Rules of Physics can be Learned Implicitly

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Abstract

Learning about one's physical environment is an important task that must be accomplished early in life to be able to successfully navigate and operate. In an attempt to explain infants' great success in this endeavor at such an early age, it has been proposed that infants are ready-equipped with some basic knowledge of physics. However, it is also possible that infants possess powerful learning mechanisms enabling them to implicitly learn rules of physics at a very young age. The two reported experiments were designed to answer this question. Participants were presented with the demonstration of object behaviors that followed a set of artificial rules. Both adults and infants implicitly learned the novel rules of object behavior well enough to predict and interpret the outcome of events.

Keywords: Cognitive Science; Psychology; Cognitive Development; Learning; Developmental Experimentation; Human Experimentation.

Introduction

One of the most important tasks that an infant must undertake is to develop an understanding of how his/her physical world operates. Although this understanding develops throughout childhood into sophisticated beliefs about the physical world (Baillargeon, 2004b), an important question focuses on how infants acquire such knowledge.

The violation of expectation method is often used to demonstrate infants' early knowledge about physical events (e.g., Baillargeon, 2004b). Baillargeon (e.g., 2004a; 2004b) presents infants with events that either violate physical laws or not, and then she compares infants' level of surprise to each of these events. This method has revealed that infants clearly demonstrate knowledge about their physical world at a very young age by demonstrating a surprise response to events that should not be physically possible. This research has provided evidence that even very young infants understand such physical principles as continuity and solidity (e.g., Baillargeon, 2004a; 2004b; Spelke, 1990; 1994).

From this early demonstration of knowledge about the physical world, Baillargeon (2004a; 2004b) and Spelke (1994) have concluded that such general physical principles are innate. However, it could be argued that early competence does not necessarily present evidence for innateness.

In particular, infants possess powerful learning mechanisms that enable them to learn regularities in their environment, including implicit statistical learning. There is ample evidence that both infants and adults can extract statistical regularities from sequentially presented information (e.g., Conway & Christiansen, 2005; Creel, Newport, & Aslin, 2004; Fiser & Aslin, 2001; Thiessen & Saffran, 2003). This research proposes that infants do not come into this world with innate knowledge about the physical environment; rather, they may simply be readily equipped to detect statistical regularities in the environment.

Additional evidence comes from other infancy researchers. For example, Schilling and Clifton (1998) found that infants are capable of learning about real physical events in just one session. These researchers presented infants with a novel action that followed the natural laws of physics. This action demonstrated issues of gravity and weight using balls. Prior to viewing this event, the infants did not demonstrate knowledge about the physical concept in this task. After a single session, Schilling and Clifton violated this physical law and the infants demonstrated a violation of expectation about the ball's movement. These researchers claim that infants quickly come to understand their physical environment by observing the behavior of objects.

However, it could be argued that the infants did have some prior knowledge about the objects and the rules that were used in the Schilling and Clifton study, and this may have facilitated learning. Therefore, a minimal amount of learning actually needed to take place in order for infants to demonstrate their understanding of this physical law. At the same time, if the learning claim is true, then infants would also come to understand their physical environment by observation even if the behavior is novel, the objects are novel, and the rules that govern their behavior are novel. This should be true for any type of object behavior, even beyond the areas of physics normally investigated in infancy (e.g., solidity, continuity, etc.)

To examine this issue, we conducted two experiments using experienced rule learners (adults; Experiment 1) and relatively novice rule learners (infants; Experiment 2).

Experiment 1: Implicit Learning in Adults

Method

Participants There were 26 participants in this experiment. The participants were undergraduate students from The Ohio State University who participated to fulfill a psychology course requirement. Five participants failed to correctly respond to at least 75% of the catch items and were excluded from this experiment.

Design and Materials There were a total of 21 3-dimensional objects. The objects were divided into three categories: 1) 7 objects that are blue, smooth, and have convex curves; 2) 7 objects that are red, have the appearance of a grid design, and are concave; and 3) 7 objects that are green, have small craters and are both convex and concave. The stimuli consisted of object collision videos created using *Macromedia Flash MX.*

The collision of the objects was based on a system of modular arithmetic. The structure of the system was that of a commutative group of order three, with Category 1 objects being an analog of 0, Category 2 being an analog of 1, and Category 3 being an analog of 2. The collision is an analog of the operation of addition in the group. Because 0 (i.e., Category 1 objects) is the identity element, collisions with Category 1 objects do not change the identity of the category (i.e., $0 + 0 = 0$, $1 + 0 = 1$, and $2 + 0 = 2$). The rest of the rules follow from addition in the commutative group of order 3: $1 + 1 = 2$, $2 + 2 = 1$, and $2 + 1 = 0$. Therefore, the resultant of each collision followed directly from the set of rules. If the collision abided by this rule system, the collision was deemed a *possible* collision.

Based on this rule system, there were 6 types of *possible* collisions between the categories of objects. See Figure 1 for an example of each type of *possible* collision.

Each trial consisted of a collision of two objects that come from either side of the screen. The collision occurred behind a small occluder, which resulted in the production of a third object (and disappearance of the original two objects and the occluder). Each collision produced a video that lasted 4 sec.

Objects of each category were randomly combined to create a set of 40 *possible* collisions (26 training collisions, 8 test collisions, and 6 filler collisions). These *possible* collisions were used in both the training and the testing phase; however, specific objects from each category were used in only either the training or the testing phase, but not both.

In addition to these events that were deemed *possible* collisions, there was also a set of *impossible* collisions that do not abide by this system of modular arithmetic. For these collisions, the resultant object does not follow the specified combination rules (e.g., results in an object not specified by the combinatory rules displayed in Figure 1). See Figure 2 for some examples of *impossible* collisions. These collisions were only used in the testing phase (8 test collisions, 6 filler collisions). Similarly to the *possible* collisions, specific objects from each category that appeared in the training phase did not appear in the testing phase.

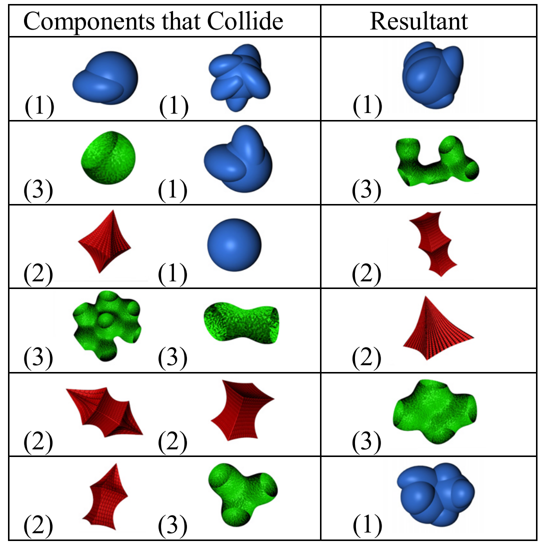

Figure 1: Sample *Possible* Collisions for Experiment 1.

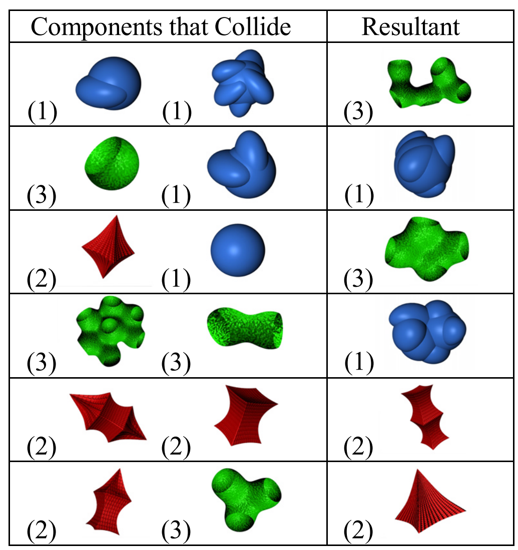

Figure 2: Sample *Impossible* Collisions for Experiment 1.

There was an additional set of 8 collisions that were used as catch trials. For these collisions, instead of resulting in an object similar to the objects that collided, these collisions resulted in the production of a cartoon animal (e.g., dog, cow). These collisions were only used in the testing phase.

All collision types varied within participants.

Procedure *Presentation* software was used to deliver the instructions, present the stimuli and record the responses.

Each participant was instructed that they would be presented with 3 kinds of particles from the planet Zoron, and they were shown one object from each category, in random order. Then, they were instructed that the particles interact according to laws of Zoron physics. It was explained that when two particles collide, a third particle will emerge. Then, the participants were asked to try to remember these interactions because they would be tested on them later.

The experiment was divided into a training phase and a testing phase. During the training phase, the participants were presented with 26 randomly presented examples of *possible* collisions (all possible combinations occurred multiple times during training). After each trial, the participants pressed the spacebar to continue to the next collision.

After training, the participants were instructed that in the first part, they were presented with interactions of Zoron particles. Now, they would be presented with some more interactions, some of which are from Zoron and some of which are not. Their job was to determine whether these particles followed the laws of Zoron physics or not. They were notified that specific particles would differ from those they saw in the first part, so when making a decision, they were asked to pay attention to interactions and not to the particles. They were also instructed that it was okay to guess if they were unsure.

From there, the participants entered the testing phase. During this phase, they were to press 1 after a collision if that collision followed these rules (*possible* event), and 0 if it did not (*impossible* event). During the first part of this phase, there were 16 test videos, half of which were *possible* collisions and half of which were *impossible* collisions, randomly presented. In the second part of this phase, the participants were presented with 12 additional test collisions similarly divided (1/2 *possible,* and 1/2 *impossible*). These collisions were used simply as filler collisions that accompanied the 8 catch collisions. They were randomly presented intermixed with the filler collisions during the second half of the test phase. The catch collisions used completely different objects, and their goal was to control for the overall accuracy.

Results and Discussion

Overall, participants were accurate on catch trials, exhibiting over 95% accuracy (M = 98.08), above chance, one-sample t (25) = 53.3, $p < .001$.

However, the accuracy of participants' responses on the *possible* and *impossible* test items was of particular interest. An accuracy score defined as the proportion of hits minus the proportion of false alarms for the 16 test items was calculated for each participant. Overall, participants were accurate in determining whether a test item was *possible* or *impossible* (M_{Accuracy} = .33), above zero, one-sample t (25) = 4.85, $p <$ .001. Thus, as expected, the participants were able to learn the rule implicitly during the training phase well enough to accurately determine the possibility or impossibility of novel examples during the testing phase.

Having established that adult participants were capable of implicitly learning novel rules of novel object behavior, we conducted Experiment 2 to determine if infants could also implicitly learn rules of object behavior after only a relatively small amount of training.

Experiment 2: Implicit Learning in Infants

Method

Participants Twenty-three 8-month-olds (14 boys and 9 girls, M = 245.91 days, *Range* = 237 - 270 days) participated in this experiment. Parents' names were collected from local birth announcements, and contact information was obtained through local directories. A majority of infants were Caucasian and had no auditory or visual deficits, as reported by parents. An additional 23 participants were excluded for failure to demonstrate novelty preference (n = 18) and failure to complete the experiment (n = 5).

Apparatus Infants were seated on parents' laps approximately 100 cm away from a 152 cm x 127 cm projection screen, which was located approximately 5 cm above the infant's eye level. A Sony DCR-TRV40 camcorder was used to capture infants' fixations and was projected to one of two Dell flat panel monitors in the observation room. An NEC GT2150 LCD projector was mounted on the ceiling approximately 30 cm behind the infant (130 cm away from the projection screen). Two Boston Acoustics 380 speakers were 76 cm apart from each other and mounted in the wall. The speakers and camcorder were concealed by black felt and located directly below the projection screen. Two small lights were located behind the infant to ensure that the room was dimly lit throughout the entire procedure.

In an adjacent room, a Dell Dimension 8200 computer with *Presentation* software was used to present stimuli to the infants, as well as to record the onset and offset of the infants' visual fixations. Fixations were recorded online by pressing a button on a 10-button USB game pad when infants were looking at the stimulus and releasing the button when infants looked away from the stimulus.

Materials The stimuli consisted of a small subset of collisions from Experiment 1 (see Figure 3). In this experiment, each video consisted of a collision repeated 3 times (13 sec/video). There were two training videos (*possible)*, and three test videos (2 *impossible* collisions and 1 *novel* collision*)*.

Procedure The first training collision video was presented and alternated with the second training video, for a total of 9 presentations of each video. This resulted in each infant viewing a total of 234 sec worth of training.

After this training phase, the test phase began seamlessly. For this phase, the two *impossible* test collisions were randomly presented followed by the presentation of the *novel* collision. For each infant, the amount of time looking to the screen for each video was recorded throughout both the training and the testing phases.

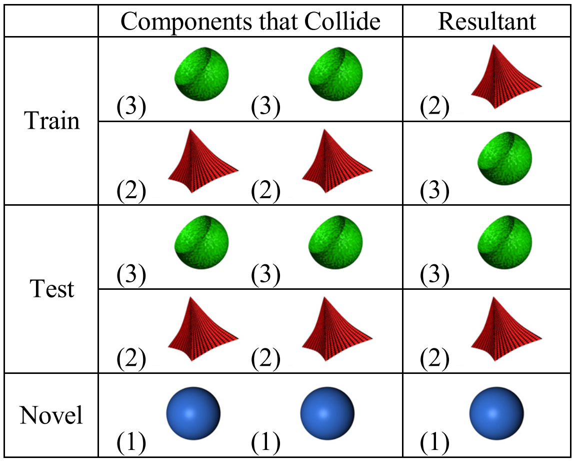

Figure 3: Training, Testing, and Novel Collisions in Experiment 2.

Results and Discussion

Three scores were calculated for each infant: average amount of time looking to the *impossible* test videos (test), average amount of time looking to the last two *possible* training videos (train), and amount of time looking to the novel video (novel). See Figure 4 for average looking times across each test trial type.

As expected, when comparing the novel events (M = 11970.84, SD = 2609.85) to the training events (M = 6403.1, SD = 703.05), the infants demonstrated an overall novelty preference, paired-samples t (23) = 9.57, $p < .001$.

However, of primary importance, is the comparison of test and train. Overall, as predicted, when comparing the test (M = 7537.86, SD = 3428.65) to the train, infants demonstrated an overall increase in looking to the videos that demonstrated an *impossible* collision, paired-samples t (23) = 2.44, p = .02.

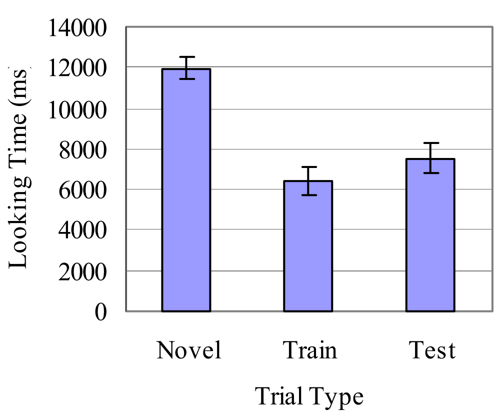

Figure 4: Average Looking Time across Test Trials for 8-Month-Olds

During training, infants appeared to have implicitly learned the rule of how the objects behave. This was evidenced by an increase in looking to the test videos when there was a violation of expectation (*impossible* collision).

General Discussion

The results of the two reported experiments clearly indicate that across both age groups, using isomorphic measures, participants were able to implicitly learn about the behavioral rules of objects. As a result, simple exposure to a rule led participants to demonstrate awareness when this rule had been broken.

In opposition to the supporters of the innate theory of physical knowledge (e.g., Baillargeon, 2004b; Spelke, 1994), the adults and infants were each able to learn the rule in one relatively simple session. These researchers claimed that since infants demonstrated such knowledge at the age of 2.5 months, then these abilities must have been innate. They proposed that infants have not encountered enough experience yet to have learned the laws of physics by this young age. However, the current research demonstrates that infants are able to learn completely arbitrary rules of object behavior in less than 4 minutes of training. This finding casts doubt on the innate theory of physical knowledge.

Therefore, this research provides evidence that both infants and adults are capable of learning rule-like interactions even when these interactions are arbitrary, with participants having no previous experience with these interactions. While presenting important evidence about the ability to learn, the current research raises a number of important questions that are to be addressed in future research.

First, the current research uses only deterministic rules, and it would be necessary to examine the ability to learn when the rules are probabilistic. In addition, it could be argued that infants are not actually learning a rule; they are just detecting a pattern of objects. Therefore, it would be necessary to examine whether or not infants (similar to adults) can extend rules to completely novel objects representing the same categories. If infants learn probabilistic rules and extend them to members of the same category (i.e., Category 1, Category 2, or Category 3), this would represent strong evidence for the ability of infants to extract physical regularities amply present in their environments and to abstract these regularities.

In sum, results of the current research suggest that when presented with novel objects that behave according to novel (but fixed) rules, both adults and infants are capable of detecting these rules. These findings suggest that people have learning mechanisms powerful enough to extract the regularities amply present in the world around them.

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