Running head: OPTIC TRAJECTORIES

The optic trajectory is not a lot of use if you want to catch the ball

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Abstract

According to linear optic trajectory (LOT) theory fielders use the direction of curvature of the optic trajectory to control the way they run to intercept the ball. Data presented by Shaffer and McBeath (2002) as support for LOT theory show that the optic trajectory of balls which will fall behind the fielder provide the cue which LOT theory predicts would send the fielder running forwards, not backwards. We show that watching these balls would provide the fielder with the cue which the Optic Acceleration Cancellation (OAC) theory of interception predicts would send the fielder running backward. It appears that the fielders studied by Shaffer and McBeath were following the cue predicted by OAC theory, not that predicted by LOT theory.

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Currently there are two approaches to how people run to the right place to catch a ball - Linear Optic Trajectory (LOT) theory and Optic Acceleration Cancellation (OAC) theory. LOT theory starts from the empirical observation that α and β increase in roughly constant proportion as the fielder runs (McBeath, Shaffer & Kaiser 1995, 1996; Shaffer & McBeath, 2002). (α and β are defined in the Appendix). According to LOT theory there is a projection plane on which the image of the ball follows a path (the optic trajectory) with a direction defined by the ratio α/β. The fielder attempts to run in such a way that this trajectory remains linear, and in consequence, α and β increase in constant proportion. If the fielder does this the ball will be intercepted. Departure of the trajectory from linearity provides the cue for the fielder to adjust the way in which he or she is running. If, on the current path of ball and fielder, the ball will land in front of the fielder, the optic trajectory curves down. This is the signal to accelerate forward. If the ball is heading behind the fielder, the optic trajectory will curve up. This is the signal to accelerate backwards (Shaffer & McBeath, 2002).

OAC theory starts from the empirical observation that fielders run at a speed such that $\tan\alpha$ increases at a constant rate (Michaels & Oudejans, 1992; Dienes & McLeod, 1993; McLeod & Dienes, 1993; McLeod & Dienes, 1996, Oudejans, Michaels, Bakker & Davids, 1999; McLeod, Reed & Dienes, 2001). If $\tan\alpha$ increases at a constant rate, α increases at a decreasing rate, asymptoting at 90°. OAC theory explains this as a solution to two requirements of an efficient interception strategy - α must increase throughout the flight (see McLeod & Dienes, 1996) but must not exceed 90°. According to OAC theory the fielder's running is controlled by the acceleration of $\tan\alpha$. If it is zero (i.e. $\tan \alpha$ is increasing at a constant rate) the fielder will intercept the ball. If the ball will land in front, $\tan\alpha$ decelerates. This is the signal to the fielder to accelerate forwards. If the ball will land behind, $\tan\alpha$

accelerates. This is the signal to accelerate backwards.

To date all papers presenting data in favor of either LOT or OAC theories have reported what happens when fielders catch the ball. In a recent paper Shaffer and McBeath (2002) presented data from catches where fielders tried to catch balls which fell beyond their reach. This is a good test of theories of interception as it has the potential to demonstrate clearly the cues which tell the fielder to run faster. If the fielder catches the ball these cues are hard to detect as fielders constantly null them as they run. If the fielder cannot run fast enough to catch the ball they will not be nulled and should be apparent in the data. If the ball is going to land out of reach behind the fielder, so he or she should have run faster backwards, LOT theory predicts that the optic trajectory will curve up. OAC theory predicts that $\tan\alpha$ will accelerate.

Shaffer and McBeath (2002) gave four representative examples of optic trajectories (i.e. plots of α against β) for balls which fell out of reach behind the fielder. Three of these are shown in the upper part of figure 1 (redrawn from their figure 8b).[1] These are shown from the moment the ball appears (when $\alpha = \beta = 0^{o}$) until just before the ball passes the fielder (when α approaches 90^{o}). Shaffer and McBeath presented their data as support for LOT theory, citing the large linear component to the regression of α on β in these trajectories as evidence that the fielders were trying to keep the optic trajectory linear as they ran. We have added a line from the beginning of the flight to the end to make the curvature of the optic trajectory apparent. In each case the optic trajectory curves downward throughout the flight, not upward as predicted by LOT theory.[2] (The quadratic component is significant in each case, $p < 0.001$, computed either on Shaffer & McBeath's original data or on the subset reproduced in figure 1.) It is true that, according to LOT theory, the fielder will be guided by the momentary slope of the optic trajectory and figure 1 shows that the curve as a whole is curved down. But there do not appear to be any appreciable times in any of the flights when the fielder would be provided with a cue to run back. According to LOT theory fielders using the optic trajectories shown in the upper part of figure 1 would be running forward to try and catch balls that were going to land behind them.

Figure 1

OAC theory predicts that if the fielder should be running faster backward to catch the ball then $\tan\alpha$ will accelerate. Thus if $\tan\alpha$ is plotted against time the trajectories should curve upward. In the lower part of figure 1 we have replotted the data for each trajectory in this way. It can be seen that the trajectories all now curve upward - that is, $\tan\alpha$ is accelerating. Watching these balls would provide the cue to which direction the fielder should run predicted by OAC theory. The fielders may not have been able to run fast enough to catch the ball but if they used this cue at least they would have been running in the right direction.

Shaffer and McBeath (2002) dismissed the significance of the curvature of the optic trajectories shown in the upper part of figure 1, commenting: "Given that optical linearity must break down eventually for uncatchable balls, it is not particularly noticeable that this occurs." Optical linearity does not break down "eventually" - curvature is apparent throughout the flights. And the "noticeable" fact is not that departure from linearity occurs, it is that the departure is in the opposite direction to that predicted by LOT theory. McLeod, Reed and Dienes (2001) showed a range of conditions under which the predictions of LOT theory did not hold. Shaffer and McBeath (2002) have now added to these.

Appendix

The relationship between a ball hit in the air and a fielder running to catch it can be represented by the angles α and β in figure 2. α is the vertical angle above the horizontal from fielder to ball. β is the horizontal angle between a line from the fielder to the place where the ball started its trajectory and a line from the fielder to the point where the vertical projection from the ball meets the ground. α defines a circle on the ground centered on the point where the vertical projection from the ball meets the ground (i.e., the locus of points from which the angle of elevation of gaze from fielder to ball is α). β defines where the fielder is on this circle.

Figure 2

Footnotes

[1] In the fourth example the ball passed well to one side of the fielder as well as behind and the part of the optic trajectory reported by Shaffer and McBeath terminated with α at around 55°. In this case it is not clear whether the fielder should be described as running forwards (towards the plane of the ball flight) or backwards (compared to the place where he started). Therefore it is not clear whether we should be looking for an optic cue telling the fielder to run faster forwards or backwards. To avoid this ambiguity we have not included this trajectory. We are grateful to Claire Michaels for drawing this problem to our attention.

[2] If the fielder fails to catch the ball α will eventually return to zero as the ball falls to the ground. Thus the optic trajectory of a ball which lands behind the fielder will eventually curve downward (provided β does not decline at the same time, see Dannemiller, Babler and Babler, 1996). The trajectories presented in figure 1 are terminated while α is still increasing so the downward curves are not related to the final part of the trajectory when the ball falls to the ground.

Author notes

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Figure captions

Figure 1. Upper. Redrawn from figure 8b of Shaffer and McBeath (2002). The initial portion of three optic trajectories for balls which eventually landed behind the fielder. Each trajectory starts at $\alpha = \beta = 0^{o}$. In the original, the curves were drawn from the same point on the β axis. Here they have been separated by 20^{o} . In the original, the data points were plotted at 33 msec intervals. Here a subset of these are shown with successive points giving the values of α and β at approximately 100 ms intervals.

Lower. The same data as figure 1, plotted as tanα vs time. The symbols identify which of the upper trajectories the lower ones correspond to.

Figure 2. The positions at successive moments of a ball and a fielder running to catch it. The fielder runs to the right and slightly forward.

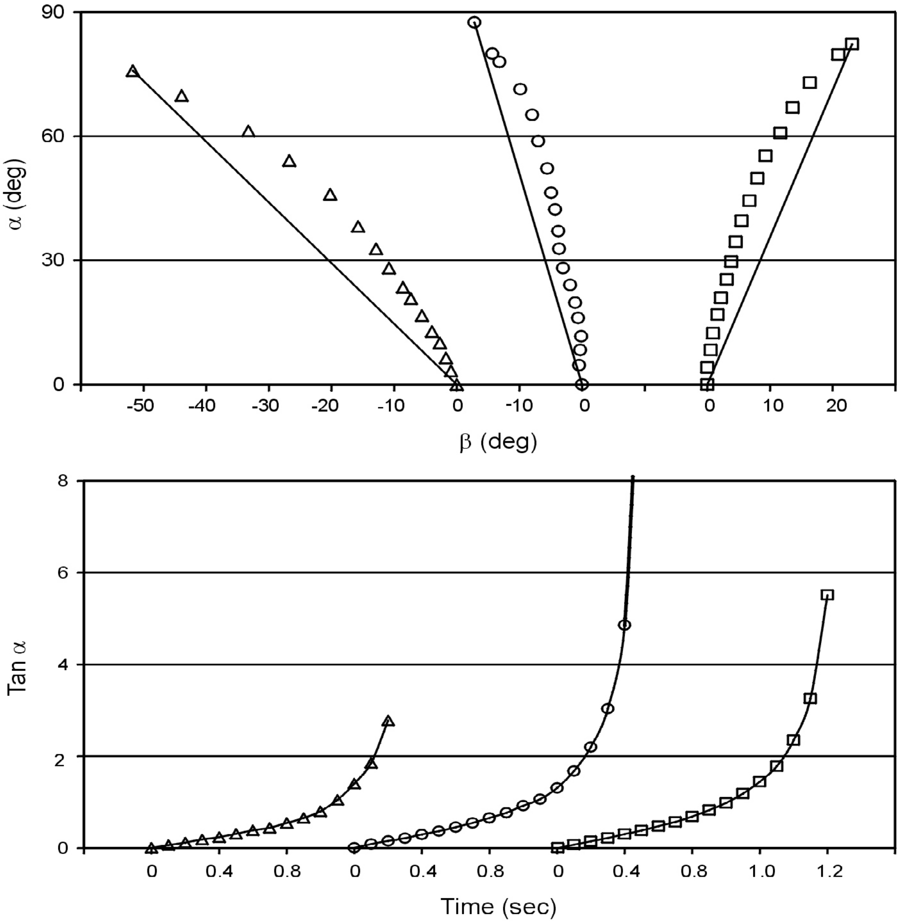
90
60
30
0
α (deg)
-50
-40
-30
-20
-10
0
-10
0
0
10
20
β (deg)
8
6
4
2
0
Tan α
0
0.4
0.8
0
0.4
0.8
0
0.4
0.8
1.0
1.2
Time (sec)

Figure 1

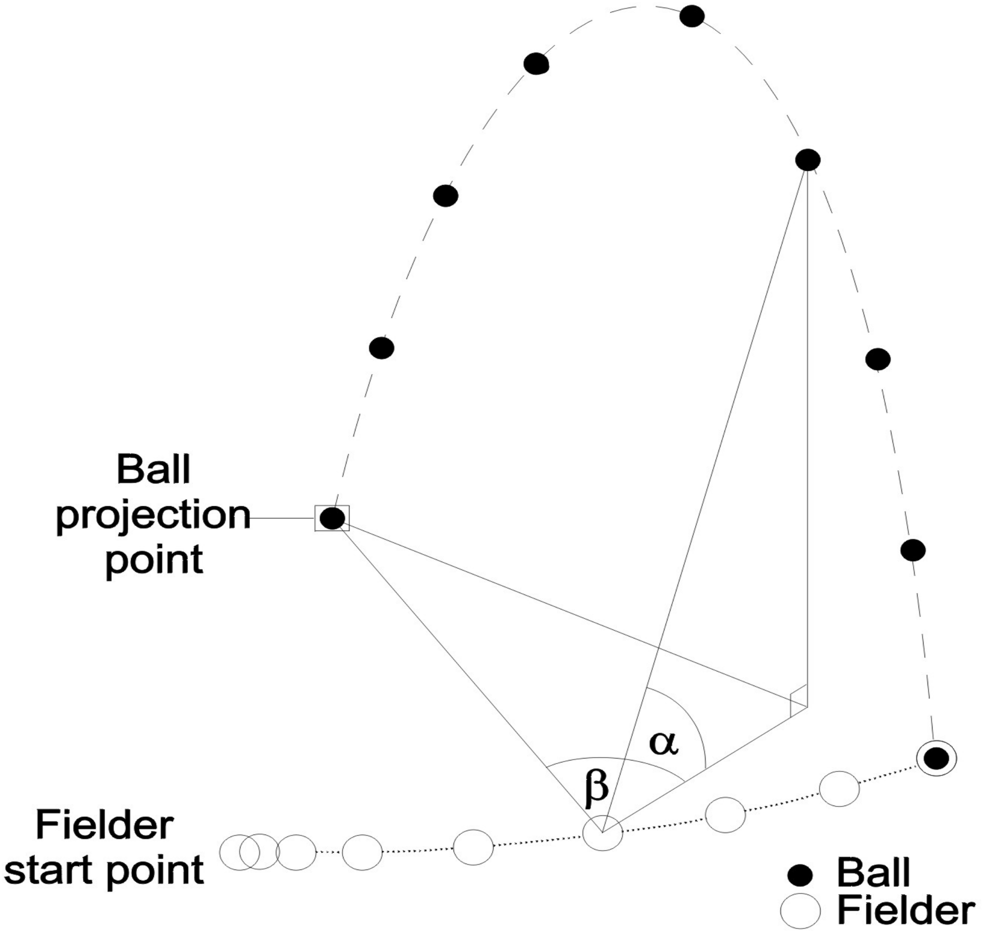

Figure 2