SCIENCE

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LETTERS

An Active National Institute of Mental Health

Eliot Marshall's article about the National Institute of Mental Health ("NIMH: Caught in the line of fire without a general," News & Comment, 5 May, p. 632) may leave readers with several misconceptions. One concerns the role of Chairman John Porter (R–IL) at the appropriations subcommittee hearing in the U.S. House of Representatives. When a citizens' watchdog group challenged the value and relevance of a small number of NIMH's basic science grants, Porter took a leadership role befitting someone who is both a representative of the American taxpayer and a strong supporter of biomedical research: He raised the group's charges in a straightforward and thoughtful manner and provided the institute with an opportunity to respond to allegations about the grants. His actions—and subsequent coverage of these issues in the press and on ABC's Prime Time Live—afforded NIMH an opportunity to highlight the work of several distinguished grantees and to explain the importance of basic science research to millions of citizens.

A second source of possible misinterpretation is found in the suggestion that "acting" leadership necessarily implies an institute in "disarray." Under acting director Rex Cowdry's leadership, NIMH's response to the allegations was swift, vigorous, professional, and effective—hardly indicative of an institute in disarray. Beyond that particular instance, NIMH is actively addressing critical scientific and management issues, including impending changes in its peer-review system and a review of its distinguished intramural research program in mental health.

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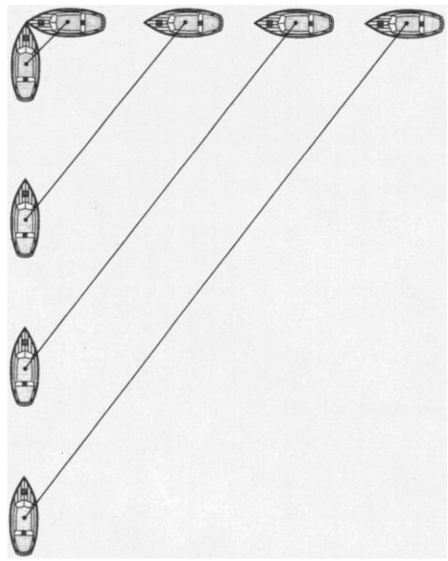
Play Ball!

The analysis by Michael K. McBeath and his colleagues, "How baseball outfielders determine where to run to catch fly balls" (Reports, 28 Apr., p. 569), illustrates a geometric solution, as opposed to a dynamical solution, to the problem of the outfielder catching a fly ball. The geometric approach is conceptually similar to the two-dimensional situation of ships on a collision course at sea. A collision course is recognized as one in which two ships approach each other so that the bearing of one as viewed from the other remains constant as the distance between them diminishes (see figure).



Collision course. Does outfielder seek collision between ball and glove?

If no course or speed alteration takes place, the ships will collide. That is precisely what the outfielder is seeking: a "collision" of his glove with the ball.

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I was delighted to see in the report by McBeath *et al.* that psychologists had solved the problem of catching fly balls, a problem that I had too often *not* solved as a youth playing baseball. And when I found the report difficult to understand, I sought Barry Cipra's explanation (Research News, 28 Apr., p. 502), which immediately provided me with a strategy. Cipra quotes McBeath as saying, "If you're running along a path that doesn't allow the ball to curve down, then in a sense you're guaranteed to catch it." So when I played centerfield and a ball was hit toward me, I should have run like mad toward second base thus keeping the ball from curving down. I recall doing just that on occasion, turning an easy out into a double as the ball landed behind me. I guess I missed something in the translation.

I see that all is solved if I keep Ψ, the ratio of the tangents of the angle up to the ball (α) to a sideways angle (β), constant. So when the ball is hit in my general direction, again I race in toward second, increasing α, but now I am careful to veer off to the side to keep β large and the ratio of tangents constant. Of course this sends me running directly away from where the ball will land but, since, like the old-time Brooklyn Dodger outfielder Babe Herman, fly balls sometimes hit me on the head, the scientific strategy keeps me safe.

A variation on the infinite number of solutions that follow from the recipe given in the report, where the fielder runs laterally so that the ball goes straight up and down from his or her view (*1*), better fits fielding in the real world. The player picks, from that set of paths, one that leads to the falling ball, using the judgment of up-down ball flight patterns gained from practice.

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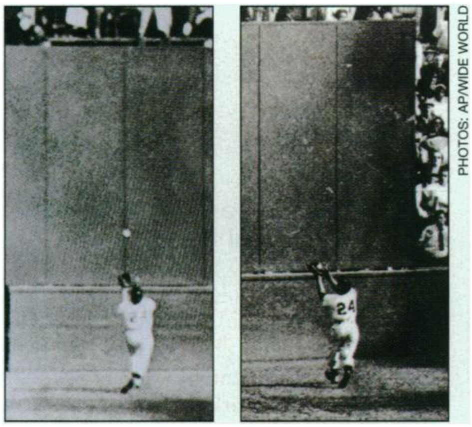
1. R. K. Adair, *The Physics of Baseball* (HarperCollins, New York, ed. 2, 1994) pp. 49–55.



PHOTOS: AP/WIDE WORLD

The catch: Willie Mays making it look easy in the 1954 World Series.

McBeath *et al.* hypothesize that an outfielder runs such that the ball's trajectory appears straight against the visual background. This model also predicts a continuously moving fielder, although she would take a curved path and her velocity is required to first increase, then decrease, in order for her to track the ball, an algorithm consistent with their own experimental results.

This hypothetical method of catching a ball conflicts with the technique actually used by adept outfielders in several important respects. Experienced outfielders do not run until the time the ball is intercepted, but rather beat the ball to the place it will land and wait for it. As Jimy Williams, fielding coach for the Atlanta Braves, affirms, "it is simply much easier to catch a ball standing still than moving. Why do you think you don't move to and fro when playing catch" (*1*). Furthermore, in a situation with runners on base, it is essential that the fielder be stationary, so that she is able to put her full force into a throw to the infield, and not have her momentum moving away from the direction of her anticipated throw. The proposed model would not allow the fielder to be set for the throw. When balls are hit a maximum distance, the fielder must be able to run at maximum speed on as direct a path as possible to catch it, and not be constrained to a ∩-shaped variable velocity curve. In addition, the model is predicated on the outfielder keeping her eye on the ball throughout its flight, but this is not the method used by experienced fielders for balls hit over their head. As Williams substantiated, "an outfielder first takes a quick drop step, then turns and runs to the point where the ball is going to be . . . you don't watch the ball the whole time. You turn and run and then pick it up again when you get close to where the ball is going" (*1*). An example of this method of fielding, a basket catch by Willie Mays, was used in the Table of Contents (p. 475) of the issue of *Science* in which McBeath *et al.*'s report appeared. A model for intuiting the trajectory of a fly ball must allow for Willie to catch the ball.

To test whether the proposed paradigm is actually used by experienced players, we analyzed all fly balls hit beyond the infield but within the field of play from 12 videotaped nonreplacement major league baseball games. We limited ourselves to game situations in which there were either no runners on base or two outs, such that the fielder had no concerns other than catching the ball. Of 179 caught fly balls, 143 (83%) were caught while the fielders were stationary; only 31 (17%) were caught by fielders on the run. A significant fraction of the 31 balls caught on the run were likely to have been hit at or near d_{max} (2), thereby necessitating that the fielder be running at the time he caught the ball. In addition, the figure of 83% may further underestimate the advantage of being stationary while making the catch, as some fielders have a tendency to adopt an alternative strategy that minimizes effort. The discrepancy with the results obtained by McBeath *et al.* may be attributable to the fact that the subjects they used were reported to have "some but not extensive outfield experience."

We conclude that the proposed model cannot be an obligate or even optimal strategy for catching a baseball. It may be used, however, by inexperienced ball players and may be useful in learning to judge a fly ball.

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References and Notes

1. J. Williams (Atlanta Braves), personal communication.
2. $d_{max} = v_{max} \cdot t$, where v_{max} is the fielder's maximum speed, t is the time the ball is in the air, and d_{max} is the distance the fielder must cover to avoid looking foolish in front of 40,000 fans (pre-strike attendance); I. Newton, *Philosophiae Naturalis Principicia Mathematica* (1687).
3. We are grateful to G. Olson (Atlanta Braves) and J. Olson (Jansport HBs) for their assistance.

As a baseball enthusiast and scientist, I found the report "How baseball outfielders determine where to run to catch fly balls" intriguing. I was, however, disappointed by the decision to use the picture of Willie Mays' famous catch of Vic Wertz's fly ball in the 1954 World Series in the Table of Contents. If fly balls are caught by maintaining a linear optical trajectory, this requires one to watch the ball while tracking it, clearly something Willie Mays was not doing when he made "the catch." Perhaps this illustrates that true greatness defies scientific explanation.

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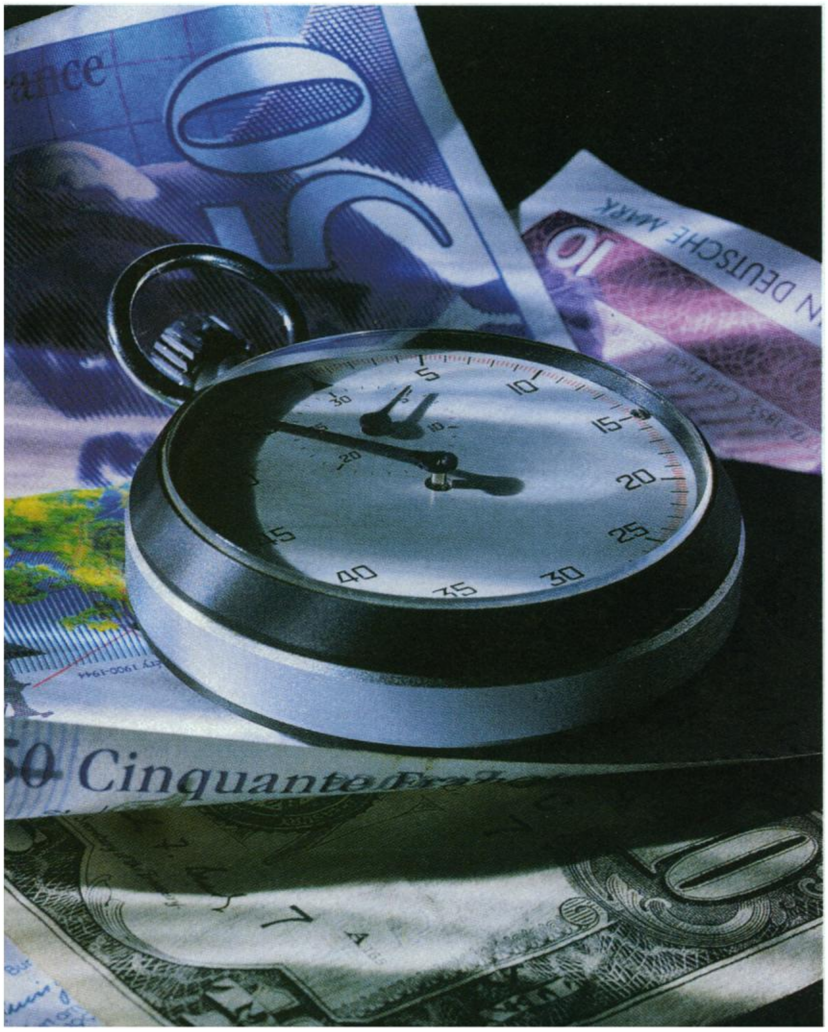
Response: The question of how a baseball outfielder determines where to run to catch a fly ball includes aspects of physics, engineering control theory, physiology, kinesthesiology, ethology, perception, and the study of expertise. It is not surprising that scientists from the various fields emphasize different aspects of the problem. The above letters respectively represent the perspectives of engineering control theory, physics, and the study of expertise.

Pollack nicely elucidates a well-known geometric solution to tracking or wayfinding from the perspective of control theory. In short, as a pursuer approaches an object, a constant optical angle from the object subtends an increasingly smaller physical distance. The nautical strategy of maintaining a constant angle of bearing relative to a target (the angle between direction of target and direction of pursuit) is also a standard method used in air-to-air ballistics to achieve collision. This strategy is only optimal for targets moving along a straight path at a constant speed, but it works for targets moving along any continuous, varying speed path, provided the pursuer is capable of catching up to the target. This is the cited apparent strategy used by teleost fish when they approach moving food. When the target varies in speed and direction, a more efficient pursuit path is achieved by varying angle of bearing as a function of the instantaneous speed and curvature of the pursuer. This is the cited apparent strategy used by houseflies chasing competitors and potential mates. The outfielder problem has the added constraint that the pursuer must intercept the target at a particular point in space (where the ball lands). If the fielder only used the strategy of keeping a constant lateral angle of bearing, he or she would cross the path of the ball, but not necessarily at its landing time. Vertical motion information is needed to help solve the temporal constraint, and the linear optical trajectory (LOT) model accomplishes this. As we suggested, angle of bearing appears to be used as an additional constraint to help determine the particular LOT chosen.

Adair takes the perspective of a physicist and suggests two thought experiments as evidence that a fielder can perform the LOT strategy and still miss the ball. We have theorized and empirically confirmed that when fielders catch fly balls launched to the side they maintain a linear optical trajectory, and when they miss they do not. We found that when the fielder heads to a point in front of the ball's destination, as in Adair's first example, the optical trajectory accelerates vertically and curves up. We also found that fielders do not and cannot arbitrarily select optical angles and rates of change, as in Adair's second example, but rather they maintain the initial optical projection angle, Ψ, which is fully determined by the perspective launch angle of the ball relative to the fielder.

Adair is correct in noting that the LOT strategy in itself does not specify a unique solution, but as we pointed out, this can be accomplished to the extent that the fielder minimizes changes in angle of bearing. One interesting aspect that has emerged from research on this problem is that for identical launches, fielders will select different running paths, particularly near the beginning and end of the task. A good model of outfielder behavior should allow for this variability, as the LOT strategy does. Near the beginning of the trajectory we expect more variability because outfielder location has less influence on the optical trajectory. Near the end we expect more variability because corrective action will commence as other depth cues become available.

Adair proposes a model in which a fielder maintains lateral alignment and then solves the problem as if the "up and down" motion of the ball was approaching directly toward him or her. Both maintenance of lateral alignment and monitoring of up and down ball motion require information that is not perceptually available from the fielder's vantage, and both conflict with empirically measured running path and optical trajectory patterns. They also imply the incorrect notions



that balls hit to the side should be harder to catch and that fielders allow the ball to optically descend. Finally, Adair's proposal that fielders simply attend to ball motion and practice does not describe how or what the fielder is doing. Perhaps this helps emphasize the point that scientists of different disciplines have different goals and methods. The goal of perceptual psychologists is to determine what information is available to an observer and to specify and empirically test how is it used. Our empirical findings indicate that fielders reliably maintain a constant speed LOT to direct them to the correct destination.

The final two letters concern an issue from the perspective of the study of expertise and skill development: how experts differ from novices. As we noted in our report, we chose to measure the behavior of recreational players. Professional players may behave fundamentally differently. Jacobs makes a good point in noting that Willie Mays did not appear to follow the LOT strategy when he made the famous 1954 World Series catch, yet Mays' extraordinary behavior during this play may be part of the reason that it is considered by many to be one of the greatest catches in the history of the sport. Chodosh, Lifson, and Tabin provide pilot data and suggest that even during mundane catches, professional fielder behavior is not consistent with maintaining a LOT. Their principal argument is that fielders do not catch the ball on the run, but rather do so while stationary. In contrast, our observations of professional players indicate that they typically alter their running speed in a manner consistent with the LOT strategy and appear to catch the ball on the run far more frequently than suggested by these authors. A definitive answer reconciling our differences would require a much more detailed description of fielder position over time. Still, the LOT model does not specify a unique solution and, in particular, does not require optical speed constancy, as we found with recreational players. Professional players could conceivably learn to favor LOT solutions that promote earlier arrival. Chodosh *et al.* also note that professional players do not always continuously maintain fixation on the ball, although our observation is that they usually do so. In order to evaluate the relevance of this point, we must determine the sampling frequency and fixation requirements that are needed to maintain a LOT. Chodosh *et al.* imply that the performance of recreational players is sufficiently inferior to that of professionals to make models of amateur behavior uninteresting. Clarifying differences between experts and novices can be an informative pursuit, but so can clarifying their commonalities. Millions of recreational players are remarkably good at catching fly balls, and in some respects approach the performance level of major league players. Our model of how they accomplish this task appears to tap into an innate strategy that uses the perceptual invariant of constancy of relative angle of motion. Knowledge of this strategy may enhance performance in countless tasks relevant to localization and navigation ranging from designing cockpit displays to herding livestock. We found that fielders catch fly balls by maintaining a linear optical trajectory. The generalizability of this principle helps explain why the outfielder problem is relevant to such a wide range of scientific disciplines.

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