The portion of time after the bounce is between 150 and 200 ms.

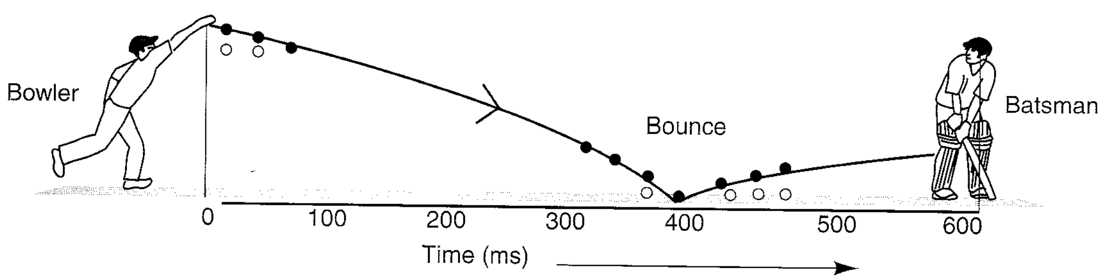
Figure 7.1 shows the pursuit tracking of the elite player (dark circles) versus a lower-skilled one (open circles) during a good pitch. Both tracked the ball immediately for 100 to 200 ms and then used an anticipatory saccade that raced ahead of the ball to the point where the ball bounced on the ground, where the fovea "lay in wait" (Land & McLeod, 2000, p. 1341). Following the bounce, the ball was tracked for about 150 ms during the final part of its flight by the high-skilled player but not by the low-skilled player. The main difference between the players was in the speed and variability of the saccade to the bounce. The elite player timed his saccade so that he could maintain a longer period of tracking both before and after the bounce, while the low-skilled player lost sight of the ball and then had greater difficulty getting the gaze back on it during the final approach.

Object Tracking and Object Control: Hitting Targets in Table Tennis

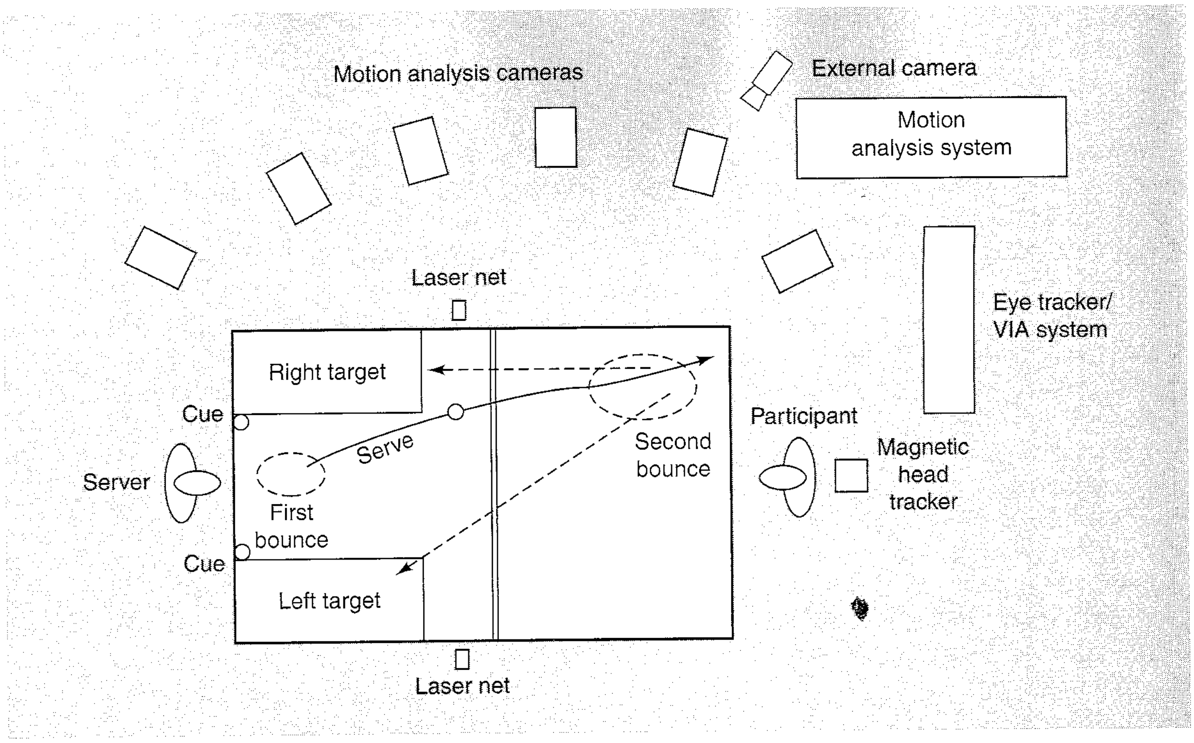
Land and McLeod's (2000) study provided new insights into tracking objects at high speeds during interceptive timing tasks, especially when the object's movement is unpredictable. But their results do not explain how athletes respond to an incoming object and then hit it successfully to another target area on the field of play. This happens often in games such as tennis, table tennis, and volleyball, where the object must not only be tracked and received but also batted, hit, kicked, or controlled to a precise location. How is the gaze controlled in these instances where there is temporal, spatial, and competitive pressure? Does the gaze have to be controlled in a specific way in order for performance to be high during the control phase? These were the questions asked by Rodrigues et al. (2002) in a table tennis study where high- and low-skilled athletes made returns to cued target locations across the table.

Figure 7.2 shows a regulation table surrounded by six motion analysis cameras that recorded the movement of the ball during its flight, as well as the movement of the hitting arm. Two target areas (one left and one right) were located on the opposite side of the table, within which the ball was to be hit as hard as possible. The participants also wore an eye tracker with a magnetic head tracker. The configuration of equipment in figure 7.2 made it possible to record the ball in flight, the gaze relative to the ball, and the movements of the arm as the forehand action was completed. The ball was served by an experienced player, who delivered it so that the second bounce landed in the circular area on the forehand side of the participant. Ball flight durations did not differ due to skill, accuracy, or the experimental conditions, and they ranged between 760 and 810 ms (*SD* range 49-70 ms). High- and low-skilled players were required to hit the ball as hard as they could with a forehand action while still maintaining a high level of accuracy.

Three temporal cues were used to signal which target to hit. During the precue condition, the cue light came on 3 s before the server began to deliver the ball, and in the early-cue condition, the cue light came on 500 ms after the serve and before the ball was contacted by the participant. In the late-cue condition, the light came on only 300 ms before contact with the ball; therefore, the ball was very close to the participant when the cue light indicated which of the two targets to hit toward.



➤ Figure 7.1 A cricket bowler delivering the ball to a batsman, with pursuit-tracking gaze of an elite player (●) and lower-skilled player (○). The solid line represents the flight of ball.



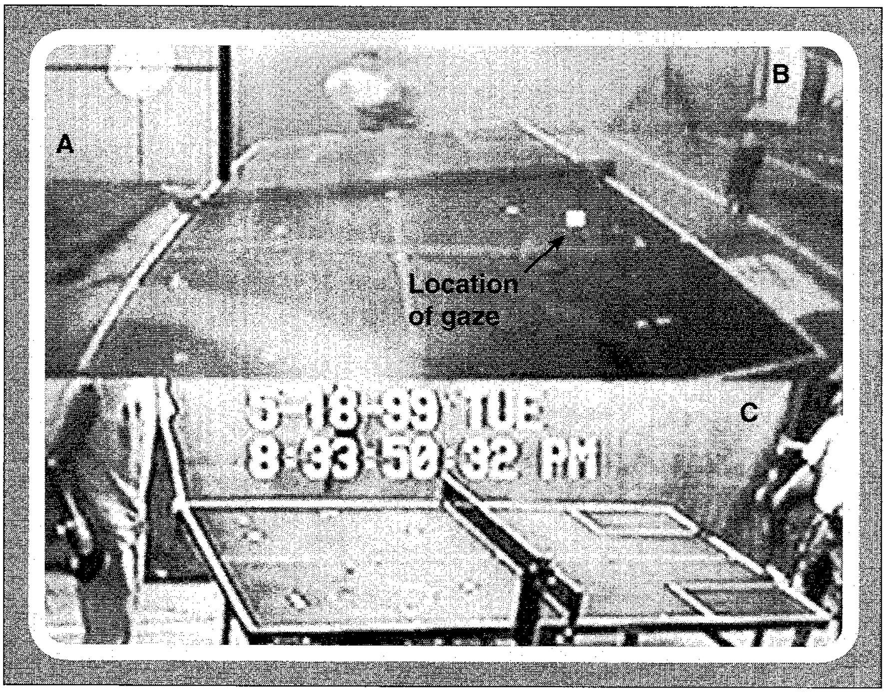
➤ **Figure 7.2** The experimental setup showing the server, the participant, the flight of the ball during the serve, and the two target areas. The eye tracker, magnetic head tracker, motion analysis system with six cameras, external camera, laser timing device, and right and left cue lights are illustrated.

Vision-in-action data were recorded concurrently, as shown in figure 7.3, in order to ensure the accuracy of calibration and also to serve as a second source of data used to verify that data collected using the motion analysis and eye–head tracking systems were accurate. Image A shows the eye of the participant, and image B shows the field of view of the participant, including the server, the two target areas, and the cue lights. The white cursor shows the location of the gaze relative to the ball and targets. An external camera (C) recorded the player's movements and that of the ball. Visible on his arm are the motion analysis markers used to determine the forward movement of the arm to contact. Gaze data were recorded at a rate of 30 Hz for the vision-in-action data and at 60 Hz relative to the eye–head integration system.

Hitting Targets Under Time Constraints

As expected, the low-skilled players were significantly less accurate, making 31% of their returns compared with 50% for the high-skilled group. The most important differences were caused by the cueing of the lights. Both groups were relatively accurate when the cue light came on 3 s before the serve, as well as when 500 ms were available, but both had low accuracy when they had only 300 ms (late cue) to select the target and make the hit. There was clearly a critical period of time between 500 ms and 300 ms when performance was negatively affected irrespective of the athlete's skill level.

An additional question that Rodrigues et al. (2002) explored was whether the difference in accuracy was due to deficiencies in the control of the arm, control of the gaze, or both. Onset, offset, and duration of arm movement did not differ significantly due to skill level, accuracy, or cueing condition. The results were therefore consistent with those of other researchers displaying an invariant motor timing (Bootsma & van Wieringen, 1990; Schmidt & Lee, 1999). Both high- and low-skill players had higher velocity values on misses than on hits, but overall the movement-time results did not shed any light on why performance was so much lower in the late-



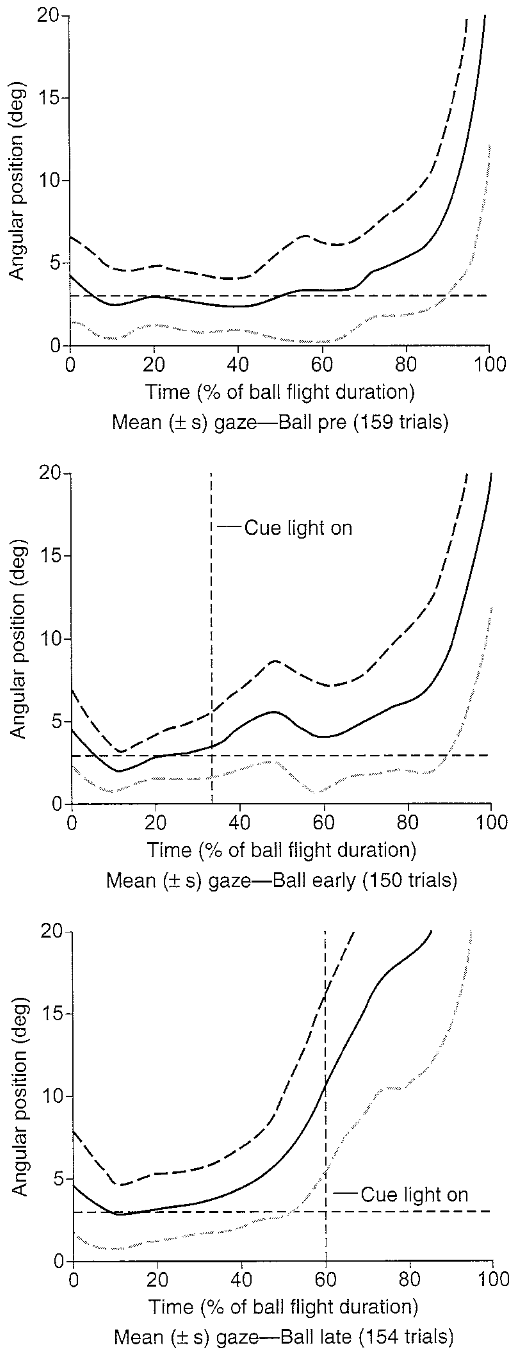
➤ **Figure 7.3** A frame of vision-in-action data collected in table tennis.

cue condition. The more important variables were those related to tracking the ball prior to hitting.

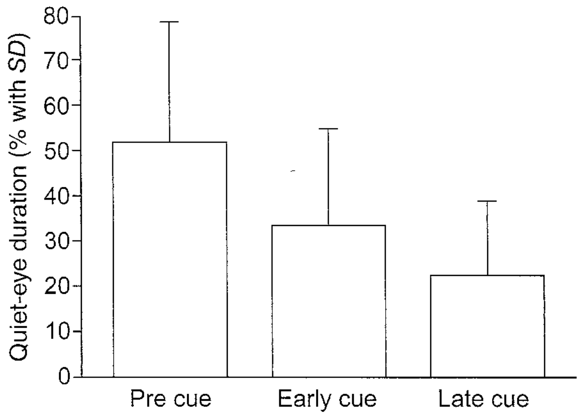
The duration of tracking on the ball was determined across the ball flight duration to see if the same type of gaze control, as reported by Land and McLeod (2000), was also found in this task, where the ball bounced close to the athlete before being returned. Figure 7.4 shows the mean pursuit tracking in the pre-, early- and late-cue conditions as determined from the eye–head analysis. The x-axis shows the percentage of ball flight from 0% to 100%, with 0% occurring as the ball left the server's bat and 100% when the participant hit the ball. The y-axis shows the gaze location relative to the ball in degrees of visual angle. A value of 0 visual angle (degrees) meant the gaze was on the ball, and above 3° (the horizontal dotted line) indicated the gaze was no longer being tracked by the focal system. The vertical dotted lines in the bottom two plots show when the cue light came on in the early and late conditions. The quiet-eye duration was defined as the duration of tracking time within 3° of visual angle before the onset of the final forward movement of the arm in the foreswing. Figure 7.4 (top) shows that a quiet eye was present in 95% of all trials when the cue light came on early. The quiet-eye duration extended from an early onset at 8% and offset at 60% of total ball flight duration. The middle plot shows the quiet-eye duration when the cue light came on 500 ms before contact. Here we see that the gaze was on the ball from 3% to 37%. The bottom plot shows the quiet-eye duration in the late-cue condition occurring only briefly, from 3% to 23%.

Quiet-Eye Duration in Table Tennis

Quiet-eye durations differed significantly, as shown in figure 7.5. Mean quiet-eye duration was 410 ms in the precue condition and 272 ms in the early-cue condition, indicating that there still was sufficient time to read the flight of the ball, but when the quiet-eye duration was only 176 ms, as occurred in the late-cue condition, there was not enough time to read the ball's flight, detect the target, and make the hit accurately. These results differ from those of Land and McLeod (2000) in two ways. First, there was no late tracking of the ball after the bounce, even in the early condition, probably due to the presence of the cue lights, which drew the gaze and attention to the target. The participants had no choice but to take their eye off the ball in order to determine which target to hit toward. Second, even the highly skilled performer needed 272 ms or more ball-tracking time in order to perform well. Once tracking on the ball averaged 176 ms, performance declined regardless of skill level.



➤ **Figure 7.4** Percent of trial spent in quiet-eye tracking on the ball (with standard deviation) in the pre-, early-, and late-cue conditions. The horizontal axis shows the percent of ball flight duration, and the vertical axis shows the gaze relative to the ball in degrees of visual angle. The horizontal dotted line shows the 3° threshold for quiet eye; vertical dotted lines show cue onset in the early and late conditions.



➤ **Figure 7.5** Quiet-eye duration during the three cue conditions (pre, early, and late).

Object Recognition, Object Tracking, and Object Control

In this section, we now look at studies in volleyball and ice hockey that have investigated all three phases (object recognition, object tracking, and object control) at once in the live sport setting. The goal was to understand how the gaze is controlled over all three phases and the type of gaze control that contributes to higher levels of performance. Many of the same perceptual problems faced by players of table tennis are also faced by receivers in volleyball, who have to study the movement of the server in order to anticipate the ball's flight, track the ball, and then control it using a pass to the setter. Previous studies presented in this chapter (e.g., Shank & Haywood, 1987) have shown that reading the delivery of the ball is critical, as is the ability to track the object once it is in flight. But these studies concentrated on separate phases of the task and did not provide a complete picture across all three phases of object recognition, object tracking, and object control.

In this section, we look at the gaze and motor behavior of elite Team Canada male volleyball athletes who received serves and passed to the setter area on a regulation court (Vickers & Adolphe, 1997). The goal was to determine if elite and near-elite players differed in gaze in the three phases of object detection—object recognition, object tracking, and object control—and the extent to which differences in gaze control accounted for their differences in being able to pass to the setter accurately.