellow cart stood immobile on a downward-sloping track. A red screen, which would otherwise have occluded the cart, was held up above the track. A green box was placed on the track next to the yellow cart in one trial and behind the track in the other trial. After seeing both familiarization trials, infants were exposed to a series of habituation trials. In each trial, they were shown an eight-second scene that repeated until they lost interest in it. They were considered to have lost interest when they looked away for at least two seconds. Because the scene was divided into two-second segments, the infants had to lose interest for at least one entire segment for the trial to end. As the scene began, the red screen stood in front of the track, occluding a small part of it. In the first two-second segment, the red screen was lifted up into the air and then lowered. In the second segment, nothing happened. In the third segment, the yellow cart appeared at the top of track, took approximately two seconds to travel down the track, briefly disappearing behind the red occluder, and then moved out of the infant's view at the bottom of the track. In the fourth segment, nothing happened again. Experimenters recorded the total time it took infants to lose interest in this scene and then repeated the habituation trials until the time in three consecutive trials was half of what it had been in the first three trials, at which point the infant was considered to have habituated to the scene. On average this required about eight habituation trials.

After habituation was achieved, each infant was given the two familiarization trials again. Then, the infant was given three more trials. For half the infants, these trials followed a possible-impossible-possible pattern, and for half the infants the trials followed an impossible-possible-impossible pattern. The possible trials were the same as the habituation trials, except that when the red screen rose into the air, the infants saw the green box sitting behind the track. The impossible trials were the same except that when the red screen rose, the infants saw the green box sitting on the track. This scene was considered impossible because the presence of the green box on the track suggested that as the cart travelled behind the occluder, the cart was actually moving through the green box. According to Baillargeon, the infants looked at the scene longer in the impossible trial because they were surprised that one object could move through another object. Since the impossible event apparently occured behind the red screen, Baillargeon concluded that infants represent the locations of objects located behind occluders, represent the velocity trajectories of objects moving behind occluders, and understand object permanence, i.e. the idea that one object cannot move through another.

## 3. An Alternative Explanatory Model

Our model begins with one of the most basic human perceptual abilities: feature detection. Every human has neurons in the brain that are activated for certain types of visual stimuli at certain locations in the visual field. These neurons respond at a pre-attentive level. They include neurons that respond to stimuli of particular colors, neurons that respond to stimuli at particular depths, and neurons that respond to stimuli with particular motion vectors [5]. When an infant sees a red ball moving through its visual field, the appropriate neurons for a red object at a particular depth moving with a particular velocity are activated.

Another basic cognitive ability that does not require conscious thought is the ability to create associations in the mind between two stimuli. Classical conditioning experiments show us that even rodents can do this [7]. Suppose, then, that human infants can build and remember associations between groups of stimuli. These associations can be seen as very basic mental constructs, which will be called elements. Imagine that an element is represented by an array of neurons, with each neuron in the array corresponding to a location in the visual field. In the case of the red ball, the infant might associate one such array with the redness, the motion vector, the location in the visual field, and the depth in the visual field. If the infant later saw a red ball moving in the same direction very close to where the red ball element was first formed, the associations between all these features and the red ball element would cause the neuron for the new red ball's location to be excited. If, on the other hand, the red ball vanished and a blue ball appeared in its place, the neuron would be excited to a lesser degree, as the element would share only the location, velocity, and depth features of the new stimulus.

Of course, remembering an element's location in the visual field is only of limited use. A human's eyes are constantly moving as the person focuses on different stimuli. Once an element disappears from view, perhaps by moving behind an occluder, its last known location in the visual field quickly becomes unreliable. Therefore, it may be more useful to remember an element's location relative to the locations of other elements, particularly if they are near each other. One can imagine that there are associations between elements in the infant's memory. If one element was last seen moving behind a second, then there will be a strong association between the elements, and simply looking at the second will excite the neuron for the first at the same location.

The model can be examined in greater detail, although details beyond the basic framework are little more than speculation. When an object appears in the visual field, if it shares any features with any elements in the infant's memory, those elements will be excited for the object's location in the visual space. If an element is sufficiently excited for a particular location, then it will become activated for that location. This has several effects. First, an element's activation at one location in space inhibits its activation at other locations, meaning an element cannot be activated for more than one location at the same time. Second, an element's activation inhibits the creation of a new element at the same location, so the infant will not make the mistake of assuming an object is both an old element and a new element. Thirdly, the element's activation causes the infant to habituate to the element, meaning the infant will find the element slightly less exciting than it has in the past. Finally, the element's activation stimulates the infant to look at the object's location in visual space. The element's activation does not inhibit the activation of another pre-existing element at the same location in space, meaning that two elements may be activated for a single object. This quirk in the infant's cognitive ability will prove important in explaining infant behavior in Baillargeon's study.

When an object disappears from the visual field, the activation of any elements associated with it will persevere for a short time and then cease. At this point, the element's last known location in the visual field will decay very quickly. Unless the object reappears in a short time, the element will lose all association with any location in visual space. The other associations, however, will remain for a longer time. As the infant gradually forgets the element, the element's level of habituation will decrease. However, the more time the infant has spent looking at the element, the harder it is for the infant to forget the element.

## 4. Interpreting Baillargeon's Results

Now, suppose we apply the model to Baillargeon's experiment. Instead of imagining that infants understand and are able to habituate to an entire scene, the model suggests that infants are merely habituating to a set of elements. In the habituation trials, the red screen is always in the infant's field of view, while the cart is only in the field of view for about two out of every eight seconds. Thus, one might assume that infants would habituate to the red screen much more quickly than they would habituate to the yellow cart. However, it seems plausible to suggest that when the stimuli associated with an object change significantly, such as when the red screen moves up and down, the degree of habituation decreases. Since the red screen remains stationary most of the time, it may become much more interesting to the infant during the two seconds when it is moving. Since the yellow cart is always moving, its motion would be less exciting. Suppose that the infant will never look away during the two seconds when the red screen is moving. Once the infant has habituated sufficiently to the red screen, the infant will look away during the two seconds before and after the red screen moves, as nothing happens during these intervals. However, the infant must look away for a total of at least two seconds for the trial to end. This means that unless the infant looks away immediately at the beginning of one of the intervals where nothing happens, the infant will need to look for some time beyond the length of these intervals for the trial to end. The only remaining interval is the two seconds when the yellow cart is visible. Thus, the infant must completely habituate to the yellow cart before the infant will look away for a total of two or more seconds.

During the intervals between trials, none of the objects are visible to the infant. Presumably, during these intervals the infant partially forgets the elements associated with the red and yellow objects, losing some of the habituation to these elements. After each trial, the infant has seen the objects for more time and thus has more trouble forgetting their elements, so after each trial the infant dehabituates to a lesser degree, causing each successive trial to take less time.

In the possible test trial, the green box is introduced. The green box was visible during the familiarization trials but not during any of the habituation trials, and thus it is much more interesting to the infant. However, the box is only visible while the red screen is moving up and down, and this is not the period when the infant looks away. Thus, the green box has little effect on the total time of the trial.

The impossible event is similar to the possible event, but with one important distinction: the green box is placed on the cart's track. The infant may not realize this, or even know what a track is. However, this distinction also means that the green box's depth, i.e. its distance from the eyes of the infant, is the same as the depth of the cart. When the red screen moves up and down, the infant creates a green box element and associates this element with its depth, with its color, and with the red screen element, since it was last seen being occluded by the red screen. During the first cycle of the impossible trial, as the yellow cart appears, it catches the infant's attention, and the infant's eyes move to follow it. As the cart moves behind the red screen, it is briefly located directly next to the screen. The infant's green box element is excited for the position of the red screen because of the association between the red screen and the green box. The green box element is also excited because the yellow cart is located at the same depth as the green box. Some of the time, this may be sufficient to activate the green box for this location. As the yellow cart comes out from behind the red screen on the other side, it again may excite the infant's green box element for that location. Since the cart moves quickly on, the activation is very brief. However, because elements that have disappeared from view persevere for a short time, the infant continues attending to the imagined green box for a little while longer, while the yellow cart moves on. Because the infant has had less time to habituate to the green box in previous trials, the infant finds the green box more interesting than the yellow cart. Thus, the infant pays less attention to the yellow cart and so habituates to the cart at a slower rate. It takes the infant more time to habituate to the yellow cart, and so the impossible trial takes more time to complete.

## 5. Methodology

The cognitive model was implemented by building a *memory* module for the robot Nico. Nico is a humanoid robot currently being developed at the Yale Social Robotics Lab. Nico is designed to both look and behave like a nine-month-old infant. Nico's head contains six motors, three of which control Nico's "eyes." One pan motor rotates each eye from side to side, while a third tilt motor rotates both eyes up and down. The eyes each consist of two small cameras. One camera possesses a wide field of view, and the other camera, which represents the fovea, possesses a narrower field of view. Nico also possesses a torso and an arm, although only software for controlling the head was used in the present experiment.

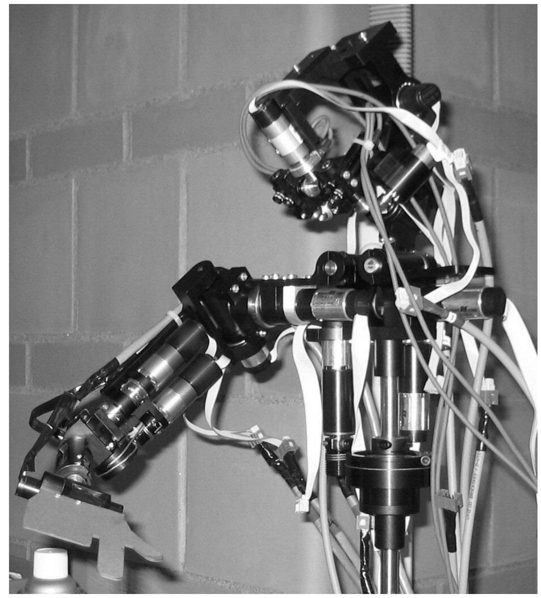

**Figure 1. Nico, an upper-torso humanoid robot used in the implementation of our alternative model**

### 5.1. Nico's Software

Nico is controlled by a set of software modules running in parallel on 16 networked computers. Some of these modules have been ported from code written for Cog, a humanoid robot at MIT, while other modules have been developed by members of the lab. The modules pass information to each other through the "port system." Each module performs a basic cognitive operation similar to a function that might be performed by a particular area in the human brain. The modules can be divided into perceptual processing modules and behavior control modules.

The basic purpose of the perceptual processing modules is to extract information from the video cameras that make up Nico's eyes. The lowest-level modules detect single-pixel features in the image. For example, the color module detects bright colors in an image. The skin module detects colors that are likely to be skin tones. The motion module detects motion in the form of changes in a single pixel's intensity over time. Each of these modules produces a saliency map, a grayscale image in which the value for

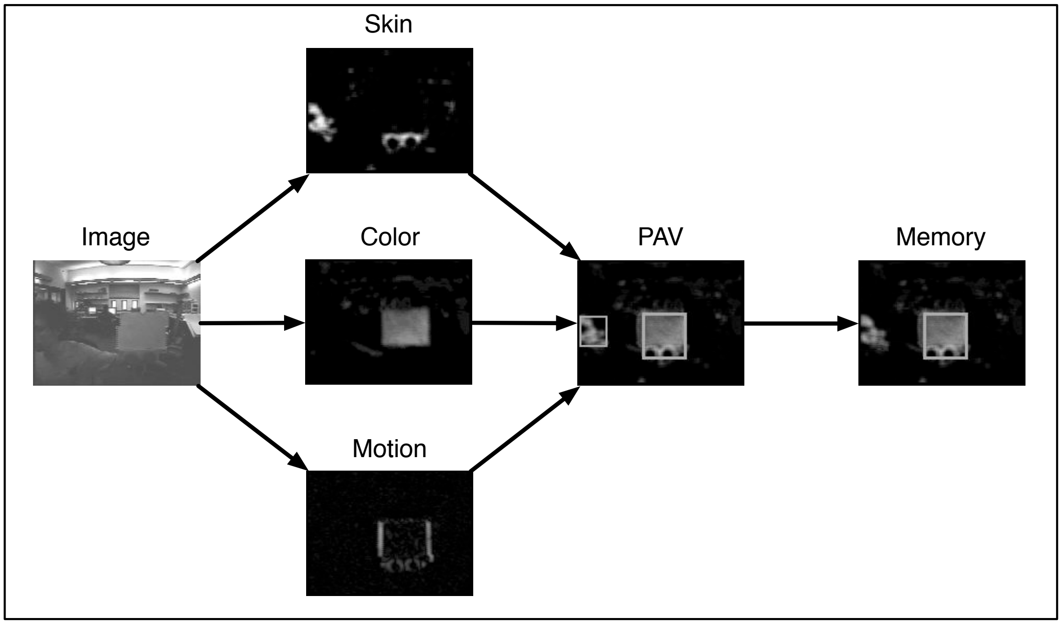


**Figure 2. The Visual Processing Pipeline: the image is passed to the Skin, Color, and Motion modules, each of which produces a saliency map; the PAV module performs a weighted summation of their output and boxes interesting objects; the *memory* module performs habituation and chooses the most salient object (the images shown above represent typical output from each module)**

each pixel represents the degree to which the module found that pixel to be salient.

The pre-attentive vision module, or PAV, receives any combination of saliency maps and performs a weighted summation of their values, using weights determined either by the user or by some other module. Because the weights are variable, PAV can be adjusted to cause Nico to pay more attention to particular types of stimuli. After computing the weighted sum, PAV groups neighboring highly salient pixels together to form boxes. These boxes generally correspond to actual objects in the physical world. For example, if PAV is attending to color and a red ball is placed in front of it, it would box all of the adjacent red pixels together to form a box representing the location of that ball in the visual field. PAV can also be adjusted to change what types of pixels will be grouped together in the same box. For example, it can be set to box skin and color separately, so that a green toy and the hand holding the toy are treated as distinct objects. It can even be set to box different colors separately, so that a blue object and a yellow object that are adjacent in the visual field are kept distinct. Once PAV has found its boxes, it sends the most salient ones on to the next module.

There are several modules which may use the output from PAV as their input. Two such modules which are used for behavioral control are saccade and smooth pursuit. These modules represent two different types of eye movements found in humans. A saccade is a movement in which, after a person first becomes interested in an object, the person's eyes quickly move to a position in which they are fixated on that object. Smooth pursuit is used after a saccade has placed an object in the center of a person's field of view. As the object moves around in space, the person's eyes follow that object, so that it remains in the center of the person's field of view. In Nico, both of these modules receive boxes from PAV telling them where in the visual space objects of interest are located. They perform basic transformations to determine how far or quickly the eye rotation motors should move to compensate for any discrepancy between the most salient object's location and the center of the visual field. They produce output in the form of motor commands that are sent to an arbiter, which keeps track of whether Nico is currently engaging in a saccade or smooth pursuit and passes on the appropriate command to the motor module, which actually communicates with the eye motors.

Because Baillargeon conducted her experiments with a red object, a yellow object, and a green object, the color module was used as the sole input to PAV in the present experiment. PAV was set to box differently colored pixels separately, based on the assumption that infants have no trouble distinguishing between two adjacent objects of different colors. A separate instance of the color and PAV modules was run for each of Nico's eyes. Only the wide field of view cameras were used, as they provided sufficient detail for a foveal view to be unnecessary. The two PAV modules each passed their output boxes to depth, a module that matches up the PAV boxes from the left and right eyes and outputs the horizontal disparity between them. Disparities values give a rough idea of the relative distance from the eyes to an object, i.e. the object's depth. However, on their own they are only reliable if the eye cameras are parallel and stationary, so they could not be used as an indicator of absolute depth in the present experiment. The output from both the left eye's PAV module and the depth module were connected to the *memory* module.

### 5.2. The *memory* Module

The *memory* module receives PAV boxes as input and produces its own modified boxes as output. The module uses an array of elements to "remember" what it has seen over time. When it first receives a box from PAV, representing an object in the visual field it has not seen before, it matches the box up with a disparity from depth, representing the object's relative depth. It then associates one of its elements with the features of the new box. It stores the element's color and location in the visual field. If there is currently another visible element that has been present for some time, it associates the new element with that old element, storing the new element's location and depth, relative to the old element. This is a somewhat simplistic treatment of the infant cognition model, since there are presumably many more features that may be associated with an object. However, the *memory* module is limited by Nico's current perceptual abilities. The features mentioned are sufficient for replicating Baillargeon's experiment.

Every timestep, *memory* receives a set of boxes from PAV. It first checks to see whether those elements that were visible the previous timestep are still visible. Elements that are currently visible are associated with a location in the visual field and with a color. *Memory* then checks to see whether elements that were not visible the last timestep are now visible. If an element was last seen near its associated relative element, it will be strongly associated both with its last known depth relative to that element and with that element's location. Suppose element A disappears while directly adjacent to element B. If a box with the same color as A later appears near B, it will activate element A. However, if a box later appears adjacent to B and that box does not have the same color as A but the box is at the same relative depth, it can still result in the activation of element A.

When Nico is attending to a particular PAV box, i.e. when that box is the most salient, Nico habituates to the element associated with the box at an especially high rate. As the element's level of habituation increases, the box's saliency decreases. However, if the box to which Nico is attending begins moving after remaining stationary for some time, the associated element's level of habituation jumps down, and the box immediately becomes more interesting. After the box stops moving, the level of habituation returns to its previous level.

Because the details of how habituation works in an infant are unimportant for the present experiment, the *memory* module does not not use a realistic implementation of habituation. The implementation is simply designed to be sufficient for fitting the data from Baillargeon's experiment. While an element is visible, Nico habituates to the element at a steady rate. This continues until the element leaves Nico's sight or it reaches a saliency of 0, at which point Nico ignores the object with which the element is associated completely. When an element disappears from Nico's view, Nico remains habituated to the element for several seconds and then slowly begins to lose habituation. However, Nico does not lose all habituation to the element. The minimum level of habituation to an element, which begins at 0 when the element is first created, gradually increases as Nico habituates to an element. After the element leaves Nico's sight, Nico's level of habituation can drop no lower than this value. Thus, every time Nico sees the element, it takes Nico less time to habituate to the element. This allows Nico to habituate more quickly on each successive trial run, just as the infants did. The minimum level of habituate cannot rise higher than a little above 1/2, so trial times will not drop significantly below half of the initial trial time.

### 5.3. The Experiment

Baillargeon's experiment was replicated by building a short metal ramp. A toy train with a yellow piece of poster board affixed to it represented the yellow cart. It traveled down the ramp behind a thin red screen, the occluder, which could be lifted and lowered. A thin green folder represented the green box. It could either be clipped to the front of the track immediately behind the red occluder or be held up in

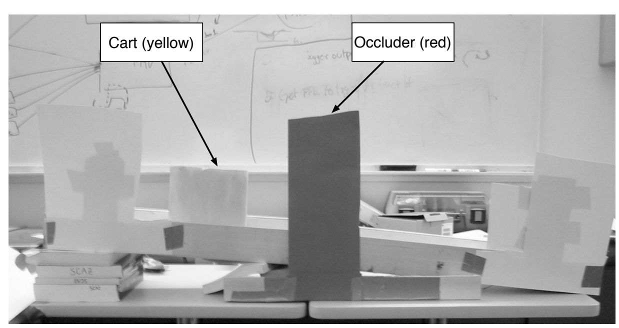


**Figure 3. The Setup: the cart moves down the ramp, behind the occluder**

a vice a good distance behind the occluder. Because Nico's depth perception is poor, the green folder appeared to be at the exact same depth as the yellow cart when it was clipped to the ramp. The fact that it was actually a thin folder rather than being a box placed across the ramp is irrelevant since Nico has no understanding of three-dimensional objects. The trials were run in a dark room with a light shining directly onto the ramp. No other brightly colored objects in the room received enough light to distract Nico.

Because Nico's habituation to objects is free of the myriad arbitrary factors that may affect infants, a simpler criterion was used for ending the habituation trials. Instead of ending when Nico concluded three consecutive trials in at most half the time of the first three trials, the trials simply ended when Nico concluded a single trial in half the time of the first trial. After each trial, the red occluder was covered so that there were no salient objects in Nico's field of view, and Nico was given time to lose habituation to the elements in its memory. If a shortcut hadn't been programmed in to speed up this process, it would have required a delay of at most 80 seconds between each trial, which does not seem to be an unreasonable amount of time. Because Nico has no understanding of the objects it sees beyond their association with elements in Nico's memory, the familiarization trials were deemed unnecessary and were not used.

Finally, because there simply was not time to run the experiment in two-second segments, the segments were lengthened to three seconds, meaning that the entire scene repeated at 12-second intervals rather than 8-second intervals. This also meant that Nico had to lose interest in the scene for three seconds before a habituation trial ended. The criterion for ending a trial was further increased to four seconds so that occasional mistakes by the experimenter that might have caused one of the boring segments to last for slightly longer than three seconds would not result in a trial ending prematurely. These changes should not have affected on the generalizability of the experiment, as Baillargeon did not claim there was anything significant about using 8-second cycles.

## 6. Results

Nico's state was saved after each trial so that if a component of the system should crash, the trials could be continued from the same point with the same habituation values used for each element. The data that will be reported was obtained from a single series of trials. However, because there is no random factor in Nico's system, there is no reason to suspect there would be any variation in multiple runs of the experiment. On occasions when trials were repeated, comparable results were achieved, with any variation resulting from differences in the way the scene was presented by the experimenter. In the initial trial run, Nico met the criterion for losing interest in the scene after 61 seconds. On the sixth trial, Nico lost interest after 25 seconds, meeting the criterion for ending the habituation trials. These results are similar to those achieved by Baillargeon, who found that infants on average showed a 50% decrease in trial times in three consecutive trials after the eighth trial.

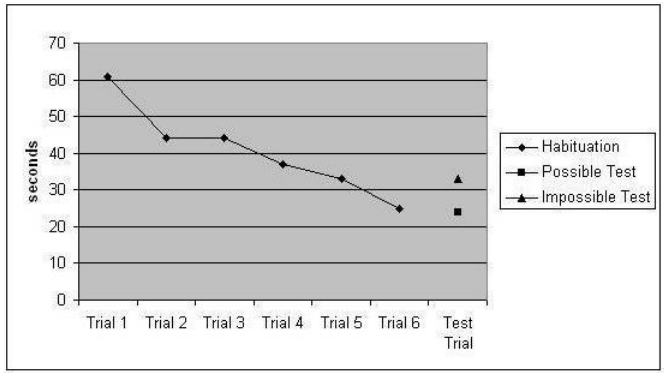


**Figure 4. Time required to habituate in the habituation and test trials**

After the sixth trial, Nico's state was saved. The saved state was tested on the "possible" and "impossible" test trials. On the "possible" test trial, in which the green folder was placed far behind the red occluder, the green folder failed to interfere with Nico's performance because its associated element was only activated while the red occluder was up. This trial took 24 seconds, about the same as the sixth habituation trial. On the "impossible" trial, in which the green folder was located directly behind the red occluder, the green folder's associated element was activated immediately before and immediately after the yellow cart moved behind the red occluder. This activation did not interfere significantly with the habituation to the yellow cart simply because Nico had already been exposed to the cart on six previous trials, and so it took Nico very little time to habituate to the cart. However, the activation did prevent Nico from losing interest in the scene when it otherwise would have because the activation of the green folder persevered for several timesteps after Nico had fully habituated to the yellow cart. As a result, the "impossible" trial lasted 33 seconds, 9 seconds longer than the "possible" trial. This difference was similar to the difference that Baillargeon found between the possible and impossible trials.

## 7. Discussion

The result from the "impossible" test trial is particularly interesting because while the increase in total time for the trial was expected, the reason for the increase was unexpected. The prediction was that the "impossible" trial would take longer because Nico would habituate to the yellow cart more slowly, whereas what actually happened was that the trial took longer because Niko took an interest in the imagined appearance of the green element. This result demonstrates one of the great advantages of robot studies: no matter how well thought-out a model may be, it is impossible to say for certain how the model will work until the model is tested in the real world. There are simply too many factors to consider all of them in theory or test all of them in simulation. With a robot, a scientist can test a theory in the real world while at the same time being able to look into the robot's head and see exactly how its cognitive operations are interacting with the feedback from the world.

Unfortunately, the results achieved in this experiment are not perfect. While they do match those predicted by the cognitive model, they do not entirely match the results reported by Baillargeon. Although Baillargeon does not report exactly how long the habituation trials took on average, she does say that trials were automatically ended if they took more than 60 seconds, implying that the first habituation trial lasted slightly under a minute, while the last habituation trial lasted well under 30 seconds. However, she reports that the ”possible” and ”impossible” test trials took about 48 seconds and 61 seconds, respectively. These results seem to suggest that even in the ”possible” trial, the mere presence of the green block in the scene caused the infants to find the scene as a whole more interesting, resulting in a longer looking time. If this is true, then infants are habituating to the entire scene, rather than to individual objects within the scene, meaning the theory proposed in this paper is incorrect.

However, there are alternative explanations. Baillargeon did not attempt to standardize the delays of time between trials. It is possible that the delays before or after the familiarization trials were longer, giving the infants more time to forget the objects before viewing the test trials. It is even possible that the infants lost habituation to the elements associated with the objects during the familiarization events themselves, perhaps because the infants were used to seeing the yellow cart moving rather than stationary. A more accurate reenactment of Baillargeon's experiment, perhaps using her own apparatus, might help to clear up this quandary.

One could easily argue that the findings from this experiment are not generalizable to most looking time studies. The *memory* module in its current form uses only a small number of features. Even one of these features, depth, is not entirely dependable, meaning that *memory* had to be modified to throw out noisy depth values, values that in another experiment might actually be valid. It seems as though the *memory* module has been designed specifically for the purpose of replicating Baillargeon's results. However, it is important to remember that Nico is still in the process of being developed. As new modules that extract new features are built for Nico, Nico will be able to more closely approximate the suggested theory of infant cognition. That theory was not merely designed to match Baillargeon's results, but was also meant to be applicable to other looking time studies. As individual studies are tested out using Nico, the model can change to accommodate those studies. Eventually, the model may have to be thrown out entirely. After all, it is designed to be a possible model, not a correct model. As long as it or some other model that can be tested with a robot remains a possibility, experimenters who use looking times to study infants will have to concede that their interpretations of cognitive abilities may be a little too generous.

## References


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