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Naive Beliefs in Baseball: Systematic Distortion in Perceived Time of Apex for Fly Balls

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When fielders catch fly balls they use geometric properties to optically maintain control over the ball. The strategy provides ongoing guidance without indicating precise positional information concerning where the ball is located in space. Here, the authors show that observers have striking misconceptions about what the motion of projectiles should look like from various perspectives and that they estimate when the physical apex of a fly ball occurs to be far later than actual, irrespective of baseball experience. Their estimations are consistent with the highest point they are looking at as the ball approaches, not with the physical apex. These findings introduce a new and robust effect in intuitive perception in which people confuse their perceptual perspective with the physical situation that they mentally represent.

Keywords: baseball, naive physics, space perception, visual perception, mental representation

Naive physics refers to observers' intuitive beliefs about principles of physics that are often at odds with what actually occurs physically or according to Newtonian mechanics. These naive beliefs include misconceptions about the surface orientation of liquids (Hecht & Proffitt, 1995; Smedslund, 1963), wheel dynamics (Proffitt & Cutting, 1979; Proffitt, Kaiser, & Whelan, 1990), the influence of intensity change on auditory pitch (McBeath & Neuhoff, 2002; Neuhoff & McBeath, 1996), representational momentum (Freyd, 1983; Freyd & Finke, 1984; Hubbard, 1996; Kozhevnikov & Hegarty, 2001; Reed & Vinson, 1996), and the trajectories of objects (Hecht & Bertamini, 2000; Krist, Fieberg, & Wilkening, 1993; McCloskey, Caramazza, & Green, 1980; McCloskey & Kohl, 1983; McCloskey, Washburn, & Felch, 1983; Oberle, McBeath, Madigan, & Sugar, 2005).

In this article, we explore possible misconceptions that people have concerning what they see and what visual information is available to them as they watch the flight paths of fly balls headed near them. That is, we investigate whether there is evidence for beliefs about perception that are at odds with what occurs perceptually. Here, we define the beliefs about perception to be how people generally think of what they see as their position relative to the flight of a ball changes (i.e., their mental representation of the flight of a ball). We define perception to be the information afforded people while they are watching the ball approach, given their position relative to the ball flight. That is, if we change where the ball lands relative to observers, their perception will be influenced by where the ball lands relative to them. Their perception can then be measured by their responses to what aspects of the ball flight they sense as the ball approaches. In this way, perception can be influenced in a systematic manner but may also be very subjective (i.e., one can influence all observers' perceptions by launching balls systematically closer and farther from them, but the observers can also have subjective experiences of their perception of the flight of the ball that can vary from one another). There is some evidence showing that observers hold naive beliefs concerning the process of vision (e.g., Winer & Cottrell, 1996; Winer, Cottrell, Karefilaki, & Chronister, 1996). In this article, a significant proportion of children and adults believe that people see by waves or rays going out of the eyes. This is at odds with the way people actually perceive aspects of shape, form, and color (i.e., by light entering the eyes). To our knowledge, there is no work to show that observers may have similar naive beliefs about how they perceive the trajectories of objects that approach them.

Ours and others' previous work have shown that baseball outfielders use a strategy of keeping the ball image moving along a monotonically increasing straight line relative to them in order to catch it (Chapman, 1968; McBeath, Shaffer, & Kaiser, 1995; McLeod & Dienes, 1993; McLeod, Reed, & Dienes, 2003; Michaels & Oudejans, 1992; Shaffer & McBeath, 2002). The strategy of attending principally to these invariant properties provides ongoing guidance without necessarily indicating precise information concerning where the ball is located in space and where it will land (Todd, 1981). However, it appears that many people believe that they have access to this precise physical information as they run to catch fly balls. For instance, several fielders and some physicists contend that they perceive the physical up–down motion of the ball as they run to catch it and imply that they perceive where the ball is located in physical space at each point in time (e.g., Adair, 1995). However, the physical information about the ball's trajectory available to a fielder who is running to catch the ball and someone who has a side view of the ball trajectory is dramatically different. A fielder who is running to catch a ball keeps their head continually tilting upward as they run underneath the ball (Chapman, 1968; McBeath et al., 1995;

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McLeod et al., 2003). This precludes the fielder from precise location information about the up–down motion of the ball. The left panel of Figure 1 shows positions of ball trajectories traveling relative to a stationary fielder from a bird's-eye view looking straight down onto the field. The right panel of Figure 1 shows the resulting optical (or perceived) trajectories of the same stationary fielder for the same physical ball trajectories shown in the left panel of Figure 1. The optical trajectories can be thought of as where the fielder is looking at the ball relative to stationary background scenery. So if one were to attach a small video camera onto the head of a fielder who watched the ball as s/he ran to catch it, the video image one would see as s/he played back the tape would correspond to the optical trajectory of the ball relative to the moving fielder. As balls land farther away from the stationary fielder (e.g., the diamonds trajectory), the optical trajectory of the fielder approaches the curved shape of the physical trajectory, similar to what observers standing far off to the side of the ball trajectory would see, as their eyes and head moved up and down to follow the ball. In this case, the fielder has more accurate information about ball location in physical space. Conversely, as the ball lands closer to the fielder, what the ball flight looks like becomes more discrepant from the physical trajectory. In the most extreme case, when the ball is headed directly toward the fielder (e.g., the squares), the perceived ball flight continues to rise throughout the entire trajectory relative to the fielder, as fielders' eyes and heads continue to move upward and remain tilted high in the air as the ball physically falls toward them (McBeath et al., 1995).[1] In this case, the fielder is precluded from information that indicates the ball is coming down until the final moments.

There are several sources of visual information that are available in the optic array and potentially informative. For example, it is possible to program a machine to analyze visual input via a camera mounted on a moving fielder to determine the trajectories of objects relative to the plane of observation. However, humans are generally either not sensitive enough to this information (e.g., second derivatives with respect to time, judging landing distance) or are not able to exploit it, even when it is essential for performing the task (Todd, 1981). For instance, Todd (1981) showed that the presence or absence of apical information had no effect on performance in judging landing distance, even when the critical source of information to judging landing distance was when the object reached its highest point.

We expect that observers in general do not take perspective into account, and so participants will indicate that the side-view and approaching-view trajectories are both roughly parabolic with perhaps a somewhat steeper descent, corresponding to the ball flight as viewed from the side, which typically ascends for a shorter period of time and falls more sharply and for a longer period of time because of forces caused by ball spin and wind resistance (Brancazio, 1985; Watts & Bahill, 2000). This would suggest that observers believe that the flight of the ball for someone toward whom the ball is approaching should appear similar to a side view of the physical flight of the ball (either a realistic physical trajectory or the parabolic ideal; i.e., the trajectory of a ball in a vacuum or a ball experiencing no aerodynamic drag). This interpretation is incorrect because the curvature in the physical ball flight does not occur from the perspective of someone toward whom an approaching ball is headed.

The present study also examines observers' ability to judge when the apex, or highest point the ball physically reaches in the air, of a fly ball approaching them will occur when they are stationary. As Figure 1 (left and right panels) shows, the farther away the ball lands from an observer (shown in Figure 1, left panel), the corresponding optical trajectory of that observer (shown in Figure 1, right panel) approaches the curved shape of the physical trajectory, and the optical apex (or the highest point where the observer is looking) approaches the physical apex (the highest point the ball is in the air). Conversely, as the ball lands closer to the fielder, the optical trajectory becomes more discrepant from the physical trajectory, and the optical apex occurs much later than the physical apex. Figure 2 shows the occurrence of the physical and optical apices for a ball that is directed at, and lands slightly in front of, a stationary fielder. There are two significant points concerning this figure. First, there is nothing notable optically about when the ball reaches its highest point in the air. The physical apex occurs at time t_4. This corresponds to the height (h) of where the observer is looking of h_4. There is nothing notable about h_4 that would indicate to an observer that the ball is at its highest point or is about to come down. Second, the optical apex occurs much later than actual. This is an example in which the optical trajectory is discrepant from the physical trajectory and, thus, the optical apex is separated in time and location from the physical apex. In the figure, the optical apex, or the highest point the ball reaches relative to where the fielder is looking, does not occur until h_5, with the first noticeable point that the ball is coming down somewhere between h_5 and h_6, long after the apex has already occurred. Optically for the outfielder, the baseball rises longer than it does physically, making accurate judgment of the apex virtually impossible. In a more extreme case than is shown in Figure 2 in which the ball is headed directly at the fielder, the ball never comes down optically, it just grows in size optically at the last moments before reaching the observer. It is due to observers attending principally to optical cues that do not give them physical location information that we expect participants to judge the apex to be reliably later than actual for all balls launched in their general vicinity.

The first experiment was designed to investigate observers' intuitions concerning the path of the optical trajectory of a fly ball from the perspective of a fielder running to catch the ball. That is, we investigated whether people understand the relationship between optical and physical trajectories and whether they understand how disparate the optical trajectory is from the physical trajectory for a fielder who runs toward and catches a ball.

Experiment 1

Method

Participants. Three hundred sixty-two college students answered questions concerning the observed trajectories of baseballs. One hundred

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[1] McBeath et al. (1995) reproduced work by Chapman (1968) showing how, for a stationary fielder, the optical trajectory, or trajectory of the ball from the fielder's perspective, would continue to rise throughout the ball's physical trajectory that rises and falls. To clarify, the optical trajectory of a ball for a fielder at whom a ball is directly projected is equivalent to the image one would see relative to the background scenery from a head-mounted camera.

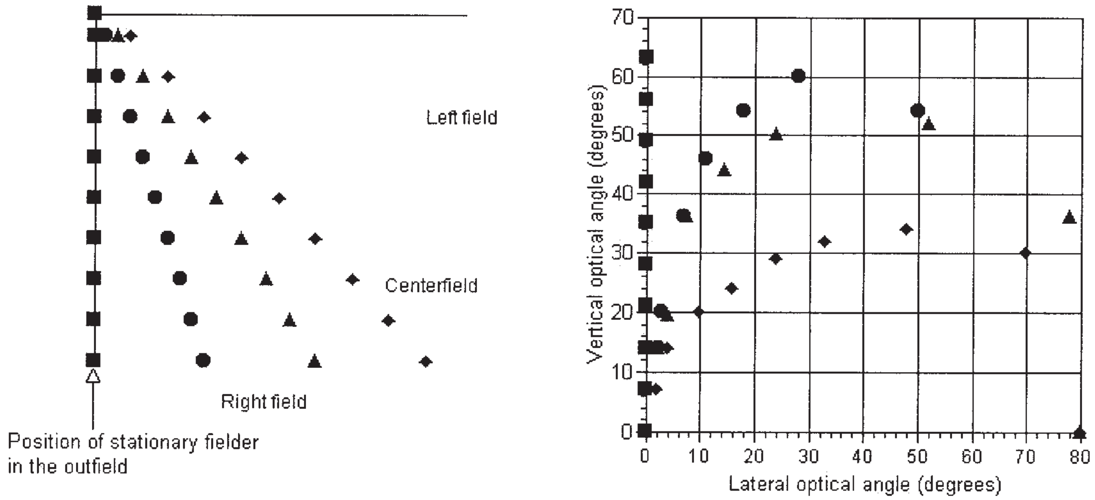

Figure 1. Bird's-eye view of four ball trajectories (represented by squares, circles, triangles and diamonds) relative to a stationary fielder. The left panel displays a bird's-eye view of four ball trajectories starting at the same position and landing in different positions on the field (ignoring effects of air resistance and ball spin). The right panel shows optical ball trajectories of a stationary fielder for the four trajectories shown in the left panel. The perspective optical parabolas appear narrower and their apparent apices are later as the destination point physically approaches the fielder.

seventy-seven participants answered the trajectory questionnaire (described below), while a different group of one hundred eighty-five participants gave confidence ratings about their ability to determine when the apex occurs.

Design and procedure. The first question asked participants to indicate what the trajectory of a fly ball looks like from the perspective of a fielder running to make the catch. Participants chose from four alternatives shown in Figure 3. A 1–6 Likert scale assessed how confident participants were in identifying when the apex of the trajectory of a fly ball occurs as addressed by the following question: "Do you think you could tell where the apex of a ball coming toward you appears?" The scale used for answering the question was as follows: 1 = *certain I could tell where the apex appears*; 2 = *fairly certain I could tell where the apex appears*; 3 = *not certain, but I think I could tell where the apex appears*; 4 = *not certain, but I don't think I could tell where the apex appears*; 5 = *fairly certain that I could not tell where the apex appears*, and 6 = *certain that I could not tell where the apex appears*. Participants were briefed on what the apex of a ball trajectory is, and none had problems understanding this.

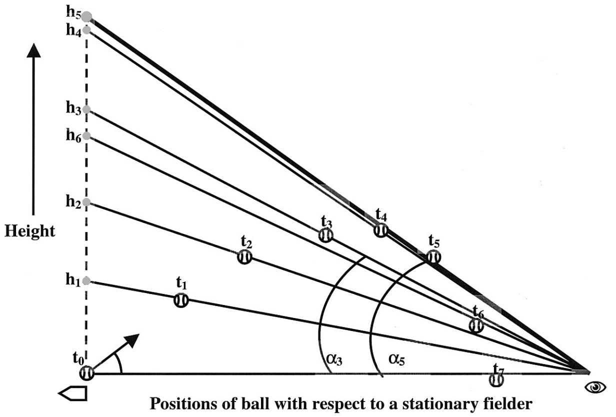

Figure 2. The occurrence of the physical and optical apices for a stationary fielder toward whom the ball is launched. In these cases, the optical apex occurs much later than the physical apex. Physical points in time for the ball (*t*) are shown along with optical points in time (*h*) that correspond to the physical points. Angles of gaze of the fielder off the ground corresponding to the highest point the ball physically reaches (i.e., the physical apex; indicated by α_3) and to the highest point the ball optically reaches (i.e., the highest point the fielder is looking; indicated by α_5) are also shown.

Results and Discussion

Only 7.5% of participants indicated that the trajectory appears to remain straight as it actually does for a fielder running to catch the ball directed to the side. This is not surprising given that this is very counterintuitive. However, what is surprising is that 63% of participants indicated that the trajectory a fielder sees while running to the side to catch the ball looks exactly like the physical trajectory a ball makes, or the path that someone standing off to the side of the trajectory would see [see alternatives (c), 36%, or (d), 27%, in Figure 3]. It's as if they don't acknowledge that their perspective relative to the ball may influence what the flight of the ball looks like to them. A slight majority of participants (51%) also indicated that they could accurately judge when the apex of a ball trajectory occurs. The confidence ratings ranged from 1 to 6 with a median of 3 (M = 3.4, SD = 1.43).

The first experiment confirms that observers have misconceptions about what the trajectory of a baseball looks like from the fielder's perspective. They mistake the path the ball physically makes (or the path one would see the ball make if standing perpendicular to the flight path of the ball and far enough away to see the beginning and end of the trajectory) for what the ball flight looks like from the perspective of a fielder running to make a catch. Observers are completely unaware that, when in the position

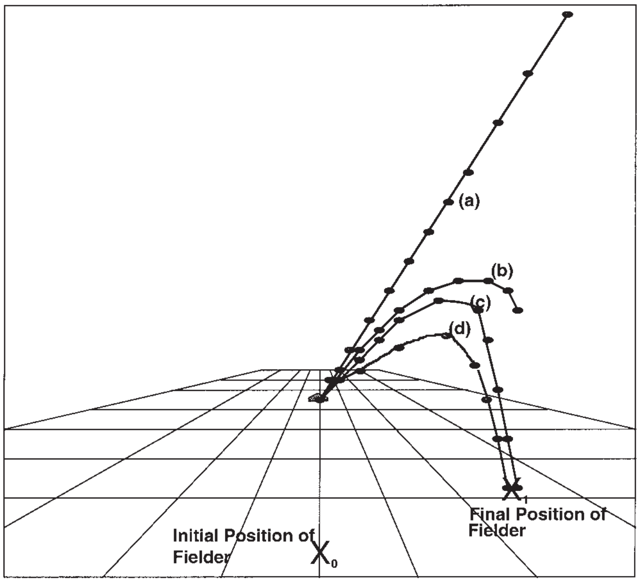

Figure 3. Participants were asked to indicate what the trajectory looks like from the perspective of a fielder running to make the catch. Trajectory (a) is the veridical optical trajectory from the perspective of the fielder running to make the catch. Trajectories (b), (c), and (d) are approximations of what the trajectory of the ball might look like from vantages off to the side; (c) approximates a parabolic ideal (i.e., what a trajectory would look like in a vacuum—ignoring wind resistance), whereas (d) approximates a trajectory taking into consideration the effects of air resistance and ball spin.

of a fielder making a catch, the information available to them is dramatically different than that available from other perspectives. They are unaware that their position relative to the ball constrains them to the types of information they can extrapolate from the ball trajectory. They are also apparently unaware that it is difficult to judge the apex from the perspective of a fielder.

Experiment 2

The rationale for the second experiment was threefold. First, we wanted to test whether people believe they have direct perceptual access to the physical apex of the trajectory of the ball (and so believe that, in general, they should be good at estimating when the apex occurs). Second, we sought to validate that the information available for someone at whom a ball is headed is consistent with the optical trajectories in the right panel of Figure 1. Finally, we wanted to show that observers actually perceive the optical trajectory rather than the physical trajectory and make their estimations of when the apex will occur on the basis of the optical trajectory. Thus, we investigated whether or not observers systematically misjudge the time of the apex of the trajectory of a baseball when they actually observe it approaching them. It is expected that they will indicate that the apex occurs later than actual because as the landing position of the ball approaches a position closer to the observer, the optical trajectory rises longer (i.e., observers keep their heads tilting back for a longer period of time) before finally watching the ball fall to the ground. This systematic change in the optical trajectories as the landing position of the ball gets closer to the observer is shown in Figure 1, whereas the expectation of observers identifying the apex to be later than actual is shown in Figure 2.

Participants

Twenty-two students estimated when the apex of the trajectory of a fly ball occurs for between 25 and 30 ball trajectories. Participants formed five groups of 3, 5, 4, 4, and 6 people. Each of the groups participated at separate times.

Survey

Participants were first asked to fill out a survey that asked them questions concerning how much experience with physics and baseball they had and how difficult they thought it would be to estimate the time the apex occurred. After participating in the rest of Experiment 2 described below, participants were again asked questions concerning the difficulty of the task.

Apparatus

A stand positioned next to, but facing away from, participants held two fluorescent lamps (one green and one yellow). The person launching the balls out of a pitching machine indicated the exact moment the ball left the pitching machine by flipping on a light switch that turned on the green light when the ball was fed through the wheels that launched the ball. A judge standing 60 m orthogonally to the trajectory of the baseball indicated when the ball reached its apex by flipping on the light switch that controlled the yellow light. Both judges also indicated when the ball hit the ground to indicate a reliable estimate of exactly how long the ball was in the air. Each participant held a flashlight and turned the flashlight on when they thought the apex occurred. A video camera was placed 6 m in front and to the right of participants and recorded both their responses and the actual launch and apex times as indicated by the lighting apparatus. Recordings of when each participant indicated the apex occurred were taken as the first movement of the hands to turn on the flashlight (measured to within one thirtieth of a second), even if the light of the flashlight was not yet lit, provided their movements eventually led to the flashlight being turned on. This reduced any lag time between their decision that the apex had occurred and their abilities to indicate it.

A movable foreground marker was placed directly behind the participants. A second video camera located immediately behind the marking fence recorded the optical trajectory of the participants or their view of the flight of the ball as it approached. This marker was a 0.92-m wide by 1.22-m high segment of 0.1-m grid fencing suspended off the ground within a wooden frame. The entire light and filming apparatus was portable and allowed us to position participants anywhere on the field.

One of two judges blind to the hypotheses of the experiment indicated when the apex occurred. In pilot work testing for reliability, two judges rated when the apex of the trajectory occurred for 30 independent trials. There was no consistent bias in responding across judges. The standard deviation of the difference in judges' responses was 4.83 one thirtieth of a second video frames (or 0.16 s).

Design and Procedure

Participants stood 60 m from where balls were launched. In the experimental condition, balls were directed in the general vicinity of participants. In the control condition, five or six balls per group were launched perpendicular to the participants' line of sight from left to right (so that the balls remained approximately 60 m from participants throughout the ball's flight, allowing a side view of the ball's flight path). For all conditions, participants were instructed to watch the ball as it approached and to indicate the point in the trajectory when the ball reached its apex by turning on a flashlight. They were all briefed on what the apex of a ball trajectory is and none had problems understanding this.

Layout of Field

The field was divided into a grid of 5 × 5 sections. The grid intersection points were marked on the field by cones that were placed at set distances from one another. This was done to determine the landing position of each ball trajectory relative to participants. Grids were between 18 and 37 m in width and depth. Figure 4 shows the grid layout.

Results

Survey. Fourteen of the participants responded that they had no experience playing baseball or softball, or they played rarely. We categorized this group as the novice group. Eight participants responded that they played regularly or competitively (i.e., they regularly play or played competitively on a varsity team in high school or college). We categorized this group as the expert group.

Estimating when the apex occurred. Judges' estimates of the time that the apex occurred for each ball trajectory were statistically compared with the time when participants indicated it occurred using repeated measures t tests (the deviation scores were compared to zero). Indications of when the apex occurred, on average, were a full second and significantly later than the time the physical apex occurred for all trials and all participants in the test condition (mean latency = 1.04 s), $t(457) = 33.77$, $p < .001$. Because the large degrees of freedom could make any small effect statistically significant, we calculated Cohen's d to measure the effect size. The effect was extremely large ($d = 1.8$ with a $d = 0.8$ typically indicating a large effect (Cohen, 1988)). The total time the ball was in the air varied from 2.67 s (balls landing far in front of participants) to 6.00 s (balls landing far beyond participants).

We also analyzed only the trials where the balls were headed directly at or virtually directly at the participants. On average, participants estimated the apex to occur 50 video frames or 1.67 s after the apex had already occurred. The average time the ball was in the air for these trials was 123 frames or 4.1 s. This means that if the physical apex occurred about halfway into the flight of the ball (the apex actually occurs slightly earlier because of aerodynamic drag or wind resistance (Brancazio, 1985; Watts & Bahill, 2000)), it would occur approximately 2 s into the flight of the ball. This translates into participants estimating that the apex occurred only one third of a second before the ball would have made impact with them if they stood in the same place to catch it, [i.e., 4.1 – (2 + 1.67)].

Greater exposure to playing baseball or softball did not lead to better performance in identifying when the apex occurred. In fact, indications from those qualified as novices (mean latency = 0.97 s) were slightly, but not significantly, closer in time to the actual apex than indications from those qualified as expert baseball fielders (mean latency = 1.15 s).

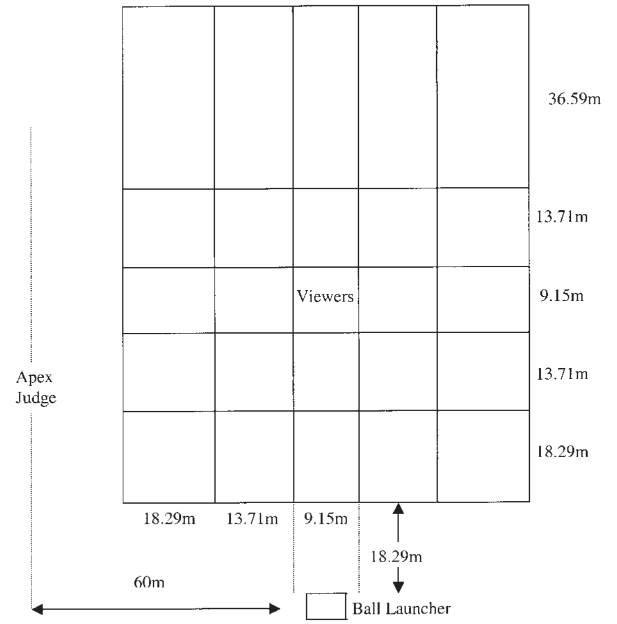

Figure 4. The general layout of the field for judging when the apex occurs. Participants ("Viewers") stood approximately 61 m from the ball-launching machine. Balls were launched randomly into one of the grids shown in the figure.

The top left panel of Figure 5 shows sample empirical optical patterns of balls landing in front of participants with the physical apex, the optical apex, and the estimations of when the apex occurred labeled with letters. The letter *A* represents the physical apex (or actual apex), *O* represents the optical apex, and *E* represents the mean estimation by the participants of when the apex occurred for that ball's trajectory. Each symbol is shown on top of the exact frame when each occurred. The delay between *A* and *E* is represented graphically in the trajectories in the top left panel of Figure 5, in which *E* is located much later (or further along) in the trajectory than *A*. The delay in *O* and its correspondence with participants' estimates is represented graphically where *O* is also much later and typically coincides with *E*. In short, participants' estimations tend to co-occur with the optical, and not the physical apex. We were not able to code when the optical apex occurred for all trials, because in several trials the ball was out of the field of view of the camera before we could be sure the optical apex occurred. Thus, to analyze the relationships among the actual apex, optical apex, and participants' mean estimations, we selected 19 trials in which the optical apex was apparent and which included 3–4 trials from each of the five participant groups, and we performed a repeated-measures analysis of variance (ANOVA) on this data. This analysis showed that the actual apex occurred significantly later than both the optical apex and mean estimations, $F(2, 17) = 83.28$, $p < .001$; $q(2, 17) = 23.78$ and 23.45, respectively, $ps < .01$. The post hoc analyses also showed no difference between when the optical apex occurred and participants' mean

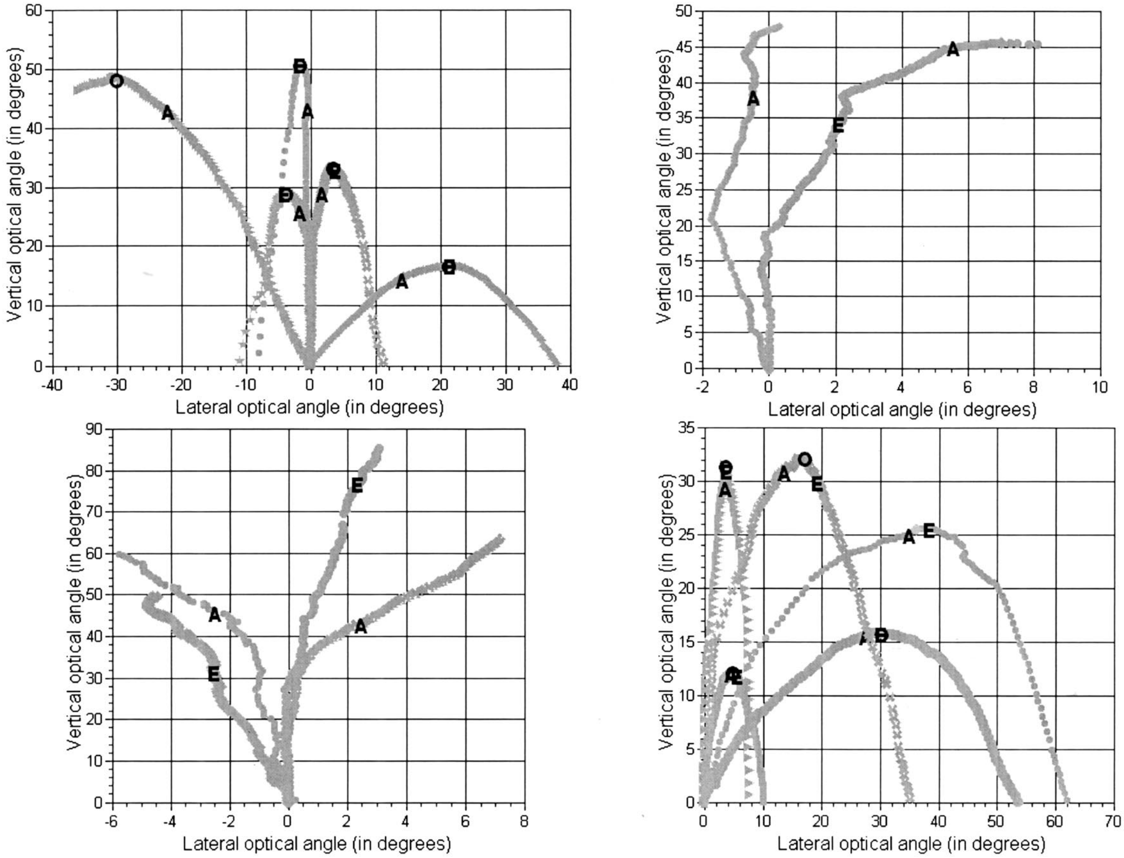

Figure 5. Optical ball trajectories in the treatment condition. The top left panel shows the empirical optical trajectories and the exact frame in time that the actual apex (*A*), participants' mean estimate (*E*), and the optical apex (*O*) occurs for balls landing in front of participants. Each frame represents the optical position of the ball (relative to where the observers are looking) at each one thirtieth of a second video frame. The top right panel displays the empirical optical trajectories for balls landing very close to participants. In the trajectory on the left, only *A* is shown because participants' indications and the optical apex occur long after the portion of the optical trajectory shown. The bottom left panel shows the empirical optical trajectories for balls going over the heads of participants. Shown also is exactly what frame in time the actual apex occurs. In all the trajectories, only *A* is shown because estimations and the optical apex occur long after the portion of the optical trajectory shown. The bottom right panel displays the empirical optical trajectories for balls in the control conditions, including *A, O,* and *E*.

estimations, $q(2, 17) = 0.33$, $p > .05$, indicating that they co-occurred. Regression analysis also confirmed that the optical apex provides a very good predictor of when participants estimated the apex occurred ($r = .88$, $p < .001$).

The top right panel of Figure 5 shows sample empirical optical patterns for balls headed very close to the participants. These are portions of optical trajectories in which the ball later goes out of the field of view of the camera (toward the end of the trajectory). The same pattern exists for balls hit very close to participants as well as balls hit in front of them. For the particular optical pattern shown to the left, the optical apex has not yet occurred and, thus, *O* is not shown. The mean estimation also occurs after the ball goes out of the field of view of the camera. Thus, for that trajectory only *A* is shown. For the trajectory on the right, the distance between *A* and both *O* and *E* is large, indicating again that they occurred long after *A*. The distances between *A* and *E* are greater for balls landing very close to observers than for balls landing in the general vicinity but not extremely close to observers. The bottom left panel of Figure 5 shows sample empirical optical patterns for balls that went over observers' heads. Similar to the balls headed very close to participants, these are portions of the perceived ball flight in which the ball later goes out of the field of view of the camera. Here, only *A* is shown, because the mean estimation occurs after the ball goes out of the field of view of the camera. It is interesting that the mean estimations here tended to co-occur not only with the optical apex but also with the time the participants stopped looking upward and backward at the ball (i.e., until the ball went out of their field of view).

Responses of the participants in the experimental condition appear to be due to the constraining of the physical information available to them as balls approached. However, this discrepancy could also be explained by a reaction time lag that may have been more exaggerated because of the task of turning their flashlights on. To test this, we also analyzed the results of the control condition. A repeated measures *t* test comparing the deviation between the actual apex and mean estimated apex for the control condition indicated that these occurred at the same time, $M = 5.99$ frames or 200 ms, $t(30) = 0.42$, $p > .10$. The bottom right panel of Figure 5 shows optical patterns for the control condition. Again, in this condition, balls were launched perpendicular to the line of sight of participants so they had a complete side view of the trajectory. *A*, *E*, and *O* are close together and sometimes on top of one another, indicating that the time when they occur is close together.

Figure 6 shows the delay between the actual and estimated time of apex as a function of where the ball landed relative to participants. The bars in this graph correspond to the grids shown in Figure 4 (cited in the *Method* section) oriented with the throwing machine located 18.29 m in front of the *x*-axis and participants in the middle (where the 9.15 and 9.15 grids meet). The bar at the very front of the graph is the mean delay found in the control condition, which corresponds to typical reaction time (approximately 200 ms). As the figure shows, the closer the ball lands to the participants both in the lateral and depth direction (until it passes overhead), the higher the bars and the more delayed their estimations of when the apex occurs.

To analyze how distance of the landing position of the ball away from the participants affected their estimations of when the apex occurred, we performed two separate one-way ANOVAs on lateral distance from observers and depth distance from observers. The way lateral and depth directions were categorized for analysis is shown in Figure 7. This is essentially Figure 5 with numbers beside the lateral and depth grids indicating how different rows and columns of grids were categorized. The entire row behind observers (away from the ball launcher) was eliminated. This was done because, as is shown in Figure 6, there was a ceiling effect for balls launched behind observers. The probable reason for this ceiling effect is clarified in the Discussion. In the depth direction, we assigned the first row (closest to the ball launcher) as the first group (designated "1"), the second row as another group ("2"), and the next two rows as the third group ("3"). In the lateral direction, there were no significant differences in time delays for mirror-image grids in the left–right direction so the left–right columns were collapsed for the analyses. The two outside columns were classified as one group (designated as "1" along the horizontal line immediately in front of the pitching machine), the next two columns inward as the second group ("2"), and the column in line with the participants as the third group ("3"). The first ANOVA used distance from the observers in the lateral direction as the independent variable and time delay between estimated and actual apex as the dependent variable. Delays in estimated time of the apex significantly increased the closer the ball landed to the participants, $F(2, 405) = 6.85$, $p = .001$. Tukey's post hoc analyses showed that the time delay for balls landing closer to participants (in the middle three columns) was significantly longer than in the outside two columns of grids (designated by "1's" in Figure 7; $ps = .001$ and $.031$; $M_1 = 0.83$ s, $M_2 = 1.08$ s, $M_3 = 1.13$ s). The second ANOVA showed that the distance where balls landed from the observers in the depth direction also significantly affected time delay in estimating when the apex occurred, $F(2, 405) = 63.75$, $p < .001$. Tukey's post hoc analyses showed that the time delay for balls landing in the row including the participants in depth (designated "3" in Figure 7; $M_3 = 1.32$ s) was significantly longer than for balls landing in either of the farther two rows, and the next nearest row to the participants (designated "2" in Figure 7; $M_2 = 0.9$ s) was also significantly different from the farthest row from the participants in depth (designated "1" in Figure 7; $M_1 = 0.4$ s; all $ps < .001$).

Before and after the experiment, participants rated within what time frame they believed they could accurately judge when the apex of a fly ball occurs for the experimental condition. Before the task, the median rating was to the nearest second (± 1 s), whereas

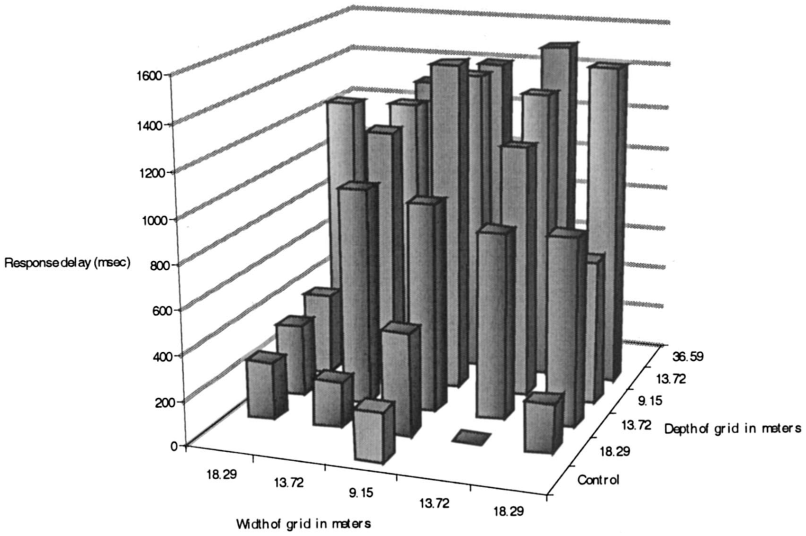

Figure 6. Delay between participant's estimations of when the apex occurred and when it actually occurred. Shown is the response delay in milliseconds (msec) between participants' responses and the physical apex for ball trajectories landing in the respective grids. The bar at the very front represents the delay for the control conditions.

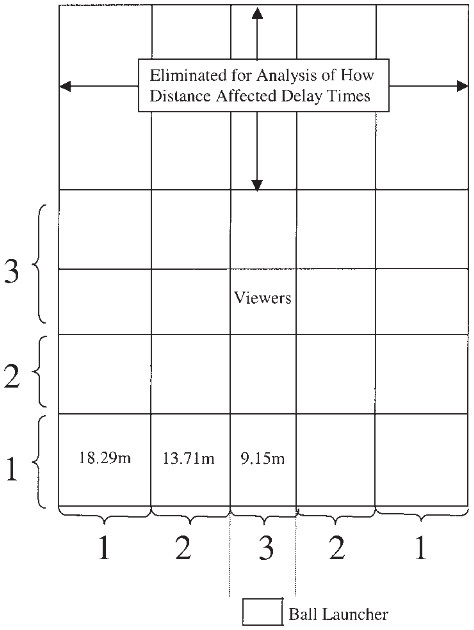

Figure 7. Categorization of distances from observers for analysis. This figure shows the general layout of the field from Figure 5. The numbers listed along the rows and columns indicate how distance was categorized in the lateral and depth direction for the analysis of landing distance and apex estimation.

after the task the median rating was to the nearest one half second (± 0.5 s). Eighty-one percent were more confident after their participation in terms of the timing accuracy in which they thought they could judge when the apex of a fly ball occurs. Thus, participants thought that identifying when the apex occurred for the experimental condition trials was significantly easier after the experiment rather than before, $t(21) = 3.81$, $p = .001$.

Discussion

Experiment 1 confirmed that observers have misconceptions about what the trajectory of a baseball looks like from the fielder's perspective and are unaware that, when in the position of a fielder making a catch, the information available to them is dramatically different than that available from other perspectives. They are also apparently unaware that it is difficult to judge the apex from the perspective of a fielder.

Experiment 2 confirmed that observers are poor at estimating the apex of the trajectory of fly balls headed near them. The findings indicate that participants estimated the apex to occur much later than it actually does. The delays in their estimates are also strongly influenced by where the balls land relative to them (and thus, what the trajectories look like as the balls approach). As balls land closer to the observer, the ball flight looks less like the physical trajectory, and the perceived apex occurs later than the physical one. This resulted in participants estimating the apex to be later as balls landed closer to them. As balls land farther away from the observer, the optical trajectory looks more like the physical trajectory, and the optical apex occurs closer to the physical apex. This resulted in participants estimating the apex to be closer in time to the physical apex for balls landing far away from them.

These findings introduce a new and robust effect in which people confuse their perceptual perspective with the physical situation that they are mentally representing. Observers mentally represent balls approaching them to ascend and descend without awareness of how different their optical view is from physical reality. Most observers appear unaware of the optical characteristics of ball movement and apparently assume they have a more gifted perspective of the up–down motion of the ball trajectory. Specifically, they appear to believe that they have a view that allows them to accurately perceive the physical location of the ball in flight, irrespective of their own location relative to its trajectory. This seems to be further perpetuated by their mistaking the optical apex for the physical apex. In spite of their poor performance, participants' confidence in their ability to accurately indicate when the apex occurred actually increased after participating. Eighty-one percent of participants in Experiment 2 indicated that they were more accurate at estimating when the physical apex of a fly ball headed toward them occurred than they thought they would be before the experiment. Three reasons can explain why observers were so confident. First, for several balls in the experimental condition (landing far away from them), their view was virtually that from a side view. As we showed in the extreme version of this in the control condition, observers were quite accurate at estimating the apex in these cases. Second, when balls landed close to them (including balls that were virtually directly at them), optical cues such as convergence, accommodation, binocular parallax, and the size of the image of the ball on the eye (or τ), all indicate that collision is near, and these cues tell the observer when to put the hand up to catch the ball or when to get out of the way (Kaiser & Mowafy, 1993; Lee, 1976; Peper, Bootsma, Mestre, & Bakker, 1994; Savelsburgh, Whiting, & Bootsma, 1991; Tresilian, 1990). In the case of balls headed directly at them, these cues begin about one third of a second before collision. This is consistent with the average time that observers indicated the apex occurred for balls headed directly at them (see *Results* section). Finally, they are probably basing their indication of when the apex occurs on the optical apex that they identify rather well. This would explain why viewers are inclined to hold these naive beliefs in the face of their poor performance. Their apparent reliance on the optical apex was also apparent to those who watched the participants make their responses to balls landing behind them. As Figure 6 shows, the bars representing the delay in estimating the apex for balls landing in the rows behind the participants are all at about the same maximum height. Many participants seemed to move their heads up and back as far as they could before estimating when the apex occurred. Some did so more than others and estimated the apex to be later. If one were to do this in an apparatus that flipped them over until their head was on the ground, the ball would not reach its highest point relative to where the observer was looking (or optical apex) essentially until the ball hit the ground.

As Figure 5 (bottom right panel) and the results from the control condition shows, participants were very good at identifying the physical apex when they were presented an orthogonal view of the trajectory. In this condition, they were given the greatest access to the information specifying when the apex occurred. Figure 6 shows that as the ball lands farther and farther in front or to the side of participants, their estimation of when the apex occurred also becomes more accurate. This is because as the ball landed farther away from participants, the trajectory of the ball begins to look more like the trajectories in the control condition, and the apparent apex more closely approaches the physical one.

The present findings also complement those found in the naive physics literature concerning the trajectories of objects. In that work, people mistakenly believe that objects travel in a way contradicted by Newtonian mechanics (Hecht & Bertamini, 2000; Kaiser, McCloskey, & Proffitt, 1986; Kaiser, Proffitt, Whelan, & Hecht, 1992; McCloskey et al., 1980; McCloskey & Kohl, 1983; McCloskey et al., 1983). One finding from this work has shown that a large percentage of children and adults believe that an object carried by an observer, plane, or train, falls straight down, rather than continuing to move forward as it falls (McCloskey, 1983; McCloskey et al., 1983). This misconception seems to occur because the carrier acts as a frame of reference against which the falling object is seen. McCloskey et al. (1983) demonstrated that a perceptual illusion like this does occur when people carry objects that are dropped. The present work demonstrates a converse phenomenon. Here, observers seem to confuse or substitute their reasonably accurate semantic knowledge of the physical flight of the ball with the information that is optically available during projectile tracking tasks.

Participants' poor performance in estimating when the apex occurred for balls landing near them need not adversely affect their performance in navigating toward and catching a fly ball. This is because those actions are based on optical control heuristics, like spatial and temporal constancy between themselves and the ball, that guide fielders to the right spot just in time to catch balls (Chapman, 1968; McBeath et al., 1995; McLeod & Dienes, 1993; McLeod et al., 2003; Michaels & Oudejans, 1992; Shaffer & McBeath, 2002). Having only a loose representation of the actual ball position appears to serve us quite adequately. Perhaps being more aware of our lack of ball position information would only be a distraction. In any case, it appears that observers do not realize the extent to which their perception of an approaching fly ball is based on their mental construct rather than reliable sensory information. Observers appear to be unable to disambiguate their sensory information and physical knowledge in their percepts of approaching projectiles.

References

Adair, R. K. (1995, June 23). Play ball! *Science, 268,* 1681–1682.

Brancazio, P. J. (1985). Looking into Chapman's homer: The physics of judging a fly ball. *American Journal of Physics, 53,* 849–855.

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

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Freyd, J. J. (1983). The mental representation of movement when static stimuli are viewed. *Perception & Psychophysics, 33,* 575–581.

Freyd, J. J., & Finke, R. A. (1984). Representational momentum. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10,* 126–132.

Hecht, H., & Bertamini, M. (2000). Understanding projectile acceleration. *Journal of Experimental Psychology: Human Perception and Performance, 26,* 730–746.

Hecht, H., & Proffitt, D. R. (1995). The price of expertise: Effects of experience on the water-level task. *Psychological Science, 6,* 90–95.

Hubbard, T. L. (1996). Representational momentum, centripetal force, and curvilinear impetus. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 1049–1060.

Kaiser, M. K., McCloskey, M., & Proffitt, D. R. (1986). Development of intuitive theories of motion: Curvilinear motion in the absence of external forces. *Developmental Psychology, 22,* 67–71.

Kaiser, M. K., & Mowafy, L. (1993). Optical specification of time-to-passage: Observers' sensitivity to global tau. Journal of Experimental Psychology: Human Perception and Performance, *19,* 1028–1040.

Kaiser, M. K., Proffitt, D. R., Whelan, S. M., & Hecht, H. (1992). Influence of animation on dynamical judgments. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 669–690.

Kozhevnikov, M., & Hegarty, M. (2001). Impetus beliefs as default heuristics: Dissociation between explicit and implicit knowledge about motion. *Psychonomic Bulletin & Review, 8,* 439–453.

Krist, H., Fieberg, E. L., & Wilkening, F. (1993). Intuitive physics in action and judgment: The development of knowledge about projectile motion. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 952–966.

Lee, D. N. (1976). A theory of visual control of braking based on information about time-to-collision. *Perception, 5,* 437–459.

McBeath, M. K., & Neuhoff, J. G. (2002). The Doppler effect is not what you think it is: Dramatic pitch change due to dynamic intensity change. *Psychonomic Bulletin & Review, 9,* 306–313.

McBeath, M. K., Shaffer, D. M., & Kaiser, M. K. (1995, April 28). How baseball outfielders determine where to run to catch fly balls. *Science, 268,* 569–573.

McCloskey, M., Caramazza, A., & Green B. (1980, December 5). Curvilinear motion in the absence of external forces: Naive beliefs about the motions of objects. *Science, 210,* 1139–1141.

McCloskey, M., & Kohl, D. (1983). Naive physics: The curvilinear impetus principle and its role in interactions with moving objects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9,* 146–156.

McCloskey, M., Washburn, A., & Felch, L. (1983). Intuitive physics: The straight-down belief and its origin. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9,* 636–649.

McLeod, P., & Dienes, Z. (1993, March 4). Running to catch the ball. *Nature, 362,* 23.

McLeod, P., Reed, N., & Dienes, Z. (2003, November 20). Psychophysics: How fielders arrive in time to catch the ball. *Nature, 426,* 244.

Michaels, C. F., & Oudejans, R. R. D. (1992). The optics and actions of catching fly balls: Zeroing out optical acceleration. *Ecological Psychology, 4,* 199–222.

Neuhoff, J. G., & McBeath, M. K. (1996). The Doppler illusion: The influence of dynamic intensity on perceived pitch. *Journal of Experimental Psychology: Human Perception and Performance, 2,* 970–985.

Oberle, C. D., McBeath, M. K., Madigan, S. C., & Sugar, T. G. (2005). The Galileo bias: A naive conceptual belief that influences people's perceptions and performance in a ball-dropping task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31,* 643–653.

Peper, L., Bootsma, R. J., Mestre, D. R., & Bakker, F. C. (1994). Catching balls: How to get the hand to the right place at the right time. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 591–612.

Proffitt, D. R., & Cutting, J. E. (1979). Perceiving the centroid of configurations on a rolling wheel. *Perception & Psychophysics, 25,* 389–398.

Proffitt, D. R., Kaiser, M. K., & Whelan, S. M. (1990). Understanding wheel dynamics. *Cognitive Psychology, 22,* 342–373.

Reed, C. L., & Vinson, N. G. (1996). Conceptual effects on representational momentum. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 839–850.

Savelsbergh, G. J. P., Whiting, H. T. A., & Bootsma, R. J. (1991). Grasping tau. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 315–322.

Shaffer, D. M., & McBeath, M. K. (2002). Baseball outfielders maintain a linear optical trajectory when tracking uncatchable fly balls. *Journal of Experimental Psychology: Human Perception and Performance, 28,* 335–348.

Smedslund, J. (1963). The effect of observation on children's representation of the spatial orientation of a water surface. *Journal of Genetic Psychology, 102,* 195–202.

Todd, J. T. (1981). Visual information about moving objects. *Journal of Experimental Psychology: Human Perception and Performance, 7,* 795–810.

Tresilian, J. R. (1990). Perceptual information for the timing of interceptive action. *Perception, 19,* 223–239.

Watts, R. G., & Bahill, A. T. (2000). *Keep your eye on the ball: Curve Balls, knuckleballs and fallacies of baseball.* NY: Freeman & Company.

Winer, G. A., & Cottrell, J. E. (1996). Does anything leave the eye when we see? Extramission beliefs of children and adults. *Current Directions in Psychological Science, 5,* 137–142.

Winer, G. A., Cottrell, J. E., Karefilaki, K. D., & Chronister, M. (1996). Conditions affecting beliefs about visual perception among children and adults. *Experimental Child Psychology, 61,* 93–115.

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