Perception, 2009, volume 38, pages 399 – 410

doi:10.1068/p6114

Evidence for axis-aligned motion bias: Football axis – trajectory misalignment causes systematic error in projected final destinations of thrown American footballs

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Received 21 June 2008, in revised form 26 August 2008; published online 2 March 2009

Abstract. The axis-aligned motion (AAM) bias is the tendency of observers to assume that symmetric moving objects maintain axis – trajectory alignment and to bias their judgments of trajectory toward the axis when they are misaligned. We tested whether humans exhibit an AAM bias in a realistic, cue-rich, 3-D setting by examining the impact of axis – trajectory misalignment on estimates of final destinations of thrown American footballs. In experiments 1 and 2 we show that observers are significantly worse in judging destinations of footballs than those of volleyballs and basketballs. This difference in performance is due to the deviation of the football's axis from trajectory in flight, as shown by the correspondence of participants' lateral judgment error and the football's lateral axial deviation from trajectory, which was predicted by passer handedness. Nearly all animals exhibit bilateral symmetry and maintain axis – trajectory alignment during locomotion, and we argue that the AAM bias is complementary mental attunement to the natural regularity of this axis-aligned motion. Furthermore, this bias is also a prototypical example of a perceptual regularity that is a mixed blessing—advantageous in perceptual judgment tasks of axis – trajectory-aligned moving entities like most living creatures, and disadvantageous in tasks demanding judgments of axis – trajectory-misaligned moving objects which are typically artifacts.

1 Introduction

The perception – action system is attuned to meaningful combinations of invariant properties of the ambient energy array that afford the organism the ability to successfully perform various actions (J J Gibson 1966, 1979). Animals are also aware of a multitude of near-invariant natural regularities; highly reliable patterns in their environment that have an impact on their well-being. Reflecting this, established behavioral (Skinner 1974), cognitive (Shepard 1987, 2001), developmental (E J Gibson 1997; Piaget 1969), Gestalt (Arnheim 1974), psychophysical (Helmholtz 1867/1962), ecological (J J Gibson 1966, 1979), and embodied cognition (Clark 1997; Glenberg 1997) theoretical frameworks posit perceptual-cognitive mechanisms, which we will call perceptual regularities in the present discussion, that are complementary mental attunements to salient physical or natural regularities.

One example of a salient natural regularity is the vertical symmetry found in nearly all living organisms, an adaptation in response to gravity that provides lifeforms with this orientation-defining shape characteristic (Hargittai and Hargittai 1994; McBeath et al 1997). Perceptual attunements to this and other symmetry-based natural regularities are evident in adults (eg Boutsen and Marendaz 2001; Evans et al 2000; Freyd and Tversky 1984; Mach 1897/1959; Palmer and Hemenway 1978; Sekuler and Swimmer 2000; Tyler 1996; Wenderoth 1994, 1996, 1997a, 1997b, 2000) and in infants (eg Bornstein and Krinsky 1985; Bornstein et al 1981; Humphrey and Humphrey 1989), who are more sensitive to the presence and violation of vertical symmetry than any other symmetries. A corollary natural regularity is that stationary lifeforms like plants typically exhibit overall radial symmetry whereas mobile organisms usually exhibit bilateral symmetry (Hargittai and Hargittai 1994) because of different weight distribution demands. In order to maintain balance with respect to the gravitational force, stationary plants are vertically radially symmetric (Chambers et al 1999; Hargittai and Hargittai 1994), whereas mobile organisms almost universally travel along a vertical bilateral symmetry plane (Chambers et al 1999; Hargittai and Hargittai 1994; Morikawa 1999), even if they also possess some local asymmetries (McBeath et al 1997). This behavior can be formalized into another corollary natural regularity, axis-aligned motion (AAM)—the correspondence between an animal's motion direction and its primary axis (typically defined by bilateral symmetry and/or elongation) that is observed in nearly all mobile organisms (Hargittai and Hargittai 1994; McBeath et al 1997; Morikawa 1999).

Recent object motion perception research (Dolgov et al, in press; Morikawa 1999) has demonstrated a perceptual attunement to the AAM natural regularity: perceived motion direction of bilaterally symmetric objects is influenced by the object's axial orientation in relation to its trajectory—a phenomenon we have named the axis-aligned motion bias. Compared to judgments of asymmetric shapes, participants are faster and more accurate in judging the estimated final destination of symmetric shapes that maintain axis–trajectory alignment and move in an ecologically consistent manner. However, when the axis is misaligned to trajectory, participants are significantly less accurate and there is a systematic perceptual bias of the perceived trajectory vector toward the axis. Since a large proportion of salient moving objects in the natural world do exhibit AAM, the AAM bias—the tendency to perceive motion as axis-aligned—is ecologically valid and typically advantageous. Nevertheless, AAM bias is occasionally disadvantageous, such as when trying to ascertain the motion direction of unusually moving creatures like sidewinding snakes (Jayne 1988) and crabs (Wootton 1999) and, more typically, in judgments of human-made bilaterally symmetric moving objects that may violate axis–trajectory alignment at times, like vehicles (eg skidding cars, planes, and sea-going vessels) and projectiles (footballs).

In the current experiments we examine perception of bilaterally symmetric axis-misaligned moving objects (those whose axial orientation differs from trajectory) in a real-world moving-object final-destination estimation task. Specifically, we compared participants' performance in judging final destinations of thrown American footballs to their judgments of spheroid objects that lack a primary axis: volleyballs in experiment 1 and basketballs in experiment 2. To our knowledge this is the first empirical study to test if projected final-destination judgment is affected by axis–trajectory misalignment in a realistic, cue-rich, 3-D setting.

2 Experiment 1

The purpose of this experiment was to investigate whether observers are subject to the AAM bias in a realistic setting by examining the effect of a primary axis on the estimation of projectile destinations after viewing only the initial three-quarters of their flightpath. Specifically, we compared participant accuracy scores in estimates of final destinations of thrown American footballs to those of volleyballs, and examined the direction and magnitude of error in relation to the football's axial tilt away from trajectory. In the course of the experiment, we verified that thrown American footballs did not travel axially aligned to their trajectory for short passes ($\sim$15 m), but rather systematically laterally tilted in the direction consistent with passer handedness, likely as the result of biomechanics.

In a pilot experiment with a right-handed Arizona State University (ASU) sophomore quarterback, we observed that, for throws to a receiver standing approximately 15 m away, footballs did not maintain axis–trajectory alignment in flight. Mean velocity was 14.2 m s^{-1} and ranged from 12.2 m s^{-1} to 17.4 m s^{-1} ($n = 20$). Mean lateral axial deviation from trajectory was 9.8° to the right of trajectory and was directionally consistent with the passer's handedness on all trials. The magnitude of the absolute mean vertical axial deviation from trajectory (4.4°) was less than half of the lateral deviation, and directionality was typically above trajectory, but not systematic within or across trials.

On the basis of football throw physics (Rae 2003) and kinematics (Fleisig et al 1996; Rash and Shapiro 1995) literature, we conjecture that our finding of a systematic axial deviation from trajectory in flight is due to an initial deviation of the football's axis from trajectory at the time of release, which is necessary for the application of the torque needed to successfully throw a tightly spiraling pass. Our pilot data suggest an empirical re-evaluation of two key assumptions made by current (Rae 2003) and past (Brancazio 1985a, 1985b) theoretical physical models: (i) perfect initial alignment between the football's axis and trajectory at the time of release; and (ii) initial throw speeds upwards of 25 m s^{-1}. Unlike the predictions of the theoretical-physics models which describe a football that travels with its axis aligned to trajectory, our empirical results show a systematic lateral deviation of the football's axis consistent with passer handedness across all the passers we tested in the course of our experiments ($n = 3$). Moreover, even the college-level quarterback failed to achieve the threshold velocity and initial axis – trajectory alignment specified by physics models for a perfect axis-aligned throw—a scenario which should be characterized by a high degree of wobble (Rae 2003), which was not the case with this passer. Therefore, although we believe these theoretical models to be elegant and parsimonious, they may not be characteristic of a football pass thrown by an amateur quarterback. Rather, they aptly reflect an idealized football throw, which is likely only achieved by professional passers in unhindered situations.

We hypothesized that owing to axis-trajectory misalignment observed in thrown footballs, (i) observers will judge the estimated destinations of thrown footballs less accurately than of volleyballs; and (ii) observers will systematically bias their destination judgments of thrown footballs in the direction that the axis is tilted away from trajectory.

2.1 *Method*

2.1.1 *Participants.* Ten students (three female and seven male) recruited from ASU's introductory psychology pool participated and received course credit as compensation. All had normal or corrected-to-normal vision.

2.1.2 *Apparatus.* Data were collected at the ASU Dynamic Motion Analysis Laboratory, which was equipped with an eight-camera Vicon motion-capture system (resolution of 1 mm) that recorded the real-time position of marked objects at a frame rate of 120 Hz over a volume of 240 m^3 (10 m $\times$ 8 m $\times$ 3 m). The thrown objects (stimuli) consisted of volleyballs and American footballs whose tips were marked with infrared retro-reflective tape (radius 10 cm) to record the football's 3-D position and orientation. Two volunteer passers (one left-handed, one right-handed) with experience of playing quarterback at an intramural level threw the balls at a 2 row $\times$ 4 column array of circular targets (1 m diameter hula hoops with 10 cm spacing, suspended in a soccer-goal-like PVC structure). Passers were instructed to throw as naturally as possible. A Canon XL1 digital video camera placed 3 m behind the passer recorded the final destinations of the projectiles at 120 Hz.

Football orientation and trajectory location were recorded by the motion-capture system and later imported into MATLAB for analysis. Two thirds of the ball's flight-path was visible to the Vicon cameras, with the remaining missing portion having been divided equally between initial and final segments by placing the target array and passer equidistant from the motion-capture recording space (see figure 1). Axial deviation data were computed with the following three-phase MATLAB algorithm: (1) pre-processing: (a) average front (array F, n elements) and back (array B, n elements) of football 3-D

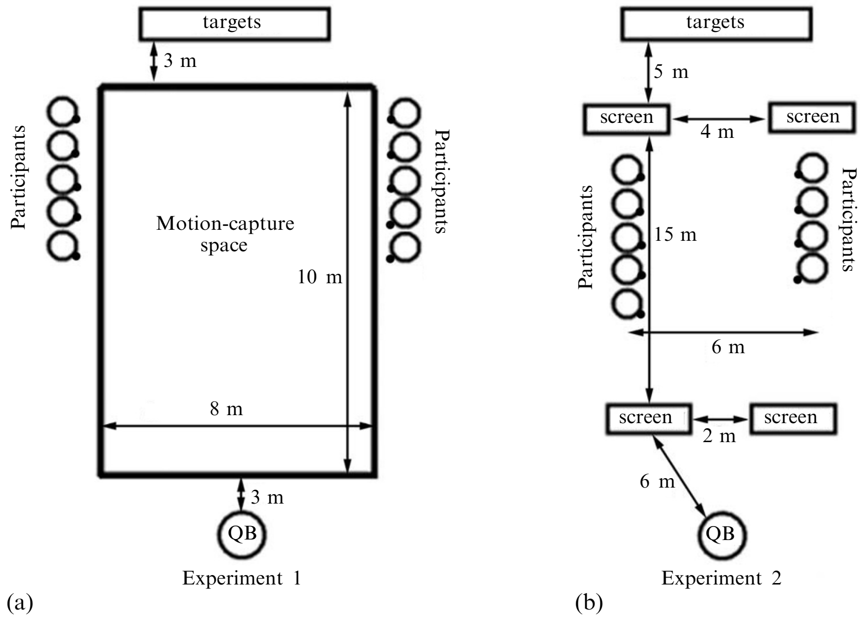

Figure 1. Bird's-eye-view diagrams of the experimental setup in (a) experiment 1 and (b) experiment 2. In experiment 1, observers' view of the target array was blocked by directional blinders. In experiment 2, observers' view of the target array and the passer was blocked by pairs of dense foam screens. QB = quarterback.

coordinates to obtain coordinates for the ball's centroid for each captured frame and reconstruct the ball's trajectory by connecting adjacent positions (array C, n elements), (b) construct an array of adjacent centroid pairs (from C) in the ball's trajectory (array T, $n-1$ pairs). This array is used in our calculations as a real-time measure of trajectory. (2) Horizontal plane deviation/yaw: (a) trajectory orientation: obtain arctangent value for each successive x, y coordinate pair in T; (b) axial orientation: obtain arctangent value for each coordinate pair defined by corresponding points across arrays F and B (drop first frame); (c) subtract values to obtain array of horizontal axial deviation angle values for the final $n-1$ frames of each recording. (3) Pitch/vertical plane deviation/pitch: (a) trajectory orientation: obtain arctangent value for each successive y, z coordinate pair in T; (b) axial orientation: obtain arctangent value for each coordinate pair defined by corresponding points across arrays F and B (drop first frame); (c) subtract values to obtain array of vertical axial deviation angle values for the final $n-1$ frames of each recording. Lateral and vertical plane axial deviations for each trial were computed by averaging the elements in the arrays obtained in steps 2c and 3c of the above algorithm. Since wobble is symmetric about the football's bilateral axis and we are sampling at a rapid pace (120 Hz), it likely did not impact our axial deviation calculations.

2.1.3 *Procedure.* Because of the demands of the motion-capture system and its confining room, we were limited to 16 m throws. Two groups of five participants were positioned in columns adjacent to the capture floor. All participants stood in front of the target array with their backs to the targets at an angle of approximately 135° and were ~0.5 m apart (see figure 1a). Participants were explicitly instructed to try to keep their eye on the ball during trials and not to collaborate in making their responses. An experimental assistant ensured this was indeed the case.

The right-handed passer threw in the first part of the session and the left-handed passer threw in the second, and target destinations were counterbalanced in advance.

24 football and 24 volleyball trials were completed in alternating groups of 6. Participants were only able to view the initial portion ($\sim$7–9 m) of each pass and were prevented from seeing the final destination of the throws by holding a rectangular plywood board (30 cm $\times$ 50 cm) that functioned as a directional blinder. Participants were asked to hold the board perpendicular to the side of their head that was closest to the target array, with one end of the board balanced along the top of the trapezius muscle on the corresponding shoulder. After viewing each throw, participants judged the final destination of the projectile by putting an 'X' in the corresponding target on their response sheets, which were collected and scored in terms of accuracy and deviation from actual final destination for trials on which participants erred.

2.2 *Results and discussion*

Our hypotheses were supported. As we previously found in the prior pilot experiment, the football's axis deviated from trajectory in flight and the lateral deviation was consistent with the handedness of the passer in 100% of the trials. Mean lateral axial deviation from trajectory ($n = 24$) was 24.6° to the right for the right-handed passer and 24.0° to the left for the left-handed passer. Overall mean velocity for both passers was 11.5 m s^{-1}. As with the college-level passer in our pilot experiment, the right-hander's mean absolute vertical axial deviation (6.9°) from trajectory was much less than the lateral deviation, and the vertical directionality was inconsistent across trials. On the other hand, the left-hander's throws exhibited systematic downward tilt of 17.2°. It appears that lateral deviation is more systematic whereas vertical deviation may vary across passers and situations.

Table 1 illustrates that participants' accuracy was greatly above chance (12.5%). Observers were significantly worse in judging the destinations of American footballs compared to volleyballs in a single-factor (ball type) within-subjects ANOVA ($F_{1,9} = 23.89$, $p < 0.01$, $\eta^2 = 0.73$). For the next analysis, we computed lateral and vertical judgment-error deviation scores for those trials in which participants misjudged the ball's final destination. The error magnitude was determined by the distance from the actual final destination of the projectile to the participant's response, in whole target units. Errors to the left or below actual destination were coded as negative, and to the right or above as positive.

Table 1. Accuracy in estimates of football and volleyball final destinations for all participants in experiment 1. Nine of ten participants were more accurate in estimating final destinations of volleyballs, and the mean difference in performance was 13.6%.

Participant number	Judgment accuracy/% correct	
	football	volleyball
1	40.0	58.3
2	40.0	54.2
3	72.0	70.8
4	60.0	70.8
5	52.0	75.0
6	20.0	50.0
7	48.0	58.3
8	36.0	45.8
9	44.0	58.3
10	40.0	45.8
Mean	45.2	58.8
SD	14.1	10.5

In the lateral direction, the pattern of errors exhibited by the participants fully supported our hypotheses. We employed two, 2-level within-subjects factors—ball type (football, volleyball) and passer handedness (left-handed, right-handed)—and one between-subjects factor—side—that indicated the positioning of the participant in the columns on the left side or right side of the throw path. Only trials in which participants erred were included in the analysis; data were collapsed to four mean judgment-error values for each participant by averaging trials in each cell of the fully crossed ball type × handedness design. A mixed ANOVA revealed a significant interaction between passer handedness and ball type ($F_{1,9} = 6.82$, $p < 0.05$, $\eta^2 = 0.46$) (see figure 2).

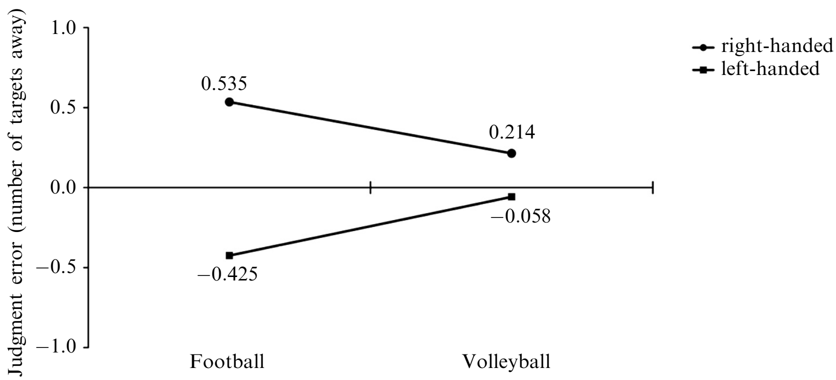

Figure 2. Experiment 1. The magnitude of judgment error was equal to the number of array targets away from actual destination; rightward error was coded as positive, leftward as negative. Right-handed throws produced laterally right-tilted balls whose estimated final destinations were experienced to the right of actual destinations, while left-handed throwers produced left-tilted balls that were experienced to the left of actual.

We identified a systematic bias in judgments of footballs' final destinations, as illustrated by the direction of lateral judgment errors corresponding to the lateral axial deviation of the football from trajectory, which was predicted by passer handedness. Pairwise comparisons revealed that the difference in mean judgment errors between the two passer-handedness conditions was significant at $\alpha = 0.05$ (Sidak adjusted). On the other hand, while the direction of error for volleyball trials also corresponded to passer handedness, the errors for judgments of volleyballs approached zero for throws from either passer and means were not significantly different from one another. We also computed a measure of average group error on any given trial by averaging judgment error across all subjects and found a significant relationship between the football's lateral axial deviation from trajectory and group lateral error ($r_{23} = 0.52$, $p < 0.01$). There was no overall contribution of side ($F_{1,9} = 1.87$, $p = \text{ns}$).

In the vertical direction, participants generally exhibited a nonsignificant tendency to judge destination somewhat above actual, but there was generally a lack of support for vertical judgment errors being associated with the footballs' axial tilt away from trajectory. We performed a mixed ANOVA on the football data with vertical axial deviation (above or below trajectory) as the within-subjects factor and side as the between-subjects factor. The analysis showed a lack of an AAM effect in the vertical direction; the interaction was not significant, nor were the main effects (all $F_{1,9}\text{s} < 2$). Furthermore, the correlation between vertical axial tilt from trajectory and group vertical error was not significant ($r_{23} = 0.13$, $p = \text{ns}$). The lack of a systematic effect in the vertical direction is not surprising because of the complexity of the trajectory in the vertical plane (parabolic), as well as the reduction of the influence of AAM bias as the result of a two-fold reduction of the mean vertical axial deviation (12.1°) as compared to the mean lateral deviation (24.3°). Additionally, the ceiling imposed by the

Vicon motion-capture system that limited the target array to two rows in height may not have allowed for sufficient variance in vertical judgment-error scores and contributed to the lack of an effect in that direction.

In summary, our results supported our hypotheses and were consistent with an AAM bias, but only for the lateral direction. The final destinations of the footballs were more difficult to estimate than those of volleyballs and participants' errors were consistent with the lateral axial deviation of the football from trajectory. In the next experiment we verified our findings with judgments of longer throws, a balanced target array, and stimuli that were equated for size and color.

3 Experiment 2

The purpose of this experiment was to confirm the results of experiment 1 in a real-world setting that was not constrained by the motion-capture system and allowed participants to observe longer, more realistic throws. Furthermore, we reduced the contribution of top–down factors to participants' real-time judgments by preventing them from seeing the passers making the throws. We again hypothesized that: (i) observers will judge the destination of thrown footballs less accurately than that of basketballs; and (ii) observers will systematically bias their judgments of football destination in the direction that the axis deviates from trajectory.

3.1 *Method*

3.1.1 *Participants.* Nine students (one female and eight male) from ASU's introductory psychology pool participated and received course credit as compensation. All had normal or corrected-to-normal vision.

3.1.2 *Apparatus.* The experiment took place at a gymnasium on ASU's campus. We utilized three professional Canon video cameras operating at a frame rate of 120 Hz to record trajectories, orientation, and final destinations of the stimuli that were matched for color and size and consisted of American footballs and junior-size basketballs. One camera was positioned directly behind and slightly above the passers to record the initial lateral deviation of the balls and their final destinations. A secondary camera was positioned 12.5 m along the throw path pointing upward to confirm the football's lateral deviation half way through its flight. The third camera was positioned 22 m away on the opposite side of the gym to obtain a sideward view of the passer and the entire throw.

Two volunteer passers (one left-handed, one right-handed) with experience playing quarterback at an intramural or high-school level threw passes at a 4×4 digital grid of square targets (1 m across) projected onto a wall that was at a distance of 25 m from the passers, with the bottom of the grid positioned 1.5 m from the floor. We used a Dell 3400MP projector that was placed 3 m behind the passers and at a height of 2 m from the floor.

3.1.3 *Procedure.* As in experiment 1, two groups of participants were positioned in columns adjacent to the ball's throw path (see figure 1b). All participants stood several meters in front of the target array with their backs to the targets at an angle of approximately 160°. A pair of opaque foam screens (120 cm wide $\times$ 200 cm tall) was positioned behind the participants to prevent them from seeing the final destination of the projectiles. The participants stood approximately 0.5 m apart and could not see the passer who was also occluded by an identical pair of foam screens. Each trial was verbally cued by the experimenter, at which point participants anticipated the ball approaching from the gap between the screens closest to the passer. Only the middle portion ($\sim$8–12 m) of the flight path was visible. As with experiment 1, after viewing a pass, the participants estimated the final destination of the projectile by putting an 'X' in the corresponding target on their response sheets. 40 football and 40 basketball trials were completed in alternating groups of 5 throws, with the left-handed passer throwing in the first half of the session and the right-hander in the second half.

The directionality of the football's lateral axial tilt from trajectory was verified by frame-by-frame video analysis from two cameras and was found to be consistent with the data observed in experiment 1 within the video segments. We limited our analysis to frames in which the balls' orientation was clearly evident, which typically amounted to approximately the first thirty frames ($\sim$0.25 s) from the camera behind the passer and about ten frames of the upwards-facing camera. We could not obtain confident estimates of the overall magnitude of axial deviation, so we constrained our analysis to a binary directionality judgment (right or left). Lateral deviation was scored by comparing the number of frames that the ball's axis deviated to the right or to the left from its trajectory, which was constructed from connecting successive ball centroids. Confirming the findings of the first experiment, we found ball lateral deviation was systematically consistent with passer handedness for both passers. In the vertical plane, the complexity of the flight profile (parabolic) and the distance of the side-view camera away from the ball unfortunately precluded us from obtaining a reliable vertical axial deviation assessment.

3.2 *Results and discussion*

As seen in table 2 and figure 3, the results of this experiment again support our hypotheses of observers exhibiting an AAM bias. Participants were notably above chance (6.25%) and exhibited inferior performance in judgments of final destinations of axis–trajectory misaligned moving objects compared to judgments of spheroids. As in experiment 1, we found that judgment error corresponded to footballs' lateral axial deviation from trajectory, as well as an interaction between passer handedness and ball type.

Table 2. Accuracy in estimates of football and basketball final destinations for all participants in experiment 2. Seven of nine participants were more accurate in estimating final destinations of basketballs, and the mean difference in performance was 13.9%.

Participant number	Judgment accuracy/% correct	
	football	basketball
1	17.5	42.5
2	15.0	32.5
3	30.0	20.0
4	12.5	27.5
5	12.5	57.5
6	7.5	22.5
7	5.0	15.0
8	55.0	50.0
9	20.0	32.5
Mean	19.4	33.3
SD	15.2	14.2

Judgments of football destinations were significantly less accurate than judgments of basketball destinations in a single-factor (ball type) within-subjects ANOVA ($F_{1,8} = 6.77$, $p < 0.05$, $\eta^2 = 0.46$). We computed judgment error scores in an identical manner to experiment 1, and performed an analogous ANOVA with the same three factors: ball type, passer handedness, and side.

As figure 3 shows, our results mirrored those of the previous experiment. We observed an interaction between ball type and passer handedness as in the previous experiment, only it was marginally significant here ($F_{1,8} = 4.00$, $p < 0.10$, $\eta^2 = 0.36$).

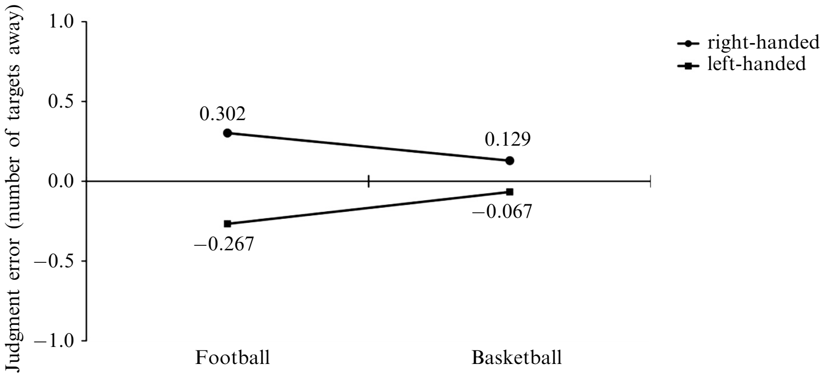

Figure 3. Experiment 2. Again, the magnitude of judgment error was equal to the number of array targets away from actual destination; rightward error was coded as positive, leftward as negative. As in experiment 1, right-handed throws produced laterally right-tilted balls whose estimated final destinations were experienced to the right of actual destinations, while left-handed throwers produced left-tilted balls that were experienced to the left of actual.

Pairwise comparisons revealed a systematic bias in participants' judgments of football destinations that was consistent with passer handedness; mean judgment error between the two passer-handedness conditions was significant at $\alpha = 0.01$ (Sidak adjusted). The same was not true of judgments of basketballs, where means approached 0 for throws from both passers. As before, there was no effect of side ($F_{1,8} = 0.29$, $p =$ ns).

Although we do not have precise measurements of the velocities and trajectories of the balls in experiment 2, we can conclude that the AAM bias affected participants approximately equivalently across the range of task demands and projectile properties in our pair of experiments. When we compare the results of the two experiments, we see that, although accuracy was higher in experiment 1, the magnitude of average lateral error was greater than what was observed in experiment 2. This decrease in mean lateral error is due to the inclusion of a higher number of errors made in the vertical direction in the overall analysis in the second experiment—a product of vertically doubling the target array. A comparison of tables 1 and 2 clearly shows that the task in our second experiment was much harder than in our first, for both spherical and ellipsoid projectiles. In fact, when we compare the decrease in performance for each projectile type, it is approximately 14% in both cases. This suggests that whichever factors influenced the difficulty of the task (projectile velocity, pass length, array size, etc), did so approximately equally for both spheroids and ellipsoids.

For perception of bilaterally symmetric objects, increased target velocity could modulate the impact of the AAM bias by decreasing its impact on perception as the result of the loss of axis-defining information, causing performance to approximate judgments of asymmetric shapes. On the other hand, projectile velocity could have the opposite effect, and impair trajectory perception thereby making final destination judgments more susceptible to any axis-aligned influences. In fact, we would expect these two components to ultimately interact in determining the degree of AAM bias in a given scenario.

In summary, the results of the current experiment replicate those of experiment 1 and provide further support for our main thesis that observers have an AAM bias and use the axis of symmetry as a cue in judging the direction of moving objects.

4 General discussion

While having 'bias' in a phenomenon's name typically implies that it is characterized by an unceasing perceptual disadvantage, for the vast majority of evolutionary history having an AAM bias would have been advantageous. Nearly all animate living things travel along their bilateral symmetry axes, and an attuned perceptual system can utilize this natural regularity to ascertain the direction of moving creatures. AAM bias, the tendency of the observer to perceive a perfect correlation between an object's motion direction and its axial orientation, regardless of its veridicality, is a prototypical example of a perceptual regularity that is a mixed blessing. It is advantageous for judgments of ecological moving objects, and occasionally unfavorable in judging the movement of some artifacts. Moreover, AAM bias is more pronounced in stationary perceptual judgment tasks. In an alternative experimental paradigm that immerses participants in a large, floor-projection-based mixed-reality environment, we recently found that the effects of the AAM bias can be ameliorated by allowing participants to make active judgments by walking to a shape's final destination and hence requiring them to engage in a natural pursuit task (Dolgov et al, in press).

We propose that AAM is just one example of an array of natural regularities, and that the human perceptual system can become attuned to perceive and utilize a number of such highly reliable patterns in the environment. As J J Gibson (1979) frequently pointed out, although we are highly visual creatures, the search for patterns that drive behavior must encompass all the perceptual domains. An example of natural regularity in the acoustic realm is the correspondence between changes in frequency and intensity of a moving sound source. McBeath and Neuhoff (2002) found support for a perceptual regularity reflecting this correspondence by demonstrating that when this relationship is broken and acoustic intensity changes while the frequency of a dynamic sound source remains constant, listeners continue to perceive a change in pitch due entirely to the intensity change, and also vice versa.

Returning to the visual domain, symmetry is a nearly ubiquitous feature of the environment and likely not only contributes to AAM bias but to many other perceptual regularities as well. One example is that object symmetry entails alternative paths in studies of apparent motion (McBeath and Shepard 1989; Shepard 2001). Combined with the findings that apparent motion achieves object conservation and traverses a kinematically simplest path in 3-D space that is specified by an object's geometry, these perceptual regularities illustrate further mental attunement to the natural movement of real objects in the world (Shepard 2001).

In addition to the current experiments and prior AAM bias research cited above, Bucher and Palmer (1985) found that AAM facilitated pointing judgments of ambiguously oriented triangles and concluded that AAM is a fundamental cue for establishing an object's reference frame. To the extent that it is a reliable regularity for salient moving objects like likeforms, AAM provides a potentially propitious cue that could be used to improve automated video-based tracking algorithms. In contrast, with the proliferation of mobile machines and human – machine interfaces, there are increasing instances in which having an AAM bias may be deleterious for humans. Specifically the AAM bias will impair performance in any situation where a stationary observer has to judge the direction of bilaterally symmetric vehicles, projectiles, and other mobile entities that are not following AAM principles. Poignant examples exist in military applications that utilize 2-D graphical interfaces for remote operation of unmanned aerial vehicles that employ human-operated machine-aided targeting systems, and also in many industrial applications that involve remote operation of heavy machinery. Other examples exist on much smaller scales, for instance in medical contexts like robotically assisted microsurgery. While interactions with technology sometimes highlight the downside of this perceptual regularity, in the vast majority of cases, the AAM bias is a beneficial mechanism for accurately judging the direction of many of the moving objects that populate our environment.

Acknowledgments. This research was supported by NSF grants BCS-0318313 and CISE-0403428. We would like to thank the NSF, Arizona State University, the Departments of Psychology and Engineering, and the Arts, Media, and Engineering Program for fostering our research. We would also especially like to thank Eric Amazeen, Clark Presson, Crystal Oberle, and Amy Dolgov for their invaluable contributions to this work.

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ISSN 0301-0066 (print) ISSN 1468-4233 (electronic)

PERCEPTION

VOLUME 38 2009

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