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The effects of baseball experience on movement initiation in catching fly balls

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Previous research has shown that skilled athletes are able to respond faster than novices to skill-specific information. The aim of this study was to ascertain whether expert outfielders are faster than non-experts in acting on information about the flight of a fly ball. It was hypothesized that expert outfielders are better attuned to this information; as a result, faster and more accurate responses were expected. This hypothesis was tested by having non-expert and expert outfielders judge, as quickly as possible, where a ball would land in the front-behind dimension (perceptual condition) and, in another condition, to attempt to catch such balls (catching condition). The results of the perceptual condition do not support the hypothesis that expert outfielders are more sensitive to ball flight information than non-experts, but the results of the catching condition reveal that experts are more likely to initiate locomotion in the correct direction.

Keywords: baseball experience, catching, movement initiation time, optical acceleration, optical information.

Introduction

Within half a second of a fly ball being hit towards the outfield in baseball, the outfielder will be running in the direction of where the ball is going to land. In baseball jargon, the speed with which an outfielder initiates his movements towards the landing site is known as 'the jump on the ball'. The aim of this study was to determine whether the ability of expert outfielders to get a better jump on the ball than non-experts is a result of their potential to pick up ball flight information faster than non-experts.

With respect to expertise in sports, two general perceptual results have been found. First, experts appear able to pick up information earlier than non-experts (Jones and Miles, 1978; Starkes and Deakin, 1984; Abernethy and Russell, 1987; Abernethy, 1990, 1991, 1993). In racquet sports, for example, expert players can use information from the arm movements of their opponents, whereas non-experts can only take advantage of racquet and ball flight information (Abernethy and Russell, 1987; Abernethy, 1990; 1991). Second, when instructed to respond as fast as possible, experts

also appear to respond faster than non-experts to such skill-specific information (Whiting and Hutt, 1972; Tyldesley *et al.*, 1983; Starkes and Deakin, 1984; Buekers and Pauwels, 1986; Noë *et al.*, 1986; Bootsma, 1988) and even to simple visual stimuli (Youngen, 1959; Whiting and Hutt, 1972).

Bootsma (1988) and Tyldesley *et al.* (1983) presented observers with slides of footballers about to take a penalty kick. They found that, when error rates were equalized, experienced goalkeepers took less time to detect where the to-be-kicked ball would enter the goal. Noë *et al.* (1986) tested this in the field, when only ball flight information was available (no kicker was present). Using vocal reaction time, they found that expert goalkeepers were faster than non-players, although no difference was found between the goalkeepers and other players. Buekers and Pauwels (1986), also using (vocal) reaction time, found that national-level volleyball players were faster and more accurate than physical education students in predicting the landing location of machine-projected volleyballs. On the basis of these results, we also expected experienced outfielders to respond faster to ball flight information (of balls with a parabolic flight trajectory) than individuals with no baseball experience.

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Obviously, the jump on the ball suggests the existence of sensory information about destination very early in the ball's trajectory. If we limit ourselves to ball flight information (e.g. as opposed to batter information) and guidance of locomotion towards the future landing location of the ball, previous research has implicated *vertical optical acceleration* as a potential source of information for balls projected in the sagittal plane of the catcher (Chapman, 1968; Todd, 1981; Michaels and Oudejans, 1992; Babler and Dannemiller, 1993; McLeod and Dienes, 1993; Tresilian, 1995). [Recently, McBeath *et al.* (1995) have proposed an information source (linear optical trajectory) that might be an alternative where there is lateral motion of the ball relative to the catcher; that is, where the ball lands to the side of the catcher. In the present study, the focus is on fly balls that are projected directly at the catcher. In such cases, vertical optical acceleration appears to be an appropriate source of information.]

Vertical optical acceleration refers to the vertical motion of the image of the ball on a projection plane. The projection of a ball with a parabolic flight trajectory ending at the eye rises linearly on the vertical image plane during its entire trajectory, including its descent. A linearly rising vertical optical position (i.e. a constant vertical optical velocity) means that vertical optical acceleration is zero. Thus, a vertical optical acceleration of zero (i.e. below the detection threshold) specifies that the ball will land at the catcher; deceleration specifies that the ball will land in front of the catcher (and hence informs the catcher to run forward to intercept the ball); and acceleration specifies that the ball will land behind the catcher and informs him or her to retreat.

As a strategy for catching, zeroing out optical acceleration (i.e. getting vertical optical velocity constant) will result in the crossing of the trajectories of ball and catcher. If one uses this strategy, a ball will not be caught by running to the landing site as fast as possible and then waiting for the ball to arrive; the locomotion pattern used will keep optical acceleration near zero during the entire flight of the ball, resulting in the arrival of the catcher at the right place at the right time. This sort of continuous coupling has also been observed by Peper *et al.* (1994), who investigated hand movements for simple one-handed ball catching. With respect to catching fly balls, previous research has shown that locomotion patterns in catching are consistent with expectations regarding optical acceleration (Michaels and Oudejans, 1992; McLeod and Dienes, 1993).

On the assumption that vertical optical acceleration is used by catchers, Babler and Dannemiller (1993, p. 28) suggested, with respect to expertise, that outfielders who get a good jump on the ball 'may simply

possess a greater sensitivity to image acceleration'. Thus, we might expect that experienced outfielders are more sensitive to, or better attuned to (Gibson, 1966), vertical optical acceleration than non-experts, as a result of which one might expect that their reactions are faster or more accurate (i.e. more closely coupled to vertical optical acceleration). But even if vertical optical acceleration is not the information source used, we expect experts to be better attuned to whatever information source is used (see Todd, 1981, for an enumeration of other possible sources).

In this study, our aim was to determine whether experts act more quickly and more accurately than non-experts on information from the flight of fly balls. Given the nature of catching and the likelihood of a continuous coupling between ball flight information and locomotory actions (Michaels and Oudejans, 1992; Babler and Dannemiller, 1993; McLeod and Dienes, 1993; Peper *et al.*, 1994; McBeath *et al.*, 1995), it is important to compare experts and non-experts not only from a purely perceptual point of view, as is usually the case, but also during actual catching, when continuous coupling may be evident.

Methods

Subjects

Twelve male subjects, six experts (experienced outfielders) and six non-experts, volunteered to participate in the experiment. The experts all had more than 5 years of competition baseball experience (15 years on average). One of them played in the Major League in the United States, three played in the highest (pro) league in the Netherlands and two played one league lower. The non-experts had no baseball experience, although some were experienced (sometimes several years) in other sports, such as football, tennis and table tennis. The average age of the experts was 24 (range 22-31) years and that of the non-experts 29 (range 22-44) years. All subjects reported normal or corrected-to-normal vision. They were paid a small fee for their participation.

Design

Each observer was tested in two conditions, the location condition and the catching condition, always in the same order. In the location condition, the observer made an arm movement to indicate as quickly as possible where, in front or behind, a projected ball was going to land. Fifty-five balls were projected (30 in front and 25 behind, in random order), preceded by 10 practice trials. In the catching condition, the observer

actually attempted to catch the balls. In this condition, 60 balls were projected, again preceded by 10 practice trials. Thirty of the 60 balls were projected in front of the observer and 30 were projected behind him, in random order.

Experimental set-up

In a gymnasium (height 9 m, length 40 m), a machine (Prince Standard, air-driven) was used to project tennis balls from behind an opaque screen (height 1.2 m) towards the observer (see Fig. 1). Both the angle of release and the speed of release of the balls could be adjusted, permitting a variety of ball trajectories (the angle of release could be varied from 10° to 90°). Calibration of the machine made it possible to fire the balls to approximate distances and heights determined beforehand. The projected balls had a near parabolic flight trajectory and landed either in front of or behind the observer's initial position (18 m from the ball projection machine). The balls were fired in the observer's sagittal plane; thus, there was no lateral motion of the balls relative to the observer.

The movements of the observer or catcher, together with the trajectories of the balls, were videotaped at 50 Hz with two cameras, one S-VHS Blaupunkt camcorder and one Panasonic camera connected to a S-VHS Blaupunkt video recorder. Both cameras were perpendicular to the plane in which the balls were fired and together covered the entire length (40 m) and height (9 m) of the gymnasium (see Fig. 1), with some overlap. Thus, the complete arc of each ball, as well as the movements of the observer or catcher, were visible.

An external synchronization and time-code generator were used to insert identical time-codes on the images of both videotapes.

Procedure

In the location condition, the balls were intended to land 2, 4, 6, 8, 10 or 12 m in front of, or 2, 4, 6, 8 or 10 m behind, the observer. As five balls were fired to each distance, 30 balls were fired in front of, and 25 balls behind, the observer. [The ball projection machine did not fire the balls exactly to the intended distances. The balls could land from about 1 m in front to about 1 m behind the intended distance. For the analyses, the actual distances the balls travelled (gathered from videotape) were used.] All balls in this condition were fired as high as possible without contacting the ceiling. The observers, who were instructed to respond as quickly as possible without sacrificing accuracy, indicated where the ball was going to land by moving their left arm backward or forward from its initial position along the body (see Fig. 1). The observers were not allowed to advance or retreat.

In the catching condition, the catchers were allowed to run freely from the same initial position as in the first condition (18 m from the ball projection machine). To provide more variability in the trajectories of the to-be-caught balls, both distances and flight-times were varied in this condition. Flight-times were varied by firing the balls to different heights. Three heights were used: the maximum height possible without contacting the ceiling, resulting in mean (\pm s) flight-times of 2.29 ± 0.05 s; approximately 75% of the maximum

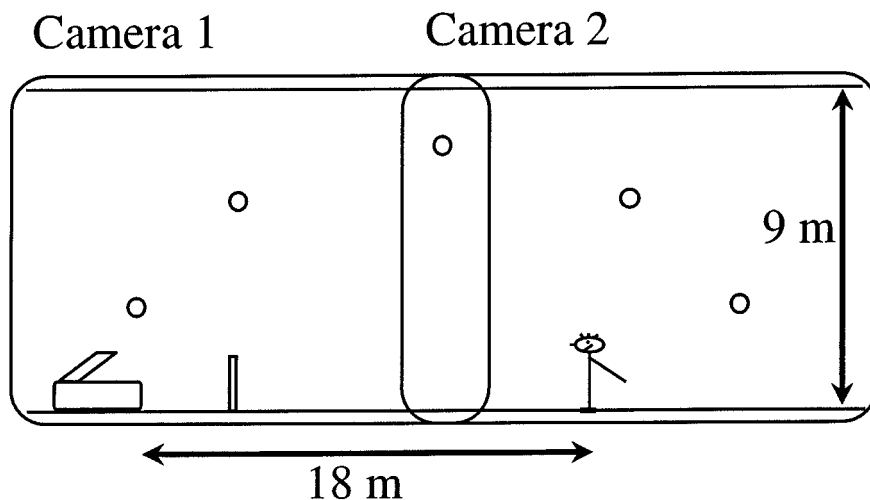


Figure 1 A schematic side-view representation of the experiment. The perceptual location condition is depicted, in which observers responded by moving their left arm (visible on video) forwards or backwards.

height, resulting in flight-times of 2.04 – 0.05 s; and approximately half the height of the gymnasium, resulting in flight-times of 1.85 – 0.06 s. In combination with these three flight-times, the first 36 balls were projected to 3–12 m in front of, and 2–9 m behind, the observer (selected during pilot investigations; one or two balls were shot to each metric distance in these ranges). The order of these 36 balls (18 in front, 18 behind) was randomized. On the basis of the number of balls that were caught during the first 36 trials, the experimenters determined which distance–time combinations should be used for the remaining 24 balls (12 in front, 12 behind), so that the number of balls caught was about equal to the number of balls not caught. Thus, the aim was to fire balls within a range that would be similar with respect to the running capabilities of the catchers. In both conditions, one of the experimenters indicated to the observer when the next ball was about to be fired.

Data reduction

Using a video-frame grabber and a digitizing program, the following variables were obtained from the videotapes: the total time each ball was in flight; the total distance each ball travelled; and the direction and movement initiation time of the arm movement in the location condition, and of the foot movements and head movements in the catching condition (movement onset was determined by selecting the first video field in which movement was visible).

Results

Location condition

With respect to the number of incorrect responses in the location condition, the experts and non-experts did not differ significantly. The number of incorrect responses was 14 out of 309 trials (4.5%) for the non-experts and 10 out of 317 trials (3.2%) for the experts ($\chi^2_{1,309} = 0.76$, n.s.). [About two or three balls accidentally landed within reach of each subject. Responses on these trials were deleted from the analysis. This explains the deviation of the number of trials analysed from the total number of trials (i.e. 330).]

The results of the movement initiation times are more complex. The movement initiation time of a subject's indication of the landing position of a ball is defined as the interval between the moment the ball is first visible and the first movement of the subject's left arm. Because of the frame rate of the video, movement initiation times could be determined to within 20 ms. [Readers may wonder whether 20 ms bins are suffi-

ciently sensitive to test hypotheses regarding movement initiation times. To assess the limitations imposed by the bin size, we simulated a set of results with several random samples of 15 movement initiation times from normal distributions with standard deviations of 10 and 25 ms; both of these standard deviations can be considered small for movement initiation times of arm or whole-body movements. We then placed the data into 20 ms bins and recomputed the means and standard deviations. For the standard deviation of 10 ms, we observed that the mean shifted an average of 1.3 ms and the standard deviation shifted an average of 1.5 ms. For the 25 ms distributions, the average mean shift was 1.1 ms and the average change in the standard deviation was 1.5 ms. With the even larger standard deviations observed here (see Tables 1, 2 and 3), the expected error from grouping data in bins is even smaller. In short, we expect negligible loss of statistical power from grouping the data in 20 ms bins.]

Using a mean split on landing distance from the observer, both the 'in front' and 'behind' ball trajectories were divided into two categories: far and near. An analysis of variance with expertise (expert *vs* non-expert) as a between-subjects factor, and distance (far *vs* near) and landing position (in front *vs* behind) as within-subjects factors, was performed on the movement initiation times of the correct responses. Table 1 shows the mean movement initiation times (MITs) for each group for each combination of distance and landing position. The ANOVA revealed one significant effect, that of distance. Observers responded faster to balls landing far from them (MIT = 545 ms) than to balls landing close to them (MIT = 598 ms) ($F_{1,10} = 18.0$, $P < 0.005$). Between-subject variability accounted for 68% of the total variance, distance for 6%, landing position for less than 1% and expertise for 4%.

No effects involving expertise were significant (all $F < 1$; each of the interaction effects accounted for less than 1% of the total variance). Thus, the location condition did not replicate the expertise effects found in other studies (e.g. Buekers and Pauwels, 1986; Noë *et al.*, 1986). Nor did it support the hypothesis that the faster responses of expert outfielders in baseball is due to their better attunement to ball flight information.

Table 1 Hand movement initiation times (ms) in the location condition for each group and condition (mean – *s*)

	Behind		In front of	
	Far	Near	Far	Near
Non-experts	577 – 159	643 – 169	558 – 66	593 – 108
Experts	512 – 82	592 – 138	533 – 74	563 – 92

Catching condition

As to the speed with which the catchers began their movements, inspection of the videotapes revealed that foot movements were the first visible signs of response initiation. The movement initiation time of the feet is defined as the interval between the moment the ball is first visible and the first movement of either foot. Unfortunately, a foot movement in a certain direction does not automatically mean that locomotion will be in the same direction. The movement of the foot could also be a counter-movement to start moving in another direction. Thus, to measure the movement initiation times of movements in the correct direction, we used the time at which the head started moving in the correct direction on each trial.

The use of movement initiation time as a measure of speed in detecting information implies that subjects begin their movements as quickly as possible. One could argue that catchers did not have to initiate their catching movements as quickly as possible on all trials. On some trials, balls could be caught easily without a speedy reaction, whereas other balls (e.g. uncaught balls) required a quick response. However, catchers *always* seemed to initiate their movements as quickly as possible, which is expected given the uncertainty of whether the next ball would be hard or easy to catch. This is supported by a comparison between caught and uncaught balls.

Two analyses of variance with expertise (expert *vs* non-expert) as a between-subjects factor, and landing position (in front of *vs* behind) and response type (caught *vs* uncaught) as within-subjects factors, were performed on the head and foot movement initiation times. There were no significant effects involving response type. Only the interaction between expertise and response type for movement initiation times of the feet approached significance ($F_{1,10} = 3.67, P = 0.084$), but it accounted for less than 1% of the total variance; between-subjects variability accounted for 62%.

Movement initiation times of the feet. Table 2 shows that, on average, and contrary to our expectations,

Table 2 Foot movement initiation times (ms) in the catching condition for each group and condition (mean - *s*)

	Behind		In front of	
	Far	Near	Far	Near
Non-experts	263 - 79	284 - 96	236 - 82	274 - 99
Experts	313 - 34	359 - 54	357 - 75	368 - 69

experts start moving their feet later than non-experts (mean MITs of 350 and 265 ms, respectively). An analysis of variance with expertise (expert *vs* non-expert) as a between-subjects factor, and distance (near *vs* far) and landing position (in front of *vs* behind) as within-subjects factors, was performed on the movement initiation times of the feet, and revealed this difference to be marginally significant ($F_{1,10} = 4.44, P = 0.06$). It accounted for less than 26% of the total variance (between-subjects variability accounted for 58%). Thus, contrary to our predictions, experts were no faster than non-experts; if anything, they were slower.

As in the location condition, there was a significant main effect of distance ($F_{1,10} = 12.5, P < 0.01$; effect intensity 3%). It appears that the catchers initiated their foot movements faster to balls landing far from them than to balls landing nearby (MITs of 293 and 321 ms respectively). [In the Discussion, we make clear that this distance effect is not inconsistent with the assumption that catchers initiated their catching actions as quickly as possible on the basis of the available perceptual information. The fact that a distance effect was also found in the location condition supports this contention.] Furthermore, it should be noted that the landing location effect was different for experts and non-experts, as indicated by the significant three-way interaction between landing position, distance and expertise ($F_{1,10} = 12.92, P < 0.005$; effect intensity less than 1%). For balls landing far away, non-experts seemed to move their feet faster to balls landing in front of them (236 ms) than to balls landing behind them (263 ms), whereas experts appeared to move their feet more slowly to balls landing in front of them (357 ms) than to balls landing behind them (313 ms).

Movement initiation times of the head. As mentioned earlier, foot movements cannot always be considered to reflect movements in the correct direction. Therefore, we examined the movement initiation times for head movements in the correct direction (Table 3). An analysis of variance with expertise (expert *vs* non-expert) as a between-subjects factor, and distance (far *vs* near) and landing position (in front of *vs* behind) as within-

Table 3 Head movement initiation times (ms) in the catching condition for each group and condition (mean - *s*)

	Behind		In front of	
	Far	Near	Far	Near
Non-experts	582 - 79	671 - 94	445 - 52	481 - 95
Experts	503 - 73	562 - 72	518 - 137	541 - 110

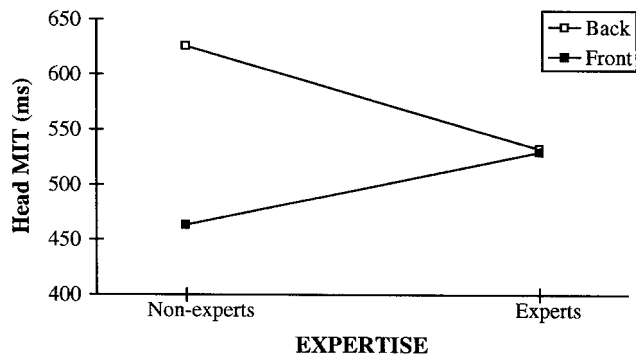


Figure 2 Graphic representation of the interaction effect between landing position and expertise with respect to the movement initiation time (MIT) of the head.

subject factors, was performed on the movement initiation times of the head. This yielded two main effects. First, we again found a significant main effect of distance. Head movements were initiated faster if the ball landed far away (MIT = 512 ms) than if it landed nearby (MIT = 564 ms) ($F_{1,10} = 32.98, P < 0.001$; effect intensity 6%). Between-subject variability accounted for 41% of the total variance. Second, catchers responded faster to balls landing in front of them (MIT = 496 ms) than to balls landing behind them (MIT = 580 ms) ($F_{1,10} = 8.78, P < 0.05$; effect intensity 15%). As shown in Fig. 2, this landing position effect is due entirely to the non-experts. Figure 2 shows the significant interaction between expertise and landing position ($F_{1,10} = 8.11, P < 0.05$), which accounted for 14% of the total variance. Experts were equally fast in the ‘in front of’ and ‘behind’ conditions (analysis of the simple main effects of the two-way interaction, $P > 0.5$; see Keppel, 1973). Non-experts, on the other hand, responded faster to balls landing in front of them than to balls landing behind them (analysis of the simple main effects of the two-way interaction, $P < 0.005$).

An analysis of the number of initial head movements made in the wrong direction helps to illuminate these effects. The errors were primarily made by the non-experts moving forward first, even though the balls landed behind them. For the experts, there was only one anterior false start in 180 trials, whereas the non-experts made 86 such movements (48%). False starts in the other direction occurred 11 (6%) times in the expert group and 7 (4%) times in the non-expert group. Obviously, a false start in the forward direction goes hand in hand with a delayed movement initiation time of the head in the backwards direction, explaining why non-experts were so ‘slow’ in that direction (see Fig. 2 and Table 3). Similarly, because the non-experts

showed clear bias in favour of initial movements in the forward direction, their mean initiation times of the head in the forward condition presumably includes a substantial number of ‘lucky’ starts. This would explain why non-experts were so fast in the ‘in front of’ condition (see Fig. 2 and Table 3).

Movement initiation times of the feet revisited. The difference in accuracy described above (non-experts erroneously moving forward on almost half of the trials in which the ball landed behind them, compared with the experts who made far fewer such mistakes) might provide a different perspective of the movement initiation times of the feet. Recall that non-experts moved their feet faster than experts, instead of the other way around. Bearing the number of false starts of the non-experts in mind, we might now infer that the non-experts traded accuracy for speed, as they started moving their feet before they knew where to run.

To find additional support for this idea, we analysed the movement initiation times of the feet in the ‘behind’ condition in more detail. The experts did not make many false starts in this condition. Hence, we can assume that they responded to ball flight information. On average, they did so 336 ms after ball release. On 52% of the trials in the ‘behind’ condition, the non-experts moved backwards within 309 ms; that is, they also moved in the correct direction. This difference was not significant ($t < 1, P = 0.25$). Thus, it would appear that the correct starts of the non-experts in the ‘behind’ condition were also in response to ball flight information.

But what happened when the non-experts moved forward first, that is, when they made a false start? On average, the first false start foot movement of the non-experts occurred 239 ms after ball release, significantly faster than the movement initiation times of the experts ($t_{11} = 2.49, P < 0.05$). It would appear that the difference between experts and non-experts with respect to the movement initiation times of the feet (see Table 2) is entirely due to the false starts of the non-experts. To conclude, the analyses clearly show that, on many occasions, the non-experts did not initiate their movements in reaction to information about the ball’s destination, whereas the experts did.

Discussion

This study tested the hypothesis that expert outfielders are better attuned than non-experts to optical information about the flight of a fly ball, as a result of which they can get a faster jump on the ball. Our working assumption was that vertical optical acceleration is the information source used by catchers to guide their

locomotion in the direction of the ball, but our results do not rule out other possible sources. In any case, because the kinematics of catching fly balls seems to be coupled to on-going ball flight information, rather than predictive information specifying where and when the ball will land (Michaels and Oudejans, 1992; Peper *et al.*, 1994; McBeath *et al.*, 1995; Tresilian, 1995), subjects were tested both in a perceptual localization task and in an actual catching task.

In the purely perceptual location condition, no effects of the level of expertise were found, suggesting that experts are not faster than non-experts in picking up visual information from the flight of fly balls. Thus, the finding of Buekers and Pauwels (1986), that expert volleyball players were faster than less experienced players in predicting the landing location of machine-projected volleyballs, was not replicated here with fly balls. Perhaps the general ball experience (tennis, football, etc.) of the non-experts provided a sufficient basis for these subjects to perform the location task as quickly and accurately as the experts. On the other hand, it may be that, if catching fly balls indeed requires a continuous relation between perceptual information and kinematics to be established, no expertise effects would be revealed in the purely perceptual task. In short, the assumption that experts can respond faster to optical information about the flight of fly balls was not supported by the results of the perceptual condition, in which no actual relation between information and running actions had to be established.

In the catching condition, an important significant interaction involving expertise did occur for movement initiation times of the head, together with a marginally significant but also important main effect of expertise with respect to movement initiation times of the feet. These effects indicate that differences between experts and non-experts do appear when the dependent variable measures actual catches. In contrast to our expectations, it was the non-experts who responded relatively quickly, especially in the forward direction, but they did so at a cost to accuracy. Presumably, this delayed their responses in the correct direction when the balls landed behind them. Although not as fast, the experts were more accurate in initiating their movements. It appears that they waited until they had detected the necessary information before they took off in the correct direction. Apparently, experts succeeded more often in initially setting up the correct relation between perceptual information and running actions, resulting in a better coupling of effected movement onto required movement. Thus, although a greater sensitivity to ball flight information is not revealed by the faster responses of the experts, the accuracy of their movement initiations

indicates that they were, in fact, better attuned to this information.

So far, we have said little about how the ball flight information is detected. Montagne *et al.* (1993) described two motion detection systems: the image-retina system, in which the eye remains motionless while the projection of the ball moves across the retina, and the eye-head system, in which the moving ball is tracked by eye and head movements. They found that the use of these systems in a simple one-handed ball-catching task depends on the flight time of the ball. For flight times in excess of about 400 ms, the eye-head system is used more frequently. Between about 250 and 400 ms, both the eye-head and the image-retina systems are used. With even shorter times (i.e. below 250 ms), the image-retina system is used, because there is not enough time to use the eye-head system.

In real fly-ball catching, it seems reasonable to assume that fly-ball catchers do not keep their heads still. They probably move their eyes and tilt their heads backward to track the ball. Thus, the eye-head system will be used to detect the necessary information provided by, for instance, the initial angular acceleration of the head - as suggested by Brancazio (1985) - or, perhaps, the optical acceleration of the ball (or the angle of elevation of gaze from catcher to ball; McLeod and Dienes, 1993) relative to the environment. Then again, it is also possible that the image-retina system is used, especially during the initial phase of the flight of the ball, 'for during this time the outfielder may fix his or her gaze on the batter' (Babler and Dannemiller, 1993). If catchers fix their gaze, vertical optical acceleration remains a potential information source for the jump on the ball. The actual pattern of eye-head movements of a fly-ball catcher needs to be established experimentally.

Do the present results have implications for the plausibility of the vertical optical acceleration hypothesis? We have adopted it as a working assumption, but it is nevertheless a matter of controversy. Both Michaels and Oudejans (1992) and McLeod and Dienes (1993) showed that movements of catchers indeed correspond to a locomotion pattern that zeroes out vertical optical acceleration (cf. Tresilian, 1995). Furthermore, Babler and Dannemiller (1993) found support for the thesis that acceleration can be perceived directly and that acceleration detection thresholds are not as high as claimed by some (Schmerler, 1976; Calderone and Kaiser, 1989). This takes the edge off one of the most important objections to the potential usefulness of optical acceleration. Babler and Dannemiller (1993) also undermined Todd's (1981) finding that people could not use optical acceleration, by making clear that the poor performance of Todd's subjects was probably due to stimulus accelerations that were

below the detection thresholds. Relatedly, Michaels and Oudejans (1992) argued that Todd's two-choice paradigm (distinguishing between balls landing at or in front of the perceiver) may have made the task too difficult, because optical accelerations of zero (below threshold) only had to be distinguished from negative optical accelerations.

Our results, again, are consistent with the use of vertical optical acceleration. First, the persistent distance effect, which showed that the subjects initiated their movements faster to balls that landed far from them compared to balls landing close to them, is consistent with the use of optical acceleration. Optical acceleration of the projected balls landing far from the subject would exceed the acceleration detection threshold earlier than optical acceleration of projected balls landing close to the subject (see also Babler and Danne-miller, 1993). In general, balls landing farther away need not have higher optical accelerations. It is possible, in principle, to have two ball trajectories, one landing nearby and one landing far away, with the same optical acceleration. But in the constrained circumstances of the experiment, where all trajectories of balls were fired to about the same height, optical acceleration or deceleration of balls landing far away was higher (and therefore sooner above threshold) than those of balls landing nearby.

Secondly, recall that the non-experts had a tendency to run forward immediately before any relevant information from the flight of the ball could have been detected. Although we cannot explain this, further analysis of the balls landing behind the non-experts revealed that, on average, both the running distances and the flight times of the balls on which a false movement forward was made, were smaller than those for balls for which no such mistake was made ($t_5 = 3.14$, $P < 0.05$ for distances; $t_5 = 2.91$, $P < 0.05$ for flight times). Both shorter distances and shorter flight times would have smaller (later above-threshold) optical accelerations. In other words, the trials on which anterior false starts were made were the trials on which optical acceleration would have been harder to detect. Thus, although the effects of expertise were not in line with earlier expectations, our results do not contradict the thesis that optical acceleration is the crucial optical variable for the jump on the ball.

In conclusion, our results did not show experts to be more 'sensitive' to optical information about the flight of a fly ball, in the sense that they showed faster movement initiation times. Instead, they appeared more able to establish the required relation between information and action when catching was involved. It remains to be seen whether latency differences will emerge if non-experts are held to the same level of accuracy as the experts, thus trading off speed for accuracy. Although

the results of the location condition do not point in this direction, such a result would certainly support a greater sensitivity to ball flight information. The failure to observe a difference between experts and non-experts in the location condition might suggest that the experts' superiority is not of perception *per se*, but of particular ('compatible') perception-action relations.

With the speed-accuracy trade-off in mind, if it is the case that good outfielders have relatively short response latencies when they catch fly balls in the field, the present results do not lend support to the idea that this is because they are faster at picking up information regarding flight of the ball. Instead, the hypothesized shorter movement initiation times (Babler and Danne-miller, 1993) would have to be a result of their capacity to pick up other information, probably at an earlier time (e.g. information from the batter's movements; cf. Abernethy, 1991, 1993), a hypothesis that should be easy to test experimentally.

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