EYE TRACKING DURING THE TENNIS FOREHAND VOLLEY

A THESIS

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We hereby recommend that the thesis prepared under our supervision by Susan Margaret Moen entitled Eye Tracking During the Tennis Forehand Volley

be accepted as fulfilling this part of the requirements for the Degree of Master of Arts.

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CHAPTER I

ORIENTATION TO THE STUDY

Introduction

Tennis specialists agree that it is important to watch the ball in tennis, but there is controversy among them concerning the optimum amount of time and periods of time during which the ball should be watched. Some experts state that the ball should be and can be watched right onto the racket. Johnson and Xanthos[1] state that, during the forehand drive, the ball must be watched throughout the stroke. The player must see the ball hit the strings of his racket. Segura[2] states that a player looks at the ball as he hits it with his mind attuned to the ball only. In discussing the backhand drive, Rosewall[3] states that the moments after impact with the ball are as critical as those before the ball is contacted. The ball must be watched right onto the racket; and, after contact, the head must not be lifted to follow the ball.

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[1] Joan D. Johnson and Paul J. Xanthos, Tennis (Dubuque, Iowa: William C. Brown Company Publishers, 1972), p. 12.

[2] Pancho Segura, "Some Easy and Not So Easy Ways to Improve Your Game," World Tennis, March, 1972, p. 38.

[3] Ken Rosewall, "Ken Rosewall Demonstrates the Way to Improve Your Backhand," Tennis, March, 1973, p. 53.

Other tennis specialists state that the action of the ball contacting the racket is too fast for the naked eye to see; most of them, however, advocate watching the ball as long as possible. Murphy[1] states that a player will probably not be able to see the ball on the racket strings because the action is too fast, but the player should be trying to do so. Smith[2] agrees and adds that it is possible to get a blurred glimpse of the action which shows that the player is doing his best to hit the ball in the center of the racket.

In the literature reviewed, no experimental data dealing with eye tracking in tennis were found. Because of this lack of research and because watching the ball in tennis is so uniformly advocated by tennis experts, it seemed appropriate to conduct this investigation.

Purpose of the Study

The purpose of the investigation was to gather photographic evidence, through use of an Eye Mark Recorder, regarding ball tracking in tennis.

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[1]Chet Murphy, Advanced Tennis (Dubuque, Iowa: William C. Brown Company Publishers, 1970), p. 16.

[2]Stan Smith, Stan Smith's Six Tennis Basics (Memphis, Tennessee: Sports Marketing, Inc., 1974), p. 12.

Statement of the Problem

The investigation was intended to contribute to literature regarding the length of time during which skilled adult women watch the ball during the tennis forehand volley. The subjects were five adult women between the ages of eighteen and twenty-two who had had four to ten years of tournament experience at the state level. A conclusion was drawn regarding eye tracking during the execution of the tennis forehand volley. Specifically the following question was answered: For what amount of time and during what periods of time is the ball tracked by skilled adult women during the tennis forehand volley?

Definitions and/or Explanations of Terms

For purposes of clarification, the following definitions and/or explanations of terms were established for use throughout the study:

1. Eye Fixation: The direction of the eyes toward an object or point.
2. Eye Tracking: Coordinated eye movements used in maintaining fixation on a moving object. For purposes of this investigation, eye fixations were measured by an Eye Mark Recorder which is capable of showing fixations for one eye only. It was assumed that the eyes were synchronized in the tracking movements. Two illustrations of the Eye Mark Recorder appear in the Appendix.

3. Fixation Point: The point or object toward which the eyes are directed at any time.

Delimitations of the Study

The study was subject to the following delimitations:

1. Five female volunteers between the ages of eighteen and twenty-two who had had four to ten years of tournament tennis experience
2. The cooperation of the subjects in their performances during the investigation while wearing the Eye Mark Recorder
3. The degree to which the instrument used to record eye fixations maintained a constant calibration throughout the testing of each subject

CHAPTER II

REVIEW OF RELATED LITERATURE

A survey of the literature disclosed that the present study did not duplicate any previous investigations with respect to scope and content. A review of the studies which were related to the present investigation and were of benefit to its development are presented.

In 1922, Carr and Osbourn[1] undertook a study to determine the effect of vision upon the performance of a skill in a situation similar to situations under which most acts of skill are acquired. The subjects were divided into five groups with regard to the amount of vision they were permitted during the experiment.

The instrument used in the study was a stylus maze with a circular disc of aluminum plate attached to the stylus to exclude the sight of the maze pattern from the subject. When vision was permitted, the subject could see the motion of the hand and the stylus with its attached disc but had no perception of this motion in relation to the pattern of the maze.

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[1]Harvey A. Carr and Ella B. Osbourn, "Influence of Vision in Acquiring Skill," Journal of Experimental Psychology 5 (October 1922): 301-11.

Comparative raw data, averages, and percentages were tabulated in various tables according to such variables as errors made and number of trials required to complete mastery of the maze. The data revealed, in the investigators' opinions, the following results: (1) vision is always effective in reducing the number of trials and errors involved in acquiring the ability to run the maze; (2) vision is much more effective in reducing the number of errors than of trials; (3) vision is more effective in reducing the number of errors not only when vision is permitted but during the subsequent mastery period when vision is excluded: (4) the longer the visual period, the greater the subsequent effect of vision; (5) vision was not very effective during the initial trial of the visual period; and (6) the subsequent effect of a given amount of vision is almost as great as the effect that would have been obtained if the use of vision had been continued until the maze was learned.

The investigators stated that the effectiveness of vision during the post-visual period was due to one or both of two factors: (1) a memory of the visual data concerning the maze pattern acquired during the preceding period, and (2) a more perfect tactual motor coordination resulting from the previous visual guidance. The investigators stated, however, that neither factor is indicated by the data.

As a subsidiary experiment, the authors investigated the influence of the sudden introduction of vision upon the performance of a mastered act. All subjects were tested until all disturbance from the introduction of vision was eliminated and three perfect successive trials were obtained. Results showed that 65 percent of the individuals were disturbed by the introduction of vision. In general, the more the individual previously had been denied vision, the more the vision disturbed his performance. Those in the standard group, allowed no vision throughout the first experiment, had probably formed an incorrect perception of the maze and made mistakes in later trying to guide their movements in terms of vision. Many individuals in all groups were not disturbed by the introduction of vision leading the authors to believe that individuals differ greatly in the extent to which they normally rely upon vision in acquiring and performing a skill.

Winograd[1] undertook a study to determine the relationship of timing and vision to successful batting in baseball. Four groups of subjects were selected who were differentiated with respect to baseball achievement.

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[1]Samuel Winograd, "The Relationship of Timing and Vision to Baseball Performance," Research Quarterly 13 (December 1942): 481-93.

The subjects were given a vision examination and a timing test designated to measure the quickness of bodily movement. From the records of games played, batting averages, number of runs batted in, and slugging averages, computations were made and used as criteria for determining batting achievement.

From the findings of the study, two of Winograd's conclusions were: (1) definite differences are reliably distinguished between varsity baseball players and non-athletes in timing and two measurements of vision, and (2) the timing test and two vision tests tend to distinguish varsity baseball players from rejected candidates and from non-athletes.

Mott[1] conducted a study to investigate eye movements during the observation of unfamiliar motor skills and to study the relationship between eye movement patterns and the initial performance of motor skills. The subjects were ten college women volunteers enrolled at the University of Southern California.

Mott photographed at twenty-eight frames per second on sixteen-millimeter motion picture film a close-up view of the subject's eyes while the subject watched two demonstrations of four motor skills, those being a throw, a stunt, a

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[1] J. A. Mott, "Eye Movements During Initial Learning of Motor Skills" (Ph.D. dissertation, University of Southern California, 1954).

locomotor movement, and a dance-gymnastic technique. A tilted mirror was placed on a platform behind and above the subject to reflect the demonstration area into a camera. The subject was seated in front of a bite board to prevent head movements. The skill was presented twice while the camera recorded a mirror reflection of the action. Scores on a twelve-point scale were awarded to the subject according to the quality of each movement skill.

Portions of the film were transferred into still pictures, traces were made of the subjects' eyes in certain frames, and a complete verbal description of the content of the films was prepared. In particular, it was noted where, when, and how often the subject fixated on various body parts of the demonstrator, and this information was correlated with successful performances in each of the skills. Correlations at the .01 and .05 levels were given for eye movements and the performance of each body part in each skill. Statistically significant correlations were found between eye movements and performance in such areas as fixation upon the movement or body part to be imitated and fixation upon essential skill elements and use of pursuit-type eye movements.

The investigator concluded the following: (1) eye movement patterns differ both among individuals and for the same individual in watching different motor skills (2) in observing a motor skill a second time, individuals exhibit an eye movement pattern similar to that shown in the first; and (3) individuals tend to observe, without verbal instructions to do so, the very elements of the motor skills to which a teacher might want to call attention.

> It is doubtful, therefore, whether much verbal instruction could have improved significantly the quality of the students' initial learning performances.[1]

Hubbard and Seng[2] undertook a study using cinematography to determine the visual basis for tracking a pitched ball in terms of head and eye movements. Twenty-nine professional baseball players were filmed during batting practice at Sportsman Park in St. Louis, Missouri.

The frames of the film were numbered to provide a basis for computing ball speed and to establish the temporal relations of the swing and eye-head movements. The findings of the study were reported according to batting movements and head and eye movements. Concerning head and eye movements, a table disclosed the number of batting sequences which showed head and/or eye movements toward and/or away from the plate according to the frame during which the movement occurred.

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[1]Ibid., p. 107.

[2]A. W. Hubbard and C. N. Seng, "Visual Movements of Batters," Research Quarterly 25 (March 1954): 42-51.

The findings revealed that head movements did not provide the basis for tracking a pitched ball when a swing occurred, and eye movements toward the plate were considerably more frequent than head movements. Although skilled batters (Ted Williams and Rogers Hornsby) have stated that they saw the bat contact the ball, Hubbard and Seng did not find any evidence of eye movements continuing up to the point of ball contact with the bat. The investigators offered two possible explanations for their observation: either the ball was not tracked throughout the hit with eye movements because at some point additional visual information would have been superfluous since the bat was already on its way, or the tracking was broken off because the visual apparatus was incapable of tracking at the very high relative velocity of a pitched ball near the plate--or both. The investigators stated, however:

> This does not mean that in teaching beginners or in coaching batters one should minimize the importance of tracking the ball as long as possible. It is probably better to emphasize tracking the ball up to the hit--knowing that it is not necessary and perhaps impossible--rather than to tell them that it is impossible and run the risk of having them not track the ball as long as possible.[1]

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[1]Ibid., p. 51.

Gottsdanker[1] undertook a study to investigate prognostic measures in prediction-motion involving several rates of movement. The subjects were eight men and eight women students between the ages of eighteen and twenty-two.

The apparatus used was a "tracking box" in which sheets of paper were driven lengthwise under a one-eighth-inch slit in an opaque mask at a constant speed of 22 millimeters per second.[2] The subject tracked a moving "target" by keeping a pencil between two lines. The penciled line was the record of the subject's responses. A tracking pattern which did not disappear was given to provide a criterion of skill. The six predictive patterns required the subject to track predictively for two seconds in the unmarked slit after termination of the printed pattern.

Distances covered following disappearance of the pattern were determined to the nearest millimeter, and the rate of continuation was given in terms of millimeters per second. Percental rates of continuation were computed to permit comparisons among patterns. No significant difference was found in tracking

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[1] Robert M. Gottsdanker, "A Further Study of Motion Prediction," American Journal of Psychology 68 (September, 1955): 432-437.

[2] Robert M. Gottsdanker, "The Accuracy of Motion Prediction," Journal of Experimental Psychology 43 (January 1952): 26-36.

performance among the three rates of speed, but significant differences were found among individuals at the .05 level of significance.

High accuracy was shown on patterns of constant rate, and relative accuracy increased slightly as the rate of target movement increased. The investigator concluded that no measure of prediction-motion provided a satisfactory forecast of skill in tracking.

Graybiel, Jokl, and Trapp[1] reviewed the first chapter of a book translated from Russian concerning the mutual relationship between some physiological components of vision and of exercise and training. The following aspects of vision were studied and reviewed: visual acuity, accomodation (the ability of the eye to adjust its focus to various distances), visual fields, ocular muscle balance, the role of peripheral and central vision in exercise, and depth perception.

Results from a study concerned with the effect of exercise on visual acuity revealed that after a 1000-meter race, 27 percent of the athletes showed no change in visual acuity while in 73 percent, visual acuity increased by as much

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[1] A. Graybiel, E. Jokl, and C. Trapp, "Russian Studies of Vision in Relation to Physical Activity and Sports," Research Quarterly 26 (December, 1955): 480-85.

as 45 percent. Greatest sharpness of vision was found either immediately after the race or ten minutes later.

Visual fields, measuring the extent of peripheral sight, were studied in seventy basketball players, 162 soccer players, fourteen hockey players, and twenty tennis players. Each subject fixed his eyes on a point in the central field of vision while a test target, usually a small bead, approached the center from outside the range of vision. No differences were found from the established norms with white (the color which normally has the largest visual field), red, and blue test objects although visual fields for green were considerably larger in the athletes than in the controls. In a separate study, a post-exercise increase was found in the size of the visual fields.

Studies were conducted concerning ocular muscle balance. From one such study involving 194 untrained individuals and twenty-five tennis champions, it was concluded that "champion" athletes have a better eye-moving apparatus than non-athletes, both at rest and after strain.

To determine the role of peripheral and central vision in exercise, athletes performed in various activities with normal vision, after exclusion of peripheral vision, after exclusion of central vision, and blindfolded. The results in most activities showed that elimination of peripheral vision produced a greater decline in efficiency than did exclusion of central vision, and full exclusion of vision caused the greatest handicap.

In a study in depth perception, thirty tennis players were found to have better depth perception than 122 football players. As a group, the athletes were found to perceive depth better than untrained controls.

Krieger[1] conducted a study to determine the relationship between figure-ground perception (perception in space) and spatial adjustment in tennis. Sixteen college men and eight college women were volunteer subjects. Krieger was concerned with the degree of spatial adjustment of the tennis court rather than with the skill level of the subjects.

To determine figure-ground perception, the Gottschaldt Embedded-Figures Test[2] was administered to the subjects. The Spatial Adjustment Tennis Test, which measures the subject's ability to move the racket into position horizontally and vertically in relation to the ball for contact, was developed for the study and administered to the subjects.

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[1]Carol Jane Krieger, "The Influence of Figrue-Ground Perception on Spatial Adjustment in Tennis" (Master's thesis, The University of California, 1962).

[2]H A. Witkin, "Individual Differences in Ease of Perception of Embedded Figures," Journal of Personality 19 (September 1950): 1-15.

Correlations were run between the spatial adjustment tennis score and the Gottschaldt Embedded-Figures Test score for each subject. The total group correlation of .4766 was significant at the .05 level. Women showed a higher correlation than men, and intermediates showed a higher correlation than beginners, .642 and .290, respectively.

The investigator noted a positive relationship existing between spatial adjustment in tennis and figure-ground perception although each subgroup did not show high statistical significance. Krieger concluded that figure-ground perception was significantly and positively related to spatial adjustment in tennis, and that, although beginners were more proficient in figure-ground perception than intermediates, intermediates were more proficient in spatial adjustment than beginners.

Fleishman and Rich[1] conducted a study to determine the relationship between spatial-visual abilities and proprioceptive feedback or "feel" in perceptual-motor learning. The subjects were forty male Yale University undergraduates enrolled in a second semester psychology course.

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[1] E. A. Fleishman and S. Rich, "Role of Kinesthetic and Spatial Visual Abilities in Perceptual Motor Learning," Journal of Experimental Psychology 66 (July 1963): 6-11.

Each subject was administered two ability measures: a standardized test of spatial orientation[1] and a test of "kinesthetic sensitivity".[2] Used as the perceptual-motor task was the Two-Hand Coordination (THC) apparatus[3] which required the subject to simultaneously rotate two handles to keep a target-follower on an irregularly-moving small target disc.

The correlations between the Aerial Orientation Test and "kinesthetic sensitivity" with total time-on-target during forty trials of THC performance were .49 and .58, respectively, significant at the .01 level. The correlation between Aerial Orientation and "kinesthetic sensitivity" was .12, not statistically significant which indicates that the two ability measures tapped independent ability traits. To relate the ability measures to different stages of THC learning, the forty THC trial scores were grouped into ten blocks of four trials each. Correlations showed that as practice

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[1]M. F. Roff, Personnel and Classification Procedures: Spatial Tests, USAF School of Aviation Medicine Report Number 21-29-002 (1951).

[2]R. L. Woodworth and H. Schlosberg, Experimental Psychology (New York: Holt, 1954), pp. 197-98.

[3]E. A. Fleishman, "Factor Structure in Relation to Task Difficulty in Psychomotor Performance," Educational and Psychological Measurement 17 (Winter 1957): 522-32.

continued, THC performance decreased with the spatial ability measure and increased with the "kinesthetic sensitivity" measure.

The investigators concluded that abilities can be thought of as capacities for utilizing different kinds of information. Initially, spatial-visual cues guide a subject's movements, but once a given level of proficiency is reached and errors tend to be smaller, spatial cues are not as effective and "kinesthetic sensitivity" provides the required finer motor adjustments.

Williams[1] undertook a study to assess the effects of systematic variation in velocity and direction of ball flight upon visuo-perceptual judgments made about moving objects in space by highly-skilled and poorly-skilled performers of varying ages. The fifty-four subjects were eighteen male students from each of three grade levels--junior high, high school and college. The subjects were further classified into skilled and unskilled groupings based upon baseball performance.

The study centered around an experimental situation in which a tennis ball was projected from behind a visual barrier and was interrupted in its flight by a canvas

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[1]Harriett G. Williams, "The Effects of Systematic Variation of Speed and Direction of Object Flight and of Skill and Age Classifications Upon Visuo-perceptual Judgments of Moving Objects" (Ph.D. dissertation, University of Wisconsin, 1968).

suspended above the subject's head. The subject never came into physical contact with the ball and saw only the first portion of its flight. The subject's task was to decide where the ball was going and to move to that spot where he judged he should be to catch the ball at chest height. Both reaction time and movement time were recorded.

The data were analyzed using a series of five univariate analyses which permitted an assessment of the five main variables of skill, age, speed, and vertical and horizontal direction of object flight upon visuo-perceptual performance. Where appropriate, Scheffe's Multiple Comparisons Test was used to compare differences between group means.

Results showed that skilled individuals judged the flight of the moving object significantly more rapidly than did unskilled individuals and were significantly more accurate in judging the flight of the ball. Individuals responsded significantly more rapidly to fast-moving objects than to slow-moving objects. Although vertical direction of flight had no significant effect upon the speed of the visuo-perceptual response, objects moving horizontally to the right or directly at the subject. There were no significant differences between age or skill groups with respect to movement time.

CHAPTER III

METHODS AND PROCEDURES

The purpose of the study was to gather photographic evidence, through use of an Eye Mark Recorder, regarding ball tracking in tennis. The specific problem of the study was to determine the length of time and periods of time during which skilled adult women watch the ball in the execution of the tennis forehand volley.

In this chapter, the methods and procedures which were followed in the development of the study are described. Included are preliminary procedures, selection and description of the subjects, selection and description of the instruments, procedures followed in filming the ball flight and in filming the eye tracking of the ball, procedures followed in analyzing the data, and preparation of the final written report.

Preliminary Procedures

The investigator studied information related to all aspects of the study and used this as the basis for a tentative outline. Permission to conduct the study was secured from the Human Research Committee at the Texas Woman's University, Denton, Texas. The investigator obtained written consent from the five subjects who participated in the study since during the experiment they were required to wear an Eye Mark Recorder.

The outline of the proposed study was developed and approved by the members of the thesis committee. A pilot study was then conducted using as a subject a twenty-three-year-old semi-skilled female tennis player. The purpose was to determine any possible complications in the wearing of the Eye Mark Recorder, in using the ballboy machine, in recording eye fixations on film, in filming the ball flight, or in any other aspect of the conduct of the study.

On July 21, 1975, the completed tentative outline of the thesis was presented at a Graduate Seminar. A prospectus of the approved study was filed in the Office of the Dean of Graduate Studies at the Texas Woman's University.

Selection and Description of the Subjects

The subjects chosen for this study were five women between the ages of eighteen and twenty-two who were skilled tennis players. Each subject had had four to ten years of tournament tennis experience at the state level. Four subjects were right-handed, and one subject was left-handed. None wore prescription eyeglasses.

Selection and Description of the Instruments

The instrument selected to measure eye tracking was an Eye Mark Recorder. It is the only portable instrument capable of recording eye fixations on film. The Eye Mark Recorder shows fixations for one eye only; however, it was assumed that each subject's eyes were synchronized in the tracking movements. The Eye Mark Recorder was obtained from Instrumentation Marketing Corporation, Grand Prairie, Texas.

The instrument used to project the tennis balls at a relatively constant velocity was a Red Lobster Ballboy Machine. The ballboy machine produced a sound immediately prior to the release of a tennis ball which forewarned the subject of the oncoming ball. Twelve new heavy-duty yellow Pennsylvania tennis balls were used in the ballboy machine.

The film data were collected by means of two sixteen-millimeter cameras and Kodak Black and White Tri-X Reversal Film, perforated on both edges. A Sekonic light meter was used to determine the f-stop setting for the two cameras.

Procedures Followed in Filming the Ball Flight and in Filming the Eye Tracking of the Ball

The subjects were filmed on an indoor tennis court in the Gymnasium Building at the Texas Woman's University, Denton, Texas. This site was chosen rather than an outdoor tennis court in order to avoid possible problems which might have been caused by uncontrollable weather and lighting conditions. The gymnasium provided adequate space, surface, and background for the filming and represented a realistic situation. Light meter readings indicated there was sufficient light.

The instruments in the gymnasium were located in a prescribed manner. The Red Lobster Ballboy Machine was located thirty-nine feet, ten inches from the tennis net. The delivery end of the plastic circular tube through which the balls were projected was eight inches above the floor; this provided a ball projection angle which allowed the ball, when crossing the net, to travel approximately two feet above it. The camera used to film ball flight from which ball velocity would later be determined was located twenty-five feet from the center of the tennis court and three feet from the net on the subject's side. This camera recorded on film the flight of the ball before, during and after ball contact. The first third of the ball flights were filmed at forty-eight frames per second, the second third were filmed at thirty-two frames per second, and the final third were filmed at twenty-four frames per second. The camera used to record the eye tracking on film was located nine feet from the tennis net and two feet to the left of the right-handed subjects. A thirty-inch long flexible tubing of fiberoptics connected the Eye Mark Recorder to the camera. The investigator stood on a stand two feet to the left of the subject where she operated the camera, periodically checked the calibration of the Eye Mark Recorder, and occasionally conversed with the subject. An illustration of the location of the cameras, the ballboy machine, and the subject appears in the Appendix.

When each subject arrived at the gymnasium, she signed a consent form to participate in the study with the understanding that she could withdraw from the study at any time. To prevent any bias in performance, the subject was given no information regarding the purpose or problem of the study prior to the filming. The investigator prepared the subject by having her first secure a bathing cap on her head before the Eye Mark Recorder was mounted. The bathing cap was used to eliminate the likelihood of the Eye Mark Recorder shifting positions after being properly located. The subject then sat in a comfortable erect position facing the investigator who, with the help of the subject, placed the Eye Mark Recorder on the subject's head so that it was both properly located and comfortable. The Eye Mark Recorder was situated so that the subject, when looking directly forward, was looking through the center of each of the two lenses. A foam rubber nosepiece was placed lengthwise along the subject's nose if she felt any discomfort. When the Eye Mark Recorder was properly and comfortably located, the investigator tightened three straps around the back of the subject's head which held the Eye Mark Recorder securely in place. The investigator then calibrated the Eye Mark Recorder by positioning a tiny lamp with a V-shaped filament so that the filament reflected directly off the cornea of the subject's right eye, thus recording eye fixations. The calibration was accomplished by having the subject direct her eyes toward several items in her view while the investigator looked through a monitor which showed the subject's field of view and the V-shaped light spot which indicated the exact fixation point of the eyes. The subject then picked up her tennis racket and walked with the investigator to the exact location for the filming. The subject placed her back foot nine feet, seven inches from the net and was asked to assume a comfortable forehand volley stance which would allow her racket, when in position to contact the ball on her forehand side, to be in direct line with the oncoming ball. The investigator then connected the thirty-inch flexible tubing of fiberoptics to the camera used to record the eye tracking on film. The distance through which the subject could move without damaging the fiberoptics system was explained and demonstrated to the subject. An assistant then hand-tossed several balls to the subject to volley until the subject grew accustomed to the Eye Mark Recorder. When the subject indicated she was ready to begin hitting balls delivered by the ballboy machine, she was given several practice trials before the filming began. When she announced that she felt adjusted to both the Eye Mark Recorder and the velocity of the balls she was hitting, the filming began. The subject hit ten forehand volleys, three of which were recorded at sixteen frames per second, four recorded at twenty frames per second, and the last three recorded at twenty-four frames per second. After the third and the seventh volleys, the ballboy machine was stopped so that the investigator could re-check the calibration of the Eye Mark Recorder. In all instances, the Eye Mark Recorder had stayed in nearly perfect calibration throughout the subject's performance. At the completion of ten volleys, the fiberoptics system was unhooked from the camera and the Eye Mark Recorder and the bathing cap were removed from the subject's head. At the completion of the study, the film from both cameras was taken to Producer's Service, Incorporated, in Dallas, Texas to be developed.

Procedures Followed in Analyzing the Data

The film which was used to calculate ball velocity was viewed frame-by-frame on a Vanguard Motion Analyzer to collect the data necessary for the study. After determining a baseline point at which the x and y coordinates of the Motion Analyzer were set at 0, the film of the ball flight was analyzed by charting the x and y coordinates of the ball in the frame of the film during which ball contact was recorded (if it was recorded) and in the three frames prior to ball contact. Then the data points of the frame immediately prior to ball contact and the third frame before contact of ball flights filmed at forty-eight frames per second were submitted to a Hewlett-Packard 9800 for calculations of ball velocities in feet per second.

The investigator analyzed the eye tracking film on the Vanguard Motion Analyzer by recording the number of frames during which the tennis ball was not touching the "V" light spot indicating that the eyes were no longer fixated on the ball. Some of the data were not usable because the exact frame in which the eye fixation point left the ball could not be definitely determined. The only data analyzed and reported in the findings of the study were those ball flights in which the frames during which the eyes were not fixated on the ball could be definitely determined. These data were analyzed by recording the frames where the ball was not touching any part of the "V".

Procedures Followed in the Preparation of the Final Written Report

Upon completion of the analysis of the data collected, the investigator organized and presented the data in appropriate tables. The data were summarized and a conclusion was drawn. A final written report of the study was submitted which contained the findings and their implications and recommendations for further studies. A bibliography and an appendix were added in order to complete the written report.

CHAPTER IV

ANALYSIS OF DATA AND RESULTS

Introduction

The purpose of the study was to gather photographic evidence, through use of an Eye Mark Recorder, regarding ball tracking in tennis. The specific problem of the study was to determine the length of time and periods of time during which skilled adult women watch the ball in the execution of the tennis forehand volley.

Film data of eye tracking and of ball flight were collected from five highly-skilled adult female tennis players by means of an Eye Mark Recorder and two sixteen-millimeter Bell and Howell 70 HR cameras. One camera was stationed twenty-five feet from the center of the tennis court and three feet from the net on the subject's side; this camera was used to record the velocity of the ball. The Eye Mark Recorder, worn by the subject, was connected by a thirty-inch long tubing of fiberoptics to a second camera which recorded eye fixations on film.

The ball flight film and the eye tracking film were viewed frame-by-frame on a Vanguard Motion Analyzer. From the ball flight film, ball velocities in feet per second were calculated from the data points entered into a Hewlett-Packard 9800. The investigator analyzed the usable eye tracking data by determining for each volley the number of frames in which the eyes were definitely not fixated on the ball.

Presentation of the Data

The subjects who participated in the study were five female tennis players between the ages of eighteen and twenty-two. The five women met the qualification of having played four to ten years of tournament tennis at the state level. In addition, all five subjects had played at least one year of women's varsity tennis in a college or university. Four subjects were right-handed and one subject was left-handed. None of the subjects wore prescription eyeglasses.

In the treatment of the data, the ball flight film was analyzed first to determine ball velocity. After having found an f-stop setting which indicated ambient light for the filming, the speeds of the camera were bracketed around it. The film data at all speeds were clear and readable, and therefore the film taken at the fastest speed--forty-eight frames per second--was selected for analysis. In each ball flight thus filmed, x and y coordinates of the center of the ball in the final four frames before and including ball contact were easily determined and recorded. The data points for nineteen ball flights filmed at forty-eight frames per second were entered into the Hewlett-Packard 9800 which calculated each ball velocity as well as the mean and standard deviation for all ball flights.

Table 1 presents each ball velocity for the ball flights filmed at forty-eight frames per second. Also shown are the mean velocity, standard deviation, and range for the data.

TABLE 1

VELOCITIES, MEAN, STANDARD DEVIATION, AND RANGE OF BALL FLIGHTS FILMED AT FORTY-EIGHT FRAMES PER SECOND

Ball Flight	Velocity*	Mean*	S.D.*	Range*
1	64.211	64.152	2.122	8.706
2	68.829			
3	64.975			Max.
4	61.812			68.829
5	62.217			
6	64.336			Min.
7	62.525			60.123
8	65.206			
9	63.143			
10	64.037			
11	66.999			
12	64.804			
13	60.311			
14	60.123			
15	64.458			
16	65.398			
17	64.858			
18	65.506			
19	65.138			

*Velocities, mean, standard deviation, and range are expressed in feet per second.

As Table 1 shows, ball velocities of the nineteen ball flights ranged from 60.123 feet per second to 68.829 feet per second with a mean ball velocity of 64.152 feet per second and a standard deviation of 2.122 feet per second. These figures indicate consistency in delivery of the balls from the ballboy machine.

Having analyzed the film of the ball flights, the eye tracking film was studied to determine the length of time and periods of time during which the eyes were not fixated on the ball. Although the light meter had indicated ambient light during the filming, some of the film data were not usable because insufficient light had made it impossible to conclusively determine the frame in which the eye fixation point left the ball. Table 2 presents, therefore, only those ball flights during which the investigator could accurately count the number of frames before contact in which the eyes were not fixated on the ball. The table includes the subject analyzed, which of the ten volleys she executed that were analyzed, the number of frames before ball contact in which the eyes were not fixated on the ball, and the time in seconds the eyes were not fixated prior to contact.

Table 2 shows that there were twenty-eight of the fifty volleys hit by the five subjects which were clear enough to be conclusively analyzed. The number of volleys for each

TABLE 2

VOLLEY EXECUTED AND NUMBER OF FRAMES, TIME IN SECONDS, AND DISTANCE IN FEET WITH SUBJECTS' EYES NOT FIXATED ON THE BALL

S[a]	V.[b]	Fr.[c]	Sec.[d]	Dist.[e]	S[a]	V.[b]	Fr.[c]	Sec.[d]	Dist.[e]
S[a]1	1	2	.10	6.4	S[a]4	1	2	.10	6.4
	2	3	.15	9.6		2	3	.15	9.6
	4	3	.15	9.6		3	3	.15	9.6
S[a]2	1	4	.20	12.8		4	4	.20	12.8
	4	2	.10	6.4		10	2	.10	6.4
	5	2	.10	6.4	S[a]5	1	1	.05	3.2
	6	1	.05	3.2		2	1	.05	3.2
	10	1	.05	3.2		3	2	.10	6.4
S[a]3	1	1	.05	3.2		4	2	.10	6.4
	6	1	.05	3.2		6	2	.10	6.4
	7	1	.05	3.2		7	2	.10	6.4
	8	1	.05	3.2		8	2	.10	6.4
	9	2	.10	6.4		9	2	.10	6.4
	10	3	.15	9.6		10	2	.10	6.4

S[a] = subjects

V[b] = volley executed

Fr.[c] = number of frames before contact that eyes were not fixated on ball

Sec.[d] = number of seconds before contact that eyes were not fixated on ball

Dist.[e] = distance in feet before contact that eyes were not fixated on ball

subject which afforded usable data ranged from three volleys for Subject 1 to nine bolleys for Subject 5. In twenty-one of the twenty eight volleys analyzed, the eyes were not fixated on the ball for either one or two frames. The fewest number of frames in which the eyes were not tracking the ball was one, .05 second; this number occurred twice for Subject 2 and for Subject 5 and four times for Subject 3. The greatest number of frames before contact during which the eyes were not fixated on the ball was four, .20 second; this occurred once for Subject 2 and for Subject 4.

Findings in addition to those presented in Table 2 were determined by further analyzing the eye tracking film. Each of the five subjects appeared to follow the same eye tracking pattern, both when the eyes were fixated on the ball and when they were not. In every instance, once the eyes were no longer fixated on the ball, they never tracked the ball again during that particular volley. When the eyes ("V") left the ball, they always remained fixated at or very near the point at which fixation was lost while the ball moved off toward the subject's preferred side. The findings showed, then, that there was only one period of time during which the eyes were not fixated on the ball, that being from the point at which the eyes first left the ball through ball contact.

In combining the findings from the two films, the length of time in seconds when the eyes were not fixated on the ball was determined. From the ball flight film, the mean velocity, 64.152 feet per second, was used to draw a conclusion with regard to the velocity at which each tennis ball was tracked as the ballboy machine proved to be very consistent in its delivery velocity. From the eye tracking film, twenty frames per second was used for calculations as there were more readable data at that camera speed than at either sixteen frames per second or twenty-four frames per second. Combining the ball speed and camera speed information, it was found that a ball traveling at a velocity of approximately sixty-four feet per second was not tracked by the eyes of the subjects during a time period ranging from .05 to .20 second before ball contact.

CHAPTER V

SUMMARY, CONCLUSION, DISCUSSION, AND RECOMMENDATIONS FOR FURTHER STUDIES

Summary

While tennis specialists agree on the importance of watching the ball in tennis, controversy exists among them concerning the amount of time and periods of time during which the ball should be watched. Some experts state that it should be and can be watched right onto the racket while others state that the ball contact with the racket occurs too rapidly for the naked eye to see. The investigator found no experimental support for either opinion as no data dealing with eye tracking were found.

The purpose of the study was to gather photographic evidence, through the use of an Eye Mark Recorder, regarding ball tracking in tennis. The investigator proposed to determine what amount of time and what periods of time a ball is tracked by skilled adult women during the tennis forehand volley. The subjects were five adult women between the ages of eighteen and twenty-two who had had four to ten years of tournament experience at the state level.

Pertinent studies and articles involved with various aspects of vision with relation to skill performance were reviewed. These references are cited in full in Chapter II.

The earliest study found which related to the topic of the investigation was undertaken by Carr and Osbourn in 1922. They conducted two experiments to determine the effect of vision upon the performance of a skill. Results indicated that vision was always beneficial in learning a skill except when the skill was first learned without vision in which case the introduction of vision generally disturbed the learner's performance.

Winograd studied the relationship of timing and vision to successful batting in baseball. He found that significant differences existed between varsity baseball players and non-athletes in timing and in two measurements of vision.

Mott investigated eye movements during the observation of unfamiliar motor skills and studied the relationship between eye movement patterns and the initial performance of motor skills. Mott found that eye movement patterns differ both among individuals and for the same individual while watching different motor skills, but in observing motor skills a second time, individuals exhibit an eye movement pattern similar to that shown in the first. She noted that individuals tend to observe, without verbal instructions to do so, the elements of a motor skill to which a teacher would probably want to call attention.

Hubbard and Seng filmed twenty-nine professional baseball players during batting practice to determine the visual basis for tracking a pitched ball in terms of head and eye movements. The findings showed that head movements did not provide the basis for tracking a pitched ball when a swing occurred, and eye movements toward the plate were considerably more frequent than head movements. Hubbard and Seng did not find any evidence of eye movements continuing up to the point of ball contact with the bat. They offered two possible explanations for their observation: either the human eye is incapable of tracking a pitched ball at the high speed at which it was moving near the plate or additional visual information would have been unnecessary since the bat was already on its way.

In a motion-prediction study by Gottsdanker involving three rates of movement, he found no significant differences in tracking performance among the three rates, but he did find significant differences among individuals. He concluded that no measure of prediction-motion provided a satisfactory forecast of skill in tracking.

Graybiel, Jokl, and Trapp reviewed a Russian book concerning the relationship between some physiological components of vision and of exercise and training. They discussed the procedures and results of studies regarding six aspects of vision: visual acuity, accomodation, visual fields, ocular muscle balance, the role of peripheral and central vision in exercise, and depth perception.

Krieger conducted a study in which she found a positive relationship existing between spatial adjustment in tennis and figure-ground perception. She concluded that, although beginners were more proficient in figure-ground perception than intermediates, intermediates were more proficient in spatial adjustment than beginners.

A study was undertaken by Fleishman and Rich to determine the relationship between spatial-visual abilities and proprioceptive feedback or "feel" in perceptual-motor learning. Correlations showed that as practice continued in the task used to measure perceptual-motor learning, the subjects' performances decreased with the spatial ability measure and increased with the kinesthetic sensitivity measure. The investigators concluded that abilities can be thought of as capacities for utilizing different kinds of information. Whereas spatial-visual cues guide a subject's movements initially, once a given level of proficiency is reached, spatial cues are not as effective and kinesthetic sensitivity provides the required finer motor adjustments.

Williams conducted a study to determine the effects of systematic variation in velocity and direction of ball flight upon visuo-perceptual judgments made about moving objects in space by highly-skilled and poorly-skilled performers of varying ages. The results showed that skilled individuals judged the ball flight significantly more rapidly and more accurately than did the unskilled individuals. Further, individuals responded more quickly to rapidly-moving objects than to slowly-moving objects.

In the present study, film data were collected during the execution of ten successful forehand volleys by five highly-skilled adult female tennis players. All of the volleys were judged to be successful in that they were struck cleanly and crossed the net to land in the opposite court. The instruments used in the collection of the data were a ballboy machine which projected tennis balls at a relatively constant velocity, an Eye Mark Recorder which recorded eye fixations, and two sixteen-millimeter cameras, one of which recorded on film the eye fixations and the other, ball flight.

The subjects were filmed on an indoor tennis court in the Gymnasium Building at the Texas Woman's University, Denton, Texas. After the subject signed a consent form to participate in the study, an Eye Mark Recorder was properly and comfortably situated on the subject's head over a bathing cap worn to prevent the Eye Mark Recorder from shifting positions. Once secured, the Eye Mark Recorder was calibrated so that a V-shaped filament, when viewed through a monitor, was located exactly where the subject's eyes were fixated. The subject then walked to the filming location where a flexible tubing of fiberoptics was connected from the Eye Mark Recorder to the camera used to record eye fixations on film. After hitting several practice volleys to become accustomed to the Eye Mark Recorder and the ball velocity, the subject was filmed at three different speeds hitting ten forehand volleys. Simultaneously, ball flights were being filmed by the second camera located twenty-five feet from the tennis court.

After developing the film data, both films were viewed frame-by-frame on a Vanguard Motion Analyzer. In the ball flight film, the exact location of the tennis ball was determined in the frame of the film during which ball contact was recorded (if it was recorded) and in the three frames prior to ball contact. For each ball flight analyzed, two of these data points were entered into a Hewlett-Packard 9800 which calculated ball velocity. In the eye tracking film, the number of frames in which the eyes (V) were not on the ball was determined and converted into time in seconds indicating the time during which the eyes were not fixated on the ball.

Results were determined from both the ball flight film and the eye tracking film. Findings from the ball flights filmed at forty-eight frames per second revealed a mean ball velocity of 64.152 feet per second and a standard deviation of 2.122 feet per second. In the eye tracking film, twenty-eight of the fifty volleys filmed were clear enough to be analyzed; these ranged from three volleys for Subject 1 to nine volleys for Subject 5. The number of frames during which the eyes of the subjects were not fixated on the ball ranged from one to four which represented a time period of from .05 second to .20 second. All subjects followed the same general eye tracking pattern in that once their eyes were no longer fixated on the ball, their eyes remained fixated at or very near the point at which fixation was lost through ball contact. In combining the findings from both films, it was found that a ball traveling at approximately sixty-four feet per second was not tracked by the eyes of the subjects during a time period ranging from .05 second to .20 second immediately prior to ball contact. Translated into feet before contact, the ball was not tracked during a distance ranging from 3.2 feet to 12.8 feet.

Conclusion

Based upon the findings of this study, two conclusions were drawn, one relative to the purpose of this study and one relative to the specific problem. It was concluded that an

Eye Mark Recorder is an appropriate device with which to gather photographic evidence regarding ball tracking in tennis. It was further concluded that adult female tennis players, in performing the forehand volley, track the ball throughout its flight except during a time period ranging from .05 second to .20 second immediately prior to ball contact.

Discussion

From a perusal of investigations dealing with the relationship between vision and physical activities, no method of recording eye tracking was found which appeared to be superior to an Eye Mark Recorder; moreover, there was no study found dealing with a sport skill which used an Eye Mark Recorder. Only two studies, both conducted in 1954, were found in the literature which attempted to record eye movements. Hubbard and Seng[1] used cinematography to determine the visual basis for tracking a pitched ball in terms of head and eye movements. Through observation of the frames of the film, they determined eye movements toward and/or away from the plate; their observations did not provide any evidence of eye movements continuing up to the point of ball contact with the bat. Hubbard and Seng were unable to conclusively explain their observations, but they did suggest that possibly the eyes were incapable of continuing the tracking or further eye tracking was not necessary. It should be noted that the authors' observations were empirical,

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[1]Hubbard and Seng, "Visual Movements of Batters," pp. 43-55.

being made by turning the frames of the film back and forth until both observers agreed that eye movement had occurred. In Mott's[1] investigation of eye movements during the initial learning of motor skills, she proposed to devise a method of recording eye movements which would be of practical use in physical education research. Mott photographed, at twenty-eight frames per second on sixteen-millimeter motion picture film, a close-up view of each subject's eyes while the subject watched several motor skills. In the treatment of the data, portions of the film were transferred into still pictures, traces were made of the subjects' eyes in certain frames, and a complete verbal description of the content of the films was prepared. In particular, it was noted where, when and how often the subjects fixated on various body parts of the demonstrator. Mott concluded that the cinematographic method used was suitable and economically practical for the study of gross eye movements. The present investigator, however, required a method of recording almost imperceptible eye movements and exact fixation points; the Eye Mark Recorder was shown to be an appropriate device for this purpose since the "V" light spot, which represented the exact fixation point of the eyes, reflected directly off the cornea of the eye. The Eye Mark

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[1]Mott, "Eye Movements During Initial Learning of Motor Skills," pp. 2-116.

Recorder, therefore, appears to yield more accurate and precise eye tracking data than the methods used by either Hubbard and Seng or Mott.

A review of the literature revealed one study dealing with ball tracking. From their study of eye tracking in baseball batting, Hubbard and Seng[1] drew a conclusion similar to the one drawn by the present investigator. Hubbard and Seng concluded that the pitched ball was not tracked up to the point of ball contact by any of their twenty-nine highly-skilled subjects.

Through analysis of the literature, no information was found regarding the velocity at which the human eye can track. It is, therefore, not known if the eyes are capable of tracking a ball traveling at approximately sixty-four feet per second at a relatively close distance.

Limitations in the present research prevent the investigator from conclusively stating that the subjects never tracked the ball to the contact point. First, it was not known, but only assumed, that the eyes moved synchronously in the ball tracking; statements can be made, therefore, only for each subject's right eye. Secondly, the lack of ambient light afforded some unreadable data, and it is possible that the data not analyzed would have revealed different results.

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[1]Hubbard and Seng, "Visual Movements of Batters," p. 57.

The present investigator shares the general opinion of Hubbard and Seng[1] regarding reasons why the ball was not tracked throughout its flight. Either the eyes are incapable of tracking a ball moving at a high velocity at a close distance or at some point additional visual information would have been superfluous since the implement was already moving to meet the ball--or both. Because the subjects in the present investigation were not asked to attempt tracking the ball to contact, the investigator cannot conclude that they were unable to do so.

The present investigator agrees with Hubbard and Seng[2] in believing it best not to tell beginners that it is impossible to track the ball up to the hit and in believing that it is important to remind them to track the ball as long as possible. Nevertheless, concern is felt that there may be overemphasis on the use of the verbal cue, "Watch the ball," which could detract from the learners'--or the teachers'--attention to other aspects of the game. That some of the subjects in the present study were able to execute a successful volley even when tracking was broken as far as 12.8 feet before contact is indicative of

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[1]Ibid., p. 51.

[2]Ibid., p. 51.

the fact that ball tracking is not the only variable leading to success. Indeed, it has been noted by such tennis experts as Van Der Meer[1] that tracking can be so emphasized that the player will interpret the object of the game to be ball tracking and may concentrate all effort in watching the ball and none in hitting it.

Recommendations for Further Studies

As a result of this study, the investigator recommends that the following studies be undertaken.

1. A study similar to the present one conducted outdoors to assure the presence of adequate light
2. A study similar to the present one in which the subjects also hit ten volleys after having been requested to track the ball as long as possible to determine if there is a difference between the amount of time a ball is tracked and can be tracked during flight
3. A study similar to the present one using players of different skill levels
4. Studies similar to the present one using different tennis strokes

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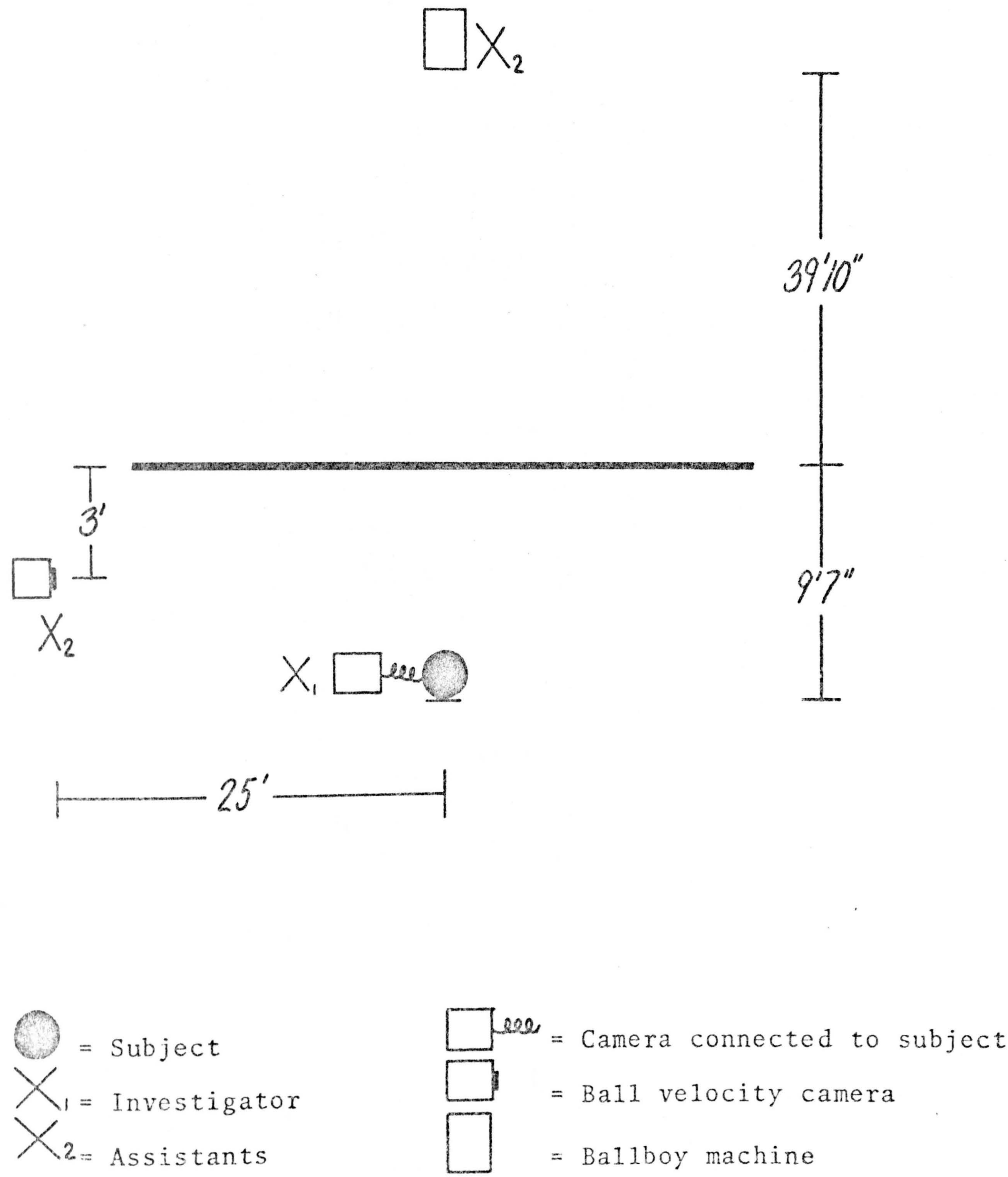
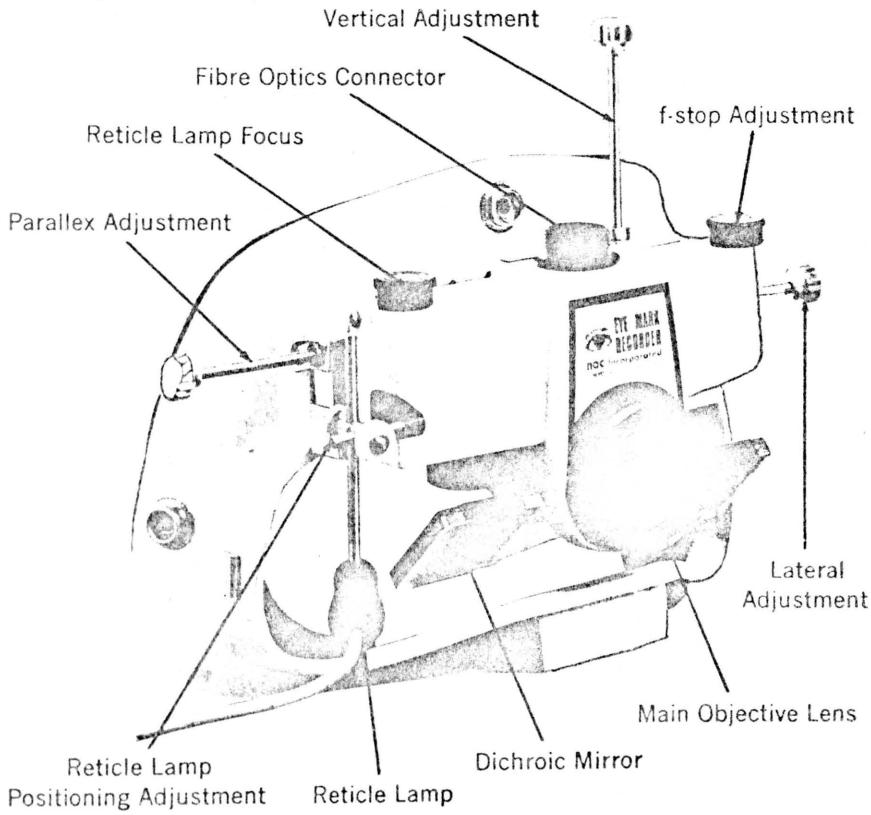
[1]Interview with Dennis Van Der Meer, Tennis Teachers' Conference, Walden-on-Lake Conroe, Texas, 11 October 1975.

A P P E N D I X

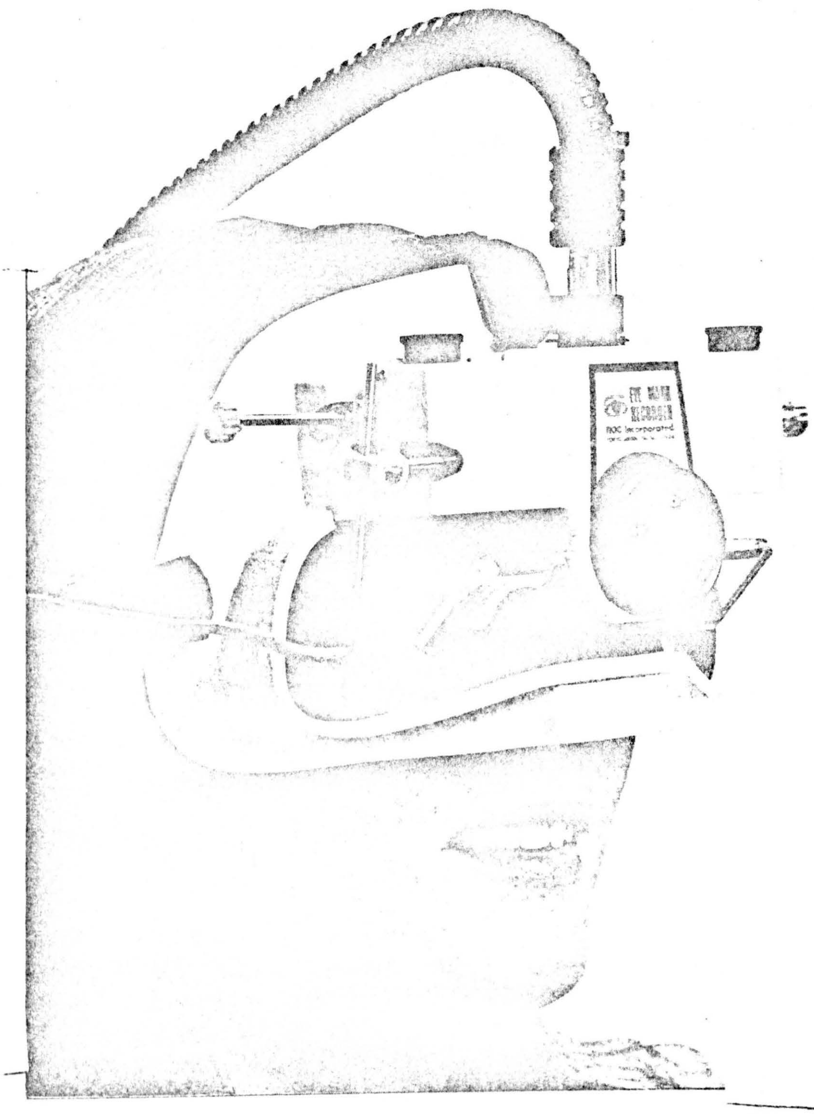
FLOOR PLAN DURING COLLECTION OF DATA



EYE MARK RECORDER



EYE MARK RECORDER WORN BY SUBJECT



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