Fielder's Choice: A Unified Theory of Catching Fly Balls

Richard S. Marken

The RAND Corporation

February 11, 2002

Mailing Address:

1700 Main Street

Santa Monica, CA 90407-2138

Phone: 310 393-0411 ext 7971

Fax: 310 451-7063

E-mail: rmarken@rand.org

Abstract. McLeod, Reed and Dienes (2001) argue that there is no ”unified fielder theory” of fly ball catching because there is no theory that can account for a fielder’s choice of one path over the many others that will also result in a catch. This “path choice” criterion is irrelevant, however, if fielders catch fly balls by controlling perceptions of the ball’s trajectory. Control theory provides the basis for a “unified fielder theory” which accounts for the running path data presented by McLeod et al in terms of the perceptions the fielder chooses to control, rather than the path the fielder chooses to take.

Many different running paths will get a fielder to the point where a fly ball can be caught. McLeod, Reed and Dienes (2001) argue that a theory of how fielders catch fly balls – a "unified fielder theory" – should be able to predict which of these many paths will be the fielder's choice. According to McLeod et al, existing theory can predict the fielder's path choice when the ball is hit directly toward but not when the ball is hit to the side of the fielder. They conclude that a "unified fielder theory " – one that can predict a fielder's path choice regardless of where the ball is hit relative to the fielder – still awaits us.

Towards a Unified Fielder Theory

One promising candidate for "unified fielder theory" is the linear optical trajectory (LOT) theory proposed by McBeath, Shaffer and Kaiser (1996). LOT theory says that fielders choose a path to the ball that keeps the optical trajectory of the ball linear. Optical trajectory is defined in terms of temporal changes in the tangents of the vertical and lateral projection angles of the ball relative to a fixed reference point, such as home plate. The vertical projection angle, α, is the angular elevation of the ball relative to home plate from the fielder's perspective. The lateral projection angle, β, is the lateral angle between lines connecting the fielder and the ball to home plate. LOT theory says that fielders choose a running path that keeps the relationship between tan (α) and tan (β) linear over time.

McLeod et al (2001) tested this prediction of LOT theory and found that for most of the catches they observed the relationship between tan (α) and tan (β) was distinctly curved rather than linear. Moreover, the direction of curvature was the same whether the ball was going over the head or landing in front of the fielder. The curvature results from non-linear changes in tan (β) rather than tan (α), a result that rejects LOT theory but is consistent with the optical acceleration cancellation (OAC) theory of fly ball catching.

OAC theory, which is based on the early work of Chapman (1968), says that fielders catch fly balls by keeping the ball's vertical optical velocity – time rate of change in tan (α) – constant. Constant velocity is equivalent to zero acceleration so OAC theory says that fielders run so as to cancel out or zero the ball's optical acceleration (Tresilian, 1995). But OAC theory is only a partial explanation of the path the fielder chooses in order to get to the ball. It explains path choice when a ball is hit directly at the fielder but it does not explain path choice when the ball is hit to the side of the fielder. McLoad et al argue that a unified fielder theory should explain the fielder's path choice regardless of where the ball is hit relative to the fielder. This "path choice" criterion is irrelevant, however, if path choice takes place in a *closed loop* (Marken, 1997).

Choosing Paths vs. Choosing Perceptions

A closed loop exists when the way a system acts influences what it perceives *while* what it perceives is influencing the way it acts. The fielder's path choice occurs in a closed loop because the way fielders act (the path chosen) influences what they perceive (the fly ball) while what they perceive is influencing the way they act. When behavior occurs in a closed loop, the behaving system is acting as a control system and the appropriate theoretical framework for understanding the system's behavior is *control theory*. Control theory shows that the behavior of a control system (such as a fielder) must be understood as a process of *controlling perception* rather than choosing action (Powers, 1973).

A control system acts to bring a perception of some aspect of its environment to a pre-determined or *reference* state while protecting it from the effects of disturbance. This process is called *control* and the perception that is brought to and maintained in the reference state is called a *controlled variable* (Powers, 1978). The actions that protect the controlled variable from disturbance are driven by error -- the difference between the reference and actual state of the controlled variable -- not by information about the disturbance itself. So the actions of a control system depend on (often invisible) disturbances to the controlled variable, not on information regarding the actions to be taken to deal with those disturbances. From a control theory perspective, therefore, a unified fielder theory must account for the perceptions a fielder chooses to control rather than the path the fielder chooses to take.

Path Choice as the Control of Perception

A unified fielder theory based on control theory is described by Marken (2001). The theory explains fly ball catching behavior in terms of control of two perceptual variables: vertical optical velocity and lateral optical displacement. Vertical optical velocity is the time rate of change in the angle of elevation, α, of the ball. The angle α is the angle made by two lines, one connecting the fielder to home plate and the other connecting the ball to home plate. Lateral optical displacement is the lateral (azimuth) angle, γ, between lines connecting the ball and the fielder to a point directly in front of the fielder. The model assumes that the fielder is always looking straight ahead so the angle γ is the angle made by lines connecting the fielder and ball to a point (which changes as the fielder runs) that is directly in front of the fielder's nose. The angle γ is, therefore, not the same as the angle β.

A diagram of the unified fielder theory is shown in Figure 1. The figure shows a theoretical fielder consisting of two independent control systems. One control system controls a perception, $p_{v,}$ of vertical optical velocity, q_v, and the other controls a perception, p_l, of lateral optical displacement, q_l. The system controlling p_v acts to keep this perception under control by moving forward or backward (represented by variations in the output variable, f_v), as necessary. The system controlling p_l acts to keep this perception under control by moving left or right (represented by variations in f_l), as appropriate.

Each control system has a different reference for the perception it controls. The reference for the system controlling p_v, is r_v. The value of r_v was a constant, 0.08, a value that gave the best fit to the data. A reference of 0.08 means that the system controlling p_v tries to keep α increasing at a constant rate (.08 radians/sec, in this case). The reference for the system controlling p_l is r_l. The value of r_l was set to 0.0, which means that the system controlling p_h is trying to keep the image of the ball aligned with the image of the point directly in front of the fielder's nose.

Figure 1 Here

The main disturbance to the variables controlled by each control system is the movement of the ball itself, d. However, the forward and backward movements produced by the system controlling a perception of q_v also act as a disturbance to q_l. Similarly, the left and right movements of the system that is controlling a perception of q_l act as a disturbance to q_v. So although the systems controlling each variable act independently of each other, the systems interact via their disturbing effects on the variables controlled by the other system.

Paths of Action and Perception

The behavior produced by the model fielder is shown in Figure 2. Figure 2a shows the running paths taken by the model fielder. These paths are similar to those observed for real fielders catching fly balls (McBeath et al, 1996, Figure 3, p. 571; McLoed et al., 2001, Figure 2, p. 1349). As in the case of real fielders, some of the paths produced by the model fielder are straight, some are concave inward, and some are concave outward. The shape of the paths produced by the model fielder depends on the trajectory of the ball (d) as well as the parameters of the two control systems. The degree and direction of concavity of the paths can be changed by changing the relative gains of the systems controlling p_v and p_l. The shape of the paths also depends on each system's reference for the perception it controls.

Figure 2 Here

Figure 2b shows the optical trajectory of the ball in terms of temporal variations in the angles α and β. These trajectories are again very similar to those observed for real fielders (McBeath et al, 1996, Figure 4, p. 572; McLoed et al., 2001, Figure 6, p. 1354). As noted by McLoed et al., the optical trajectories are often curved, especially when the ball is hit well to the side of the fielder. It is important to note that the optical trajectories shown in Figure 2b are not those of the controlled variables (p_v and p_l) themselves. Figure 2b shows optical trajectories as they were plotted by McBeath et al and McLoed et al, in terms of the angles α and β. These optical trajectories were created by a model that was actually controlling perceptions of α and γ.

Conceptualizing Control

McLoed et al. describe their own control theory-based fielder model that catches fly balls by controlling elevation of gaze (p. 1349). Nevertheless, they conclude that there is still no unified fielder theory because we do not yet know why fielders choose a particular path to the ball. This conclusion is based on a concept of control that does not derive from control theory. The concept is that of a fielder who controls by choosing a particular path to the ball. This “control of action” concept of control assumes that the fielder’s controlling consists of control actions (the paths taken) that are guided by perceptions (such as elevation of gaze). Control theory takes into account the fact that the fielder’s actions actually occur in a closed loop. The result is a concept of control as “control of perception”, where the fielder’s controlling consists of actions that guide perceptions to reference states and protect them from disturbance.

Both the “control of action” and “control of perception” concepts of control are evident in 57 descriptions of the fielder’s control processes that were found in McLoad et al. The majority of these descriptions (60%) explained the fielder's control process in terms of the "control of perception" concept of control. An example of a "control of perception" description of the fielder's control process is as follows: "OAC theory suggests that [fielders] run so as to keep the rate of increase of tan (α) constant." (McLoed et al, p. on p. 1350). This statement reflects a concept of control as "control of perception" because it describes the control process as actions guiding perceptions: the fielder's action (running) guides the perception (rate of increase of tan (α)) to a reference state (constant).

The remaining 40% of the descriptions of the fielder's control process explain this process in terms of the "control of action" concept of control. An example of a "control of action" description of the fielder's control process is as follows: "OAC theory claims that the fielder decides which way to run by the way tan (α) changes with time." (McLoed et al, p. 1350). This statement reflects a concept of control as "control of action" because it describes the control process as perception guiding action: a perception (time changes in tan (α)) guides the fielder's action (the decision regarding which way to run).

McLoed et al usually conceptualize the controlling done by fielders as the "control of perception". Unfortunately, they also conceptualize this controlling as "control of action". Apparently, McLoed et al see no conflict between these two ways of conceptualizing control and, thus, are able to look at control from these two perspectives simultaneously. The only problem with doing this is that it has led to the "discovery " of obstacles to a unified fielder theory that do not actually exist. McLoed et al were looking at the fielder's controlling from a "control of action" perspective when they discovered that optical trajectory "offers no clue to the fielder about which way to run" (p. 1350) and, thus, cannot be the basis for the fielder's path choice. If McLoed at al were able to consistently look at the fielder's controlling as "control of perception" they would have known that this finding is irrelevant. A unified fielder theory depends on identifying the perceptions the fielder chooses to control, not the perceptions that tell the fielder which path to choose.

Conclusion

Control theory provides the basis for a unified fielder theory. McLoed et al (2001) were hot on the trail of such a theory but lost the scent to a red herring: the idea that we need to know the perceptual basis of the fielder's choice of a particular path to the ball. This red herring appeared as a result of conceptualizing the fielder's behavior in terms of "control of action". A unified fielder theory, based on a conception of the fielder's behavior as "control of perception", accounts for the paths taken by the fielder in terms of the perceptions the fielder chooses to control rather than the paths the fielders choose to take.

References

Chapman, S. (1968). Catching a baseball. *American Journal of Physics*, 36, 868-870.

Marken, R. S. (1997) The dancer and the dance: Methods in the study of living control systems, *Psychological Methods,* 2,436-446

Marken, R. S. (2001) Controlled variables: Psychology as the center fielder views it, *American Journal of Psychology*, 114(2), 259-282

McBeath, M.K, Shaffer, D. M. & Kaiser, M. K. (1996). On catching fly balls. *Science,* 273, 258-260.

McLoed, P., Reed, N. and Dienes, Z. (2001) Towards a unified fielder theory: What we do not know about how people run to catch a ball. *Journal of Experimental Psychology: Human Perception and Performance*, 120, 135-987

Powers, W. T. (1973) *Behavior: The control of perception*. Aldine-DeGruyter

Powers, W. T. (1978) Quantitative analysis of purposive systems: Some spadework at the foundations of experimental psychology, *Psychological Review*, 85, 417-43

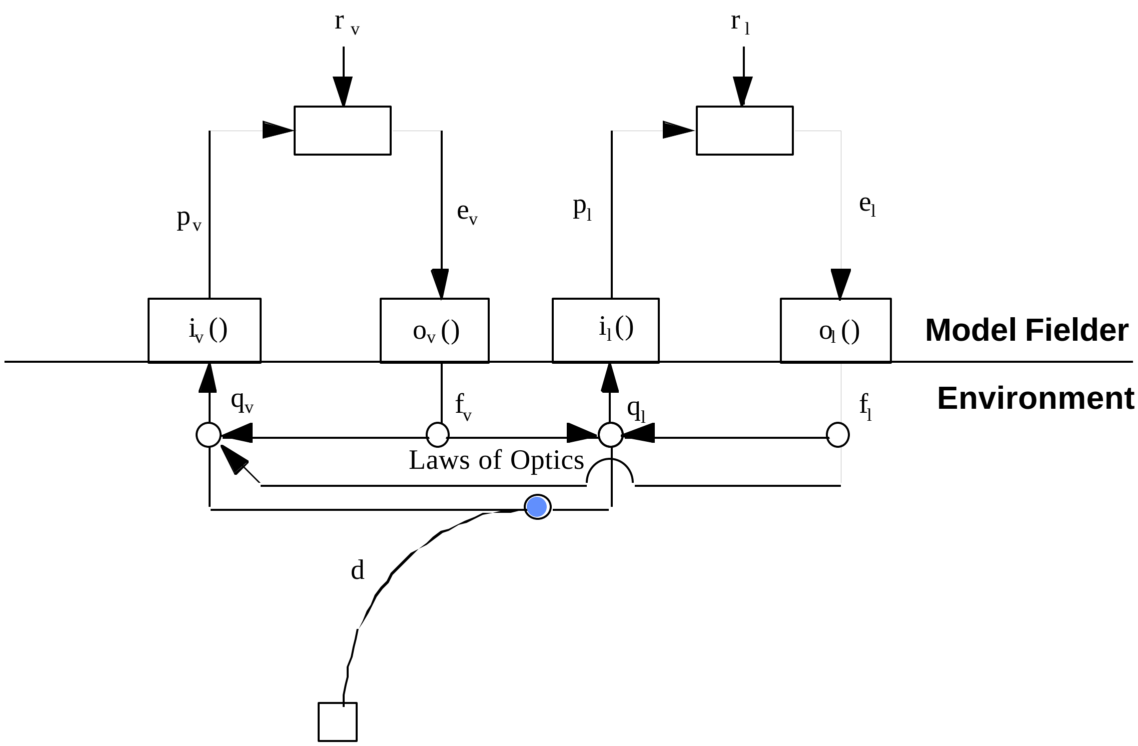
Tresilian, J. R. (1995) Study of a servo-control strategy for projectile interception, *The Quarterly Journal of Experimental Psychology*, 48A, 688-715

Figure Captions

Figure 1. Unified fielder model based on control theory.

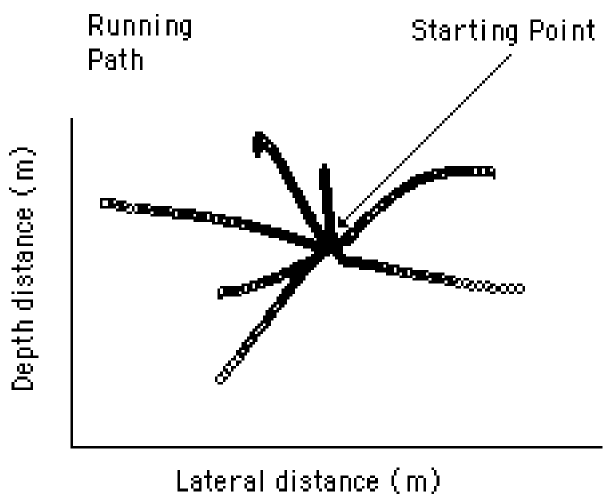
Figure 2. a) Paths of model fielder to intercept fly balls hit at various angles relative to the fielder's starting position. b) Optical trajectories, in α, β space, as seen by the model fielder running to intercept different fly balls.

Figure 1

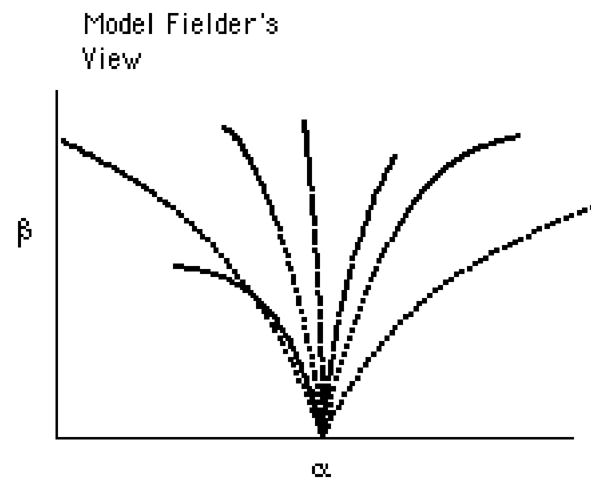


r v
r l
pv
ev
pl
el
iv ()
ov ()
il ()
ol ()
Model Fielder
Environment
qv
fv
ql
fl
Laws of Optics
d

Figure 2



Running
Path
Starting Point
Depth distance (m)
Lateral distance (m)



Model Fielder's
View
β
α

a

b