Michael K. McBeath et al. (1) make several statements about the process that fielders use to determine where to run to catch a fly ball: (i) that optical acceleration cancellation (OAC) (2) would require the fielder to precisely discriminate optical accelerations—a task at which, McBeath et al. argue, humans are not very good; (ii) that, because of this poor sensitivity to acceleration, fielders turn the problem of catching a fly ball from a temporal one of detecting velocity differences into a spatial one of detecting optical curvature—a task at which, McBeath et al. say, humans are very good; and (iii) that maintaining a two-dimensional projection of the ball on a linear optical trajectory (LOT) is sufficient to get the fielder to the right place at the right time to catch the ball. The first statement is not correct when the velocities and accelerations of fly balls typically encountered by a fielder are used. The second statement may be correct, but it is not supported by the types of studies that McBeath et al. cited in their report. Finally, we show that the third statement is incorrect by presenting an example in which a LOT is maintained, yet the fielder arrives 5.7 m away from the ball’s landing site at the instant the ball hits the ground.

OAC models do not require a precise ability to discriminate accelerations, only the ability to detect acceleration (and deceleration). Several of the studies cited by McBeath et al. in support of the statement that humans are poor at detecting accelerations (3) used velocities and accelerations that are not typically encountered by an outfielder. When more representative values are used, observers can discriminate approximately a 20% change in average velocity over a period of about 1 s (4). A more recent study (5) also showed that humans can detect successive differences in speed better than McBeath et al. Thus, rejecting OAC models because of a supposed poor sensitivity to successive speed differences is not warranted by existing data.

McBeath et al. argue that a fielder runs in such a way as to maintain the fly ball on a LOT with respect to home plate. The fielder adjusts his position so that he prevents the ball from taking a curved optical path. Humans are purported to be much better at detecting optical trajectory curvature than they are at detecting changes in speed. But the studies cited by McBeath et al. in support of this position (6, 7) required subjects to respond to straight versus curved lines, and one of these (7) had human infants discriminating large arcs with different radii of curvature. Because fly balls do not leave trails in the sky, this line curvature sensitivity (a spatial problem) is of questionable relevance to the trajectory curvature sensitivity (a spatiotemporal problem) required by the LOT model. More relevant data show that humans require a deviation of approximately 5° at low temporal frequencies to detect perturbations from a straight path for a slowly moving object (5). Whether this is sufficient sensitivity to support the LOT model remains to be determined.

Consider two paths of a fielder running toward a fly ball (Fig. 1). The fielder starts in a straight-away center field at a distance of 67 m from home plate. The ball is launched at a speed of 24.38 m/s, at an elevation angle of 50°, and at an azimuthal angle of 20° (toward left field) from the line connecting home to second base. The ball is in the air for 3.83 s and it lands 23.1 m from the fielder’s starting position—20.5 m to the fielder’s right and 10.6 m in front of his starting position (8). The path ending away from the landing point results in an error, while the path ending at the landing point gets the fielder in position in time to catch the ball (Fig. 1). We discuss the erroneous path first. To generate it, we simulated a fielder running in depth (toward home) at 50% of the speed necessary to null the vertical optical acceleration. We calculated the corresponding constant lateral running speed that would keep the lateral component of the optical projection proportional to the vertical component and maintain the initial angle of launch in the projection (what McBeath et al. call Ψ). Two path images (Fig. 2) were derived by projecting the fly ball onto a plane that remained perpendicular to the ground line-of-sight to the ball and that was 1 unit (arbitrary) behind the nodal point of the fielder’s eye; that is, the projection plane rotated, and the nodal point moved with the fielder. These images can be thought of as relational projections and correspond to scaled versions of what the fielder would see over time (9). The curved trajectory (Fig. 2) shows what the fielder would see if he stood still. The straight projection (Fig. 2) is that which results when the fielder takes the erroneous path (Fig. 1). This latter projection is linear over the entire flight, and maintains the initial angle (Ψ) in the projection. The fielder has thus followed the LOT strategy, yet is far from the ball when it hits the ground.

The LOT strategy results in this error because it provides too weak a constraint on the fielder’s behavior. One must also null the vertical optical acceleration, as was proposed in the original OAC models. Without this added constraint, it is possible to maintain the projection on a LOT for a majority of the ball’s flight only to have the trajectory reverse direction during the remaining flight time. The image of the ball in this example (Fig. 1) reverses direction on its LOT at 3 s for the erroneous path. At this point, the fielder is 7.1 m from the eventual landing sight and has 0.83 s to correct his direction and catch the ball. The LOT model is silent on how the fielder would determine the necessary corrections at these reversal points because McBeath et al. precluded them from ever occurring.
They added the constraint that the vertical and lateral projections had to be proportional to one another and monotonicallly increasing ([figure 2 in their report (1)] (italics ours). One must ask how the fielder ([Fig. 2]) is supposed to realize that his current path will produce a nonmonotonic projection later in the flight if he simply monitors the linearity of the optical trajectory. From the perspective of the fielder, he has satisfied the conditions required by the LOT model through the first 3 s of this 3.8-s flight. However, the vertical and lateral projections corresponding to this erroneous LOT are (Fig. 3) proportional to each other over the whole time-of-flight resulting in a LOT, monotonically increasing through most of the flight, but decelerating through the ball’s flight. The fielder is doomed to be far from the ball’s landing site if he relies only on the linearity of the optical trajectory without also sensing this vertical deceleration and nulling it. Also, running in depth too fast and too far toward the ball will produce a vertical component that is monotonically increasing (accelerating) throughout the flight until the ball goes over the fielder’s head (as he overruns the ball). Monotonicity is no substitute for the invariant provided by nulling the vertical optical acceleration.

There are many paths that produce LOTs (Fig. 1), but only one of these preserves the original invariant captured by the OAC models—constancy of the vertical optical speed. This path ends at the landing site at the correct time. Consider this successful running path (Fig. 1). The vertical component of the projection is linear ([Fig. 4]). The difference between the OAC and the LOT models is clear (Figs. 3 and 4). If the fielder only relies on the linearity of the optical trajectory, he will make errors because the two projections can be held proportional to each other, yet the image of the ball can reverse direction (Fig. 3). The OAC model imposes the further constraint that the vertical component itself must also be linear, eliminating the possibility of the image of the ball reversing direction when it is too late to correct the error. Fielders apparently null the vertical optical acceleration in the experiment run by McBeath et al. ([figure 4 and p. 572 of the report (1)]. McBeath et al. state that (1, p. 572) “on median a linear function accounted for over 99% of the variance of the tangent of the vertical optical angle, tan α.” In the LOT model this behavior is a curiosity that must be explained by appealing to extraoptical constraints; paths that null the vertical optical acceleration require the least expenditure of energy (figure 2 in the report). In contrast, the OAC models directly predict such behavior because only by nulling this component can such errors be avoided.

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**REFERENCES AND NOTES**

8. This is a true parabolic trajectory; it neglects the effects of air resistance, which cause the ball to travel a shorter distance. For more on the effects of air resistance see P. Brancato (Am. J. Phys. Teach. 53, 849 (1985)).
9. We have neglected the expansion of the image of the ball as it approaches the fielder. This cue may be important near the end of the flight as the fielder prepares to make the catch.
10. We thank R. Oudejans for helpful comments on a draft of this commentary.

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McBeath et al. describe a simple perceptual strategy for judging a fly ball, which, if followed, would always take an outfielder to the correct location so that the ball could be caught. In practice, however, outfielders do not appear to follow this strategy. This conclusion is based on new measurements of the motion of outfielders while judging fly balls.

The location of a fly ball, as viewed by an outfielder, can be described by the angles α and β (defined in Fig. 1A). Previous discussions of this problem (for example, (2)) have usually considered only balls hit directly at the fielder, that is, β = 0. An interesting discussion of fly balls not hit directly at the fielder was given recently by McBeath, Shaffer, and Kaiser (1). They pointed out that if the fielder moves in such a way that tan α and tan β increase in the same way with time, that is, in proportion to one another so that the ratio tan α/tan β is constant, the ball will appear to move in a straight line from the perspective of the outfielder. That is, the ball will appear to move along the ray which is drawn at an angle θ from the horizontal (Fig. 1A). If such an appearance is maintained, the fielder will always be “below” the ball, and thus in position to make the catch when it lands. This strategy of maintaining a linear optical trajectory has been termed the LOT model.
On Catching Fly Balls
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