APPENDIX A: Ball Timing Measurements

Those data on the time required for the pitch to traverse various distances were measured in the following way. To measure the time at which the ball was released from the pitching machine PVC tube, at the distal end of the tube a vertically oriented laser (top of tube) was placed directly in-line with a photodiode (bottom of tube). When the tennis ball passed through the plane of the laser a drop in the photocell output voltage was recorded. The change in voltage was detected by a computer equipped with an 11 bit analog-to-digital converter (ADC) (USB-1208FS, Measurement Computing Corporation; Norton, MA). In a similar way, the time at which the ball arrived at various distances was measured using a timing window (Model 57 photoelectric ballistic screen, Oehler Research Inc; Austin, TX). These distances were measured along a line from the pitching machine to the plate, and did not account for the angular vertical ball drop due to gravity. A connector supplied with the timing window was routed into the same ADC as that used for recording from the photocell. A change in voltage could be detected from the timing window when the ball passed through this window. Synchronized analog recordings from the photocell at the end of the tube and the timing window were made at 2000Hz at various distances from the pitching machine tube. This high sampling rate was necessary to ensure that every pitch was detected. The ADC recorded from the photocell and the timing window in an alternating fashion (0.25ms between samples).

APPENDIX B: Assessment of Cross-talk in the ISCAN

As there was some vertical motion of the pitched ball in the main experiment, it was of interest to measure the horizontal artifacts produced by vertical motion for ISCAN eye trackers.

For the ISCAN eye tracker, one subject participated. The subject wore an ISCAN eye tracker. His chin was placed in a chin rest 56 inches from a wall upon which calibration targets were affixed. The subject viewed the calibration target at 15 deg left. This target was roughly at eye level vertically. He then alternated his gaze vertically between the target at eye level and another target 30 degrees below the first target. Next, he alternated his gaze vertically between a target that was straight ahead laterally (and roughly at eye level) with a second target 30 degrees below the first target. Finally, he alternated his gaze vertically between a target 15 deg right and roughly at eye level and a second target 30 degrees below this first target.

At each position, a horizontal movement associated with the vertical movement was recorded. At each lateral starting position, the horizontal changes in eye position associated with vertical eye movement were averaged. The average change in horizontal position was 2.16deg or less for all three lateral starting positions. The cross-talk was therefore about 6% or less in all cases.

APPENDIX C: Assessment of ISCAN Accuracy and Precision

The accuracy and precision of the horizontal measurements produced by ISCAN eye trackers was assessed in the following way. Two subjects participated. Subjects wore both a scleral search coil (the gold standard eye tracker)[41] on the left (lead) eye and an ISCAN video eye-tracker. The scleral search coil was obtained from Skalar Medical B.V. (Delft) The subjects stood within a magnetic field coil cage (Remmel Labs, Katy, TX) placed 41 feet 6 inches from the pitching machine used in the main experiment. The magnetic field coil method is based on the principle that when a coil of wire is rotated within a magnetic field, a voltage is produced from this coil that is proportional to the sine of the angle between the coil and the magnetic field. The magnetic field coil method is different from video camera systems such as the ISCAN. Gaze position (eye position in space) is measured with the magnetic field coil method while eye-in-head position is measured with the ISCAN.

Subjects then attempted to partially or fully track pitches thrown by the pitching machine with the eyes while the head was kept as still as possible. Analog signals from both the search coil and the ISCAN video-tracker (left eye) were recorded simultaneously at 200Hz for 10 pitches using the same analog-to-digital converter used in the main experiment. The eye movement recordings for both eye tracking methods were calibrated based on a five-point calibration performed at the beginning of the experiment. A linear calibration (digitized value versus angle) was used for those data from the ISCAN, while a quadratic equation was fit to the digitized value versus angle data for the search coil.

For subject 1 the calibration factor (slope of digitized value versus angle) for the ISCAN calculated from the two extreme lateral points (analogous to what was done in the main experiment) yielded a calibration factor within 0.04% of that obtained using five points to obtain this factor. For subject 2, the calibration factor calculated from the two extreme lateral points yielded a calibration factor within 0.05% of that obtained using five points.

Once those data from each device were calibrated (that is, converted to degrees of rotation), then the ISCAN data were shifted by a delay (<50ms) recorded previously. Any measurement error in this delay is reflected in the comparisons between the ISCAN recordings and the search coil recordings. Next these data were parsed into 10 separate data sets. Each data set was associated with an individual pitch. Only those data obtained during the eye movements were included in the final analyses. Finally, those data at the beginning of the pitch for both devices were zeroed.

For subject 1, the eye movement amplitudes (as determined from the search coil) ranged from 26.91deg to 43.01deg (mean = 34.53 ± 5.69deg). The difference in ISCAN and search coil positions was determined for all pitches. Differences were determined every 0.005s. This resulted in 469 comparisons. The mean difference in position between the two eye trackers was – 0.74 deg (the minus sign indicates that the ISCAN lead the search coil). The standard deviation of this mean was 0.71 deg.

For subject 2, the eye movement amplitudes (as determined from the search coil) ranged from 1.45 deg to 26.61 deg (mean = 12.23 ± 10.89 deg). The difference in ISCAN and search coil positions was determined for all pitches. Differences were determined every 0.005s. This resulted in 422 comparisons. The mean difference in position between the two eye trackers was 0.04 deg (the plus sign indicates that the ISCAN lagged behind the search coil). The standard deviation of this mean was 0.30 deg.

Because those ISCAN data obtained during the main experiment were recorded at a relatively high sampling rate (2000Hz), it was of practical interest to compare the ISCAN data to those obtained from the scleral search coil at this high sampling rate.

Only one subject participated (subject 1 above). The subject wore both a scleral search coil on the left (lead) eye and the ISCAN video eye-tracker used in the main experiment. The subject stood within a magnetic field coil cage (Remmel Labs, Katy, TX) placed 39 feet 7 inches from the pitching machine used in the main experiment.

The subject then attempted to partially or fully track pitches thrown by the pitching machine with the eyes while the head was kept as still as possible. Analog signals from both the search coil and the ISCAN video-tracker (left eye) were recorded simultaneously at 2000Hz. The first 10 pitches were used for the data analyses.

The eye movement recordings for both eye tracking methods were calibrated based on a five-point calibration performed at the beginning of the experiment. A linear calibration was used for the ISCAN tracking data, while a quadratic equation was fit to the search coil calibration data. Those data from both devices were then smoothed using a 40 point averaging filter.

Those data from the two devices were parsed up into 10 separate data sets. Each data set included only eye positions associated with the tracking movement. The eye movement traces from the two devices were similar, but it was clear that the ISCAN had a discernible delay compared to the search coil as noted above. This delay was similar from pitch to pitch. The ISCAN data were “corrected” for this delay, and then the angular values from the eye trackers were each adjusted such that the beginning of each data set was zero degrees. The eye movement amplitudes (as determined from the search coil) ranged from 22.6 deg to 37.8 deg (mean = 30.5deg ± 4.8deg).

After that the difference in ISCAN and coil positions was determined for all pitches. Differences were determined every 8ms. This resulted in 1167 comparisons. The mean difference in position between the two eye trackers was – 0.39 deg (the minus sign indicates that the ISCAN lead the search coil). The standard deviation of this mean was 0.74 deg.

APPENDIX D: Assessment of Head Tracker Accuracy and Precision

Head movements were recorded using the 3DM-GX1 (MicroStrain®, Williston, VA) inertial sensor. In the main experiment, this device was mounted to the top of a batting helmet worn by the subjects. It is important to note that the MicroStrain® device measures the horizontal position relative to the earth's magnetic field, so the "zero" position of this device and the calibration factor will not vary between subjects. Therefore, rather than assessing the accuracy and precision of the 3DM-GX1 inertial sensor while subjects wore the MicroStrain® device on a helmet, the inertial sensor was assessed in the following manner.

A protractor (oriented in a plane parallel to the ground) was mounted on a vertical rod. The MicroStrain® device was rigidly mounted on a piece of wood attached to the protractor. Also mounted on the piece of wood was a coil of wire (Figure 8). Thus, the protractor, the MicroStrain® device, and the coil of wire could all be rotated together about the vertical rod (which was placed through a hole drilled through a table) on the bottom of the apparatus.

The investigator moved the entire apparatus such that it was placed at known angles using the protractor to obtain a calibration equation for both the MicroStrain® device and the coil. Analog signals were measured from the MicroStrain® device and the coil at each of the known angles using an analog-to-digital converter. Using these data, a linear equation (digital value versus angle) was applied to those data from the MicroStrain®, and a quadratic equation relating digital value to angle was applied to the coil data. Next, the investigator rapidly rotated the apparatus in the same direction as that of the pitches in the main experiment (i.e. left to right). Ten rotations were executed. Synchronized analog recordings were made from both the MicroStrain® head tracker and the search coil at 2000 Hz during these rotations.

Once these data were gathered, they were calibrated and then those data from both the MicroStrain® and the coil were smoothed using a 40 point averaging filter. The MicroStrain® data were also adjusted for a discernible delay (<50ms). Those data for each of the 10 rotations of the apparatus were parsed and analyzed independently. The beginning and end of the movements was identified, and only those data during the movements were analyzed. Finally, the MicroStrain® and coil data were zeroed at the time the movement started.

The movements of the apparatus ranged from 4.66 to 50.8 deg, and the mean rotation was 31.18 ± 17.06 deg. The difference in angular position between the MicroStrain® and coil was determined every 8ms for each pitch, resulting in 374 comparisons. The mean difference was 0.10 deg ± 0.86 deg. The positive value indicates that the MicroStrain® lagged behind the coil.

APPENDIX E: Batting Helmet Slippage

The following experiment was performed to determine the likely influence of helmet slippage on those horizontal data obtained from the MicroStrain® device. This assessment was performed in the following way. Two subjects participated. The subjects stood within a magnetic field coil cage (Remmel Labs, Katy, TX) placed 41 feet 6 inches from the pitching machine used in the main experiment.

Subjects wore the batting helmet used in the main experiment. A chin strap was used with the helmet. The MicroStrain® device was mounted to the top of the helmet just as in the experiment. A scleral search coil was taped to the subject's forehead. In this way, any motion of the batting helmet would result in differences in the values obtained from the search coil and the MicroStrain® device. The output from the search coil and the MicroStrain® device were recorded simultaneously by an 11-bit analog-to-digital converter at 200Hz (2.5ms between samples) as the subjects attempted to turn the head with balls thrown by the pitching machine. The first 10 pitches were used for the data analyses.

The recordings from both the search coil and the MicroStrain® device were calibrated using a linear calibration. Those data from the two devices were then parsed up into 10 separate data sets. Each data set included only those data associated with the tracking movement. Finally, the the angular values from the two devices were adjusted such that the beginning of each data set was zero degrees.

The head movement amplitudes for subject 1 were generally very large. Since head movements larger than 60deg were very rare in the main experiment, comparisons between the calibrated values from the two devices were only made for amplitudes of head movement less than 60deg. The output of the two devices were compared every 0.005s, resulting in 3767 comparisons. The mean difference in position between the two devices was 0.16 deg (the plus sign indicates that the MicroStrain® device lagged behind the search coil). The standard deviation of this mean was 0.78 deg.

The head movements for subject 2 were much smaller than those of subject 1. The mean head movement (as determined from the search coil) for subject 2 was 17.57 ± 8.62deg (range 7.16–26.88deg). The output of the two devices were compared every 0.005s, resulting in 464 comparisons. The mean difference in position between the two devices was 0.02 deg (the plus sign indicates that the MicroStrain® device lagged behind the search coil). The standard deviation of this mean was 0.93 deg.

The mean and standard deviation of the difference between the search coil and the MicroStrain® device is similar to the mean and standard deviation of the difference between the two devices obtained with the protractor device (Appendix D).

APPENDIX F: ISCAN Calibration

Two subjects participated in this experiment. The purpose of this experiment was to demonstrate the linearity of ISCAN eye trackers and to compare two-point calibrations to five-point calibrations. The subjects, wearing an ISCAN eye tracker, were placed in a chin rest such that the eyes were 56 inches from a wall. On the wall, calibration marks were placed at 30 degrees left, 15 degrees left, 0 degrees or straight ahead, 15 degrees right, and 30 degrees right. Subjects fixated each of these calibration targets, and at each location the analog output of the ISCAN eye tracker was recorded by an analog-to-digital converter at 200Hz.

The resultant mean digital numbers obtained at each fixation location were linearly regressed (least squares method) against the angle of the calibration target. For subject one, the coefficient of determination (r^2) of this regression line was 1.00. The slope of the regression line for the five-point calibration was compared to the slope as determined with two-point calibrations (that is, the slope as determined with those data only points 30 deg left and 15 deg right, or the slope as determined with only calibration points 30 deg left and 15 deg right). This was done to demonstrate the validity of using a two-point calibration in the main experiment. For subject one, the slope of the regression line as determined using the two-point calibrations was within 1% of the slope using the five-point calibration. For subject two, the coefficient of determine (r^2) for the five-point calibration was 0.999. In comparing the two-point and five-point calibrations, the slope of the regression line as determined using the two-point calibrations was within 3% of that using the five-point calibration.

APPENDIX G: Initial Head and Eye Positions

We assumed that subjects were looking at or near the pitching machine tube when the ball was released from this tube. We did not instruct subjects specifically on where to look but we believe our assumption regarding the initial gaze position is valid for the following reasons.

First, we looked at the eye position over the first 250ms of the pitch for the first group of 49 pitches thrown to the subjects. At that point, 16 subjects were included in the analysis. The 250ms period was chosen because the eyes are not likely to be moved significantly over this period of time. Six obvious outliers were removed prior to completing these analyses. Between 46 and 49 pitches were examined for each subject. We compared the mean position of the eyes over the first 250ms of the pitches with the location of the eyes documented during the calibration. The mean eye position over the first 250ms differed by more than 10 deg from the eye position recorded during the calibration procedure in only one case. We were aware that the equipment had slipped on this subject. Once this latter individual's data were discarded (leaving 15 remaining subjects), the mean difference between the eye calibration position and the eye position over the first 250ms of the pitch for all subjects was 0.55deg ± 5.68deg. Finally, the standard deviation of the mean eye positions (intra-observer variability) measured over the first 250 ms ranged from 0.81deg to 8.48deg (mean = 2.59deg ± 1.89deg). For most subjects, the eye was therefore aligned in a similar fashion relative to the head for each pitch.

Regarding the head position, the mean head position during the first 250ms of each pitch can be compared directly between the 15 remaining subjects. This is because the MicroStrain® device measures the horizontal position of the device (and therefore the head) relative to the earth's magnetic field. The standard deviation of the mean positions (inter-observer variability) for the right-handed subjects was 5.80deg and 8.14deg for the left-handed subjects. These values demonstrate that subjects tended to align the head in a similar position to that of other subjects. The standard deviation of the mean head positions over the first 250ms of the pitch (intra-observer variability) ranged from 1.12deg to 10.12deg (mean = 3.52deg ± 2.19deg) demonstrating that for each pitch, most subjects aligned the head in a very similar fashion. The similarities in head position within and between subjects provide some evidence that subjects align their heads so as to fixate on a common location.

Both the head and eye assessments over the first 250ms of the pitch suggest that subjects were most likely fixating at or near the tube of the pitching machine early in the pitch trajectory.