Curvilinear Impetus Bias: A General Heuristic to Favor Natural Regularities of Motion

by

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ABSTRACT

When a rolling ball exits a spiral tube, it typically maintains its final inertial state and travels along straight line in concordance with Newton's first law of motion. Yet, most people predict that the ball will curve, a "naive physics" misconception called the curvilinear impetus (CI) bias. In the current paper, we explore the ecological hypothesis that the CI bias arises from overgeneralization of correct motion of biological agents. Previous research has established that humans curve when exiting a spiral maze, and college students believe this motion is the same for balls and humans. The current paper consists of two follow up experiments. The first experiment tested the exiting behavior of rodents from a spiral rat maze. Though there were weaknesses in design and procedures of the maze, the findings support that rats do not behave like humans who exhibit the CI bias when exiting a spiral maze. These results are consistent with the CI bias being an overgeneralization of human motion, rather than generic biological motion. The second experiment tested physics teachers on their conception of how a humans and balls behave when exiting a spiral tube. Teachers demonstrated correct knowledge of the straight trajectory of a ball, but generalized the ball's behavior to human motion. Thus physics teachers exhibit the opposite bias from college students and presume that all motion is like inanimate motion. This evidence supports that this type of naive physics inertial bias is at least partly due to participants overgeneralizing both inanimate and animate motion to be the same, perhaps in an effort to minimize cognitive reference memory load. In short, physics training appears not to eliminate the bias, but rather to simply shift it from the presumption of stereotypical animate to stereotypical inanimate behavior.

DEDICATION

To Joshua Johnson, Thomas Crawford, Norm Dye and J.R. Evans. Thank you all for your past and continued support, without which, I would never have been able to complete this achievement. To J.R., thank you for being a light in my life that has guided me through it all. To Thomas, thank you for believing in me when times were darkest and for guiding me through the storm. To Norm, Dad, thank you for being a sanctuary in my life, to which I can always turn. To Joshua, thank you for making the world bright again and for a future full of hope, laughter and love.

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The science of object motion spans over two thousand years dating back at least to Aristotle (Dennis, trans. 1996). Aristotle's model of motion was derived from direct observations of the world that he called “principles of nature”. During medieval times, these principles evolved into an impetus model of physics, in which a force acting upon an object imbues it with an impetus, or an internal desire to continue moving in a specific way. This impetus within the object was expected to eventually dissipate (Dijksterhuis 1961, Clagett 1959). The impetus model was eventually replaced with the Newtonian laws of motion, which accurately describe large-scale inanimate object motion in the world. However, many people still favor alternative viewpoints that contradict Newtonian laws and the way that objects like rolling balls move in the world. These types of beliefs, known as naive physics, are both pervasive and are resistant to physics education (McCloskey 1980). In the present review, we examine the phenomena of naive physics. This is followed with a review of physics instruction literature and rat motion to build a foundation for the two interdisciplinary experiments presented here.

Naive Physics

Naive physics is a system of thought or beliefs that people have about the movement of objects and other phenomenon that contradict real-world physics principles. Examples of these kinds of beliefs occur in judgments of the following: hill steepness (Proffitt, 1995), acceleration dynamics (Rohrer, 2002; McBeath et al, 2013), location of the apex of a fly ball (Schaffer & McBeath 2005), orientation of the surface of different liquids (Hecht & Proffitt, 1995; Smedsland, 1963), gravity (Bascandziev & Harris, 2011), motion dynamics associated with the Doppler effect (Newhoff & McBeath, 1997; McBeath & Newhoff, 2002), how momentum is represented (Freyd & Finke, 1984;

Kozhevnikov & Hegarty, 2001; Hubbard, 1996; Reed & Vinson, 1996; Freyd, 1983), and most relevant to the current task, object motion (McCloskey, Washburn, & Felcch, 1983; Oberle, McBeath, Madigan, & Sugar, 2005; Hetch & Bertamini, 2000; Krist, Fieberg, & Wilkening, 1993; McCloskey, Caramazza, & Green, 1980; McCloskey & Kohl, 1983, Caramazza, McCloskey & Green, 1981). These types of phenomena are frequently experienced in everyday life and yet are not well understood by many people. Such systematic biases may seem very counter-intuitive considering the amount of effort people typically expend trying to understand the environment in order to accurately interact with it. In short, the sources of the naive physics phenomenon have been widely debated and often appear to not be well explained yet.

In the current study we specifically look at the curvilinear impetus (CI) bias naive physics belief that a ball continues to curve after it is released from circular motion. Much research has been performed examining this particular type of naive physics with two general explanations for the bias. The first is that people simply have a fundamental lack of understanding of physics (McCloskey, 1980). The other explanation is that the bias arises from natural visual motion mechanisms continue in a curved path, such that people appear to be assuming a kind of perceptual regularity and applying it to all objects (Freyd and Jones, 1994; Sanborn, Mansinghka & Griffiths, 2013). Here we explore these two explanations in depth.

McCloskey originally asked participants to draw the path of a metal ball in two scenarios. One, where the ball was being twirled around on a string that suddenly breaks, and the other where a ball emerges from a spiral tube. In both cases McCloskey found that a significant portion of the participants drew that the ball would continue to curve after the external force of the tube or string ceased. When participants were asked where the ball on the string would go after the string broke, thirty percent of participants said that the ball would continue to curve. In the case of the spiral tube, fully *half* of the participants drew the ball continuing to curve. He also reported that those participants who drew curved lines for one of the tasks, tended to draw it for the other task as well. McCloskey noted that his finding implied that these participants had a systematic conceptual misunderstanding. Surprisingly, a notable portion of people who had physics training also report continued curvature, though in much lower numbers. The findings appears to support that physics training has some effect on beliefs of how objects move, however there remains a very strong bias for people to believe that objects curve even after receiving training that demonstrates otherwise. McCloskey's experiment demonstrated that people hold "erroneous" beliefs about how objects behave, but offered no explanation as to why people would believe this. One explanation for these results could hinge upon experimenters using only paper and pencil tasks to test participants' beliefs. People may have a fundamental understanding of physics yet, paper-and-pencil problems may fail to activate this knowledge (McCloskey & Kohl 1983; Kaiser, McCloskey, & Proffitt, 1986). Other studies have examined different ways of testing these beliefs, and shown differing stimulus presentation and response methodologies can yield different results.

One such method is having participants look at computer screens showing animations or simulations of the tasks in the original experiment. McCloskey and Kohl (1983) had college students watch a computer simulation of a ball being twirled on a string as well as a ball rolling through a tube. In both experiments the participants were asked to watch six possible trajectories of the ball and then chose the correct one. In the simulation involving the twirling ball and spiral tube, one third of participants chose responses that indicated a naive understanding of physics. This experiment confirms that this bias occurs not only present in paper and pencil tasks, but also in tasks where subjects are shown actual movements of the ball through simulation. These results support that many people assume a CI model at the foundation of their physics knowledge, even when observing actual motion. McCloskey's interpretation is that perhaps people simply have a poor sense of spatial reasoning with regard to general physics knowledge of object motion. If so, it is possible people might perform better when physically interacting with moving objects.

To test this, McCloskey and Kohl (1983) had participants manipulate a puck and were given the task to move it across a circular table without allowing the object to touch the sides. The puck had ink on the bottom to allow recording of its trajectory as the participant directed it sliding across the table. On this task, one third of participants selected a curved path. These results are very similar to both the paper-and-pencil tasks and the computer simulation tasks.

The above experiments demonstrated that participants with varying levels of education in physics, systematically make mistakes on tasks that test understanding of a simple Newtonian inertial principle. The work supports that the reason for this mistake is that a robust CI bias that is difficult to train away (McCloskey 1980). In contrast, others argue that the source of the bias is ecologically based on natural and ubiquitous motion patterns in everyday life. For example, Freyd and Jones (1994) provide evidence supporting that the bias is consistent with natural patterns of curved motion to which our perceptual system may be attuned.

Freyd and Jones (1994) used a computer simulation of the spiral tube task and replicated the paper and pencil task from McCloskey (1980). However, their task for the participants was very different. The participant started the simulation with their foot using a pedal. Once the pedal was pushed pictures of a ball at different positions inside the spiral tube were presented to simulate the ball moving. The last picture was of either the ball exiting in a spiral path, a straight path or a constantly curved path. There were blocks of each of these exits presented to each of the participants with order randomized. The participant was then asked to remember the last position of the ball. Then they were shown a test simulation presented in the same manner and asked to respond whether it was the same or different as the original presentation. The results showed significant shifts in participant memory. The smallest memory shift was for the straight path followed by the curved and then spiral paths. The authors explained this as support for people having a natural perceptual tendency to continue the curvature of the ball trajectory (Freyd and Jones, 1994; Hubbard, 1996).

Like Freyd and Jones (1994), we posit that the CI bias is based on ubiquitous natural tendencies. However, we focus on a potential source of bias that is previously underexplored in reference to the CI: biological movement. Previous research has shown that humans have a tendency to curve when walking (Bestaven, Guillaud & Cazalets, 2012; Schafffer, 1928; Souman, Frissen, Sreenivasa & Ernst, 2009; Takei, Grasso, Amorim & Berthoz, 1997; Boyadjian, Marin & Danion, 1999) Support for a curvilinear impetus bias is based upon three pieces of preliminary research by the author.

The first is a study that posited that people were indicating the CI based upon their own experiences, or human motion (Dye, McBeath, Holloway, Miller, & Tyler, 2013). A chalk spiral was drawn upon the concrete between the psychology buildings at Arizona State University. Each participant was asked to run through the spiral as fast as they could and cross an equidistant curved finish line that was eight feet away from the exit. Every three feet a cone was placed on the finish line to indicate zone areas. There were 8 zone areas in all. We found that on average, people significantly curved upon exiting the spiral, giving some evidence for our hypothesis that animate human motion does typically continue to curve. The second study was a scaled down version of the first study with 2-5 year old children running out of a spiral maze (Dye, McBeath, Holloway, Miller, & Tyler, 2013). The rationale for this study was to confirm or deny that the curving bias was biological in nature, and generalized across a wide range of ages to very young children. As with the first experiment, we also found that the children significantly curved upon exiting the spiral, see Figure 1.

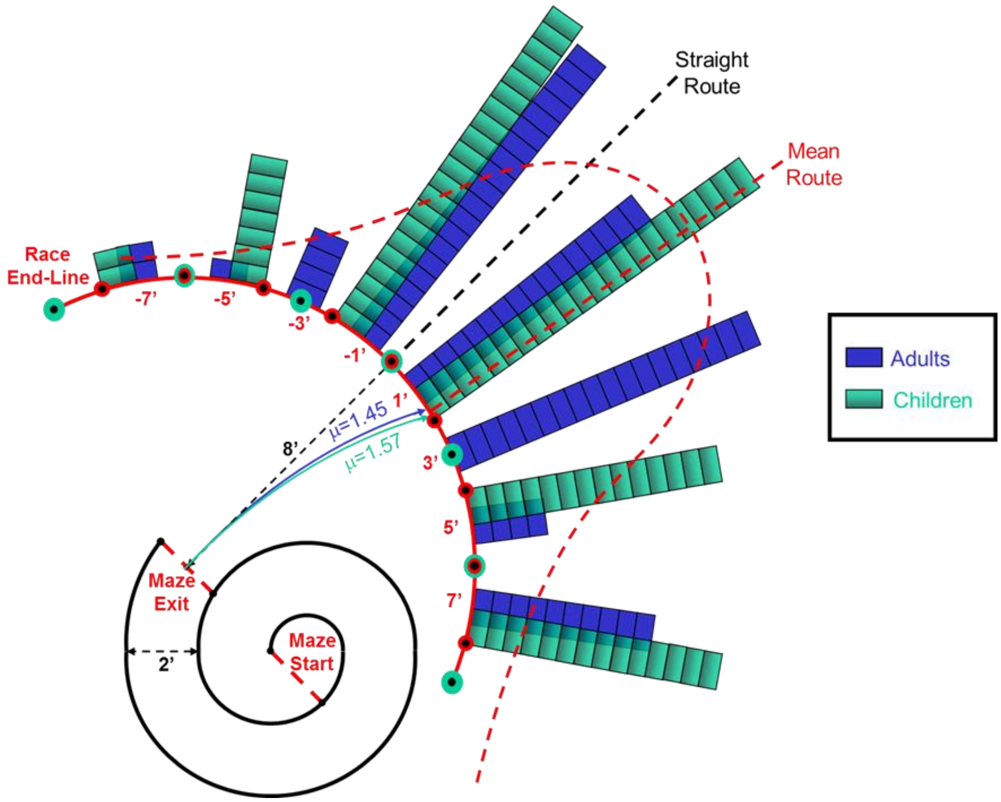

Figure 1. A graph summarizing the findings of the preliminary research of Dye et al.

The third preliminary study was designed to look at the conceptual framework of the CI bias (Dye, McBeath, Holloway, Miller, & Tyler, 2013). As with McCloskey's (1980) experiment, we asked participants about how a metal ball behaves when exiting a spiral tube. Our study replicated McCloskey's (1980) findings. However, we included an additional question asking how a humans behave when exiting a spiral drawn in chalk. The participants revealed the same degree of CI bias for both humans and balls, regardless of what order they were asked, humans then balls, or balls then humans. This led us to conclude that people appear to be using a general heuristic for solving these kinds of problems, with a large percentage exhibiting a presumption of their own animate motion as representative for all object motion.

Beyond McCloskey

Since McCloskey and colleagues published their work about the CI bias, many have added to this research with both new theoretical explanations and new ways of correcting the bias.

Some research has focused upon improving the way that the CI bias is corrected via education. One study developed a new interactive computer simulation that was preferred by participants over traditional lecture instruction (Zhou, Han, Pelz, Wang, Peng, Xiao & Bao, 2011). Another tested a video game as an education tool and found it was better at correcting a bias in middle school aged children (Masson, Bub & Lalonde, 2011).

One important improvement to teaching naive physics and the CI bias has been to have physics teachers teach students to model the problem they are trying to solve using scientific models (Hestenes, 1987; Wells, Hestenes & Swackhamer, 1995). This came about by first understanding that students were using a more "common-sense" way of solving the problems (Halloun & Hestenes, 1985; Halloun & Hestenes, 1985). By having the students mentally go through the process of constructing a model, using scientific models, significantly improves their understanding and performance on knowledge tests (Hestenes, 1987; Wells, Hestenes & Swackhamer, 1995). This way of teaching is so effective and popular that there are training programs and even a degree offered by Arizona State University that incorporates this method (Hestenes, Megowan-Romanowicz, Popp, Jackson & Culbertson, 2011). However, this method is not so effective that it eliminates naive physics and the CI bias entirely. More research needs to be done into other methods and explanations for the CI bias.

Other research is interested in explaining the source of the CI bias in new ways. One such theory is that the CI bias is due to linguistic issues as well as ontological issues (Brookes & Etkina, 2009). The authors argue that the reason the CI bias exists is because of a difference in the meaning of "force" in the scientific term. The authors review throughout history the change in the meaning of the word "force" to illustrate the confusion that could cause the CI bias. The authors then relate these findings to the current literature about curvilinear motion. While this theory is fascinating, it has not yet been tested empirically so it remains speculative.

In another paper, White (2012) posits that the CI bias is based upon how humans interact with objects. In this paper, White states that people use a heuristic to solve the CI problem, a heuristic based upon human perception of causality. Humans have a lot of experience with manipulating objects, causing the objects to do what they wish. After observing and participating in many such interactions characteristics of outcomes are transferred into a general heuristic of objects being manipulated. White refers to this as a property transmission heuristic, and asserts that it is this type of heuristic and not impetus theory that is responsible for the CI bias. While this paper is groundbreaking in that it combines the use of a heuristic with natural regularities, it does not empirically test this theory against other alternative explanations of the CI bias.

As an empirical test of heuristics driving CI bias, two experiments were designed in the present study. First, an experiment testing if rats exhibit CI, and second, an experiment testing if physics experts ignore CI in biological agents. The rat study was designed to establish generalizability to motion patterns of other biological agents. This provides a test of the hypothesis that the CI bias is based upon internalization of a generic natural regularity of animate biological motion, consistent with previously documented cases of animals maintaining a tendency to curve (Guldberg, 1897; Schaeffer, 1928; Marczinski, Perrot-Sinal, Kavaliers & Ossenkopp, 1998).

Rat Biological Motion

Rat mazes have been used over the last hundred years to do many types of research (Small, 1901; Hicks & Carr, 1912; Hicks, 1911; Proffenberger, 1916; Camp, Gerson, Tsang, Villa, Acosta, Blair Braden, Hoffman and Bimonte-Nelson, 2012; Morris, 1984; Graeff, Ferreira Netto, & Zangrossi, 1998; Hodges, 1996). Such mazes create situations that require rats to use specific skills that the researcher is interested in testing. One of the main areas of focus in rodent research is comparative studies: using rats as stand-ins for research that researchers cannot do on humans. A subset of these studies are comparative studies, in which researchers use parallel populations of both rodents and humans to understand the similarities and differences between these groups (Lathan and Fields, 1936; Husband, 1921; Palarea, Gonzalez & Rodriguez, 1987). These research studies show that people are interested in how both rats and humans navigate through mazes, however, the main goals for these navigations was not to study the navigation itself, but to use the navigation as a secondary measure for other more abstract constructs (Camp, Grunfeld, Engler-Chiurazzi, Acosta, Mennenga, Braden, Tsang, Kingston, Hewitt, Brewer, Baxter, McBeath and Bimonte-Nelson, 2011; Barnes, 1979).

Lathan and Fields (1936) set up an experiment that in some key ways, is similar to the ideas to be tested in the present paper. They built two mazes, one for humans and one for rats that were proportionally the same given the different sizes of the participants. Everything was similar, except for motivational factors (the rats were motivated with food) and the humans were blindfolded. Both rats and humans (on hands and knees) went through a series of T-maze junctions and their learning time and error rates were recorded. The researchers found that the rats learned much quicker than humans, but that they also forgot much faster than humans. Interestingly, the researchers found that humans had a rightward turning bias, but that the rats did not. These findings may be due to the human participants wearing blindfolds, for which the authors gave no reasoning behind.

There are also a few navigation biases that rats exhibit. Rats have a right turning bias when going through T-mazes (Palarea, Gonzalez & Rodriguez, 1987; Glick & Ross, 1981). All rats when navigating typically exhibit a phenomena called thigmotaxis (Treit & Fundytus, 1988; Hoh & Cain, 1997). This navigation bias is the tendency, when the rat is stressed, to navigate right next to walls of the maze they are in. One way to alleviate this is to have the rats become more familiar with the maze they are going to go through (Hoh & Cain, 1997). Having established that humans exhibit CI, and that other animals exhibit curving tendencies, do rats and other biological agents exhibit CI like humans do?

Experiment 1

In Experiment 1 we investigated the motion of other biological agents going through a spiral, specifically rodents. Hypothesis1: We predict that rats behave like humans when exiting spiral mazes and continue to curve consistent with CI, (i.e. $\mu_{curvature} < 0$). Hypothesis 2: We also predict that the fastest paths are ones that continuing to curve consistent with CI, (i.e. when plotting time as a function of route curvature, the minimum of the best quadratic fit of route curvature < 0).

Method

Subjects.

Ten albino male Sprague Dawleys rats were used in the study. The average weight of the rats was three hundred seventy three grams with a standard deviation of thirty grams. All of the rats were born on January 19th, 2013. On the first day of testing the rats were six months and five days old. All ethical requirements were followed before, during and after the experiment. This protocol was approved via the Arizona State University IACUC.

Apparatus.

We built a custom rat maze and habituation maze constructed using the same proportional dimensions of the human mazes of Dye, McBeath, Holloway, Miller, & Tyler (2013) previous work. The top and bottom were constructed out of plexiglass, 3/8th inch thick. The walls of the maze were constructed out of 3/8th inch thick plexiglass, and were held in place using gorilla glue. The top and bottom sheets of glass each had an opening to be able to put the rats in the starting point at the center of the maze. This was designed to enable the rats to be run both clockwise and counterclockwise on different trials without constructing two mazes. The end of the spiral has an equidistant curving wall that was broken up into four small aluminum chambers. The habituation maze was made of the same materials above, but was made to fit the area between the spiral maze exit line on the blueprint and the two adjacent destination boxes. The completed blueprint can be seen below in Figure 2. The completed habituation maze for training purposes can be seen below in Figure 3. The complete constructed maze can be seen below in Figure 4. The spiral portion of the maze was designed with 4 inch wide pathway that twisted around 540°, and the end line had 4 destination boxes each equidistantly 16 inches from the spiral end line. The walls on both sides at the end line were symmetrically shaped to minimize the effects of rats favoring thigmotaxis, the tendency for them to remain along walls.

The maze was modified during data collection due to some unforeseen difficulties. The tool that was used to cut the aluminum boxes failed during the cutting of the last box, rendering it unusable. To adjust for this, the number of boxes was reduced to four to make the maze have an even number of exit locations. Also, due to rat safety and the maze partially breaking, we were unable to flip the maze over to do a counterclockwise spiral. All results of the maze are therefore for a clockwise spiral maze.

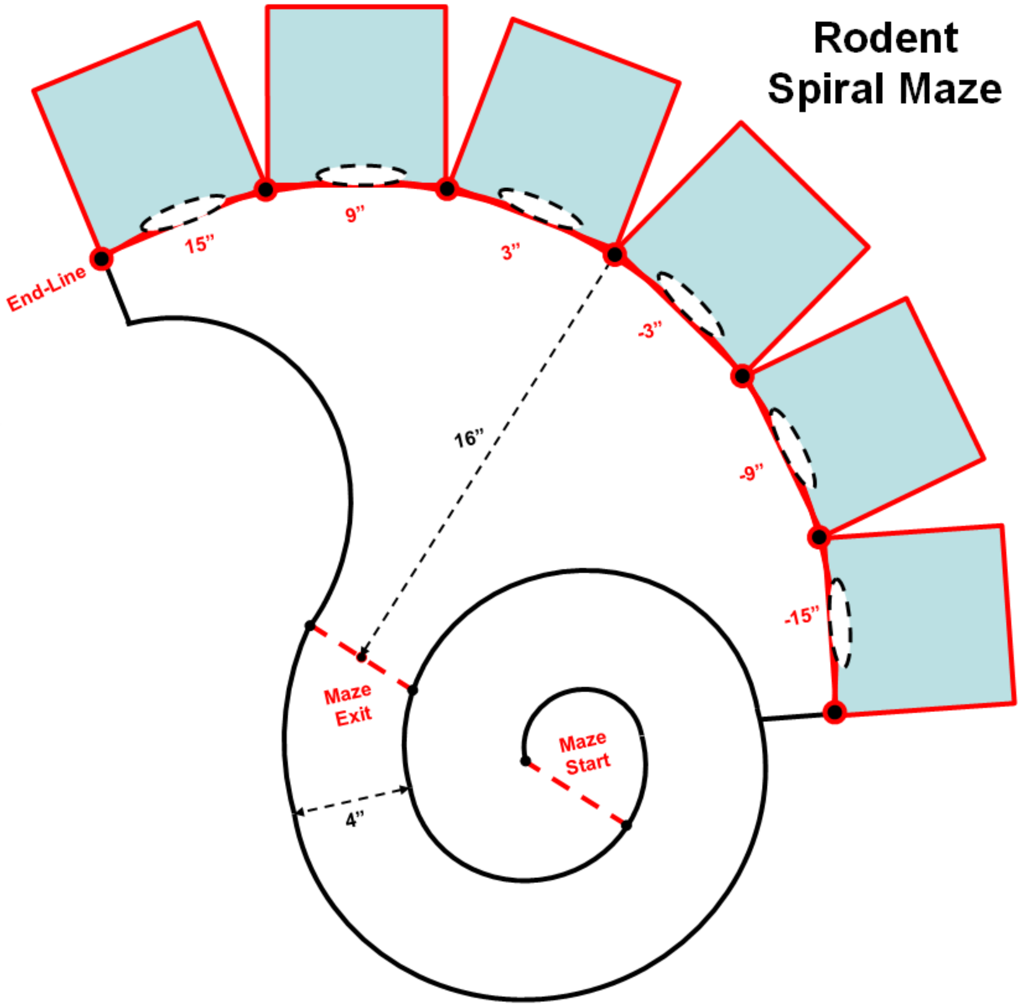

Figure 2. The blueprint for the spiral rat maze. Each of the blue boxes at the edge of the semicircle consists of aluminum. The 16 inch long dashed line from the exit point represents the equidistant radius used to make the outside semicircle.

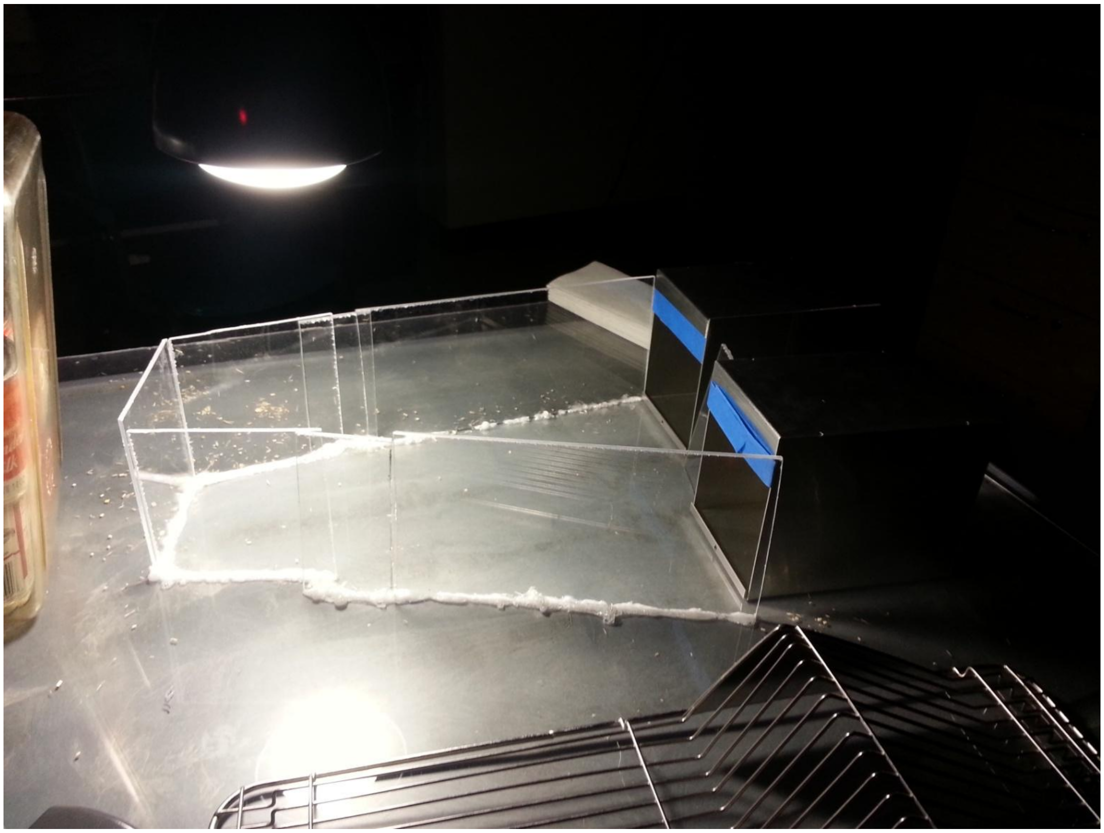

Figure 3. The habituation maze.

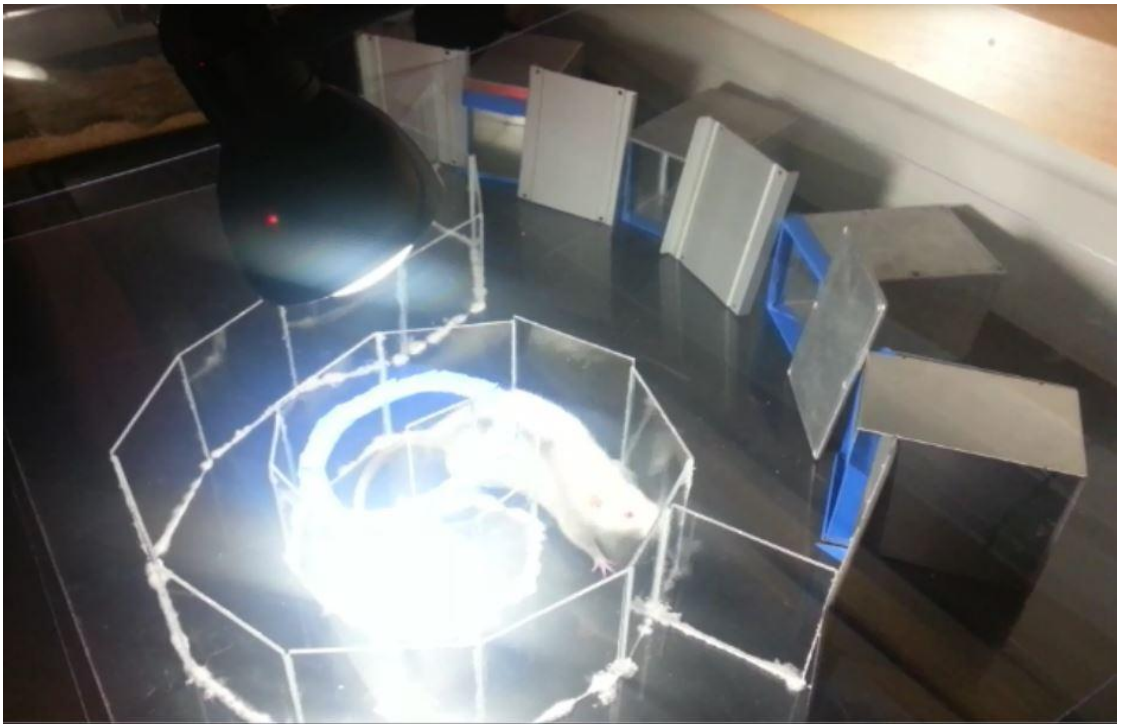

Figure 4. A picture of the built rat maze.

Procedure.

Each rat first had 10 trials over the course of two days in a straight mini maze, referred to as the habituation maze, made of the same materials to familiarize them with the way these mazes function. These trials consisted of putting the rats at the beginning of the maze and letting them go to a box. After they stuck their nose into a box, the rat was taken out and the maze was sanitized using a seventy percent isopropyl alcohol solution. This trial period was additionally used to test if there were any lateral biases, of which we predicted none, (i.e. left vs right $\chi^2 = 0$). A day after this familiarization trial period, each rat ran ten trials through the spiral maze. Unfortunately the spiral maze was not able to be flipped over as designed due to cracking of the plexiglass and the safety of the rats. Bright light avoidance was used as the motivating factor to try to induce the rats to rapidly run through and out of the maze. The chamber the rat went to was recorded as the dependent variable. After each trial, the maze was sanitized with a seventy percent isopropyl alcohol solution to eliminate potential odor cues on later trials.

Results

Data were recorded for the second day of habituation training only, due to a malfunction of the recording equipment on the first day. Overall, 15 of the rat trials went left and 29 went right. A chi-squared test was run to determine if the rats had any lateral biases. There was a significant bias to the right, $\chi^2(1) = 4.455$, $p=.035$. Below in Figure 5 is a graph of the proportion of rats that went right and left.

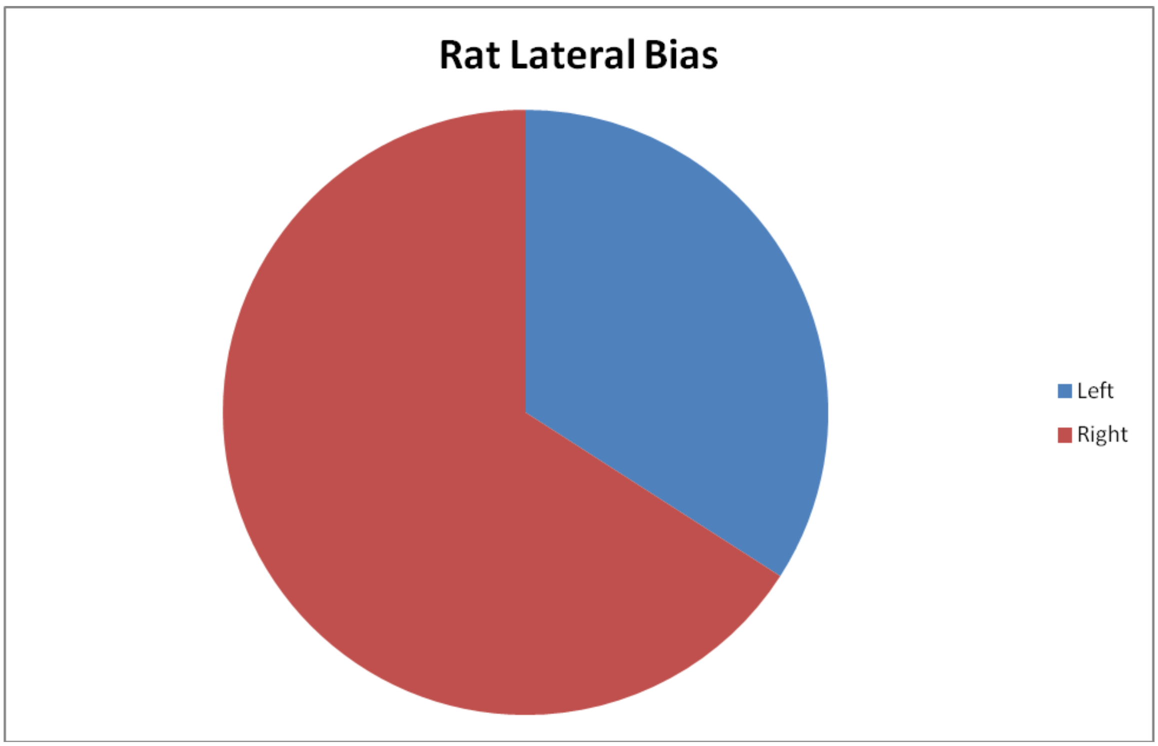

Figure 5. The proportion of rats that went to the right and left.

In order to analyze the curvature data, a coding system was used. In this coding system, the box that was at the far right was coded as -1.5. The next box, the one to the near right, was coded as a -.5. The next box, the one to the near left was coded as .5, followed by the box to the far left coded as 1.5. The boxes were coded as such to calculate the average deviation from a straight path at 0. A valid trial was a trial in which a rat made it to a box and stuck its nose into the box. An invalid trial was considered a trial in which the rat did not pass the maze exit line within a minute, or a trial in which the rat tried to escape by going through the entry hole, or in which the rat chewed on a part of the maze for longer than five seconds. The trials that were terminated due to chewing were stopped in order to keep the rats from accidentally ingesting pieces of glue or other maze materials that could be harmful. 60 of the trials were valid and 40 were invalid. The rats generally were not motivated to move through the maze quickly as humans did. Below, in Figure 6 is a picture of this coding applied to the blueprint.

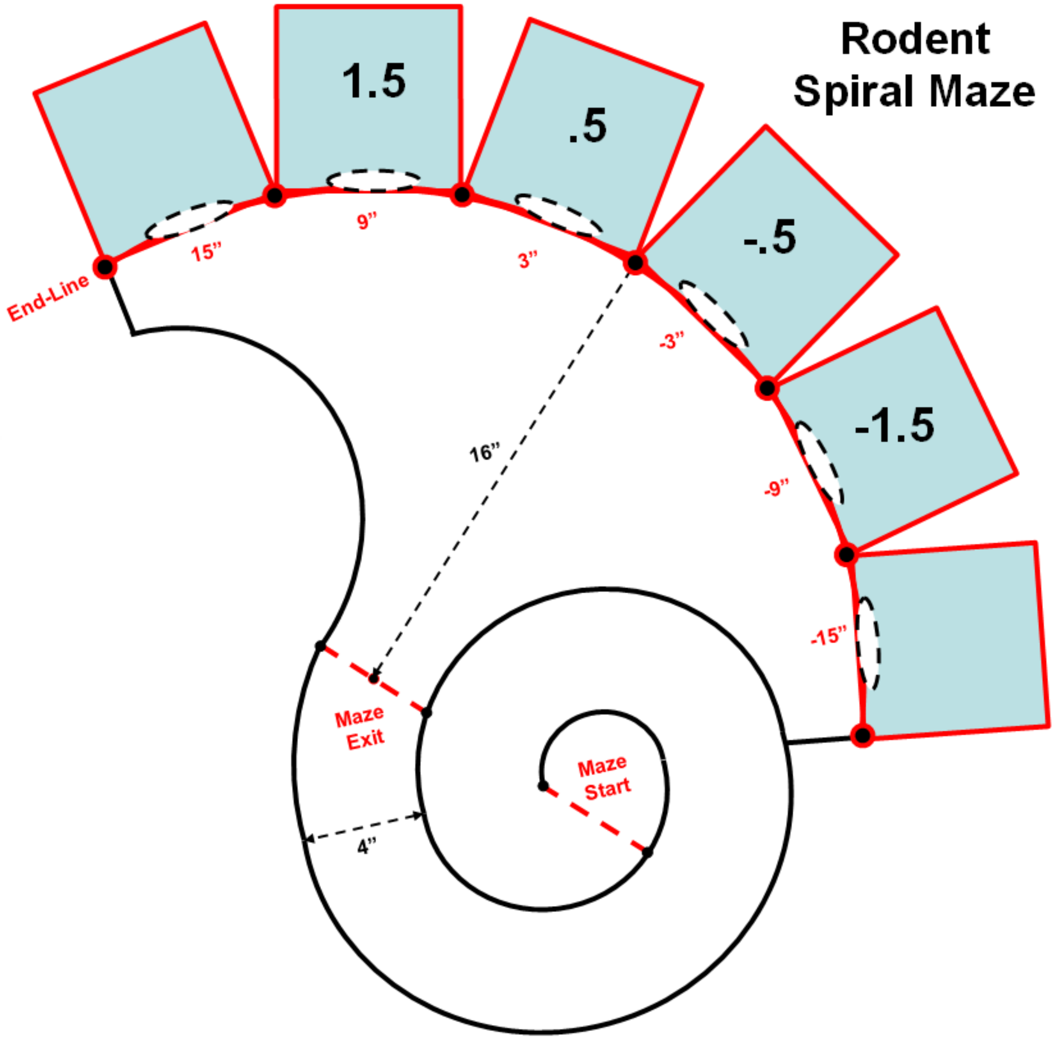

Figure 6: The spiral rat maze blueprint with coding in large black numbers.

When analyzed as individuals, nine of the ten rats exhibited an average deviation curving leftward, a significant bias as indicated by a sign test that opposes the direction of CI, z=2.215, p=.027. A single sample t-test treating every trial as an independent also indicated that overall rats curved to the left, t(59)= 3.082, p=.003. Because these results are the opposite of predicted, the findings disconfirm hypothesis 1 rats will continue to curve consistent with the CI bias. Below in Figure 7 is a graph of the rats exiting trajectories and in Table 1 is the raw data with coded exit boxes. Periods were used for invalid trials.

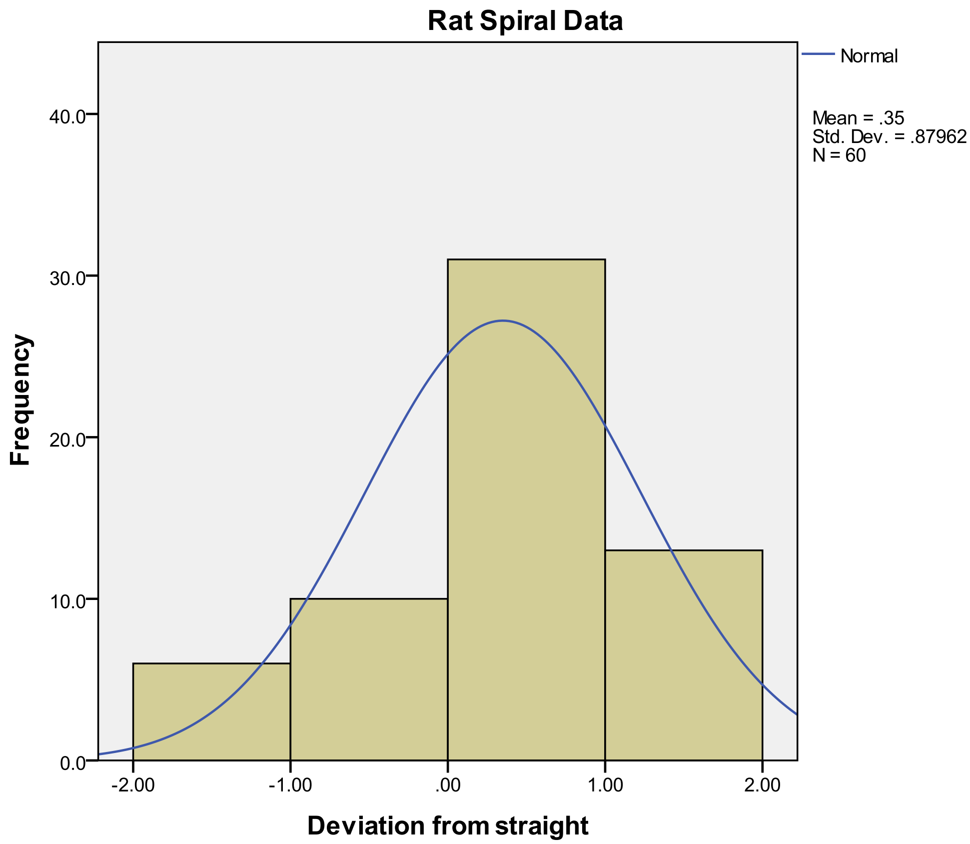

Figure 7. Rat exiting trajectories.

Table 1

Raw Data of Rat Spiral Maze Coded (Rat number by Trial number)

Rat #	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
1	0.5	0.5	1.5	1.5	-1.5	-0.5	0.5	-1.5	-0.5	.
2	1.5	.	.	.	1.5	0.5	.	1.5	0.5	.
3	-0.5	.	-0.5	-0.5	0.5	0.5	0.5	0.5	0.5	-1.5
4	.	.	.	-0.5	0.5	0.5	.	.	.	.
5	.	.	.	.	0.5	-1.5	.	.	.	.
6	0.5	0.5	0.5	0.5	.	.	0.5	.	.	.
7	.	0.5	.	0.5	.	0.5	.	.	.	.
8	.	.	-0.5	1.5	-1.5	-0.5	-0.5	0.5	.	1.5
9	0.5	0.5	0.5	1.5	.	1.5	0.5	0.5	1.5	0.5
10	0.5	0.5	1.5	1.5	.	1.5	0.5	-0.5	1.5	.

Additionally, to test hypothesis 2, time for each valid trial was observed through watching the individual videos of each trial. A time curvature plot was made and the best quadratic fit revealed a time minimum at 0.048 (equivalent to a mere 0.29 inches from dead center), very nearly equal to no curvature. This also disconfirmed hypothesis 2 that there would be a speed advantage for paths that continued to curve. Below in figure 8 is a graph of this relationship.

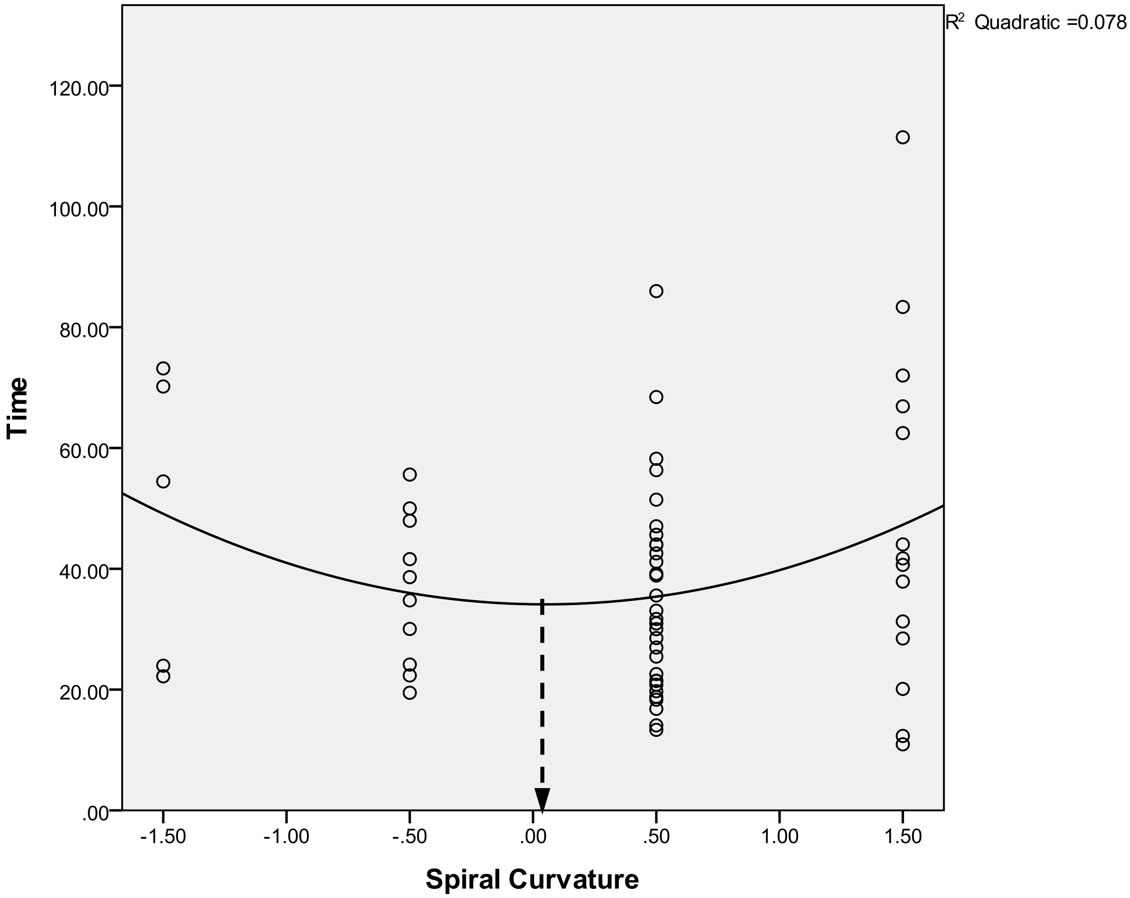

Figure 8. A graph of the relationship between time and spiral curvature for the rats that were subjects.

Discussion

The results are not consistent with rats behaving the same as humans. There are many possible reasons for difference, both: ones external to the research and ones internal to the research.

There were several internal issues with this study that call into question the reliability of the results. The habituation maze bias supports that there was something about the maze itself, the rats, or the handling of the rats that led to a bias that has not been supported by previous research examining lateral bias going through the maze, which is consistent with some literature and inconsistent with others (Lathan and Fields, 1936; Vallortigara & Rogers, 2005). Another issue was that only sixty of the one hundred trials were valid. It appears that the light that was designed to motivate the rats to move quickly through the maze, did not motivate them. A majority of rats took over thirty seconds to exit the spiral. In previous research it was established that a curving path produced the fastest exit route from the maze for humans. Therefore, the lack of a procedure that induced speed for the rats may have nullified the producing a bias of curving. In future research it is likely a more promising motivator would be to use food deprivation along with light to more strongly induce the rats to run. The biomechanics of the rat may also be a source of the difference between rat and human motion. Humans are bipedal and thus tilt when running through a spiral. Rats on the other hand, are quadrupedal and have a low center of gravity, thus perhaps limiting them from tilting much. The rats' low center of gravity could also be the factor preventing them from continuing to curve. More research is needed to determine if the design of the current study is preventing curving motion or if rats truly do not continue to curve when exiting a spiral with speed. Given the current limitations of this study, and the current data, it is parsimonious to simply conclude that rats, at least in the spiral that was used, do not behave as humans do when exiting spirals. These results suggest that people are basing the CI bias upon patterns of human motion, thus meaning that people are at minimum, anthropomorphizing the ball from human behavior when solving curvilinear motion physics problems. However, it cannot yet be concluded that human motion is the sole motion being thought of, as there are many different species of animals, including different variations of the rat species that might be more promising to test.

In previous research we showed that people conceptualize a ball and human motion similarly. Based on our survey findings, participants may generally have had more experience with animate regularities of biological motion laws, than with the inanimate Newtonian laws of physics. However, those with more physics education were much less likely to conceptualize the ball consistently with the CI bias. This observation lead to the hypothesis that those people with more physics expertise may have learned to base their notions of object movement more on inanimate Newtonian laws of motion such as linear inertia. Specifically, the following study investigates physics teachers' conceptualizations of biological and physical object motion to test if they exhibit a bias reverse that of typical students. We hypothesize that they will instead exhibiting a tendency to assume that animate motion out of a spiral will be straight.

Experiment 2

In the second experiment, physics experts were presented the same spiral maze questions with both balls and humans to uncover if they exhibit an opposite bias that assumes that people will produce a straight path. This experiment also tested if there is a tendency for physics experts to simplify their notion of animate and inanimate motion into a single solution. However, in this case is biased toward the straight path representative of inanimate motion as typically modeled in Newtonian physics.

Hypothesis 3: We predict that teachers will exhibit no difference in their estimation of amount of curvature for objects exiting clockwise (right curving) versus counterclockwise (left curving) spiral mazes, $\mu_{left} = \mu_{right}$. Hypothesis 4: We predict that the mean estimated exit curvature of the ball versus the person not be significantly different from each other, $\mu_{person} = \mu_{ball}$. Hypothesis 5: We predict that the mean estimated exit curvature for both ball and person is straight, not exhibiting CI, μ_{person} and $\mu_{ball} = 0$.

Method

Participants.

Participants consist of two hundred seventy one physics teachers from various areas of the United States. The ages of participants ranged from twenty four years of age to eighty years of age, with a standard deviation of about twelve years. The participants consisted of one hundred forty nine males, one hundred two females and twenty participants chose not to respond about their sex. The participants reported that twenty eight were left-handed, two hundred fourteen they were right-handed, nine reported they were ambidextrous and twenty chose not to respond. The teachers reported that they had been teaching for a range of one to forty five years, with an average of about sixteen years and a ten year standard deviation. Participants also reported that they on average had 2.5 children. Participants indicated their consent to participate via completing the survey.

Procedure.

An email was sent to two national listservs of physics teachers. A brief explanation of the study was accompanied by the link to the survey on Qualtrics. The survey consisted of the four questions asking about human and object motion, one question per direction of spiral, after emerging from a spiral maze, along with several other naive physics questions to distract the participants from perseverating on any connection between these two questions. The midpoint of the exit line is tangent to the midpoint between the areas labeled 5 and 3 for the right spiral and between D and E on the left spiral. There may have been distortion of this figure due to formatting on different monitors used by the participants that could not be avoided due to the distribution method of the survey. The findings with the distracter questions are reported elsewhere. The order of the questions was counterbalanced with the other questions randomized. The questions of interest can be found in below in figures 9-12.

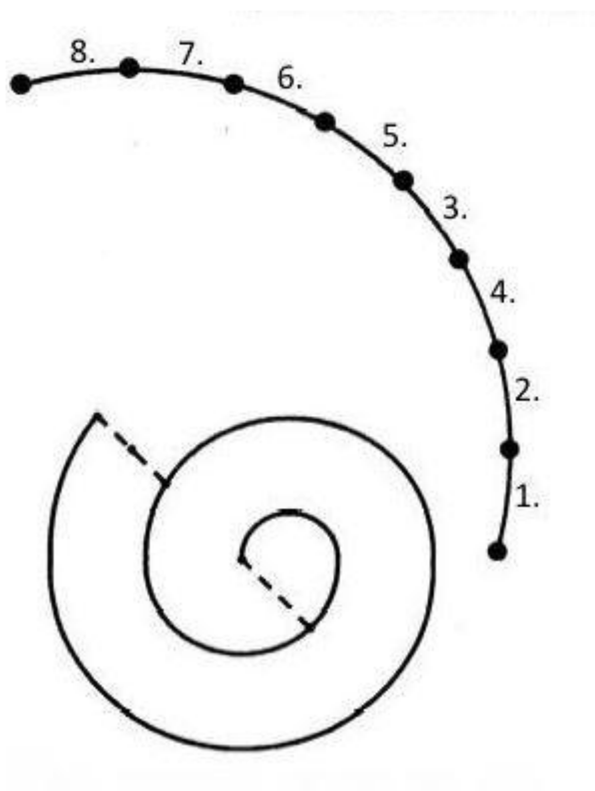

Figure 9. A picture of the rightward person spiral with the following instructions: Pictured here is a spiral drawn in chalk on the cement. In the diagram you are looking down on the chalk spiral. A person is standing at the center of the spiral. The person

begins running through the spiral as fast as they can. Your task is to indicate the path the person will follow after they come out of the chalk spiral.

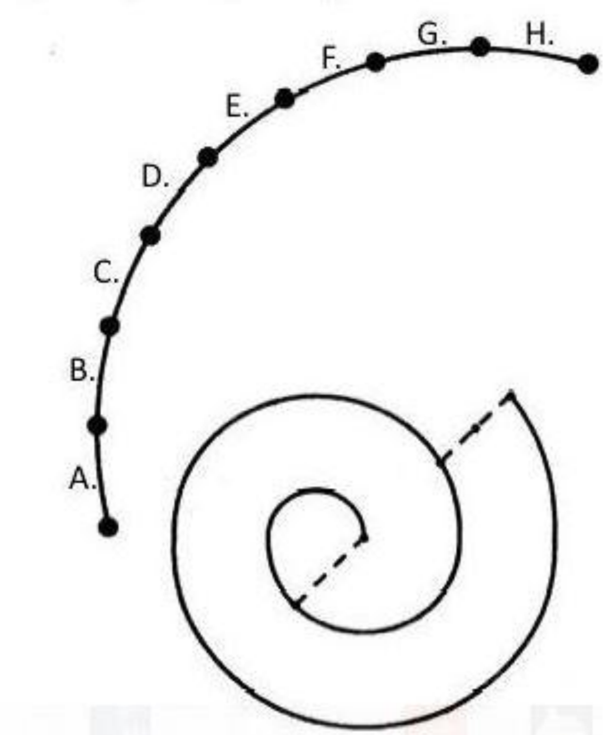

Figure 10. A picture of the left person spiral with instructions: Pictured here is a spiral drawn in chalk on the cement. In the diagram you are looking down on the chalk spiral. A person is standing at the center of the spiral. The person begins running through the spiral as fast as they can. Your task is to indicate the path the person will follow after they come out of the chalk spiral.

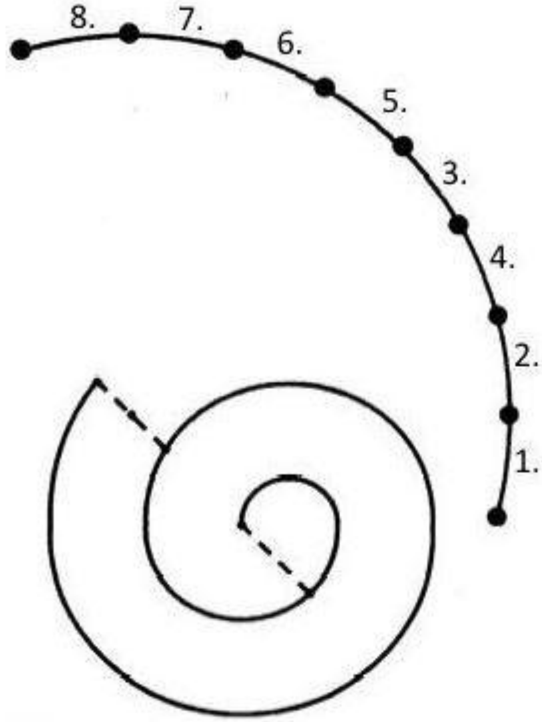

Figure 11. A picture of the right ball spiral with instructions: Pictured here is a curved metal tube. In the diagram you are looking down on the tube. A metal ball is put in the center of the spiral. The ball is then shot out of the center of the tube at high speed. Your task is to select the correct path that the ball will follow once it leaves the metal tube. Please ignore air resistance.

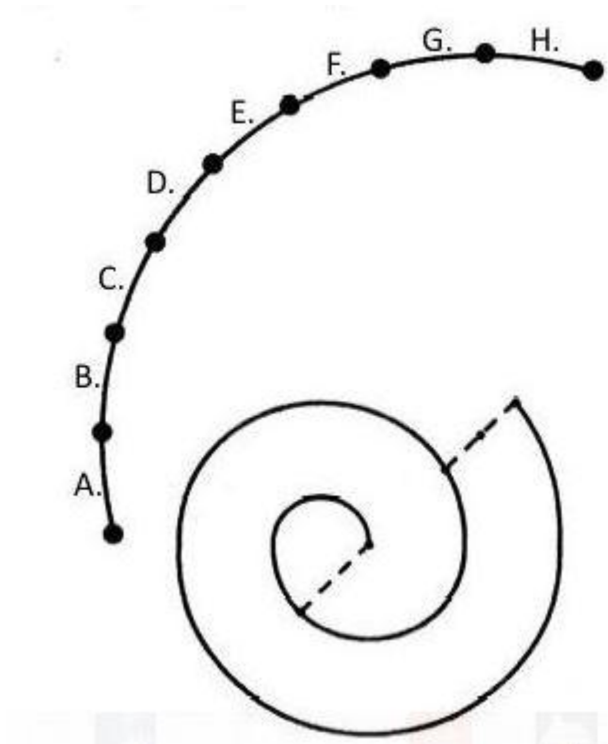

Figure 12. A picture of the left ball spiral question with instructions: Pictured here is a curved metal tube. In the diagram you are looking down on the tube. A metal ball is put in the center of the spiral. The ball is then shot out of the center of the tube at high speed. Your task is to select the correct path that the ball will follow once it leaves the metal tube. Please ignore air resistance.

Results

The exit trajectories were coded in a similar fashion as the rat trajectories. The difference between the two was that there were twice as many exit trajectories available for the experts to answer. This resulted in larger numbers, but overall comparable proportions. Below in Figure 13 is a picture of the coding schema.

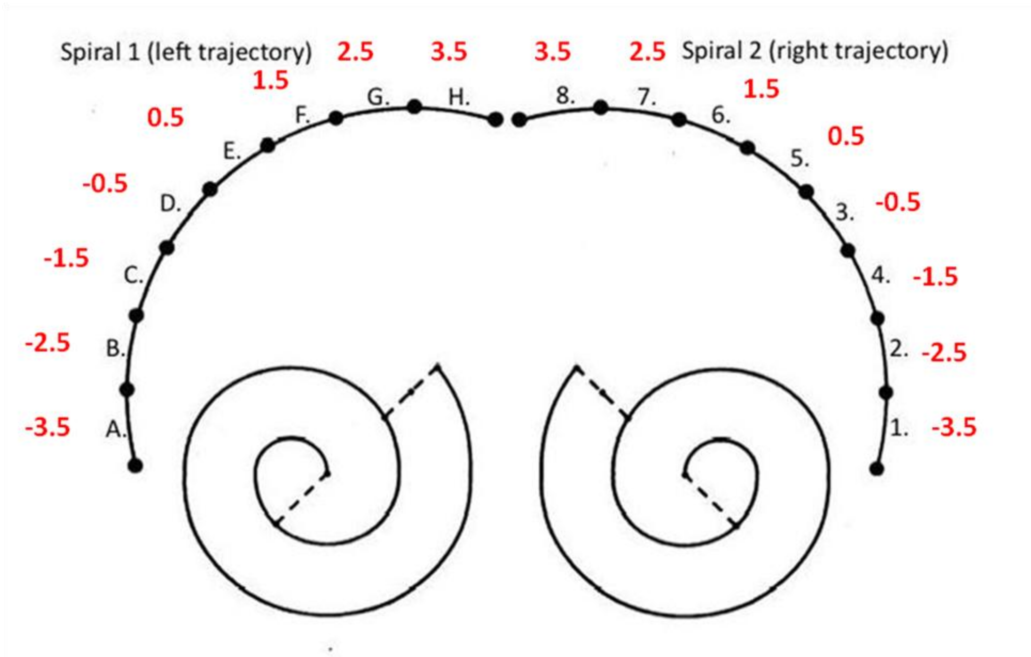

Figure 13. The coding schema for both left and right spirals. In the survey teachers saw one direction of the spiral at a time.

There was no difference between the right ball and left ball answers using a repeated measures ANOVA, $\mu_{differnce}$ = 0.0327, F(1,215) = .427, p=.514, NS, Cohen's d = 0.051. There also was no difference between the right person and left person using a repeated measures ANOVA, $\mu_{differnce}$ = 0.0369, F(1, 214) = .373, p=.542, NS, Cohen's d = 0.035. This confirmed hypothesis 3, and therefore the rest of the results take a collapsed average of the answers for the right and left version of the ball and person mazes. The experts demonstrated a significant curvature opposite that of the CI bias for the ball using a single sample t-test, $\mu_{curvature}$ = 0.6088, t(215)= 10.415, p<.001, Cohen's d= 1.42. A single sample t-test was run for the answers pertaining to the person running through the spiral. Here too, the experts demonstrated a significant curvature opposite of the CI bias, $\mu_{curvature}$=0.246, t(214)= 3.345, p=.001, Cohen's d = .457. To adjust for the fact that the teachers could not answer straight, we also ran the above analyses coding both the .5 box and -.5 box as 0 for straight. A single sample t-test was run for the ball, $\mu_{curvature}$ = 0.33, that showed the average ball answer still curved opposite the CI bias, t(215) = 5.494, p< .001, Cohen's d = .749. A single sample t-test was run for the person, $\mu_{curvature}$ = 0.07 that showed that the average person answer went straight, t(214) = 1.105, p=.270, Cohen's d = 0.151. A repeated measures ANOVA using the .5 and -.5 as 0 coding was run to determine if experts thought of balls and people differently, $\mu_{difference}$ = 0.26 which showed they conceptualize them differently, F(1, 209)= 15.600, p< .001, Cohen's d = 0.252. Below are figures 10 and 11 showing the trajectory answers from the experts. Statistically, the data disconfirm Hypotheses 4 and 5, and indicate that physics experts do not classify balls and people as curving the same amount, but in absolute terms, both are inconsistent with CI bias, with both exhibiting means that are very close to zero curvature, with a general tendency to compensate away from CI bias.

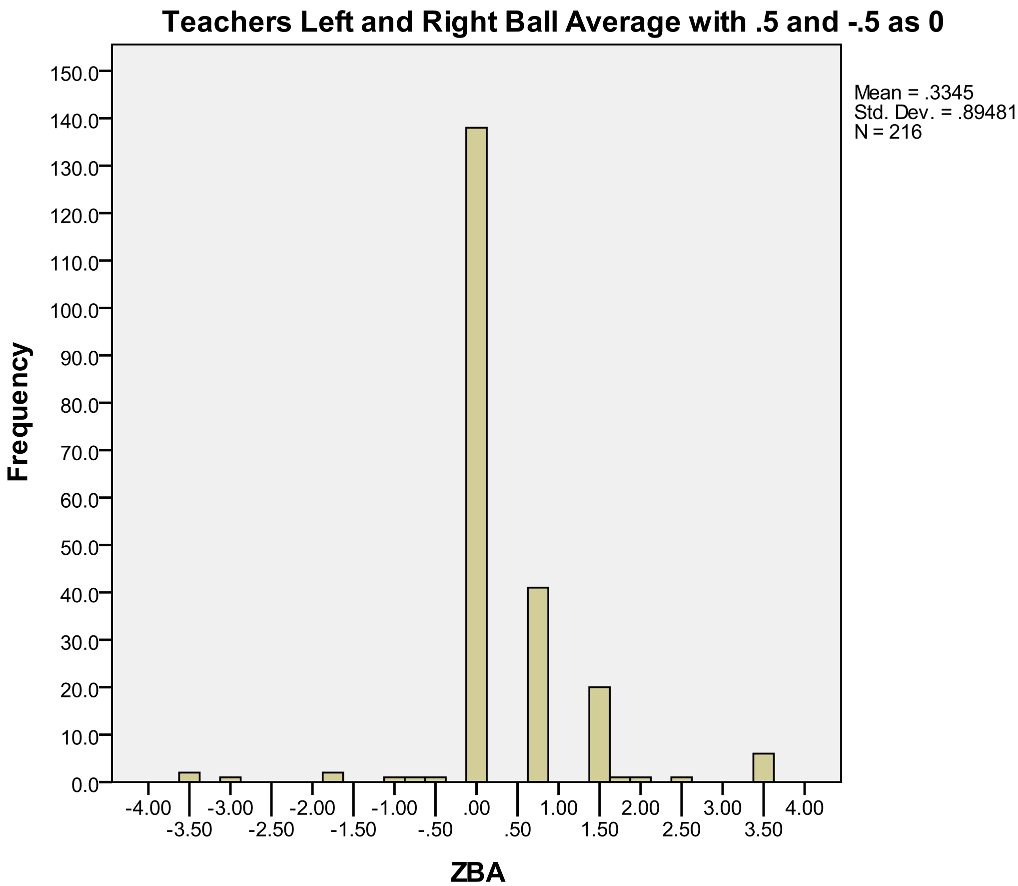

Figure 14. The average trajectories answered for a metal ball by teaching experts in physics.

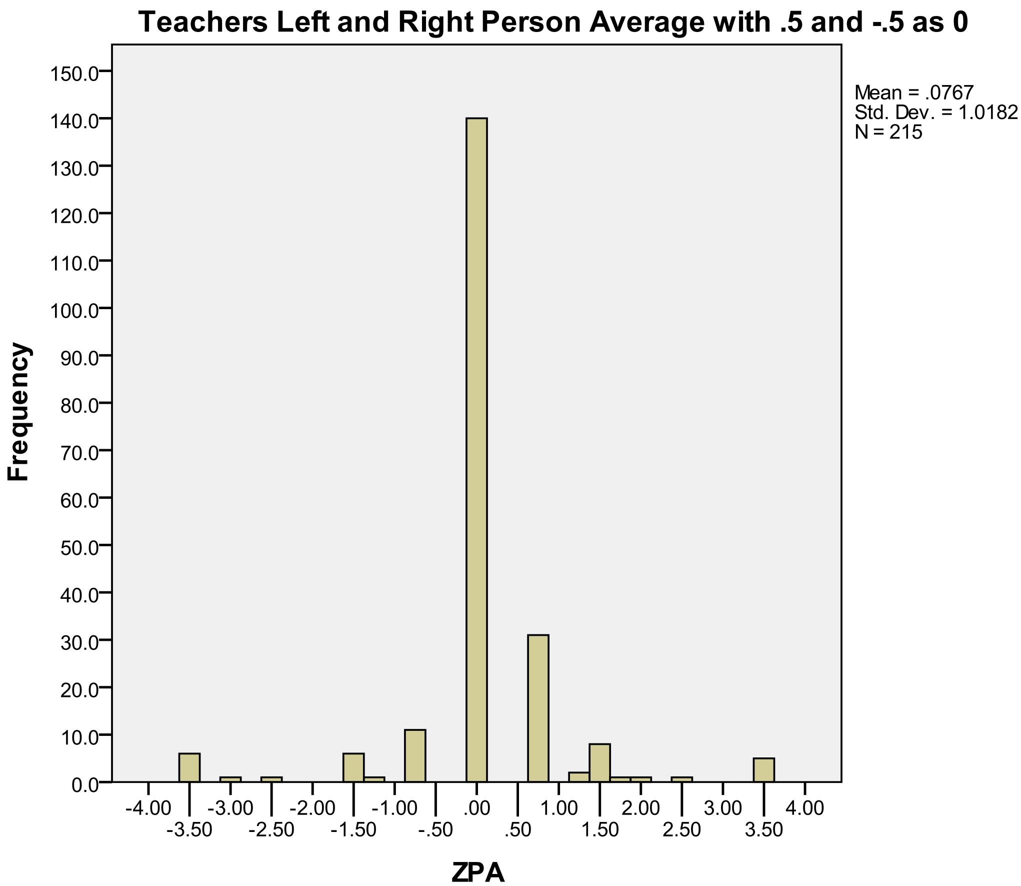

Figure 15. The average trajectories answered by experts for people running through spirals.

Discussion

The results for the experts appear consistent with the notion that physics generally support that experts think that both balls and people go straight. Since we did not allow for the experts to chose the straight path, they appear to have chosen the next closest approximation, which would have been to pick the trajectory in the .5 box or the -.5 box. For both the ball and person, well over half indicated this answer. Though it may look like there was a difference in variability, there is no significant difference between the variances in ball and person responses, $F(214,215) = 1.236$, $p=.146$, NS. The teachers indicated that the ball curved opposite the CI bias, leading us to conclude that there is an overcorrection factor with the ball answers. This overcorrection may be due to the teachers making sure that they got the correct answer of not indicating the CI bias. The results support that teachers believe that balls and people do not continue to curve, thus showing that they are generically using a model of ball motion for curvilinear motion of all objects in this problem, with slightly more of an overcorrection for the ball.

General Discussion

Naive physics has previously been described as a subset of the population's failure to grasp the fundamental principles of Newtonian physics. However, the results of the current study offer a different interpretation for these types of seemingly naïve biases. Our findings support that a basic foundation for human understanding of physics for spiral motion is likely biased by our own human biological movement tendencies. Since humans continue to curve when they run out of a spiral maze, there may be a functional advantage for people to understand motion in a way that is biased toward biological motion patterns. However, our results suggest that not all biological motion behaves the way that human motion does. Though rats in our maze did not curve, they may do so in other settings in which they are more rushed, or there may be other species that do more universally curve. It would be difficult for people to memorize all of the different forms of motion, or outcomes of motion, produced by running in a spiral or curving pathway. By generalizing patterns of human biological motion to both animate biological and inanimate non-biological objects, people may reduce ongoing cognitive load with little cost to the occurrences of misestimating non-biological spiral motion. Such a heuristic, or generalized model of motion, serves the purpose of saving mental time and effort for generic cases of motion. This heuristic could make it easier and more accurate for humans to interact using quick judgments with animals and other people, thus enabling more ongoing cognitive resources to be spent on other mental activities. For those that are more experienced in thinking about how objects move, such as physics teachers, it may be easier for them to think of curvilinear motion as behaving with the type of motion they think about most. Our findings are consistent with this type of reasoning: object motion.

The bias to simplify one's conception of curved motion behavior to a single generic solution is also consistent with our findings testing physics teaching experts. It appears that a pedagogy that assumes CI bias is an error in need of correction may simply lead to a new kind of bias, the notion that no objects including biological motions will exhibit curvature. Similar research examining teaching of the physics of gravity has shown that people may actually become worse in relative judgments of falling rates of objects as physics training increases due to their learning to ignoring air resistance (Oberle, McBeath, Madigan, & Sugar, 2005). It appears that the common practice of instructing students to ignore air resistance in calculations of falling objects results in students assuming that it is an unimportant factor. Thus results in systematic errors of overgeneralizing that all objects fall at the same rate, (a phenomena named the Galileo Bias). The current findings support that an overly simplistic pedagogy that simply promotes that CI bias is wrong could produce a similar over-orthodoxy to emerge with increased physics education.

Conclusion

Previous research involving naive physics has shown that many people carry a belief about the movement of objects that is in conflict with the Newtonian physics model. Previously this has been explained as the people conceptualizing motion via the curvilinear impetus model simply due to being uneducated. However, the current research supports the idea that judgments of object motion, for people who demonstrate the CI bias, are based upon a bias to assume human biological motion tendencies to favor continuing to curve when running out of a curved pathway like a spiral maze. Even though we established that rats do not necessarily curve upon exiting a spiral, there may be other animals or situations in which they do. Regardless, our results support that people are basing their conceptual framework of curvilinear motion using a heuristic with the type of motion they encounter and think about most. A heuristic, or mental short-cut can help reduce cognitive load by generalizing human biological motion to that of all object motion. Our survey findings and previous research demonstrates that this heuristic is both pervasive and resistant to physics training. Our findings support that these “naive” beliefs should not be viewed as merely a failure of understanding, but rather as a potentially practical generalization of motion based on natural regularities of how human agents behave in action.

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