On Catching Fly Balls

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 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 retinal 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.

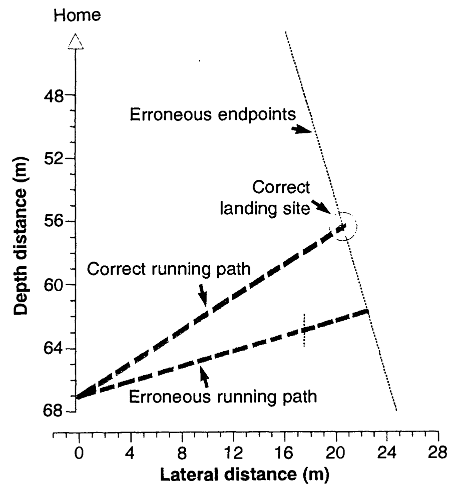

Fig. 1. Two running paths for pursuing a fly ball landing at the site in the center of the large circle. Dotted line that contains the landing sight of the ball and home plate (not shown) represents the terminal loci of erroneous running paths that would produce LOTs. Vertical hash through the erroneous path shows where the image of the ball reverses direction from the fielder's perspective.

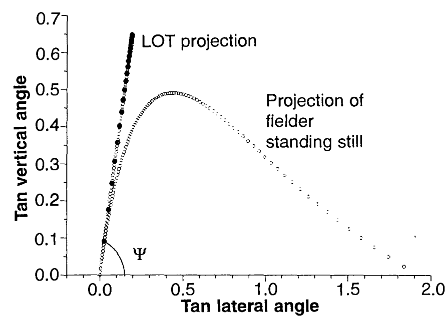

Fig. 2. Two projections of the same fly ball contingent on the fielder's movement. The fielder runs on the erroneous path shown in Fig. 1 to produce the LOT. He stands still to produce the descending curve. Open circles on the LOT show the monotonically increasing portion of the trajectory in 1/30-s increments. Closed circles show the trajectory after the image of the ball has reversed direction.

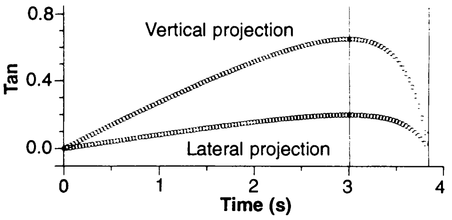

Fig. 3. Separated vertical and lateral optical projections for the erroneous running path shown in Fig. 1 that produced the LOT shown in Fig. 2. Time at which the image of the ball reverses direction is marked by dotted vertical line on the left (at 3 s). Dotted vertical line on the right indicates the time at which the ball strikes the ground. The ratio of these two projections is constant as required by the LOT model.

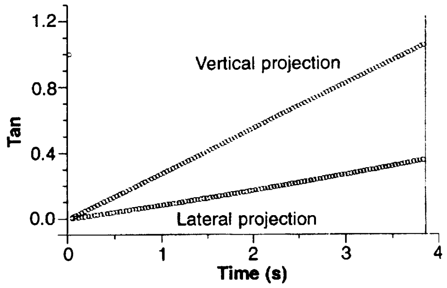

Fig. 4. Separated vertical and lateral optical projections for the successful running path shown in Fig. 1. Vertical projection is linear (optical deceleration has been nulled) as required by the OAC models. Vertical line indicates when the ball strikes the ground.

They added the constraint that the vertical and lateral projections had to be proportional to one another *and monotonically 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 nulled 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 extraperceptual 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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7. J. R. Hopkins, J. Kagan, S. Brachfeld, S. Hans, S. Linn, *Child Dev.* **17**, 1166 (1976).
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. Brancazio [*Am. J. Physics 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, $\beta = 0$. An interesting discussion of fly balls not hit directly towards 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 a 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 ψ 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.

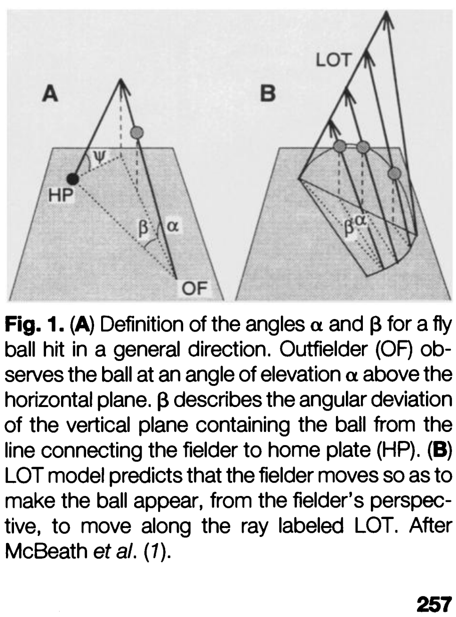

Fig. 1. (A) Definition of the angles α and β for a fly ball hit in a general direction. Outfielder (OF) observes the ball at an angle of elevation α above the horizontal plane. β describes the angular deviation of the vertical plane containing the ball from the line connecting the fielder to home plate (HP). **(B)** LOT model predicts that the fielder moves so as to make the ball appear, from the fielder's perspective, to move along the ray labeled LOT. After McBeath *et al.* (*1*).

Our interest in this problem was stimulated by statements [for examples, see (*1*, *2*)] that an outfielder moves at an approximately constant speed while he runs to intercept the ball, and that he does not slow appreciably before the catch. This is also a prediction of the proposals made by McBeath *et al.* (*1*). However, such behavior is completely at odds with our own impressions of how outfielders actually move. From many hours spent observing major league outfielders, it was our belief that in many (or even most) cases they run relatively quickly to the spot where the ball will land and are usually moving only slowly, or not at all, when they make the catch (*3*). This belief is supported by new, quantitative measurements of the motion of outfielders as they move to catch fly balls, which we now describe. Our measurements do not support the basic premise of the LOT model, namely that the fielder moves so as to keep the ratio tan α/tan β constant.

The movements of several consenting outfielders, as they judged and caught fly balls hit by a live batter, were recorded. From the measured time of flight and landing point of the ball, we calculated its trajectory (*4*). This was combined with the trajectory of the fielder to derive the angles α and β as functions of time. The particular results shown below were obtained from observing a skilled high school baseball outfielder. Similar findings were obtained for other fly balls with the same fielder, with a recreational softball player, and several other fielders of different skill levels.

Typically, the outfielder slowed considerably toward the end of his run (Fig. 2). This is quite different from the LOT prediction for the same fly ball (Fig. 2B). Strictly speaking, the LOT model asserts only that tan α/tan β is a constant, so that the time variation of these angles is not actually specified. McBeath *et al.* also propose that tan α will vary linearly with time, and we have used that assumption in computing the LOT prediction for the outfielder's speed. This prediction does not resemble our results (Fig. 2B). However, the inadequacy of the LOT model can be seen even more clearly from the resulting values for α and β. Initially, tan α varied almost linearly with time, but by midflight there was significant upwards curvature. The variation of tan β is especially intriguing; while it initially increased roughly linearly with time, it decreased to zero before the ball landed. This means that the fielder moved so as to make $\beta = 0$ before ($\approx$0.2 s) the end of his run. This result was observed for many different fly balls and is in direct contradiction with the basic premise of the LOT model, which is that the fielder always keeps the ball to one side of his body (to keep ψ constant), rather than "centering" himself under the ball as observed in our experiments (*5*).

As we have argued that the LOT model is not employed by outfielders, it remains to consider what strategy is used. With regard to the situation near the end of the fielder's run, that is, for $t > 2.5$ s (Fig. 2), as the fielder begins to slow down: A central question is how the fielder determines how much to slow down. This could be accomplished with the use of the velocity of the ball perpendicular to the line of sight, v_p. If $v_p = 0$ and $\beta = 0$, then the ball is moving directly at the fielder, as desired. We propose that the fielder moves so as to make tan β and v_p vanish at the same time. The role of v_p is then similar to that proposed by Brancazio (*6*). We will discuss these issues in more detail, and present further data (including for cases in which the ball is hit directly at the fielder), elsewhere.

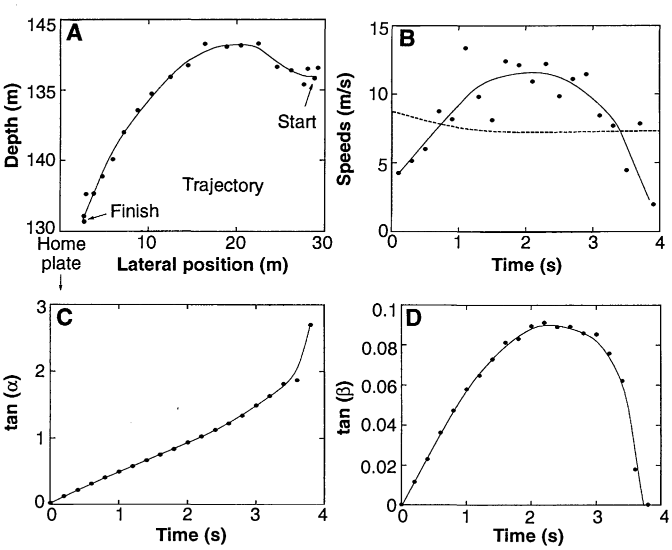

Fig 2. Experimental results for a typical fly ball. This fly ball was hit with an initial speed of 25 m/s, at an angle of elevation of 58°. (**A**) Trajectory of the fielder. Ball was hit from the location $x = 0$, $y = 0$. Dots show the fielder's position at 0.2-s intervals; smooth curves here and elsewhere are guides to the eye. (**B**) Speed of the fielder as a function of time, derived from the data in (A). Ball landed at $t = 4.00 \pm 0.05$ s. The dashed curve is the prediction of the LOT model, assuming that tan α and tan β increase linearly with time as also proposed by McBeath *et al.* (*1*). (**C** and **D**) Tan α and tan β as functions of time, respectively.

In conclusion, the LOT approach, while appealing, does not appear to be the way fielders catch fly balls in practice. Instead, they move so as to make β vanish well before the ball arrives.

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3. This point has also been made by L. A. Chodosh, L. E Lifson, C. Tabin, *Science* **268**, 1682 (1995).
4. In our calculations of the ball's trajectory, we have included the effect of air drag, as discussed in R. K. Adair [*The Physics of Baseball* (Harper and Row, New York, 1990)]; (see also N. Giordano, [*Computational Physics*, (Prentice Hall, New York, 1996)]. Full details of our calculation are available from the authors on request.
5. In this comment we are concerned only with cases in which the fly ball lands well within the fielder's range. Balls hit far from the fielder can require that he run at his maximum speed for much of the event. We cannot rule out the possibility that *some* fielders use the LOT approach for *some* fly balls. However, we know of no experimental evidence that this is the case.
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7. We are grateful to J. Grove and M. Walker for serving as outfielders, and the Tippecanoe School Corporation and J. Galema for permission to use their facilities for our filming. We also thank T. Statnick and T. Grams for expert advice on data processing.

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Response: In our article (*1*) introducing the LOT model of how baseball outfielders determine where to run to catch fly balls, we had several goals: The first was to elucidate that there are solutions based on maintaining control of optical variables that include optical acceleration cancellation in the vertical direction (the OAC model) and matched optical acceleration cancellation in both vertical and lateral directions (the LOT model). We wanted to demonstrate how principles of control theory can be utilized not only in the temporal domain (OAC), but in the spatial domain as well (LOT). We clarified how such perceptual models specify solutions in terms of optical variables from the perspective of the fielder, rather than direct knowledge of the physical pattern of ball movement. Second, we wanted to empirically test actual fielder behavior in the case where balls are hit off to the side. We used a camera on the moving fielder and directly measured optical ball trajectory. We addressed the issue of why it seems easier for fielders to solve the more computationally complex problem of catching balls hit off to the side than the computationally simpler problem of catching balls hit in the plane directly toward them. Finally, we wanted to relate the problem of baseball tracking to the larger fields of navigational, ballistic, and predator tracking behavior.

Dannemiller *et al.* present a proof of why temporal cues cannot be entirely excluded. They also provide a cogent theoretical argument defending the elegance and simplicity of the traditional OAC model with its straight-line, constant-speed running path. However, we did not say that maintaining optical linearity is a "sufficient" condition to solve the outfielder problem as Dannemiller *et al.* state. Our position is that when a ball is hit in the plane directly toward a fielder, he or she must resort to OAC as the principal cue to control position relative to the ball, but the task is difficult. When the ball is hit off to the side, the fielder utilizes linearity of the optical trajectory as the principal cue to control position relative to the ball, and this makes the task easier. OAC simply becomes a secondary cue, one which our empirical results indicate is clearly not abandoned. With regard to our choice of relaxing the OAC constraint to the point of monotonicity, we merely wanted to point out that the LOT heuristic is still guaranteed to work even when OAC performance is reduced to this extremity.

Dannemiller *et al.* argue that as a single cue, OAC is superior because it is more universal. We see no reason to suppose that fielders limit themselves to only one cue. Part of our motivation in proposing the LOT model was to define a mechanism beyond OAC that could account for improved performance when balls are hit to the side.

Dannemiller *et al.* dispute our claim that viewers are better at detecting motion curvature than acceleration, and they question our choice of references. The evidence supporting superiority of curvature detection is extensive. We elected to include references that emphasized evidence of neural curvature detectors, early developmental emergence of curvature perception, and superthreshold detection of curvature (*2*). We can bolster our case with a quote from the one article that Dannemiller *et al.* cite in questioning the superiority of curvature detection [(*3*), p. 322].

> The fact that the human visual motion system is more sensitive to direction than to speed is a well known phenomena in motion discrimination experiments where Weber fractions for speed discrimination are typically twice the Weber fractions for direction discrimination.

One reason for this superiority is that curved motion has an acceleration component perpendicular to the direction of movement. Thus, the family of sensors that register trajectory acceleration also assist in registering trajectory curvature. This emphasizes why the two-dimensional LOT control mechanism can be considered more encompassing than the one-dimensional OAC control mechanism.

The issue of precision of acceleration discrimination is further clouded when we consider that the constant velocity maintained in OAC is not a constant change in the vertical optical angle, α, but in the vertical optical tangent, tan α. This distinction is merely a mathematical formality for small angles where $\tan \alpha \approx \alpha$, but it becomes substantial when angles approach those of fly balls. For example, a source that maintains a constant increase in the optical tangent, $\partial(\tan \alpha)/\partial t$ = constant, will decrease to 1/2 its initial optical speed, $\partial\alpha/\partial t$, by the time the vertical angle $\alpha = 45°$, and 1/10 its initial optical speed at $\alpha = 72°$. This shrinkage of actual optical speed can account for why ascending rockets and outside elevators may appear to slow down as they rise when viewed from a vantage point near their origin.

Dannemiller *et al.* do not attempt to rectify theory with empirical behavior of fielders. First, they do not discuss why balls hit to the side seem easier to catch, one of the fundamental arguments that justifies the need for something like a LOT strategy. Second, they singularly promote the elegance and uniqueness of the straight-line constant-velocity running path solution that is specified by the traditional OAC model, yet we know of no evidence that fielders use such a path. McLeod and Dienes (*4*) demonstrated that even when balls are hit in the plane directly toward the fielder they rarely run at a constant speed. Our findings confirm that for balls hit to the side, fielders run at neither a constant speed nor a straight line, and Jacobs *et al.* argue that even our description is overly conservative. A question that ought to be addressed is: What strategy are fielders using to account for why they do not run along constant-velocity straight-line paths specified by the traditional OAC model? The argument by Dannemiller *et al.* that the uniqueness of the solution for the traditional OAC model makes it superior to the family of LOT solutions conflicts with empirical findings that there is considerable variability in running paths chosen. When it comes to describing fielder behavior, some lack of specificity seems appropriate.

Finally, given the findings supporting spatial tracking strategies in navigational, ballistic, and animal tracking literatures, we should consider similar mechanisms in the case of baseball outfielders. In short, there is a need for a model that supersedes OAC to account for the following empirical findings: (i) balls hit to the side seem easier to catch, (ii) fielders generally run along curved paths with ∩-shaped speed functions, and (iii) spatial strategies are noted in other domains of tracking. Our proposal of the LOT model addresses these issues.

Jacobs *et al.* present a clear case supporting that fielders do not generally run along straight-line constant-velocity paths and that fielders use a strategy other than LOT near the end of their catch. They propose an alternative termination strategy in which fielders simultaneously null out vertical and lateral motion components to place themselves at the correct destination point before time of constant.

First, as we said in our article (*1*), there is considerable evidence that during the final portion of the trajectory, fielders make use of a variety of cues that were not available initially. In the perception literature it is typically assumed that the tracking strategy of outfielders is at least a two step process, an initial reduced cue process and a final fuller cue process. Our study specifically explored the strategy used during the initial portion of the task, when the only apparent information is the optical ball trajectory. Consistent with this goal, we did not even include the last 0.5 s of the optical trajectory in our analyses.

There has been considerable research done exploring the behavior of people catching and hitting balls under full cue conditions (*5*, *6*). The general findings support that the principal cue is rate of optical expansion of the ball. This cue provides highly reliable location and time-to-arrival information, but other cues like binocular disparity also become available. Jacobs *et al.* suggest a model of the terminal strategy based on eliminating the lateral optical change at the same time as nulling the vertical velocity of the ball perpendicular to the line of sight, v_P. Although we would argue that abandoning use of the optically specified variable, α, for the physical variable, v_P is misguided, the general approach seems in other respects similar to well-known findings in the perceptual literature based on centering optical expansion (*6*).

Given these results, one would expect that fielders, in particular well trained ones, might adjust their terminal behavior to arrive at the destination with some leeway to stop before catching the ball. Here Jacobs *et al.* noted that, on a "typical" trial, the fielder arrives 0.2 s before the ball. This finding might help clarify the ongoing debate concerning the extent to which fielders intentionally catch the ball on the run. In the perceptual domain, 0.2 s represents about the minimum gross motor reaction time. Thus, although the finding of Jacobs *et al.* does indicate that fielders stop, it also supports the idea that they often do so close to the last possible instant. Considering the pattern of deceleration near the catch, it appears that the fielder is intentionally maintaining some optical ball movement as long as possible. This is consistent with other control theory findings that for tracking displays it is typically easier to maintain a trajectory with constant motion than it is to null out all movement (7).

In our article we hypothesized that fielders would exhibit a ∩-shaped running speed function. This was based on the fact that initially, the fielder is stationary and needs time to accelerate up to speed and that later, near the end, the LOT geometry generally specifies some slowing. We chose not to make more precise running speed predictions because the range of running paths that maintain a LOT within a 5% error band allows for substantial variance, particularly near the beginning of the trajectory. That Jacobs *et al.* found a ∩-shaped running speed function replicates our reported results, and is consistent with the LOT model given a realistic envelope for perceptual error. They also assert that their fielder exhibited notable deviation from vertical OAC, but this conclusion does not appear statistically justified. Allowing for perceptual error, their vertical speed function appears remarkably linear.

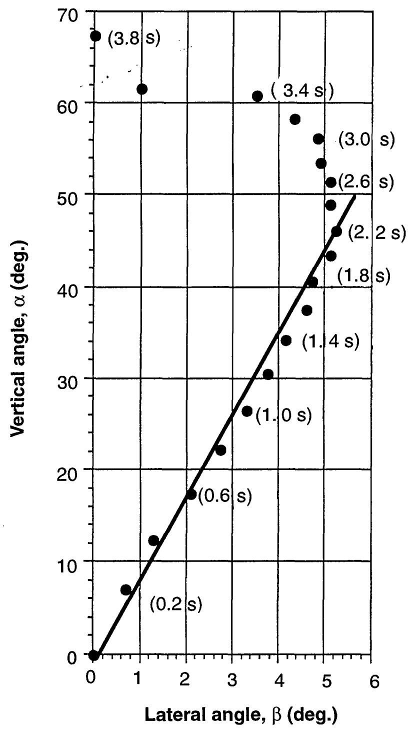

Fig. 1. Plot of the optical trajectory of the ball (fielder's view) for the trial described by Jacobs *et al.* Linearity is maintained through 2.5 s.

The one area in which the empirical finding of Jacobs *et al.* appears substantially different from ours is in the length of time that fielders maintain a LOT before they resort to an alternate terminal strategy. One possible contributor to the inconsistency is that because Jacobs *et al.* are modeling the ball trajectory, it may not be traveling along the exact path they assume. Factors such as ball spin and atmospheric pressure can account for lateral and distance deviations of many meters (8).

In any case, rather than abandoning our findings based on 30 trials, we make a suggestion that may account for both our findings. As we discussed earlier, there is reason to debate the appropriateness of using the tangent functions as perceptual invariants rather than the vertical and lateral optical angles, α and β, themselves. It is common practice in perceptual work to use projection plane geometry because it is simpler, and for small visual angles $\tan \alpha \approx \alpha$, so the distinction between the two is moot. In our article, we followed this convention and used the tangents in our mathematical description of the LOT model, but because we recorded the optical trajectories directly onto video, we elected to analyze linearity directly in terms of α and β. We also had constraints on the height of the trajectory because we filmed in an indoor field house with background markings. Unlike our trials, the single result reported by Jacobs *et al.* is plotted out using the tangent transformation, and the vertical optical angle, α, climbs to 70°, a towering, almost pop fly. In this region, the rate of change in α significantly decreases, approaching one tenth that of $\tan \alpha$. In contrast, because β is small where $\tan \beta \approx \beta$, the rate of change in β remains similar to that of $\tan \beta$. Thus, when the data of Jacobs *et al.* replotted as function of α versus β (Fig. 1), the function remains linear within a 5% margin of error up through 2.5 s, well beyond the point ascertained by Jacobs *et al.* This still results in a loss of linearity somewhat earlier in the trajectory than we found, but we suggest this may be due to fielders revising their strategy when the ball passes well over 45° into the region where it exhibits notable optical deceleration.

Perhaps the weakest point of the comment by Jacobs *et al.* is that they do not propose an alternate model that predicts the initial portion of tracking based on available perceptual information. There is no guidance theory suggested to compare to the LOT model. We agree that in the case of very high, towering fly balls, the LOT strategy may be dominated by an alternate strategy somewhat earlier in the trajectory than we earlier proposed. Yet even in those cases, it still appears that fielders continue to utilize spatial cues and follow the general principles of control theory that we forwarded. Perhaps a more complete study will be able to determine if and when fielders move to a strategy of simultaneously nulling lateral and vertical optical movement.

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