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An anti-inertial motion bias explains people discounting inertial motion of carried objects

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Abstract
In this paper we propose an anti-inertial motion (AIM) bias that can explain several intuitive physics beliefs including the straight-down belief and beliefs held concerning the pendulum problem. We show how the AIM bias also explains two new beliefs that we explore – a straight-up-and-down belief as well as a straight-out/backward bias that occurs for objects traveling in one plane that are then thrown in another plane, ostensibly affording a greater opportunity for perception of canonical motion. We then show how the AIM bias in general is invariant across perceived/imagined speed of the object carrier, only altering percentages of straight-out from backward responses, and why occluding the carrier once the object is released into a second plane does not result in more veridical perception. The AIM bias serves as a simple explanation for a family of beliefs including those in the current paper as well as those shown in previous work.

Keywords Naïve physics · Intuitive beliefs · Anti-inertial motion

Introduction

Intuitive physics refers to observers' intuitive beliefs about the principles of physics that are often at odds with what occurs physically or according to classical or Newtonian mechanics. Intuitive beliefs that have been documented include everything from observers' misconceptions of wheel dynamics (Proffitt et al., 1990), to observers believing that the surface orientation of liquids tilted in a glass is more parallel to the bottom surface of the glass even though the surface orientation of liquids remains invariably horizontal (Hecht & Proffitt, 1995; Smedslund, 1963), to the influence of intensity change on auditory pitch (McBeath & Neuhoff, 2002; Neuhoff & McBeath, 1996). Intuitive beliefs more germane to the current paper include the tendency to believe that a ball will continue to accelerate after it has left the thrower's hand (Hecht & Bertamini, 2000), to assume that object axis defines object heading direction (Dolgov et al., 2009), to assume that all objects fall at the same rate (Oberle et al., 2005), and to assume that one will be good at identifying physical characteristics of the trajectories of objects (Shaffer & McBeath, 2005; Shaffer et al., 2015; Shaffer et al., 2009). The most oft-studied beliefs of intuitive physics have to do with the motion of objects for generally two types of problems, which is the focus of the studies in the current work.

The first type of problem is called the *pendulum problem* (Caramazza et al., 1981; Kaiser et al., 1992). In this problem, a ball is shown in a line drawing as being held at the end of a string and swinging back and forth. Participants are asked what the motion of the ball would be if the string were to break at different points along the arc of motion the ball makes. Forty-five to 75% of participants demonstrate misconceptions of the motion of the ball after it breaks. Participants do not realize that the ball will fall straight down at either one of its end points where the velocity is zero, or that it will move forward in a parabolic path as it falls to the ground in the same direction it was traveling if it is cut from the string for the areas between the end points (Caramazza et al., 1981; Kaiser et al., 1992).

The second type of problem results (for a slight majority or large minority of participants) in what is called the *straight-down belief* (Howe, 2017; Kaiser et al., 1985; Kaiser et al., 1992; Krist, 2000; McCloskey, 1983; McCloskey & Kargon, 1988; McCloskey et al., 1983). For this problem, participants are asked to either draw or choose

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from several options to describe the path that a ball will travel once it is released by either a man who is walking with or without a ball in his hands, a toy train that is moving on tracks, a computer-generated hot air balloon that is flying at a constant velocity, or that of a keg dropped from an airplane. About 50% of participants (children and adults) falsely believe that the ball will fall straight down when asked using a diagram, after watching a person walking with or without a ball and predicting what path the ball would take if the person were to drop it, when watching a toy train moving on tracks, and ~80–90% of children when watching a ball drop from a computer-generated moving hot air balloon (Howe, 2017; Kaiser et al., 1985; McCloskey et al., 1983). In each of these cases, the ball is moving as it is being carried at the same constant velocity of the carrier when it is released. Due to this and gravity, the ball moves forward and downward, resulting in a parabolic trajectory to the ground (ignoring air resistance).

Together, the straight-down belief and answers to what happens when the ball reaches the nadir in the pendulum problem may be thought of as *anti-inertial motion (*or *AIM)* biases, as these erroneous beliefs about the motion of objects contradict Newton's first law of motion – the law of inertia – which states that an object in motion (in this case in one direction) stays in motion at the same velocity unless acted on by a force. The current work was performed for several reasons. First, we wanted to establish the AIM bias as a cognitive-perceptual bias that can help explain the existing beliefs (the straight-down belief and answers to the pendulum problem). In the first experiment we first wanted to extend the straight-down belief to a straight "up-and-down" belief, if you will, for objects thrown up in the air from a moving carrier before coming back down that may also be explained by the AIM bias. We then wanted to establish and investigate a new motion bias regarding objects carried in a forward direction and then released horizontally/sent in a lateral direction through the air. We wanted to test specifically whether people hold an AIM bias for the first of two motion directions – the intuitive (mis)conception that when an object or person is moving in one direction and then begins moving in a different direction, people fail to apply the inertia from the first direction in their conceived or perceived movement of the object or person. That is, we wanted to test whether the inertia or movement in the first direction is discounted by people, resulting in an AIM bias (for the first direction). For our purposes this means that just because motion is introduced as an additional force in a different direction does not mean that inertia in the first direction halts and gives way to only inertia in the second direction. We chose such a situation because this physical situation occurs frequently in everyday life and so we have greater access to the physical variables that may be involved and more frequent perceptual experience than we do for a lot of the intuitive physics phenomena that have been studied. For instance, examples of these physical situations from the perspective of an observer include, but are not limited to: throwing trash into an open garbage can as one is walking by, a "pass" in rugby, a soccer ball being crossed to the middle of the pitch as it's moving forward, anything thrown out the window of a vehicle while it's moving, or freight and train hopping – -a person jumping off of a moving train. The familiarity with these situations is important as work has shown that systematic errors that have been documented on paper-and-pencil tests and drawing motion that unfolds later in time are reduced when familiar examples of problems are used instead of their more abstract counterparts (Kaiser et al., 1986). Thus, we wanted to draw on characteristics we have encountered in more familiar contexts. In the second experiment, we wanted to test whether this belief still holds for two different video sequences that differ in speed of the object carrier and throwing motion. In the third experiment we wanted to see whether isolating the motion of the ball from the object carrier once the object was released would result in perception of canonical motion. Finally, in Experiment 4 we tested whether this belief infiltrates action processes.

In Experiment 1 we first tested and predicted that the AIM bias would also explain people's beliefs about up-down motion of an object released from a moving carrier. We then tested whether the conceptual idea of projected movement in one direction would be halted when the object began moving in an orthogonal direction. For instance, when someone is jumping off a railroad car to the ground while the train is moving in one direction (say northbound) and they are jumping to a direction orthogonal to the direction of the movement of the train (say westbound), do people understand that after jumping off the railroad car and prior to hitting the ground the person continues to travel some distance northbound as the train does, in addition to moving in a westbound direction, or will people ignore the northbound direction of motion of the train and how it will affect the jumper's motion and instead pay attention only to the westbound motion of the jumper after s/he has left the train?

Experiment 1

We first wanted to establish whether people have a conceptual understanding of inertial movement consistent with an AIM bias in one direction as has been found in past work, only now with up-and-down motion of the object, and then whether they demonstrate a straight-out/backward (or *SO/B*) belief for the same object when we conceptually added movement in a second, orthogonal direction. We did this by first asking participants a question concerning a person standing on a car that is moving in one direction at a constant velocity, who then jumps straight up in the air. We did this to establish a baseline for an intuitive belief similar to the straight-down belief but directing the question toward up-down motion, as well as to use a question that was well matched to the question we were asking concerning movement in two directions. We then asked participants a question concerning a person standing inside a railroad car who then jumps out of it while it is moving forward at a constant velocity to establish whether people hold an SO/B belief for objects that are first moving in one direction, and then are launched in a separate direction from the first direction.

Previous work has shown that diagrams including stick figures and impoverished stimuli make it more likely that people will make errors in their judgments about the motion of objects. Specifically, it has been found that only a third of participants drawing the path of an object swinging on a pendulum and one-quarter of them choosing from one of five alternatives, correctly indicate the appropriate movement, whereas they choose the correct trajectory 75% of the time in a dynamic condition, where the pendulum swings for two full cycles prior to the cord being cut and the object falling compared to ~57% when viewing a static diagram (Kaiser et al., 1992). Participants also perform rather poorly when drawing the predicted motion of objects that is represented by a static image implying motion (Kaiser et al., 1992) and when compared to choosing from a limited set of alternatives (Cooke & Breedin, 1994). It is for these reasons that we did the following things so that our diagrams, even though they were static drawings, would not mislead our participants or lead them to make larger errors as they might if we were to use more impoverished stimuli. First, we used static diagrams that conveyed information concerning movement, as our pictures were rich illustrations of the descriptions we used. Second, they were drawn with pictorial depth cues that you would see if viewing these from the given perspective. Third, both illustrations were drawn from a top-down or birds-eye view so the question we were asking of our participants would be clear. Finally, in the car jumping question, we asked participants to choose from one of three alternatives; in the train hopping question, we had participants mark an X on the figure indicating where the person would land on the ground instead of having them draw the person's path or trajectory to the ground.

Method

We conducted a power analysis using G*Power (Faul et al., 2007) for Experiments 1, 2A, 2B, and 4 in this paper (we did not hold to the same standard in Experiment 3 as we viewed this as a more exploratory analysis). This revealed that if we conduct a χ^2 test on the groups answering either correctly or with an AIM bias we would require a sample size of at least 42 to achieve statistical power equal to at least 90%.[1] While 42 participants would satisfy our statistical power analysis for Experiment 2, we used 43 and 64 participants in Experiments 2A and 2B, respectively, as this was our first attempt at investigating this phenomenon using video, and we had no prior basis for what kind of effect size we might expect like we had for questionnaire data similar to that used in Experiment 1.

Participants

Forty-two undergraduates (24 male) from The Ohio State University at Mansfield (mean age = 18.95 years, *SD* = 1.84 years) participated in fulfillment of an Introductory Psychology requirement. Research was performed with the approval of and in accordance with The Ohio State University Institutional Review Board. Informed consent was obtained from all participants in all experiments.

Materials and procedure

A nine-item questionnaire was used. The first three questions asked participants their sex, age, and experience with physics. Four additional questions concerned air resistance and its effect on balls of different sizes and weights. These four questions were used as distractor questions from the questions in which we were truly interested and are listed here: (1) If a small ball and a large ball (that weigh the same) are dropped from the top of a three-story building, which ball will hit the ground first? (2) If a light ball and a heavy ball (that are the same size) are dropped from the top of a three-story building, which ball will hit the ground first? (3) Of a small ball and a large ball (that weigh the same), which ball is the most affected by air resistance? and (4) Of a light ball and a heavy ball (that are the same size), which ball is the most affected by air resistance? The first critical question concerning conceptual beliefs about inertial motion in one direction was orally asked of the participants and used the picture shown in Fig. 1 as its basis. We asked participants: "Suppose you are standing on the roof of a car that is traveling at a constant velocity of 25 mph. You are facing the front of the car. Ignoring air

[1] G*Power (3.1) has you choose a Test Family (χ^2 Tests), Statistical Test (Goodness-of-fit tests: Contingency Tables), Type of power analysis (a priori: Compute required sample size – given α, power, and effect size). It then has you put in "Input parameters" including Effect size (w), for which we put in 0.5 indicating a large effect size, α error probability, Power, and df. Assuming an effect size of 0.5, with an α error probability of 0.05 using two groups (df = 1), Power = 0.9 and df = 1.

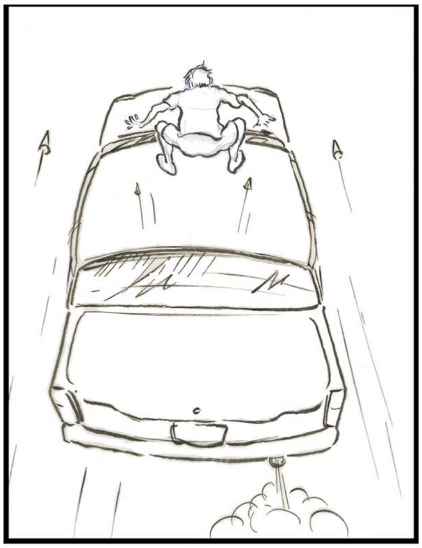

Fig. 1 Shown is the first critical anti-inertial motion (AIM) bias question assessing conceptual beliefs about motion in one direction

resistance,[2] where would you land if you were to jump high in the air like the person is shown in the illustration?" The three potential answers were: (1) On the trunk or behind the car; (2) On the roof where you jumped; and (3) On the hood or in front of the car. The order of answers was presented pseudorandomly across participants.

The second critical question concerning conceptual beliefs about inertial motion in two directions, was orally asked of the participants and used the picture shown in Fig. 2 as its basis. We asked participants: "Suppose you are 'train hopping' on a train that is moving along at a constant speed of 25 mph (and in the leftward direction as shown in the picture). You start by standing in the railroad car like the man shown in the picture and then jump off of the train to the ground. Please place an 'X' on the ground where you would land." For this question, participants then confirmed if the 'X' meant that it was in the same direction of motion of the train from where the man is standing in the railroad car, in the opposite direction of the motion of the train from where the man is standing in the railroad car, or straight out from where the man is standing in the railroad car. Figure 3 shows three 'X' locations that would count as each of the three possible answers. One critical question was asked before participants filled out the six-item questionnaire concerning sex, age, and distractor questions, and the other after the filled out the questionnaire. The order of the two critical questions was counterbalanced across participants.

[2] The reason we told participants to ignore air resistance (AR) is twofold. First, AR would result in negligible effects given the velocity (25 mph), the mass of the individual jumping from the car/train, and the height at which they started (on top of the car or in the train). Second, in previous work participants have been told to ignore AR even when the velocity (~20 times) and height (~150 times) are far greater that that used in the current scenario and we wanted to be able to make straightforward comparisons to previous work. Finally, work has shown that the majority of people show deficiencies in their understanding of AR both in their conceptual understanding measured via paper-and-pencil tasks as well as in their actions (Oberle et al., 2005).

Results

Table 1 shows frequencies of the car jumping question.[3] Over 73% of participants demonstrated an AIM bias. We recoded the car jumping answers into the correct answer (i.e., "On the roof where you jumped") and "SO/B bias" answer (i.e., "On the trunk" or "behind the car"). We eliminated the "On the hood or in front of the car" answer as it was neither correct nor an AIM bias answer, and only one participant chose this option. A chi-square test on the recoded data revealed that significantly more participants demonstrated a SO/B bias than who answered the question correctly, χ^2 (1) = 10.0, p = .002. This was a large effect, Cohen's w = 0.5.

Table 2 shows frequencies of the train hopping question. We recoded the train hopping answers into the correct answer (i.e., "In the direction of motion of the train") and SO/B bias answers (i.e., "Straight out from where the person jumped" and "In the direction opposite of the motion of the train"). While a chi-square test on the recoded data did not reveal a significant difference between the two groups, χ^2 (1) = 1.2, p > .05, over 58% of participants demonstrated an SO/B motion bias. We also recoded "physics instruction" into "physics instruction" and "novice" groups by assigning participants with at least one high school class (one high school class, one college class, or more than one college class) as one group (n = 20) and no physics instruction as another group (n = 21). We then performed a binomial logistic regression analysis using the recoded physics instruction as a factor to test whether physics instruction significantly predicted their answers. The counts for the physics instruction and no physics instruction groups crossed with the results of both the car and train hopping questions are shown in Table 3.

[3] In a pilot study, we asked participants the same car jumping question without showing them a picture of what we meant – we simply asked the question. The frequencies of their answers shown below are nearly identical across questions. We recoded the car jumping answers into the correct answer (i.e., "On the roof where you jumped") and "AIM bias" answer (i.e., "On the trunk or behind the car"). We eliminated the "On the hood or in front of the car" answer as it was neither correct nor an AIM bias answer and only three participants across both groups chose this option. A chi-square test on the recoded and now combined data revealed that significantly more participants demonstrated an AIM bias than who answered the question correctly, χ^2 (1) = 23.84, p < .001. This was a large effect, Cohen's w = 0.57.

Answers given to both versions of the car jumping question

	On the hood or in front of the car	On the roof where you jumped	On the trunk or behind the car
Frequencies (%'s) w/out Picture	2 (5.6%)	6 (16.7%)	28 (77.8%)
Frequencies (%'s) w/Picture	1 (2.4%)	10 (24.4%)	30 (73.2%)

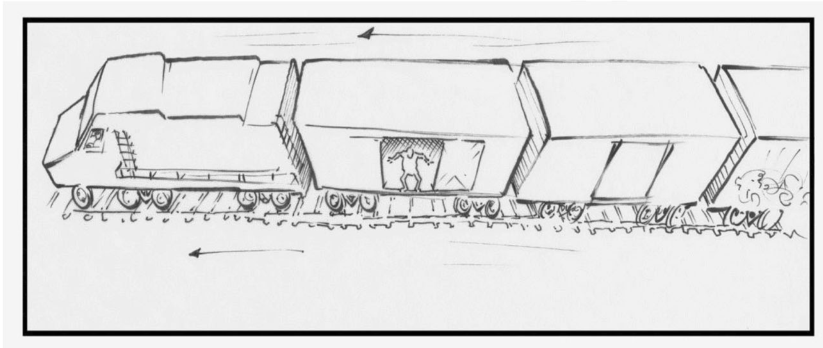

Fig. 2 Shown is the second critical anti-inertial motion (AIM) bias question assessing conceptual beliefs about motion in two directions

Standard binomial logistic regression revealed that the overall model including physics instruction did not statistically predict whether people answered correctly or with a SO/B bias, χ^2 (1) = 0.536, p= .464. Forty-three percent of the participants who answered the car jumping question with an AIM bias also answered the train hopping question with an AIM bias. Seventy-five percent of participants demonstrated an AIM bias on one or both questions.

Discussion

Experiment 1 showed that over 73% of participants held an AIM bias when answering the car hopping question, indicating that participants were more likely to believe the person would land on the trunk of a car after jumping straight up when standing on the roof of the car. Experiment 1 also established that a majority of people hold a belief that when an object is removed from the vehicle it was traveling on in one direction and moves in a second direction, perception of movement from the first direction seems to be largely discounted or reduced, consistent with an SO/B belief for the first direction of motion. Experiment 1 showed that 58.5% of participants held a SO/B belief for the train hopping question, indicating they falsely believed the person jumping would either land straight out from where they jumped or would land backward from where they jumped. These results were not influenced by physics experience as we defined it. Only two more participants with no physics experience answered the car hopping question correctly compared to those with physics experience, while only three more participants with physics experience answered the train hopping question correctly compared to those with no physics experience.

This extends the straight-down belief to not only objects dropped from a moving carrier but also to those launched upward from a moving carrier. The SO/B belief is similar to the straight-down belief in that people seem to ignore Newton's first law of motion, the law of inertia, which states that an object in motion stays in motion at the same velocity unless acted on by a force. With both the pendulum problem and the straight-down belief problems, people conceptually seem to separate the components of carrier and object and impart inertia or continued movement to the carrier and remove it from the object (Caramazza et al., 1981; Howe, 2017; Kaiser et al., 1992; Kaiser et al., 1985; McCloskey et al., 1983). The SO/B belief seems to show a similar "reassignment" of inertia or movement. However, with the SO/B belief it seems that people seem to conceptualize movement to the object in the lateral direction while de-emphasizing or even ignoring the forward motion initially imparted to it by the carrier. One difference between the results of Experiment 1

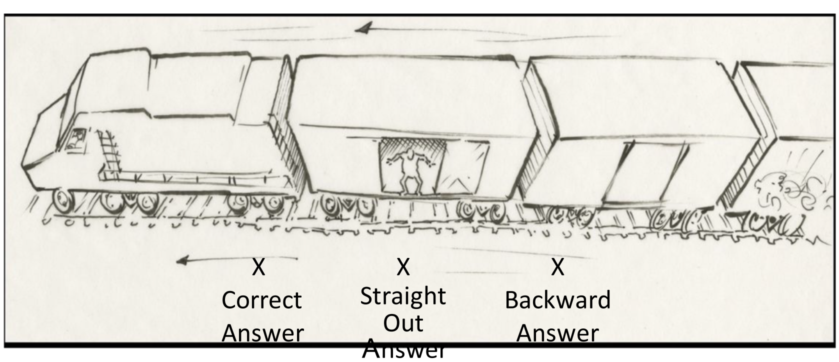

Fig. 3 Shown is the second critical anti-inertial motion (AIM) bias question assessing conceptual beliefs about motion in two directions along with Xs marking positions that would count as in the same direction of motion of the train from where the man is standing in the railroad car ("Correct Answer"), straight out from where the man is standing in the railroad car ("Straight Out Answer"), and in the opposite direction of the motion of the train from where the man is standing in the railroad car ("Backward Answer")

Table 1 Answers given to the car jumping question

	On the hood or in front of the car	On the roof where you jumped	On the trunk or behind the car
Frequency (%)	1 (2.4%)	10 (24.4%)	30 (73.2%)

and those from the work on the straight-down belief is that the percentage of participants holding a SO/B bias is somewhat (train hopping question) and far (car jumping question) greater than percentages typically reported for participants holding a straight-down belief (25–50%) (Howe, 2017; Kaiser et al., 1985; McCloskey et al., 1983). We believe that this may have to do with the complexity of the extended-body problem that forward plus lateral plus gravitational motion may represent compared to the simpler forward plus gravitational motion that the straight-down problem represents. A multidimensional problem like the SO/B scenario has more moving parts, is more difficult to analyze, and may not be as accessible to perception. We view the AIM bias as a cognitive-perceptual bias that conceptualizes well the straight-down belief, answers to the pendulum problem, the "straight-up" belief, and the SO/B belief into a family of beliefs that seem to be well explained by the AIM bias, as these erroneous beliefs about the motion of objects contradict Newton's first law of motion – the law of inertia – which states that an object in motion (in this case in one direction) stays in motion at the same velocity unless acted on by a force.

Experiment 2A tested whether this SO/B belief would occur when viewing a dynamic event showing an object moving in one direction with a carrier and then launched in a second direction. Experiment 2B tested whether the SO/B responses changed when the speed of the moving carrier increases and the throwing motion of the moving carrier is a backward motion compared to that used in Experiment 2A.

Experiment 2

Experiment 1 showed that people hold a SO/B motion belief for objects that are depicted as first being carried in one direction and at the same time then moving in a second direction independent of the first. In the present experiment, we first wanted to test whether the SO/B belief remains when people watch a video of two people running in the same direction ~6 m apart and where a ball is thrown from one person to another. Seeing this on video provides a much more cue-rich environment with depth perception cues like linear perspective, optical shrinkage, motion parallax, and a background scenery to enhance these cues. If an AIM bias is a strong generic bias where observers fail to account for inertial motion of carried objects, then it should overwhelm the cue-rich environment and still occur when adding a perceptible second (lateral) plane of motion. We also wanted to test whether the AIM bias occurs across different imagined or perceived speed of the moving carrier. If observers do not display an AIM bias, then more people should indicate that the object moves farther forward (or forward) when the carrier is moving faster. However, if observers do display an AIM bias, we would predict that the largest difference in percentages of responses should occur across "backward" and "straight-out" responses. Specifically, we should see an increase of "backward" compared to "straight-out" responses. This is because if the motion of the carrier increases, but the forward (or initial) motion of the object released is still discounted then it should have the perceived effect that the carrier moved faster in the initial direction, while the motion of the object in that same direction is ignored, leaving the object to seem like it is left farther behind the distance travelled by the carrier in the initial direction.

Experiment 2A

Method

Participants

Forty-three undergraduates (19 male) from The Ohio State University Mansfield (mean age = 21.28 years, *SD* = 6.34 years) participated in fulfillment of an Introductory Psychology requirement. Research was performed with the approval of and in accordance with The Ohio State University Institutional Review Board. Informed consent was obtained from all participants in all experiments.

Table 2 Answers given to the train hopping question.

	In the direction of motion of the train	Straight out from where the person jumped	In the direction opposite of the motion of train
Frequency (%)	17 (41.5%)	12 (29.3%)	12 (29.3%)

Table 3 Shown are counts for different answers for car and train hopping questions crossed with physics instruction/no physics instruction

Physics instruction	Car hopping question		Train hopping question	
	Correct	SO/B	Correct	SO/B
None	6	14	7	14
At least one high school class	4	16	10	10

Materials

A recording was created of a ball that was thrown from one person to another person while they were running in parallel paths orthogonal to the view of the camera. An illustration of how this played out is shown in Fig. 4. The recording itself is approximately 3 s long. The recording was made using an iPhone XS that was mounted on a tripod standing 1.25 m high approximately 6 m from the receiver's path of motion and ~12 m from the thrower's path of motion. As shown in Fig. 4 and the video, we asked the thrower (higher up/farther away who starts with the ball) to throw the ball overhand to the receiver (lower down/closer to who ends up with the ball) and for the initial movements of the ball and hands of the thrower to be forward and/or straight across in order to minimize the effect that initial movement of the thrower might be used to judge the motion of the ball after it was thrown. The speed of the person throwing the ball was 3.86 m/s. This was done especially because an underhand backward-type throw might make it more likely for the motion to be judged as straight across or backwards, in line with people holding an AIM bias.

Procedure

Participants were first asked the physics instruction question used in Experiment 2 and their age. Next participants watched the recording of the ball being thrown. After they finished watching the recording, they were asked by the experimenter: "How did the ball travel once it was released by the thrower?" The experimenter gave them three options from which to choose, which were randomized each time to avoid any order effects. The answer choices were: (1) Straight; (2) In the direction of motion of the thrower; and (3) In the opposite direction of motion of the thrower. If participants answered in the direction of motion with the thrower or in the opposite direction of motion of the thrower, they were then asked to estimate how far the ball traveled.

Results

Table 4 shows frequencies of the ball movement answers participants gave regarding the video. We recoded the answers into the correct answer (i.e., "In the direction of motion of the thrower") and "AIM bias" answers (i.e., "Straight" and "In the opposite direction of motion of the thrower"). A chi-square test on the recoded data revealed that significantly more participants demonstrated an "AIM bias" (69.8%) than who answered the questions correctly, χ^2 (1) = 6.72, p = .010. This was a medium effect, Cohen's w = 0.4.

Table 4 also shows the average estimated distance the ball traveled for the two "non-straight" answer groups. The 95% confidence interval for those participants indicating the ball traveled backward was [0.2, -1.32], while that for the participants indicating the ball traveled forward was [+0.67, +1.62]. We then performed two separate one-sample t-tests comparing the estimated distance the ball traveled to the actual distance it traveled (6.1 m) for both the "forward" (in the

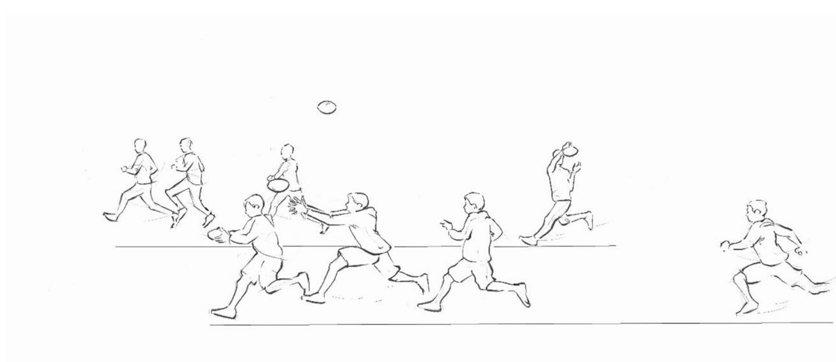

Fig. 4 Shown is an illustration of how the video participants saw in Experiment 2A played out. The thrower (higher up in picture/farther away and always just above the top line) starts with the ball and is the one throwing the ball, and the receiver (lower down in the picture/closer and always just above the lower line, but beneath the top line) begins behind and to the side of the thrower. Figures represent four simultaneous time instantiations of thrower and receiver

Table 4 Answers given to the question concerning the direction of the motion of the ball in the video

	In the direction of motion of the thrower	Straight	In the opposite direction of motion of the thrower
Frequencies (%'s)	13 (30.2%)	14 (32.6%)	16 (37.2%)
Mean Distance (SD) (meters)	1.15 (0.79)	-----------	-0.76 (1.06)

direction of the motion of the thrower) answering group and the "AIM bias" (straight or opposite the motion of the thrower) group. In order to do this, we used a value of 0 for the "straight" group. The AIM bias group significantly underestimated the distance the ball traveled forward, $t(29) = -41.77$, $p < .001$. This was a very large effect, Cohen's $d = 7.65$. The forward answering group (i.e., the group who qualitatively answered correctly that the ball moved forward) also significantly underestimated how much the ball moved forward, $t(12) = 22.63$, $p < .001$. This was also a very large effect, Cohen's $d = 6.27$.

We recoded physics instruction into expert ($n = 5$) and novice ($n = 38$) groups as we did in Experiment 1. We also recoded participant's answers into "correct" or "AIM bias" (i.e., answers of "straight out" or "opposite the motion of the thrower") as we did for the train hopping question in Experiment 1. We then performed a binomial logistic regression analysis using recoded physics instruction as a factor to test whether physics instruction significantly predicted their answers. Standard binomial logistic regression revealed that the overall model including physics instruction did not statistically predict whether people answered correctly or with a SO/B bias, $\chi^2(1) = 0.34$, $p = .558$. The counts for the physics instruction and no-physics instruction groups crossed with the results of the video question and shown in Table 5.

Discussion

Experiment 2A found that when viewing a carrier moving forward and throwing an object laterally to a receiver in a cue-rich environment when introducing a perceptible second plane of motion, 70% of participants still hold an AIM bias indicating that participants were more likely to incorrectly believe the ball traveled backward or straight across after leaving the carrier's hands as opposed to moving forward as it actually does according to Newton's first law of motion. While there was a large minority of participants (30%) who did *not* hold an AIM bias (i.e., those who correctly answered that the ball would travel forward), they seemed to succumb to an "inertial amelioration bias" in that they significantly underestimated exactly how far forward the ball moved (estimating it moved forward ~1 m when it actually moved forward ~6 m – over an 80% reduction of the distance it moved forward). So even those who are correct in a qualitative way drastically underestimate the inertial effect of the first vector of movement. This is in spite of the fact that we purposely showed participants a recording of a side-view (a perspective orthogonal to the motion of travel of both carrier and receiver), which gave them a more privileged view for better revealing the forward distance traveled. Previous physics instruction did not influence participants' answers. As in Experiment 1, very few participants were classified as experts (12.5%). Experiments 1 and 2A showed that when conceiving of a scenario brought about by a scenario and illustration or by viewing a recording of an event showing motion of an object in two directions, people hold an AIM bias. As it did in Experiment 1, the AIM bias seems to show a similar "splitting of inertia," with people imparting inertia to the object in the lateral direction only and removing it from the motion initially imparted by the carrier, mostly ignoring (or ameliorating in the case of the participants answering correctly) Newton's first law of motion.

Table 5 Shown are counts for different answers for the video question crossed with physics instruction/no physics instruction

Physics instruction	Direction of motion of the ball in the video	
	Correct	SO/B
None	5	16
At least one high school class	8	14

Experiment 2B

Method

Participants

Sixty-four undergraduates who had not participated in Experiment 1 (26 male) from The Ohio State University at Mansfield (mean age = 19.01 years, SD= 2.1 years) participated in fulfillment of an Introductory Psychology requirement.

Materials

The recording that was used was one in which the ball that was thrown was from one person to another person while they were running in parallel paths orthogonal to the view of the camera. The camera remained stationary. An illustration of how the video was played out is shown in Fig. 4. The video itself is approximately 3 s long and may be found here: https://www.bing.com/videos/search?q=rugby+pass+forward+video&view=detail&mid=40F42A0E9A4A93CDE51440F42A0E9A4A93CDE514&FORM=VIRE (from 0:26 to 0:30 s of the video). As shown in the video, a rugby player passed the ball to another rugby player just once. The speed of the thrower was 5.33 m/s.

Procedure

Participants watched the video of the ball being thrown. After they finished watching the video, they were shown the form shown in Fig. 5, as opposed to giving them three possible answers as we did in Experiment 1. The experimenter then asked them: "The form shows a top-down view of the paths of the thrower (right) and the catcher (left) as indicated by the straight lines. If you are standing far above the thrower and catcher looking down reflecting what you see in the drawing, you would not see the up-down movement of the ball as it traveled from thrower to catcher – only the movement of the ball relative to the ground surface. Please draw a line showing how the ball traveled relative to the ground surface from thrower to catcher." All participants understood the instructions. In the present experiment (and in Experiment 3), we had participants draw a line from the thrower to the target (in this experiment the catcher) as opposed to simply telling which of three answers they chose. We specifically did this for two reasons. First, we thought having them draw the line might give us a fairer and more accurate sense of their cognition/perception as they had to display their cognitive-perceptual estimation of what happened through their own behavior. The second reason we did this was that the endpoint (the catcher) was already set as appearing somewhere along the line, so we wanted them to indicate where the catcher would be when the ball was caught by drawing the line. We also wanted there to be no ambiguity that they were drawing the landing point of the ball and not the catcher relative to the thrower's initial position. This was the same reason we did this in Experiment 3, except there the target endpoint was set and not moving.

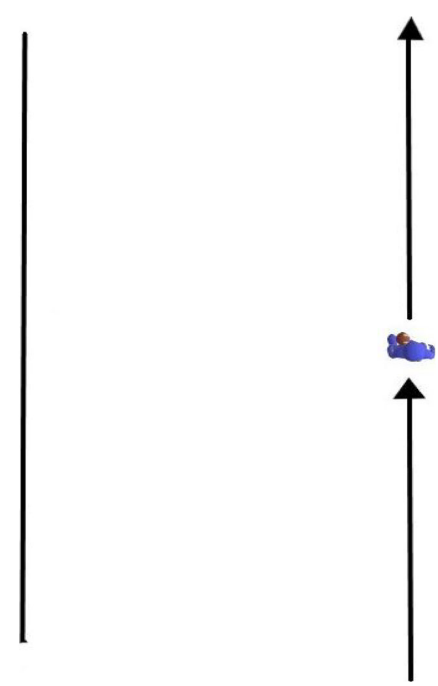

Fig. 5 Shown is the form given to participants for indicating where the ball landed along the path of the catcher when it landed in the catcher's hands. Participants drew a line from the rugby ball in the thrower's hands to the line to the left, marking the path of the catcher

If participants drew a line that was not directly orthogonal to the thrower's position in the figure, they were first asked to confirm that they indicated that it went forward or backward from the thrower (and the researcher pointed in the direction forward and backward on the figure) and were then asked by how many feet did it land in front of or behind the thrower.

Results

Table 6 shows frequencies of the ball movement answers participants gave regarding the video. We recoded the answers into the correct answer (i.e., "In the direction of motion of the thrower") and SO/B answers (i.e., "Straight" and "In the opposite direction of motion of the thrower"). Over 87% of participants gave SO/B motion bias answers. A chi-square test on the recoded data revealed that significantly more participants demonstrated an SO/SB bias than who answered the questions correctly, χ^2 (1) = 36, $p < .001$. This was a very large effect, Cohen's $w = 0.75$.

Table 6 also shows the average estimated distance the ball traveled in the forward/backward direction in the direction both thrower and catcher were moving from where the ball left the thrower's hands to where it was caught by the catcher for the two "non-straight" answer groups (the ball physically traveled 2 m forward in the same direction both thrower and catcher were moving). The 95% confidence interval for those participants indicating the ball traveled backward was [-1.06, -0.52], while that for the participants indicating the ball traveled forward was [+0.21, +1.01]. We then performed two one-sample t-tests comparing the estimated distance the ball traveled to the actual distance it traveled (2 m) for both the "forward" (in the direction of the motion of the thrower) answering group and the collective SO/B motion bias (straight or opposite the motion of the thrower) group. In order to do this, we used a value of 0 for the "straight" group. The SO/B bias group significantly underestimated the distance the ball traveled forward, $t(56) = -25.67$, $p < .001$, $M = -0.6$ m, $SD = 0.68$ m. This was a large effect, Cohen's $d = 3.83$.

Table 6 Answers given to the question concerning the direction of the motion of the ball in the video

	In the direction of motion of the thrower	Straight	In the opposite direction of motion of the thrower
Frequency (%)	8 (12.5%)	19 (29.7%)	37 (57.8%)
Mean estimated distance in feet and then meters (SD)	2 ft. (0.61m (0.22m))	0.0	2.59ft. (-0.79m (0.75m))

We also recoded "physics instruction" into "no physics instruction" groups by assigning participants with no physics instruction as one group (n = 32), and those participants with at least one high school class (one high school class, one college class, or more than one college class) as another group (n = 32). We then performed a binomial logistic regression analysis using the recoded physics instruction as a factor to test whether physics instruction significantly predicted their answers. Standard binomial logistic regression revealed that the overall model including physics instruction did not statistically predict whether people answered correctly or with a SO/B bias, χ^2 (1) = 1.18, p= .278. Table 7 shows the counts for correct and SO/B answers for the question asking about the direction of the motion of the ball in the video.

Discussion

Experiment 2B found that when viewing a carrier moving forward and throwing an object laterally to a receiver in a recorded dynamic event, 87.5% of participants hold a SO/B belief indicating that participants were more likely to incorrectly believe the ball traveled backward or straight out after leaving the carrier's hands as opposed to moving forward as well as laterally as it does according to Newton's first law of motion. Though we had participants draw a line, their drawing was not of the entire predicted trajectory of the object and was not a drawing of the entire trajectory when looking at a static diagram, but a straight line from the perspective of someone with a "birds-eye view" indicating the lateral direction of movement of the rugby ball in the recording they viewed. In this way, it does not fall into the same issues that previous work has (Kaiser et al., 1992). These results were not influenced by physics experience as we defined it. Out of 64 participants (32 per group), only four more participants with physics experience answered the question about the direction of motion of the ball in the video correctly compared to those with no physics experience.

Table 7 Shown are counts for different answers for the question asking about the direction of motion of the ball in the video

Physics instruction	Direction of motion of the ball in the video	
	Correct	SO/B
None	2	30
At least one high school class	6	26

A small minority of participants (12.5%) did *not* hold a SO/B motion bias (i.e., those who correctly answered that the ball would travel forward in the direction of the runners). Those participants, however, still seemed to hold a weaker SO/B motion bias in that they significantly underestimated exactly how far forward the ball moved (estimating it moved forward ~0.6 m when it physically moved forward 2 m – a 70% reduction of the distance it moved forward). So even those who are correct in a qualitative way drastically underestimate the effect of the first vector of movement. A similar underestimation of forward movement has also been shown with the straight-down belief (Kaiser et al., 1992; McCloskey et al., 1983). This is in spite of the fact that we purposely showed participants a recording of a side-view (a perspective orthogonal to the motion of travel of both carrier and receiver) and with the view from a stationary camera, which gave them a more privileged view for better revealing the forward distance traveled (cf. Kaiser et al., 1992, Experiment 2A). As it did in Experiments 1 and 2A, the SO/B motion bias seems to show a similar "reassignment" of movement, with people conceptualizing movement to the object largely in the lateral direction, largely discounting or removing it from the motion initially imparted to it by the carrier, mostly ignoring (or ameliorating in the case of the participants answering correctly) Newton's first law of motion.

Discussion of Experiments 2A and 2B

Both Experiment 2A and Experiment 2B show that even when observers watched a video providing them with a more cue rich environment than the illustrations used in Experiment 1, they still show an AIM bias. Both videos provided observers with depth perception cues like linear perspective, optical shrinkage, motion parallax, and a background scenery to enhance these cues and ostensibly provide them with more information to help them discern the direction of motion of the ball after it was released. However, the AIM bias seems to overwhelm these cues and was even more evident with the videos than with the illustration used in Experiment 1. It should also be noted that across these two experiments the methodology changed, but in both cases a large majority of participants still displayed the AIM bias.

Experiments 2A and 2B also demonstrated that the AIM bias occurs across different speeds of a moving carrier. If observers did not display an AIM bias, more participants should have indicated that the object moves farther forward (or forward) when the carrier is moving faster. However, participants displayed an AIM bias, where the biggest difference in percentages of responses occurred between "backward" and "straight-out" responses. Specifically, there was an increase of "backward" compared to "straight-out" responses when the carrier was moving faster. Table 8 shows the different percentages for correct, straight-out/straight-down, and backward responses given in Experiments 1 and 4 in McCloskey et al. (1983), and Experiments 2A and 2B in the current work. The difference in speed of the moving carrier across the experiments is dramatic. While the walking carrier in McCloskey et al.'s (1983) experiments are moving at ~1 m/s, the running carriers move at 3.86 m/s in Experiment 2A and 5.33 m/s in Experiment 2B. For the walking carriers, the straight-down and backward responses average ~ 53.4% and 16.5%, respectively. When you introduce a carrier moving at ~4–5 times as fast, the straight-out and backward responses average ~31.15% and 47.5%, respectively. When the speed of the carrier increases from 3.86 m/s to 5.33 m/s from Experiment 2A to 2B, these numbers go from 32.6% and 37.2%, respectively, to 29.7% and 57.8%, respectively. Thus, the majority and large majority of responses change from straight-out/straight-down to backward the faster the carrier is moving. While these are four different experiments with different participants, the pattern of responses is telling. We believe that this is a byproduct of the AIM bias. That is, if the motion of the carrier increases, but the forward (or initial) motion of the object released is still discounted then it should have the effect that the carrier moved faster in the initial direction, while the motion of the object in that same direction is ignored, leaving the object to seem like it is left farther behind the distance travelled by the carrier in the initial direction.

Figure 6 shows 12 different experiments where participants answered questions about falling or thrown objects and also shows the percentage of them who responded with a correct, straight-out/straight-down, or backward response. These are grouped into categories where there was no reference frame, where there was a static picture or a question concerning the straight-down belief, where there was live, video, or in-person viewing of a man, box, or train carrying a ball and then dropping it, and where there was a static picture or video shown of a ball being thrown laterally while the carrier was moving forward. There are at least three things that stick out from the figure. First, when there is no perceptual reference frame against which a ball is dropped, all observers see the veridical motion, and when there is a perceptual reference frame present, the averages for a correct response all drop below 50%. This may occur because stimuli used in previous work such as dot moving on its own across a screen is a particle motion, which is much simpler than an extended-body motion. When viewing a dot being released from a box compared to a dot moving on its own, or a ball once it is rolled out of or passes through a tube, one is analyzing an extended-body motion in the former and particle motions in the latter (Kaiser et al., 1992). Particle motion may be understood in terms of the displacement of mass whereas extended-body motion includes multiple dimensions and is thus far more complex to analyze, may provide more uncertainty, and may not be as available to perception (Kaiser et al., 1992). Second, the straight-down belief occurs at about the same percentage as long as there is a perceptible reference frame (straight-down/straight-out line for the middle two categories in the figure). Third, for the experiments in the current paper, there is a higher percentage of backward responses compared to all other categories, while there are the fewest correct responses of any category. As we stated earlier in this discussion, the higher percentage of backward responses is most likely due to the AIM bias and the greater implied or actual speed of the moving carrier prior to the object being released laterally. Another explanation for this may be that participants may believe an object only moves in a direction in which it was last pushed as has been found previously (DiSessa, 1982). In this work, DiSessa observed eight sixth-grade students play a video game in which the goal was to provide impulses to a moving object in order to cause it to hit a target that was located at 90° relative to the object's original path of motion. Children provided impulses to the object perpendicular to its original path of movement, thinking that a

Table 8 Shown are the percentages for correct, straight-out/straight-down, and backward responses for Experiments 1 and 4 in McCloskey et al., 1983 and Experiments 2A and 2B in the current work

Experiment	Correct	Straight-out/ straight-down	Backward
Experiment 1 – McCloskey et al. (1983) –Watching a man walk across a room without a ball moving at 1.14 m/s	38	51	11
Experiment 4 – McCloskey et al. (1983) – Watching a video of man walking and dropping a ball moving at 0.87 m/s	22	56	22
Experiment 2A – Throwing ball while carrier is moving at 3.86 m/s	30.2	32.6	37.2
Experiment 2B – Throwing ball while carrier is moving at 5.33 m/s	12.5	29.7	57.8

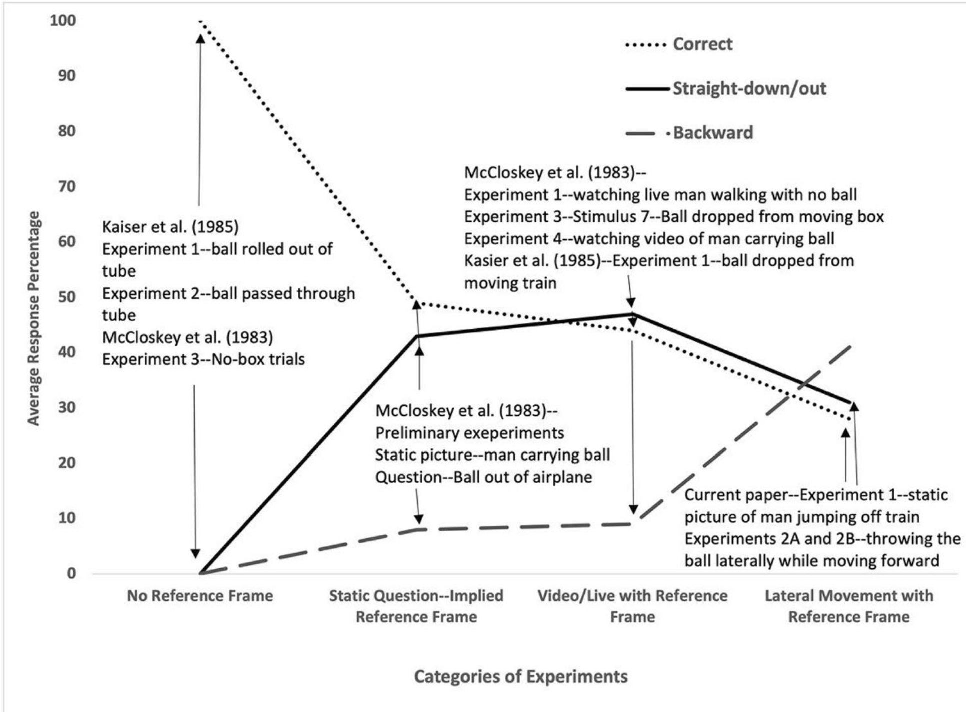

Fig. 6 Shown are the percentages of correct, straight-down/straight-out, and backward responses answers in 12 different experiments by where there was a static picture or a question concerning the straight-down belief, where there was live, video, or in-person viewing of a man, box, or train carrying a ball and then dropping it, and where there was a static picture or video shown of a ball being thrown laterally while the carrier was moving forward

perpendicular or "last" push would make the object move perpendicularly. They essentially ignored the original direction of movement, causing the object to move 135° when they meant it to go 90° relative to its original path of motion.

McCloskey et al. (1983) showed that compared to the motion when a dot was first moving with a carrier (a box – Experiment 3) and then dropped, the judgments of the motion of a dot moving alone (the box was never shown in the no-box trials) displayed veridical motion. In Experiment 3, we tested whether removing the carrier from the ball as soon as the ball is released would also result in perception of veridical motion.

Experiment 3

In the dynamic sequences mentioned in the last paragraphs in the *Discussion* section of Experiments 2A and 2B, we talked about the differences between particle motion and extended-body problems like the one investigated in Experiment 2. In the aforementioned experiments the absolute motion of the dot once released from the carrier or ball once released out of the tube are particle motions and may be perceived more easily, leading to the decrease in straight-down belief frequency. The passing of the rugby ball between players represents a complex extended-body system. In the recording, the rugby players provide both the foreground and background for the ball being passed between them, and the motion of all three together makes for a very complex extended-body system significantly reducing the possibility that the absolute motion of the ball will be perceived as easily as a ball dropped from a carrier on an otherwise blank stimulus display once the carrier disappears (e.g., McCloskey et al., 1983, Experiment 3). This makes other aspects of the recording important to making judgments about the motion of the ball between players. Focusing on aspects of the problem like the direction of the ball, the relative positions of players (receiver in front of, straight across from, or behind the thrower), and the type of throw (overhand/underhand) that may be the salient aspects relied upon for participants to make their judgments is beyond the scope of the current paper. However, we wanted to investigate whether occluding the player throwing the ball once the ball was thrown might reduce (or eliminate) the SO/B bias.

While Experiment 1 shows that people hold a SO/B conceptual belief, Experiments 2A and 2B seem to indicate that this belief is probably exacerbated in the current context due to a perceptible reference frame because the extended-body problem does not easily translate to a perception of the absolute motion of the rugby ball between players. Experiment 3 was performed to test whether this would be the case for the extended-body problem presented in the video used in Experiment 2B.

Table 9 Answers given to the question concerning the direction of the motion of the ball in the video

	In the direction of motion of the thrower	Straight	In the opposite direction of motion of the thrower
Full view condition	6	5	12
Occlusion condition	8	8	7

Method

Participants

Forty-six undergraduates who had not participated in Experiments 1 or 2 (23 female) from The Ohio State University at Mansfield (mean age = 19.67 years, SD= 2.73 years) participated in fulfillment of an Introductory Psychology requirement.

Materials

The recording that was the one used in Experiment 2.

Procedure

Participants watched the video of the ball being thrown. For half of the participants, the procedure was identical to that used in Experiment 2B. For the other half, they watched the same video, but as the thrower passed the ball, then disappeared from view for the remaining video sequence. The rest of the procedure was identical to that of Experiment 2B.

Results

Table 9 shows frequencies of the ball movement answers participants in both conditions gave regarding the video. We recoded the answers into the correct answer (i.e., "In the direction of motion of the thrower") and SO/B answers (i.e., "Straight" and "In the opposite direction of motion of the thrower"). Almost 70% of participants gave SO/B motion bias answers (73.91% full view condition, 65.22% occlusion condition). A chi-square goodness-of-fit test on the recoded data revealed that significantly more participants demonstrated an SO/B bias than who answered the questions correctly, χ^2 (1) = 7.043, p = .008. This was a medium effect, Cohen's w = 0.39.

We also performed a chi-square test of independence comparing frequencies of recoded responses across conditions. This revealed that responses across full-view and occlusion conditions were the same, χ^2 (1) = 0.41, p = .522.

We also recoded "physics instruction" into "no physics instruction" groups by assigning participants with no physics instruction as one group (n = 28), and those participants with at least one high school class (one high school class, one college class, or more than one college class) as another group (n = 18). We then performed a binomial logistic regression analysis using the recoded physics instruction as a factor to test whether physics instruction significantly predicted their answers. Standard binomial logistic regression revealed that the overall model including physics instruction did not statistically predict whether people answered correctly or with a SO/B bias, χ^2 (1) = 0.117, p= .733. A little over 70% (71.43%) of "naïve" observers and over 64% of "experts" (66.67%) demonstrated an SO/B bias. Table 10 shows the counts for correct and SO/B answers for the question asking about the direction of the motion of the ball in the video.

Discussion

Experiment 3 showed that there was very little difference between occlusion and no occlusion groups and the SO/B motion bias. Almost 70% (69.6%) of participants still showed a SO/B motion bias in the current experiment. We believe there are several reasons why our results in the current experiment are different from those of McCloskey et al.'s (1983) no-box trials in Experiment 3. First, unlike McCloskey et al. (1983), we left many components of the reference frame in the video (e.g., the field and the receiver of the throw) even though we removed the thrower from view. Second, the extended-body problem does not easily translate to a perception of the absolute motion of the rugby ball between players – that is, it is difficult to separately perceive the direction of the ball moving in-between players. Third, we believe that given the complicated perceptual scenario a ball travelling to a receiver across a monitor creates, observers may rely on more salient perceptual cues like where the receiver was located relative to the thrower prior to the thrower disappearing from view. In the video that we used the receiver was behind the passer in depth. We believe that remembering where the receiver was relative to

Table 10 Shown are counts for different answers for the question asking about the direction of motion of the ball in the video

Physics instruction	Direction of motion of the ball in the video	
	Correct	SO/B
None	8	20
At least one high school class	6	12

the thrower before he disappeared from view may have been the salient perceptual cue on which the large majority of our observers relied.

Experiment 4

In some of the work on intuitive physics, it has been shown that when both 6- to 12-year-old and adult participants are asked to perform an action task by dropping a tennis or golf ball to hit a target on the floor as they are walking past it, the actions of many of those same participants who held straight-down beliefs generally corresponded with those same participants trying to drop the ball directly over the target. This shows that they neglect inertia both in their beliefs and with their actions (Krist, 2000; McCloskey et al., 1983). For instance, in Experiment 1 of Krist (2000), it was found that judgment of most 6- to 8-year-olds exhibited straight-down beliefs and these same children released a ball to hit a target significantly later than those who did not hold the straight-down beliefs. This showed that these children were using their beliefs to also plan their actions.

Work independent of the straight-down belief that is more closely related to student's core knowledge about the rate at which objects with different object properties fall has also shown that people's beliefs about moving objects may also constrain their interaction with those objects. For instance, in one study concerning the *Galileo bias* – the idea that all objects fall at the same rate irrespective of aerodynamic drag or wind resistance – participants believe that objects differing in mass with volume held constant, and those varying in volume with mass held constant will hit the ground at the same time when dropped from the top of a three-story building (~10 m high) when in fact balls having lesser volume but the same mass, and those having greater mass but the same volume will hit the ground first. When asked to drop objects differing in mass with volume held constant and those varying in volume with mass held constant from a two-story building, for the majority participants holding a Galileo bias – about 68% when varying mass and 55% for varying volume with the other held constant, participants intended to and did drop the balls at about the same time, consistent with their beliefs (Oberle et al., 2005).

A wealth of work in visual perception shows that observers' actions are *not* in line with their intuitive beliefs concerning the motion or orientation of objects. For instance, recreational outfielders who have no problem navigating to and catching fly balls are very poor at predicting where a fly ball will land after viewing one-quarter to one-half of the ball's trajectory and are very poor at identifying the apex of a fly ball (Shaffer et al., 2009; Shaffer & McBeath, 2005). More work consistent with observers' actions being inconsistent with their beliefs shows that American football players' abilities to intercept stationary or moving targets with a thrown football do not fall in line with their intuitions (Dolgov et al., 2009; Shaffer & Maynor, 2011). An independent line of work investigating the visual perception of geographical and man-made slopes has found that people overestimate the slopes of varying surfaces by a factor of ~1.5 whether using haptic, pedal, whole-body, or verbal estimates (Bhalla & Proffitt, 1999; Bridgeman & Hoover, 2008; Durgin & Li, 2011; Hajnal et al., 2011; Li & Durgin, 2010; Proffitt et al., 1995; Shaffer et al., 2018a, b; Shaffer & Flint, 2011; Shaffer & McMamana, 2015; Shaffer & Taylor, 2017). This is contrary to the fact that people have no problem climbing up geographical and made-made slopes, keeping us balanced in an upright position and from tipping over backward, and placing ladders at appropriate orientations to climb.

In Experiment 4 we tested whether, when being moved in a forward direction and asked to throw an object to a target in a lateral direction, participants holding SO/B conceptual beliefs would use these beliefs to guide their motor actions or whether these beliefs are independent of their motor actions. In order to do this, we created an action-based task where people tried to slide a bean bag off a platform to a target located on the floor while they were moving in a direction orthogonal to the target.

Method

Participants

Forty-two undergraduates who had not participated in either of the two previous experiments (26 male) from The Ohio State University at Mansfield (mean age = 19.3, *SD* = 1.85 years) participated in fulfillment of an Introductory Psychology requirement.

Materials

In order to move participants in a direction orthogonal to the target at a specified speed without having them controlling the speed, we pushed them in a Drive Medical Blue Streak Wheelchair with swing away footrests. We securely attached a 0.97-m long piece of .06-m wide by .02-m thick wood to the handles of the wheelchair. The wooden piece extended 0.2-m past the left and right handles of the wheelchair. The target was a cross of 0.02 m painters' tape, each piece 0.15 m × 0.15 m long, that was placed on the floor. A bean bag weighing 0.45 kg was used to push off of the board to try to hit the target. This setup is shown in Fig. 7.

Procedure

The experiment took place in the Campus Recreation Center gymnasium on the campus of The Ohio State University at Mansfield. Participants were asked to sit in the wheelchair.

Fig. 7 The apparatus and setup for Experiment 3 is shown here. The participant sits in wheelchair and slides bean bag off of the wooden board as she is moving in the direction of the viewer of the photo at ~1.45 m/s

Fig. 8 The diagram shown to participants in Experiment 3. Details are discussed in the text

They were pushed for 6.71 m before they reached the target. This was done so that the speed achieved would be equivalent to a slow jogging speed for humans, and so we could achieve approximately the same speed for all participants. We measured the speed of the wheelchair for every participant and the mean speed was 1.45 m/s (*SD* = .095 m/s), and the 95% confidence interval was [1.42, 1.48].

Participants held the bean bag on the piece of wood over the handle of the wheelchair and were asked to slide the bean bag off the piece of wood onto the target located 1.83 m to their right. They were told that the bean bag must be slid along the board and leave the end of the board. All participants complied. The target covered the same area as the bean bag. After participants released the bean bag, the person pushing them continued past the experimental setup for another 5 m. Participants were told to look forward in front of them after releasing the bean bag to prevent them from seeing where it landed. One experimenter pushed the wheelchair and another stood directly in front of the path of the wheelchair looking directly at the face of the participant in the wheelchair. They both made sure that each participant was not looking to the side toward the bean bag with their eyes once it was launched (experimenter in front) or turning their head to the side toward the bean bag once it was launched (both experimenters). All participants complied with this request. A third experimenter measured the depth distance of the bean bag from the target and removed the bean bag from the floor. Participants were not able to see the bean bag landing location relative to the target as they were answering these questions.

Next, participants were asked about how the bean bag traveled from when it left the board to when it landed on the ground. Participants were given the figure shown in Fig. 8 and were told: "The form shows a top-down view of the path of the wheelchair." We then told them: "If you are standing far above the wheelchair looking down reflecting what you see in the drawing, you would not see the downward movement of the bean bag as it traveled from the board to the ground – only the movement of the bean bag relative to the ground surface.

Please draw a line showing how the bean bag traveled relative to the ground surface from the board to the ground where it landed." All participants understood the instructions. If participants drew a line that was not directly orthogonal to the path of the board from which the bean bag was launched, they were asked to first confirm that they indicated it went forward or backward from that point (and the researcher pointed in the direction forward and backward on the figure), and then asked by how many feet did it land in front of or behind the point from which it was launched.

Results

Three participants made multiple marks on the figure making it ambiguous as to how they thought the bean bag moved after being launched. That left 39 participants. For two participants we failed to measure the speed of the wheelchair and the distance the bean bag landed relative to the target. Therefore, for analyses regarding wheelchair speed, distance the bean bag landed from the target, and for when they should have launched the bean bag, we used the remaining 37 participants. For analyses regarding their estimations of the bean bag's travel, we used 39 participants. Average speed of the wheelchair for the remaining 37 participants was 1.56 m/s, $SD = 0.55$, 95% CI: [1.53, 1.6]. The bean bag was both released and landed prior to getting to the target (or short of the target in the depth direction or the direction of the wheelchair's movement) for all but one participant. The mean actual distance from the target was 0.995 meters before reaching the target, $t(35) = 10.87$, $p < .001$, $SD = .55$, 95% CI: [.81, 1.18]. We calculated the distance from the target that each participant (based on the speed of the wheelchair for each participant and the time it would take the bean bag to travel to the ground from the board) should have launched the bean bag and actually did release the bean bag. We assumed that launching velocity would be similar across participants. The mean distance from the target participants should have released the bean bag was 0.61 m ($SD = .04$); the mean distance from the target they did release the bean bag was 1.6 m ($SD = .56$). This means that participants released the bean bag almost one full meter before they should have.

In spite of their releasing the bean bag prior to the target (and the bean bag landing prior to the target), over 69% of participants demonstrated a SO/B motion bias. Eighteen participants indicated that the motion of the bean bag after being released was straight off to the side. Nine participants believed it traveled in a backward direction after being released. We recoded answers into correct ($n = 12$) and SO/B motion bias answers ($n = 27$) as we did in Experiments 2 and 3. A chi-square analysis revealed that a significant number of people demonstrated a SO/SB bias, χ^2 (1)= 5.77, p=.016. This was a medium effect, Cohen's $w = 0.39$. The participants who correctly indicated that the bean bag traveled forward in the direction of the motion of the wheelchair after it left the board also slightly *over*estimated how far it traveled forward, $t(9) = 2.31$, $p = .041$, $M_{Actual} = 0.61$ m ($SD_{Actual} = 0.04$m), $M_{Estimated} = 1.07$ m ($SD_{Estimated} = 0.68$ m). This was a medium effect, Cohen's $d = 0.67$.

In order to test whether participants' actions were in-line with or independent of their intuitive beliefs, we performed an independent-samples t-test comparing participants actual release points in the SO/SB bias conditions (the bean bag traveled straight out or backward after being released) to the correct answer (the bean bag traveled forward after being released). There was no statistical evidence that these were connected, $t(34) = .844$, $p = .404$, $M_{AIMBias} = -1.55$ m, $SD_{AIMBias} = 0.12$, $M_{Correct} = -1.72$, $SD_{Correct} = 0.16$. The pattern of the means for all three possibilities (forward, straight out, and backward) are not systematically in line with their intuitive beliefs and are shown in Table 11.

Discussion

Experiment 4 showed that the majority of participants (over 69%) revealed a SO/B motion bias in their conceptual beliefs, but this did not translate into an action of releasing an object too late to hit a target located laterally relative to the direction they were moving as has been shown in work in the past (cf. Krist, 2000; McCloskey et al., 1983). Participants holding an intuitive belief that the bean bag moved backward after being released, released the bean bag after the "forward" group, but prior to the "straight out" group. If we had found consistent evidence for actions being in line with participants' conceptual beliefs, the "forward" group should have released the bean bag first (having the largest negative number – negative indicating it was released prior to the target), the "backward" group should have the smallest negative number, and the "straight out" group should have been somewhere in-between.

In Experiment 4, participants' actions showed that people understand that the bean bag must be released prior to reaching the target in order to hit it. However, participants' conceptual beliefs overwhelmingly showed that they believed that the bean bag moved straight across or backward when they were moving forward. The disconnect between their intuitive beliefs and actions is something that has been found in past work concerning identifying aspects of an object's trajectory (Shaffer et al., 2013; Shaffer & Maynor, 2011; Shaffer et al., 2009; Shaffer & McBeath, 2005), but is at odds with what has been found in past work concerning the straight-down belief (Krist, 2000; McCloskey et al., 1983). We believe that this discrepancy may be explained by the differences in what we asked participants to describe. In the current work we asked them to explain the path of the bean bag to the target after it was released. Regarding the straight-down belief, participants were asked to drop a ball to hit a target while walking by it, and their drop times were compared to a group that were

Table 11 Answers given to the question concerning the direction of the motion of the bean bag and the mean release times of the bean bag

	In the direction of motion of the thrower	Straight	In the opposite direction of motion of the thrower
Frequency (%)	12 (30.77%)	18 (46.15%)	9 (23.08%)
Mean release time in meters (SD)	-1.71 (0.56)	-1.48 (0.65)	-1.68 (0.37)

asked to drop a ball directly over the target. Participants were then asked what their intentions were. Someone in the current work could have intended to and did release the bean bag prior to reaching the target but thought that it traveled straight out to the target when it was released, while someone else may have intended to and actually did release the bean bag later but thought that it traveled forward to the target when it was released. That is, where the participant intended to release it may be correlated with release time. However, this may or may not be connected to their perception/conceptualization of how the target moved.

While the data show that participants' actions did not match their conceptual beliefs, this result may be explained by the fact that the visual eccentricity of the target played a role in participants undershooting the target in the depth direction. For instance, it has been shown that when targets are located in a more eccentric position, arm movements guided by peripheral vision are even more eccentric than the target, which in Experiment 4 would result in the undershooting that was seen in all but one participant, provided that perception of the lateral distance (from board on wheelchair to the target) remained unchanged (Bédard & Proteau, 2003; Bock, 1986). Therefore, the explanation of the difference between conceptual beliefs and action in Experiment 4 may be due to a perceptual bias in the action portion that forced participants to rely on feedback from peripheral vision to guide motor movements. This feedback has been shown to be controlled by a set of parietal regions distinct from those used by foveal vision (Prado et al., 2005).

General discussion

The AIM bias is a cognitive-perceptual bias where the inertial motion of the moving carrier that releases an object is discounted by anywhere between ~60% and 88% of observers. We have shown that the AIM bias explains the straight-down belief, the "straight-up-and-down" belief, the SO/B belief, and why the backward responses increase as the moving carrier increases in speed. The AIM bias also explains the inertial amelioration bias for observers who indicate that the object moves forward – while they indicate it moves forward, they underestimate the distance that it moves forward.

We have also shown that when there is no perceptual reference frame against which a ball is dropped, all observers see the veridical motion, and when there is a perceptual reference frame present, the averages for a correct response all drop below 50% (please see Fig. 6).

This suggests that the 'seeing-is-believing" hypothesis given by McCloskey et al. (1983) plays a large role in observers' responses. Krist (2000) showed that children dropping two different types of balls, dropped the lighter "cotton wool" ball at the same time as a heavier ball. Krist (2000) argued that that the straight-down belief results from a cognitive belief that is already in place and is not generated by a perceptual illusion. This claim has at least one problem. First, Oberle et al. (2005) first found that a majority of participants demonstrated a Galileo bias – falsely believing that balls differing in mass and volume fall at the same rate. These people dropped balls differing in volume and mass at approximately the same time. There is a strong argument to be made that this could explain the results of Krist (2000).

We do not believe that any experiment could tease apart whether the belief originates from perception independent of cognition, or vice versa. We believe that a combination of the two are likely responsible for the responses in previous work as well as those in the current paper. This would explain why people hold the AIM bias for static pictures (either from a cognitive belief about the way things work and/or from perceptual experience leading to a more cognitive belief). This would also explain why when a perceptible reference frame added, straight-down and SO/B responses increase and when faster movement is added to the carrier, one sees an increase in backward responses. These mimic more perceptual experiences, whether they are from previous experience or the current experience while viewing the scenario, resulting in an AIM bias. The AIM bias serves as a simple explanation for a family of beliefs including those in the current paper as well as those shown in previous work. This work joins a large body of work showing that people's intuitive beliefs about principles of physics are often at odds with what occurs physically or according to Newtonian mechanics.

Author Note Kirsten Greer is now at Indiana University, School of Public Health.

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Data Availability None of the data or materials for the experiments reported here is available, and none of the experiments was preregistered.

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