NOTATIONAL ANALYSIS IN SPORT - A REVIEW

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1. Introduction.

In introducing research work in notational analysis, it is customary to begin wih a justification of the need for objectivity within the feedback process between coach and athlete . There are many other publications that would satisfy the needs of anyone wishing to pursue this line of enquiry (e.g. Franks et al., 1983a; Hughes, 1988). This review is structured, therefore, to follow the main developments in notational analysis. After tracing a historical perspective of the roots of notation, the application of notational systems to sport are then developed. These early systems were all hand notation systems: their emerging sophistication is followed until the advent of computerised notation. Although the emphasis is given to the main research developments in both hand and computerised notational systems, where possible the innovations of new systems and any significant data outputs within specific sports are also assessed.

2. Historical Perspective.

General, rudimentary and unsophisticated forms of notation have existed for centuries. The Egyptians, thousands of years ago, made use of hieroglyphs to read dance, and the

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Romans employed a primitive method of notation for recording salutatory gestures. Research shows that the earliest recorded form of music notation was conceived in the eleventh century (Hutchinson, 1970; Thornton, 1971), although it did not become established as a uniform system until the eighteenth century. Hutchinson (1970) cited evidence indicating that for at least five centuries attempts had been made to devise and develop a system of movement notation and historical texts give substantial evidence pointing to the emergence of a crude form of dance notation, in about the fifteenth century. Thornton (1971) stated that the early attempts at movement notation may well have 'kept step' with the development of dance in society, and as a consequence the early systems were essentially designed to record particular movement patterns as opposed to movement in general.

It becomes apparent, then, that dance notation actually constituted the 'starting base' for the development of a general movement notation system. Arguably the greatest development in dance notation was the emergence of the system referred to as 'Labanotation' or 'Kinetography-Laban', so-called after its creator, Rudolph Laban, in 1948. The next 'step' in the development of movement notation came in 1947 with the conception of another form of dance notation, known as Choreology (Benesh and Benesh, 1956).

Movement notation systems, developed primarily in the field of expressive movement, gradually diversified into game analysis, specifically related to sport. Ensuing research proved severely limited both in variety and detail, as reported by Sanderson (1983):-

> The majority of little-published research that there is in game analysis is concerned with soccer - and at a fairly global and unsophisticated level.

3. Notation Systems in Sport - Hand Notation.

Tha absence of literature on some sports does not mean that systems for those sports do not exist, or are not used. For purposes of clarity and reference the following section has been sub-divided into specific sports, even though in some areas the information to report is sparse. The major areas of publication, both in hand notation and computerised notation, are in soccer and squash. The research work with these two sports has also produced the greatest number of innovations. Consequently, the review of the research in these sports is a little more detailed, reflecting as it does the development of notational analysis as a whole.

3.01 Tennis

The first publication of a comprehensive racquet sport notation was when Downey (1973) developed a detailed system which allowed the comprehensive notation of lawn tennis matches. Detail in this particular system was so intricate that not only did it permit notation of such variables as shots used, player positions, and so on, but it catered for the type of spin used in a particular shot. This notation system has served as a useful base for the development of systems for other racquet sports, specifically badminton and squash.

3.02 Squash

Several systems have been developed for the notation of squash, the most prominent being that by Sanderson and Way (1977). Most of the different squash notation systems possess many basic similarities. The method of Sanderson and Way made use of illustrative symbols to notate seventeen different strokes, as well as incorporating court plans for recording accurate positional information. The major emphasis of this system was on the gathering of information concerning 'play patterns' as well as the comprehensive

collection of descriptive match data. Sanderson (1983) felt that 'suggestive' symbols were better than codes, being easier for the operator to learn and remember (see Fig.1). These were used on a series of court representations, one court per activity, so that the player, action and position of the action were all notated . In addition, outcomes of rallies were recorded, together with the score and the initials of the server (see Fig.2). The position was specified using an acetate overlay with the courts divided into 28 cells. The system took an estimated 5-8 hours of use and practise before an operator was sufficiently skilful to record a full match during the game. Processing the data could take as long as 40 hours of further work. Sanderson (1983) used this system to form a data-base and show that individual squash players exhibit consistent patterns, winning or losing, despite the established coaching maxim that a player should change tactics if losing. It would seem that the majority of players are unable to change the patterns in which they play.

FIGURES 1 AND 2 ABOUT HERE

Most of the data that Sanderson and Way reported were in the form of frequency distributions of shots with respect to position on the court. There was a problem of presenting data in three dimensions - two for the court and one for the

value of the frequency of the shots. Sanderson and Way (1977) overcame this problem by using longitudinal and lateral summations (see Fig.3). Not only were the patterns of rally-ending shots examined in detail, but also those shots (N-1) that preceded the end shot, and the shots that preceded those (N-2). In this way the rally-ending patterns of play were analysed. The major pitfall inherent in this system, as with all long-hand systems, was the time taken to learn to use it and the amount of raw data generated, requiring so much time to process.

FIGURE 3 ABOUT HERE

3.03 Soccer

Reep and Benjamin (1968) collected data from 3,213 matches between 1953 and 1968. These data included 9,175 goals, the passes leading to these goals, how possession was gained and the position of these actions. Several findings of interest were reported including the observation that 80% of goals resulted from a sequence of three passes or less and 50% of all goals came from possession gained in the final attacking quarter of the pitch. Reep and Benjamin interpreted their results after applying the binomial theorem and probability theory to their data. Since the binomial theorem requires

each event to have equal probability, this would seem to be a flawed application of this particular theory. Nevertheless their model of successful soccer has gained a degree of acceptibility within the English Football League. Clubs, notably Wimbledon, Watford and Sheffield Wednesday, have attained a certain amount of success with admittedly limited resources using a style of play promoted by the work of Reep and Benjamin. The reduction of the tactics of the game to this simple application of statistics and probability negates the obvious and lasting success of those teams that employ more skilful players in more complex tactical patterns, e.g. Liverpool, Arsenal, Nottingham Forrest, and Everton.

The comprehensive statistics on goal scores has led some practitioners towards the formulation of coaching laws. Bate (1988) explored aspects of chance in football and its relation to tactics and strategy in the light of the results of Reep and Benjamin (1968) and data from English First Division games in 1987. Bate claimed that goals are not scored unless the attacking team gets the ball and one, or more, attackers into the attacking third of the field. Also, the greater the number of possessions a team has the greater chance it has of entering the attacking third of the field, therefore creating more chances to score. The higher the number of passes per possession, the lower will be:

i) the total number of match possessions,

ii) the total number of entries into the attacking third, and

iii) the total chances of shooting at goal.

These principles reject the concept of 'possession football', (i.e. the team that has possession of the ball controls the game) and favour a more direct strategy. Bate concluded that to increase the number of scoring opportunities a team should:

i) Play the ball forward as often as posible.

ii) Reduce the cross-field and back passes to a minimum.

iii) Increase the number of forward passes and forward runs with the ball of 40 yards (36m) or more.

iv) Play the ball into space as often as possible.

Pollard et al. (1988) used Reep and Benjamin's (1968) method of notation, supplemented by principal components analysis, to assess determinants and consequences of different styles of play. It was suggested that elaborate styles relied upon multi-pass sequences of possession and that direct styles of play significantly relied on long forward passes and long goal clearances. In addition it was found that there was no relation between the degree of elaborate style and the use of players running with the ball into the attacking areas near the touchlines, i.e. using 'width'. Pollard et al. concluded that it was important for the coach to build up a

style profile of each opponent for future analysis by using this type of quantitative assessment of playing style.

Bate (1988) cited the analysis of international soccer in the 1980's conducted by C.F.Hughes, F.A. Director of Coaching. It was found that 94% of goals scored at all levels of international soccer were scored from movements involving four or less passes, and that 50-60% of all movements leading to shots on goal originated in the attacking third of the field.

Harris and Reilly (1988) considered attacking success in relation to space and team strategy, by concentrating mainly upon overall success of an attacking sequence, and attempted to link this with space in relation to the defence. This was a considerable departure from many of the systems previously mentioned which have tended to disseminate each sequence into discrete actions. Harris and Reilly provided a variable index describing the ratio of attackers to defenders in particular instances, while simultaneously assessing the "space" (distance) between a defender and an attacker in possession of the ball. The variances of these were analysed in relation to attacking success, where a successful attack resulted in a goal, an intermediate level of success was one that resulted in a non-scoring shot on goal, and an unsuccessful attack was one ending without a shot. The results showed that successful attacks tended to involve a

positive creation of space, where an attacker passes a defender - an unsuccessful attack generally involved a negative use of space which enabled the defence to provide sufficient players in depth and concentration. This would seem to support Bate's (1988) conclusions concerning square and backward passing slowing an attacking sequence in terms of its approach to goal.

Brooke and Knowles (1974) described methods and procedures for the recording and subsequent analysis of behaviour in soccer, and sought to establish the reliability of their methods. Shorthand symbols were utilized to represent variables and parameters to be measured. Reliability coefficients were low and no attempt was made to assess the objectivity of the system. An alternative method was employed by Reilly and Thomas (1976) to record and analyse the intensity and extent of discrete activities during match play in soccer. They combined hand notation with the use of an audio tape recorder, to analyse in detail the movements of English First Division soccer players. They were able to specify work-rates of the different positions, distances covered in a game and the percentage time for each position in each of the different ambulatory classifications (see Fig.4). This has become a standard against which other similar research projects can compare their results and procedures.

FIGURE 4 ABOUT HERE

A very detailed analysis of the movement patterns of the outfield positions of Australian professional soccer players was completed by Withers et al. (1982). They classified players into four categories: full backs, central defenders, midfield and forwards. The subject was video-taped in various modes of movement: walking, jogging, striding, sprinting, moving sideways, walking backwards and jogging backwards. The average stride length was then calculated for each of these types of locomotion. The data produced by Withers et al. agreed to a great extent with that of Reilly and Thomas. Both studies showed that players spend 98% of the match without the ball, and were in agreement in most of the rest of the data, the main difference being that the English First Division players (Reilly and Thomas) were stationary a great deal more (143 s) than the Australian players (45 s). Withers et al. went on to link their very detailed data analysis with training methods specific to the position of the player within the tactical system of the team.

3.04 Wrestling

Ichiguchi, with a variety of different sets of colleagues (1977, 1978a, 1978b, 1978c, 1979, 1981a and 1981b) developed

a detailed system for notating wrestling and used this system at a series of major wrestling competitions. His detailed analysis of these competitions enabled him to produce a complex and informative discussion of the data. The group was able to detail such parameters as the mean scorings in the bouts, probabilities of winning once the first score was made, the types of activity that won bouts, and the successful techniques employed in winning. This type of stochastis modelling of performance has potential for further development.

3.05 Volleyball

A method for recording team statistics in volleyball was devised by Byra and Scott (1983) at Dalhousie University, Nova Scotia. The system was designed to record only one team's actions, and needed a 'quick, accurate and efficient' statistician to operate it. In some situations the authors felt that it would be most efficient to use two statisticians. Compilation of the data after the match required only 20-25 min. An additional notation system was introduced by Byra and Scott for scouting purposes which was based upon six main items that the authors felt should be monitored by a coach when assessing the opposition. These were starting line-ups, individual spiking tendencies,

setter tendencies, individual service reception strengths and weaknesses, and team service reception patterns.

3.06 Netball

Otago (1983) completed a study on netball players that utilised the similar techniques as was used by Withers et al. (1982). Amongst the conclusions drawn in this piece of work were the following:

1. Players in the same position demonstrate different activity patterns depending upon the tactics of their team and/or opponents.

2. Each position has a unique activity pattern.

3. Centres spend the highest mean time active during a game.

4. Defensive players spend the highest percentage of time 'shuffling'.

5. The anaerobic alactic energy system is the dominant energy source during a netball game. This observation was

based upon behavioural measures, no physiological investigation being conducted.

Miller and Winter (1984) used the same techniques of video analysis not only to examine the specific movement patterns unique to the different positions in netball, but to combine this with an analysis of the accuracy of passing when players are subjected to varying degrees of "pressure". The degree of pressure under which a player is operating can only be assessed subjectively; inclusion of this type of measure within a notational system must be processed very carefully. To obtain results that are in any way meaningful usually requires sophisticated statistical techniques. Not only were Miller and Winter able to suggest specific training routines for the different positions, but they went on to make strong recommendations about the need for better preparation for competition. Although the suggestions seemed acceptable ways for netball players to prepare for the game, there was no direct link between their conclusions and their data.

An analysis of the statistics of netball shooting for 12 highly skilled 'shooters' selected from eight grade 'A' netball teams competing in Western Australia was completed by Elliott and Smith (1983). Using a squad of data recorders, the performance of these shooters was monitored throughout a whole season. The procedures and analysis forms

for the notation were designed on the basis of recommendations by Embrey (1978) and Barham (1980). They produced a comprehensive analysis of the percentage accuracy of this standard of player, also breaking down the analysis with respect to distance from the hoop.

3.07 Field Hockey

Andrews (1985) developed a system of notation specifically for the analysis of attacking circle play in field hockey. Although a substantial degree of detail was produced, the obvious disadvantage in the notation system was that it was merely concerned with a particularly limited area of the playing area as opposed to encompassing the game as a whole.

3.08 Rugby Union

Rugby Union presents unique problems for analysis with its set piece moves, the 'scrum' and the 'line-out', and also the activity ensuing from a tackle in either 'rucks' or 'mauls'. Lyons (1988) has gathered data by hand on the Home International Championship for a period of ten years and has created a sound data-base. From this data-base he claimed

to predict the actions, e.g. the number of scrums, lineouts, passes , kicks, penalties and so on, in the England-Wales match in the '86-'87 season to within 3 passes and 2 kicks.

3.09 Analysis of Coaching Behaviour

Dodds and Rife (1985) developed a system of notational analysis that examined coaching behaviours that were exhibited during practice. A winning collegiate field hockey coach was observed across seventeen practice sessions through one complete competitive season. A category system for recording verbal and non-verbal behaviours delivered to the team or individual players, produced descriptive-analytic information about relative behaviour frequencies for offense and defense, starters and non-starters, and field players and goalies. Players and coach ranked team members on perceived amounts of coach attention during the season. The coach was interviewed at the end of the season. Players' and coach's perceptions were more closely correlated with each other than either perception correlated with observed data. Most frequently used behaviour categories included 'praise', 'instruction', 'criticism/cue',and 'alert' (management).

3.10 OVERVIEW OF HAND NOTATION SYSTEMS

Hand notation systems are in general very accurate but they do have some disadvantages. The more sophisticated systems involve considerable learning time. In addition, the amount of data that these systems produce can take many hours of work to process them into forms of output that are meaningful to the coach, athlete or sports scientist. Even in a simple game like squash the amount of data produced by the notation system of Sanderson and Way (1977) required forty hours of work to process one match. The introduction of computerised notation systems has helped to overcome these two problems, in particular that of data-processing.

4. Notation Systems in Sport - Computerised Notation.

Computers have only recently impinged on the concept of notation analysis. Franks et al. (1983a) maintained that this form of technology is likely to enhance manipulation and presentation of data, and inherently its interpretation, due to improved efficiency. Four major purposes of notation have been delineated (Hughes,1986):-

(i) analysis of movement;

(ii) tactical evaluation;

(iii) technical evaluation;

(iv) statistical compilation;

Many of the traditional systems outlined above are concerned with the statistical analysis of events which previously had to be recorded by hand. The advent of on-line computer facilities overcame this problem, since the game could then be digitally represented first, via data collection directly onto the computer, and then later documented via the response to queries pertaining to the game.

The information derived from this type of computerised system can be used for several purposes as suggested by Franks et al. (1983a):-

(i) immediate feedback;

(ii) development of a database;

(iii) indication of areas requiring improvement;

(iv) evaluation;

(v) as a mechanism for selective searching through a video recording of the game;

All of the above functions are of paramount importance to the coaching process, the initial raison-d'etre of notational analysis. The development of a data-base is a crucial element, since it is possible, if the data-base is large enough, to formulate predictive models as an aid to the analysis of different sports, subsequently enhancing future training and performance.

4.01 Soccer

One of the major developments in computerised notation was the mini-system devised by Franks et al. (1983a).A keyboard on a mini-computer was configured to resemble the layout of a soccer field and a program designed which yielded frequency tallies of various features of play. The path of the ball during the game was followed, so off-ball incidents were considered extraneous. A video was time-locked into the system so that relevant sections of the match could be replayed visually alongside the computer analysis.

Church and Hughes (1987) developed a computerised notation system for analysing soccer matches using an alternative

type of keyboard, called a concept keyboard. This is a touch sensitive pad that can be programmed to accept input to the computer. This permitted pitch representation to be graphically accurate and action and player keys to be specific and labelled (see Fig.5). This considerably reduced the time needed to learn to use the system, and enhanced the quality of the data input. The system facilitated analysis of patterns of play for both team and individual players, and with respect to match outcome. An analysis of six matches played by Liverpool F.C. during the 1985-6 season led to a number of conclusions, the most important of which were:

(i) a greater number of passes was attempted when losing than when winning;

(ii) possession was lost through error more often when losing;

(iii) a greater number of shots was taken when losing than when winning. These shots were on average also taken from greater distances when losing as opposed to winning.

(FIG. 5. ABOUT HERE)

Hughes, Robertson and Nicholson (1988) used the same concept keyboard and hardware system developed by Church and Hughes (1987), but with modified software, to analyse the 1986 World Cup finals. Patterns of play of successful teams,

those teams that reached the semi-finals, were compared with those of unsuccessful teams, i.e. teams that were eliminated at the end of the first rounds. They found that successful teams played significantly more touches of the ball per possession than unsuccessful teams. Their observations showed that there were significant differences in the patterns of play between successful and unsuccessful teams and these patterns could be accurately described.

Hughes and Lewis (1987) extended this work, analysing attacking plays only, to examine whether such unsuccessful teams use different attacking patterns to successful teams. An attack was defined as any move or sequence of moves that culminated, successfully or otherwise, in a shot on goal. Altogether 37 individual action variables and 18 different pitch divisions were employed in the data collection program.It was concluded that successful teams passed the ball more frequently than unsuccessful teams when attacking, particularly out of defence and in the final attacking end of the pitch. As in the previous work of Hughes et al. (1988) the successful teams used the centre of the pitch significantly more than did unsuccessful teams. Further differences demonstrated that successful and unsuccessful teams used patterns of play that vary significantly in attack.

A hand notation system developed by Ali (1987) recorded 13 basic factors of the game. The data were then entered into a computer in terms of X and Y co-ordinates on the pitch diagram and compared in relation to pattern and constituent elements of activity. The final action of each type of pattern was analysed to determine its influence on the game. It was found that attacking patterns that proceeded along the wing were more successful than those through the centre, the most likely result of a long pass was off-side, and that set-plays involving a great number of passes increased the likelihood of a goal.

Partridge and Franks (1989a and 1989b) produced a detailed analysis of the opportunities to cross the ball during offeces in the 1986 World Cup. They carefully defined a cross, and gathered data on the following aspects of crosses:

1. Build up;
2. Area of build up;
3. Area from which the cross was taken;
4. Type of cross;
5. Player positions and movements;
6. Specific result of the cross;
7. General result, if the opportunity to cross was not taken.

Fifty of the 52 games of the competition were analysed from video tape, using specifically designed software on an IBM XT Microcomputer that enabled each piece of information relating to crossing opportunities to be recorded and stored. The authors summarised their results by considering, what they termed, 'key factors'. These were the factors that were significant in successful crossing of the ball, i.e. creating scoring opportunities. Partridge and Franks were able to list these factors and, in conclusion, related their results to the design of coaching practices to help players understand their roles in the successful performance of crossing in soccer.

The work of Reilly and Thomas (1976) and Withers et al. (1982) established criterion data for the analysis of physiological output in any sport, but in particular soccer. Mayhew and Wenger (1985) used the principle ideas behind these works and calculated the time spent by three professional soccer players in different match-play activities by analysing videotapes using a specially designed computer program. The results indicated that soccer is predominantly an aerobic activity, with only 12% of game time spent in activities that would primarily stress the anaerobic energy pathways. The mean time of 4.4 s for such high intensity exercise led the authors to conclude that the alactacid energy supply system was the anaerobic system of primary importance. The intermittent nature of soccer was

partly described, and suggestions for the design of soccer specific training programmes were offered. The work did not extend in any way the previous efforts of Withers et at. (1982) or Reilly and Thomas (1976) whose purpose was to relate such work-rate profiles to the physiological fitness levels of players..

4.02 Squash

Hughes (1985) modified the method of Sanderson and Way (1977) so that the hand-notated data could be processed on a mainframe computer. The manual method was modified so that a match could be notated live at courtside using a microcomputer. Due to the speed at which the game is played, and the storage capacity of the computer, only one player's game was notated. Hughes established a considerable database on different standards of squash players and compared the differences in patterns of play between recreational players, county players and nationally ranked players (Hughes, 1986). The method involved the digitization of all the shots and court positions and these were entered via the QWERTY keyboard.

Analysis of the frequency distribution of shots showed that the recreational players were not accurate enough to sustain

a tactical plan, being erratic with both their straight drives and their cross-court drives. As a group, they played more short shots than the other two groups, and although they hit more winners they also hit more errors.

The county players played a simple tactical game generally, keeping the ball deep and predominantly on the backhand, the weaker side of most players. They hit significantly more winners with straight drives than both the other groups. Their array of short shots, consisting of boasts, drops and rally-drops, although significantly less accurate than the nationally ranked players, was significantly more accurate than the recreational players.

The nationally ranked players, because of their far greater level of fitness, covering ability and better technique, employed the more complex tactics, using an 'all-court' game, i.e. they did not concentrate on one area of weakness such as the backhand, but played their shots over the whole of the court relying on both speed and accuracy of shot. Finally, the serves of the county players and the recreational players, because of shorter rallies, assumed greater importance than the serves of the ranked players.

In an attempt to circumvent the problems posed by presenting frequency distributions on two dimensional representations of the playing area, Hughes and McGarry (1988) developed a

system that updated the system of Hughes, (1985), using a concept keyboard for input and an Acorn BBC microcomputer. They specifically tackled the problem of three dimensional graphical output of the data from a squash match. Their system presented the frequency distributions in colour 3-D histograms, with the capability of rotation. Comparative presentations of data were also possible, figure 6 illustrates a comparative distribution of drive shots for all the players taking part in an international match between England and Finland in 1988. It is interesting to compare this form of presentation with that of Sanderson (Fig. 3).

(FIG. 6 ABOUT HERE)

In an attempt to address the problems of analysing not only the techniques but also the movements of squash players, Hughes, Franks and Nagelkerke (1989) designed a system that would allow fast and efficient motion analysis of athletes by videotape. They designed a tracking system that utilised the immediacy of video. Mixed images on the same VDU screen, of both the actual playing area and a simulation of the playing area on a digitisation pad, enabled accurate tracking of a player. Measurements of the velocities and accelerations of the players were made with an accuracy usually associated with film analysis.

Hughes and Franks (1989) utilised this system and applied it to squash comparing the motions of players of differing

standards. They presented comparative profiles for four different standard of players, spanning from club players to the world elite. The profiles consisted of analyses of distance travelled, velocities and accelerations during rallies. The work provides reference data against which physiological studies of squash play can be compared. In addition the distance travelled during rallies by both recreational and regular club players was surprisingly short, the mean distance being approximately 12 m for both top club players and recreational players (see Fig.7). Hughes and Franks were able to present suggestions about specific training drills for the sport. Their system could also compare the individual profile of a player to those of his peer group so giving a direct expression of his relative fitness.

(FIG. 7 ABOUT HERE)

4.03 Field Hockey

Franks, Wilson & Goodman (1987) developed an analysis program for hockey using the Apple IIe computer. During half time and after the game the sequential data were stored (some 2,000 events) on disc and a menu driven analysis program was accessed. The key factors of performance were identified as:- goals scored and conceded; shots taken and the results of such shots; possession of the ball and where

possession was lost or gained; types and number of passes made; success or failure at set plays, including free hits, side-line hits, penalty corners and corners; and information relating to the goalkeeper's performance. This analysis system is presently in use with the Canadian Women's Field Hockey team.

The field hockey analyst formerly used the computer keyboard as a representation of the field to enter the data. After extensive trials, a digitisation pad was preferred to ease the data entry.

Hughes and Cunliffe (1986) observed the England Ladies Hockey team to study the effect of different surfaces on the patterns of play in field hockey, and to provide feedback on performance to the England coaching staff. This consisted of the patterns in which the team was playing and also individual player profiles i.e. analyses of all actions by each individual, to whom she passed and where, from whom each received passes, tackles, free hits and so on. The data were entered via the QWERTY keyboard. It was concluded that tactics adopted on artificial turf differs from tactics applied on grass. The rolling resistance on artificial surfaces is less than that on grass, an artificial surface is also more uniform so that the ball rolls more evenly. Both these factors were thought to be the major reasons that players on artificial surfaces ran with the ball more than

on grass, and that there were more touches per possession in play on artificial surfaces.

The printed feedback provided for the coaches was modified to meet the coaches' own perceived requirements. These requirements inevitably changed each time they received analyses of matches so the data processing software had to be continually modified. This would seem to be a natural and inevitable part of this feedback process.

Hughes and Billingham (1986) developed another system for field hockey that analysed patterns in passing sequences among team members. All data were entered via a digitisation pad in the specific order of player number, pitch position and action variable. The system was applied to analyse six women's International hockey teams, with match data for the analysis provided in the form of pre-recorded video tapes. Results showed that the successful teams made significantly greater use of the right hand side of the pitch, forced more short corners and were tackled in possession significantly fewer times, than the non-successful teams. Significantly more successful shots were taken from the left hand side of the shooting circle for all teams, although successful teams took a significantly greater number of shots at goal than non-successful teams. The significance of the former is linked with the successful teams attacking significantly more on the right wing wherefrom crosses would enable

players on the left-side of the circle greater shooting opportunities.

4.04 Water Polo

Franks and Goodman (1986) developed a computerised system for water-polo. It was attack-based, whereby the events of the action,the player responsible for that action, and the reason (e.g. 'pick') were recorded. A Radio Shack model 100 portable computer produced a complete history of the game. This 'script' of the game could then be reviewed by the coach or players, either alone or in concert with a video tape.A complete game analysis was also provided with respect to almost all the desired details of the game. For instance, for any player, it could be determined how many shots he took, how many goals were scored, how often and why he either gained or lost an advantage over an opponent, and so on.

4.05 Fencing

The speed of this sport required Elliott (cited by Franks and Goodman, 1986) to examine the overall structure of

combat rather than the specific techniques being used. Therefore, Elliott described fencing in terms of who takes the initiative in a given exchange, where the exchange takes place on the 'piste', and the opponents involved in the exchange. Specific techniques used and targets hit were recorded only when a point was scored. A database of past international games was derived and from this database several key aspects of successful performance have been formulated. In addition, training programmes are being developed that will assist coaches in the use of such an analysis system.

4.06 Wrestling

The system developed by Gardiner (cited by Franks & Goodman, 1986) for wrestling, used the Pascal language and was first based on an Apple IIe microcomputer and later adapted to an IBM compatible laptop computer. This system allowed for the collection of individual data, such as type of move (e.g., single-leg dive), the time during the bout that the move was made, and where it occurred on the mat. The results of each move are also coded and stored on diskette.

An extensive database was being compiled using world championship and Olympic finals of every weight class. The

type of information that could be made available from such a database relates both to the monitoring of Canada's athletes and to the scouting of the anticipated opponents. Detailed analysis of most favoured moves, their success and failure rates, and moves that opponents have trouble countering, can all be accessed with relative ease and counter-offensive action employed. It was possible to record live-action play. Taking this idea one step further, basic success and failure information collected on specific athletes could be applied to the structure of decisions and actions in simulated combat. Thus, various tactical plans were tested for their effect on the outcome.

4.07 Ice Hockey

A detailed and complex system for ice hockey was developed at the UBC Centre for Sports Analysis (Franks et al., 1986), and has subsequently been improved and modified. This system utilised two digitisation pads, touch sensitive keyboards, very similar to the concept keyboards described above. Because the rate of change of substitutes is so high in ice-hockey, one of these pads was used solely to keep track of who was on the ice at any particular time. The other was used for recording the game actions in the usual way. Both pads were connected to a laptop IBM-compatible PC, the

matches were notated live. The system is currently being used by a number of the top professional ice-hockey teams, on a commercial basis; the system has not yet been used for any published research projects.

4.08 Basketball

Hughes and Feery (1986) worked on a system to notate basketball matches. Their aim was to develop and validate computerised systems that recorded and analysed in-event occurrences of basketball in respect to the position, the action, and which member of the team being analysed, performed the action. A BBC B+ microcomputer, memory capacity 64K, was used but because of the amount of data collected the software systems had to be sub-divided into separate programs. A digitisation pad, a 'concept keyboard' - a touch sensitive pad consisting of 128 cells - was used as an auxiliary keyboard to input the information about player, action and position.

There were two parts to the overall system.The major part of the system was used to record all relevant match-play data and the second part, for shot analysis, was used to record shot data in respect to four defensive options.The scoring patterns were found to be dependent upon the defence being

played but the patterns were also different depending upon the type of game, i.e. American, English National League or European. The three point line had no effect on the shooting pattern in America; there were observable differences in England but these were non-significant.

4.09 Sailing

Analysis of tactics in inland dinghy racing was performed by Hughes and Nicholson (1986). In dinghy racing some uncertainty exists as to whether the racing speed of boats or the tactical ability of helms is the dominant parameter in determining skill levels. It was felt that an understanding of this would greatly aid coaching techniques in the sport.

Using a video-based computerised notation system the positions of boats were recorded throughout a race, within an accuracy of 12 m. Twelve helms were split into three ability groups - expert, intermediate and beginners - based on the sailing handicapping system. Eight races were notated and a significant difference in mean group velocity was found for races 1 - 4 between expert and beginner, and for races 5 - 8 between expert and intermediate.

4.10 Rugby Union

Treadwell (1987) developed software, that utilised the concept keyboard, to analyse Rugby Union. Hughes and Williams (1987) developed software using similar hardware, (in line with the work on soccer reviewed earlier). The system was designed to notate the matches post-event using video tapes. The system was used to notate five matches from the Home International Series over the seasons 1985-86, 1986-87, involving all the participating nations. A comparison was made for each match between the two playing sides and the results were analysed for differences in patterns of play between the French, Scottish and Irish compared to the English and Welsh sides.

No significant differences were found between playing patterns of successful and unsuccessful teams, although a number of differences were found between the patterns of play of the three nations compared to the other two. France, Scotland and Ireland have played, for these two seasons, in different patterns to England and Wales, using more passing movements and less kicking to advance the ball. France and Scotland used over 100 passes per game whilst England and Wales both used 42 passes only. Although France used almost as many kicks as Wales (43), over half of these were tactical kicks that did not go into touch.

4.11 American Football

A computerised notation system for American Football was developed by Hughes and Charlish (1987) using a DEC-20 mainframe computer. The amount of data being collected precluded the use of a microcomputer. The data were collected using the QWERTY keyboard, all relevant variables being assigned a certain coding and positioning in the play. The structure of the analysis allowed information to be collected on firstly, the position of the play; secondly, offensive and defensive formations prior to the snap of the ball; and thirdly, the action and result of the play. The notation was performed post-event using video-tapes of televised games.

The system was validated by comparing the computerised results of one whole match with data recorded by hand using slow motion replays to ensure accuracy. The two sets of results were similar.

An analysis of 329 offensive plays produced results that showed no significant difference in the patterns of play of winning and losing offences. However, trends in the data suggested that further analysis of differing patterns was merited. The analysis also showed that from plays which started within 10-20 yards (9-18 m) of the defense's end

zone, a significantly higher proportion of passing plays resulted in touchdowns compared to running plays.

4.12 Volleyball

Quantitative analysis of performance in volleyball is not a new concept, but Eom (1988) added sophistication to his system, by designing a quantitative assessment of the degree of difficulty of the skill required for the action being notated. Several studies have already attempted to collect objective data for volleyball match-play (Baacke, 1982; Penner, 1987) but, as in most notation studies, when an action or skill was being notated, no account was taken of the quality of the skill performance that preceded it. In addition, these skills were treated in the same manner irrespective of whether they occurred in an attack or in a counterattack.

A sample of 164 games from the 3rd F.I.V.B. Korean Cup (1989) was taped for analysis. A computer interactive recording system was used to store and analyse the data in sequential form. A 5-point numerical rating system, developed by Eom (1987), was used to quantify the playing actions. Stochastic analysis using a Markov model (first- and second-order) was applied to detect the sequential

dependencies of the events in each process. The data, represented in a form of a transition matrix, were analysed using a Chi-Square test to investigate whether a skill that occurred at time (t+1) or time (t+2) is dependent upon a skill occurring at time t. Further analyses were conducted to compare a transitional matrix in the attacking process with that in the counter-atttack and among the different types of attacking play, i.e. quick, medium and high attack.

Initial work with this system has shown the following results:

a) The transition probability matrices were not equivalent for the attacking process and the counter-attack. For the attack, success was more dependent upon the preceding events (i.e.r=0.81 between the serve reception and the set, and 0.83 between the set and spike).

b) For both attack and counter-attack, the second-order transition probabilities were highly significant. That is, spike success was strongly dependent upon the quality of the pass, r values being 0.79 and 0.73 respectively.

c) Among the types of spike, success in the quick and medium attack were highly dependent upon the quality of the set, r=0.87 and 0.92 respectively.

This mathematical approach could well be the logical outcome of further development of notation systems, as the emphasis moves from data collection and feedback, to prediction. Because of the sophistication of the statistics applied by Eom, this system could enable a coach to quantitatively assess his/her team's weaknesses and strengths and predict patterns that would benefit their performance.

4.13 Australian Rules Football

Patrick and McKenna (1988) developed a system for the computerised analysis of Australian Rules Football which they called the CABER system, a mnemonic for 'Capture and Analysis of Behavioural Events in Real-time'. Data recording consisted of entering quantitative and qualitative information about the game. The quantitative data included all the actions in the game such as ball possessions and disposals, team events, defensive and offensive actions. The qualitative data included adjectival qualifiers such as the quality (good, poor), pressure (uncontested, contested), and the location (wings, back pocket). Two operators were required to use the system, one verbalising the actions, the other entering the data on a special 'football key-board'. The system could be used for analysis of single player analysis, systematic breach of the rules and the defensive

pressure placed on the possessions of the opposition. The authors were unable to differentiate between successful and unsuccessful teams on the basis of a simple summation of match statistics, stating that a complex interaction of many variables affects the outcome of the game. They are currently working on this interaction, which may have importance not only in Australian Rules' Football but also Gaelic Football.

McKenna et al. (1988) completed a computer-video analysis of activity patterns in Australian Rules Football. Four Victorian Football League players were videotaped over a complete game. The activity of each player was classified according to:- a) movement type and b) game related activities. Movement types used were the same as earlier reported (Mayhew and Wenger, 1985), comprising stationary, walk, jog and high intensity run. The game related activities were comprised of all ball contacts, body contacts (including tackles and bumps), and physical efforts such as jumps, dives and fall over/get up. The action was then further sub-divided into high intensity (HI) and low intensity (LI) activities.

A computer-video system was used in the analysis. Analysis was conducted from a video-tape replay, although the authors stated that real-time analysis was possible. The authors claimed high reliability was found between repeated

4.15 Computer controlled video

One of the most exciting and potentially significant outgrowths of computerised sport analysis is the recent advent of interactive video technology. The ability of computers to control the video image has now made it possible to enhance existing sport specific analytical procedures. An inexpensive IBM based system was described by Franks, Nagelkerke and Goodman (1989).

Franks and Nagelkerke (1988) developed such a system for the team sport of field hockey. The system, described by Franks and Goodman (1986), required a trained analyst to input, via a digitization pad, the game related data into a microcomputer (see Fig.8). Following the field hockey game, a menu driven analysis program allowed the analyst to query the sequentially stored time-data pairs. Because of the historical nature of these game related sequences of action, it was possible to perform both post-event and pre-event examination of the data. That is to say, questions relating to what led up to a particular event or what followed a particular event could now be addressed. In addition to presenting the sports analyst with digital and graphical data on team performance, the computer was also programmed to control and edit the videotape of the game.

(FIG.8. ABOUT HERE)

The interactive video computer program accessed the times of all specific events such as goals, shots, set plays, and so on, from the stored database. Then, from a menu of these events, the analyst could choose to view any or all of these events within one specific category. The computer was programmed to control the video such that it found the time of the event on the video and then played back that excerpt of game action. It was also possible to review the same excerpt with an extended 'lead in' or 'trail' time around that chosen event. This system is at present being tested and used by the Canadian National Women's hockey team.

The system has recently been modified for use to analyse and provide feedback for ice-hockey and soccer. A number of professional ice-hockey clubs are currently using it, as well as the national Canadian team. The soccer system has only recently become available, and at the time of writing there are no examples of its application.

4.16 OVERVIEW OF COMPUTERISED NOTATIONAL ANALYSIS

To summarise the developments in computerised notational analysis, one can trace the innovative steps used in overcoming the two main problems of dealing with computers. These refer to data input and data output.

A major difficulty in using a computer is entering information. The traditional method is using the QWERTY keyboard. Unless the operator possesses considerable skills, this can be a lengthy and boring task. By assigning codes to the different actions, positions or players, that have some meaning to the operator then the key entry can be easier. The next step is to assign areas of the keyboard to represent areas of the pitch, numbers for the players, and another section of the keyboard for the actions. An alternative to this approach to this problem is to use a specifically designed keyboard (Franks et al., 1983; Alderson and McKinnon, 1985), that has key entry designed ergonomically to meet the particular needs of the sport under analysis.

The major innovation in this area that eased considerably the problems of data entry both in terms of skill requirements and learning time, was the introduction of the digitization pad. In Britain most workers have utilised the 'Concept keyboard' (Hughes and Feery, 1986; Sharp, 1986; Treadwell, 1988) whereas in Canada, another pad with the trade name 'Power Pad' has been utilised (Franks et al., 1986). These are programmable, touch sensitive, pads, over which one can place an overlay that has a graphic represention of the pitch and aptly labelled keypad areas for the actions and the players. This considerably reduces

the skill required for fast data entry, and the learning time to gain this required level of skill.

The most recent innovation is the introduction of voice entry of data into the computer. Taylor and Hughes (1988) were able to demonstrate that this type of system can and will be used by the computer 'non-expert'. Although systems are expensive at the moment, computer technology is a field of rapidly decreasing costs, even as the technology races ahead, so one can expect that this will be the next big step forward in the use of computers, in general, and sports systems in particular.

Notational analysis, whilst having been the platform for considerable research, has its foundations in practical applications to sport. In these situations, it is imperative that the output is as immediate as possible and, perhaps more important, clear, concise and to the point. Consequently, a second strand of innovation can be traced through the development of different systems to improve output.

The first systems tended to produce tables of data, often incorporated with statistical tests for significance.Coaches or athletes attempting to adopt these systems were frequently confused by this form of communicating of match data. Some researchers attempted to tackle the problem

(Sanderson and Way, 1977), but often the graphics served to confuse rather than simplify. Representations of frequency distributions across graphics of the playing area (Hughes et al.,1986), traces of the path of the ball prior to a shot or a goal (Hughes and Cunliffe, 1986; Franks and Nagelkerke, 1989), and similar ploys, have made the output of some systems far more attractive and easier to understand. The system developed by Hughes and McGarry (1989) specifically tackled this problem and produced some 3-D colour graphics that presented the data in a compact form, very easy to assimilate. The potential of computers to ease feedback in this way has hardly been tapped. Finally the computer controlled video, interactive systems (Franks et al., 1989) present the users with the possibility of immediate analysis combined with the visual presentation of feedback of the action.

5. THE FUTURE OF NOTATIONAL ANALYSIS

In terms of technological development, notational analysis will undoubtedly move as rapidly as the developments in computer technology and video technology as we approach the twenty-first century. There are two developments that will almost certainly happen over the next few years. The first will be the development of 'all-purpose', generic software.

Work in some centres has almost reached this point now. Another technological advance that will make computerised notation more easily handled by the non-specialist will be the introduction of "voice-over" methods of data entry. Taylor and Hughes (1988) have demonstrated that this is possible now, but relatively expensive at present day prices. These are expected to drop rapidly over the next couple of years and voice-interaction should therefore be a natural extension of any computing hardware system.

The integration of both these technological developments with computerised-video feedback will enable both detailed objective analysis of competition and the immediate presentation of the most important elements of play. Computerised systems on sale now enable the analysis, selection, compilation and re-presentation of any game on video to be processed in a matter of seconds. The coach can then use this facility as a visual aid to support the detailed analysis. Franks (1988) devised a more detailed model of the feedback process that could be possible with this type of technology (see Fig. 9).

(FIG 9. ABOUT HERE)

As these systems are used more and more, and larger databases are created a clearer understanding of each sport will follow. The mathematical approach, typified by Eom (1988), will make these systems more and more accurate in their predictions. At the moment the main functions of the

systems are analysis, diagnosis and feedback - few sports have gathered enough data to allow prediction of optimum tactics in set situations. Where large databases have been collected (e.g. soccer and squash) models of the games have been created and this has enabled predictive assertions of winning tactics. This has led to some controversy, particularly in soccer, due to the lack of understanding of the statistics involved and their range of application. Nevertheless, the function of the systems could well change, particularly as the financial rewards in certain sports are providing such large incentives for success.

Technological advances aside, the real future of notational analysis lies in the growing awareness by coaches, athletes and sports scientists of its potential applications to all sports. Whether the most sophisticated and expensive of systems is being used, or a simple pen and paper analysis, as long as either system produces accurate results that are easy to understand, then coaches, athletes, sports scientists will increase their insights into sport performance.

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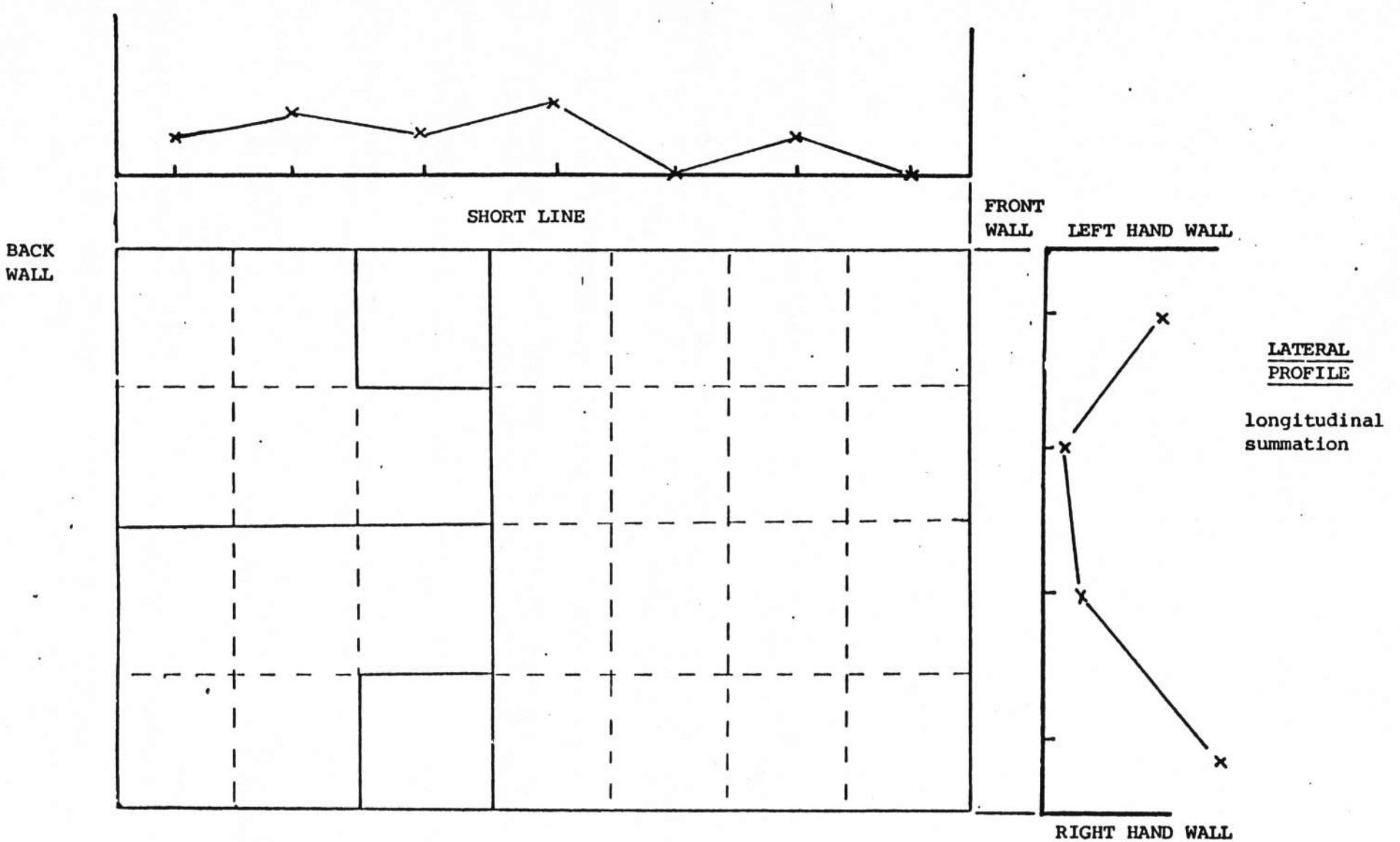
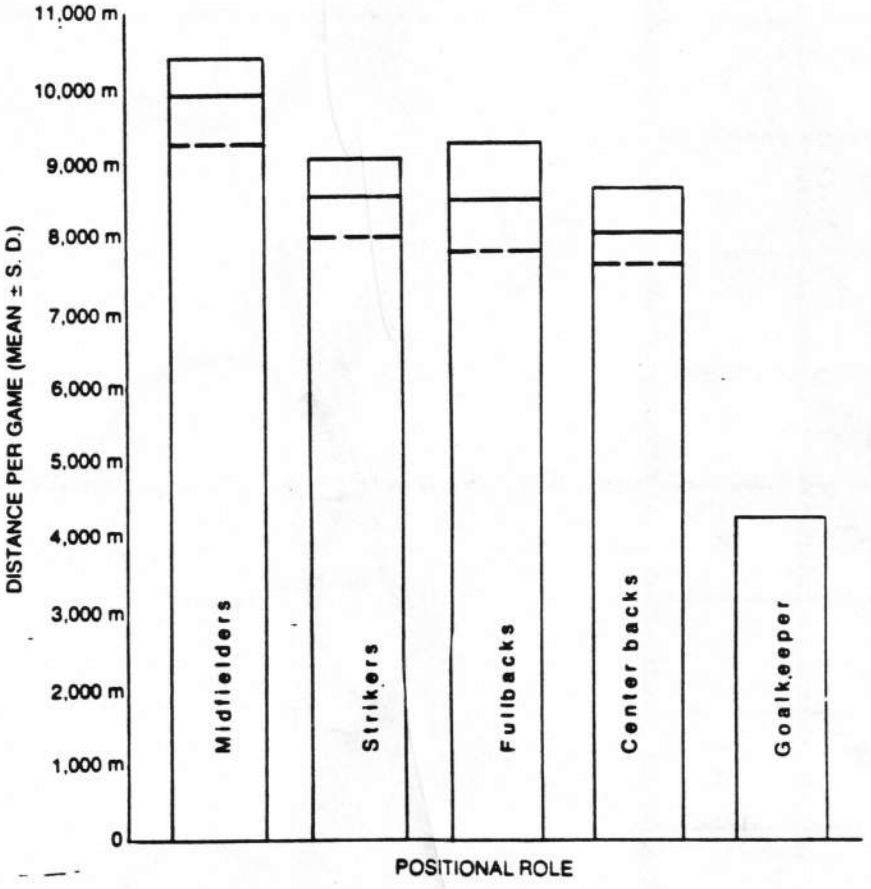
LONGITUDINAL PROFILE - Lateral summation

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DISTANCE PER GAME (MEAN ± S. D.)
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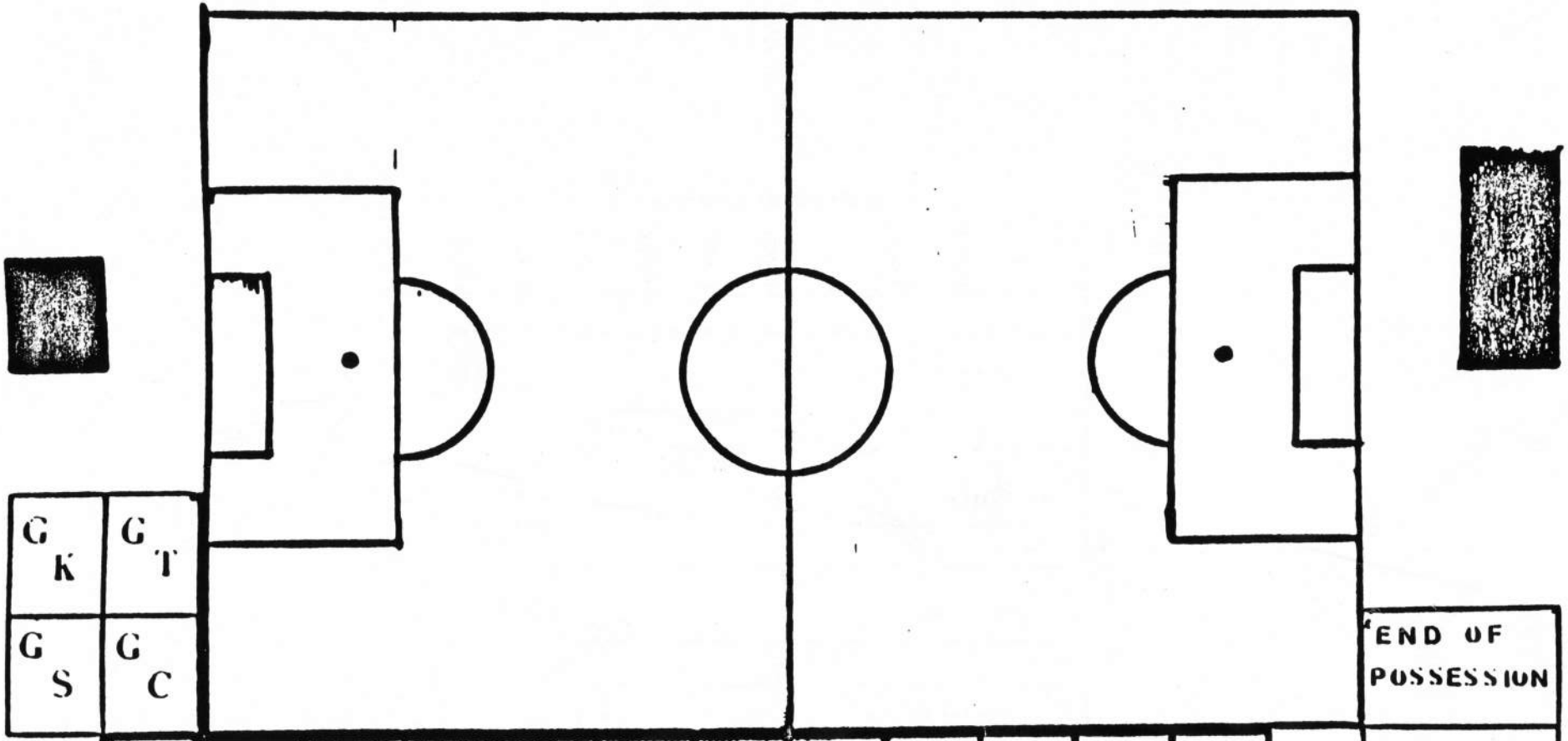
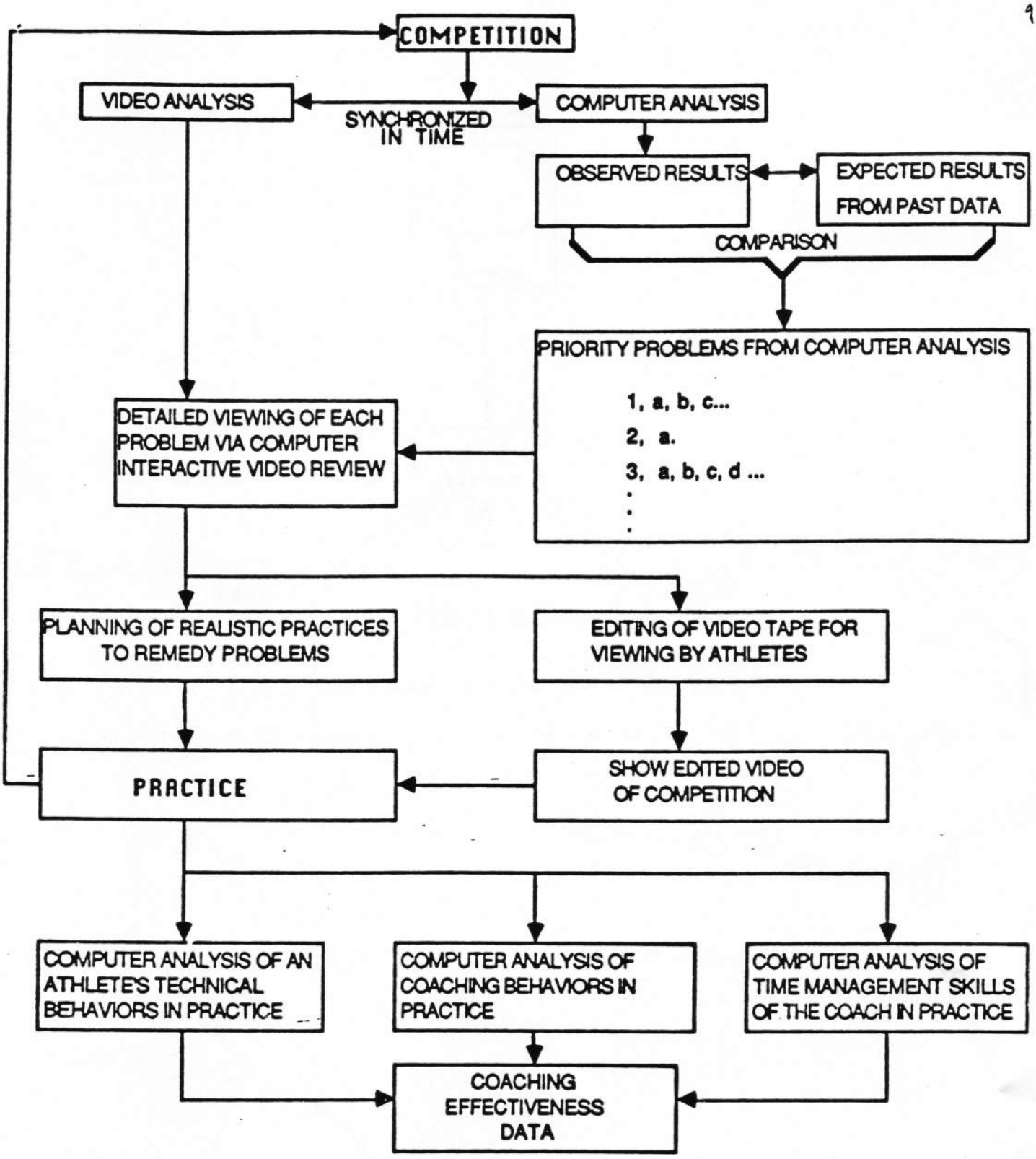
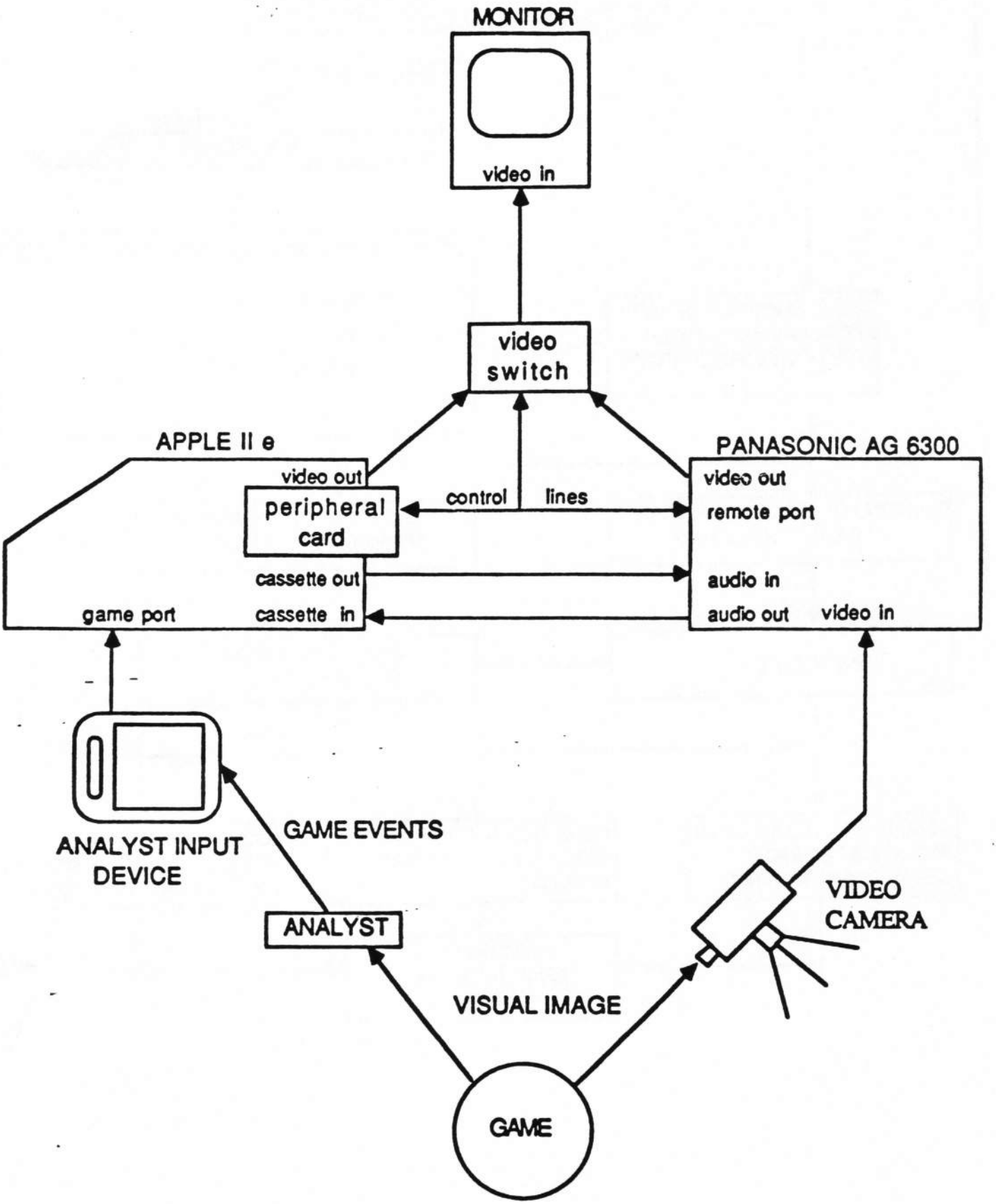
Strikers
Fullbacks
Center backs
Goalkeeper
POSITIONAL ROLE

SOCCER NOTATION OVERLAY

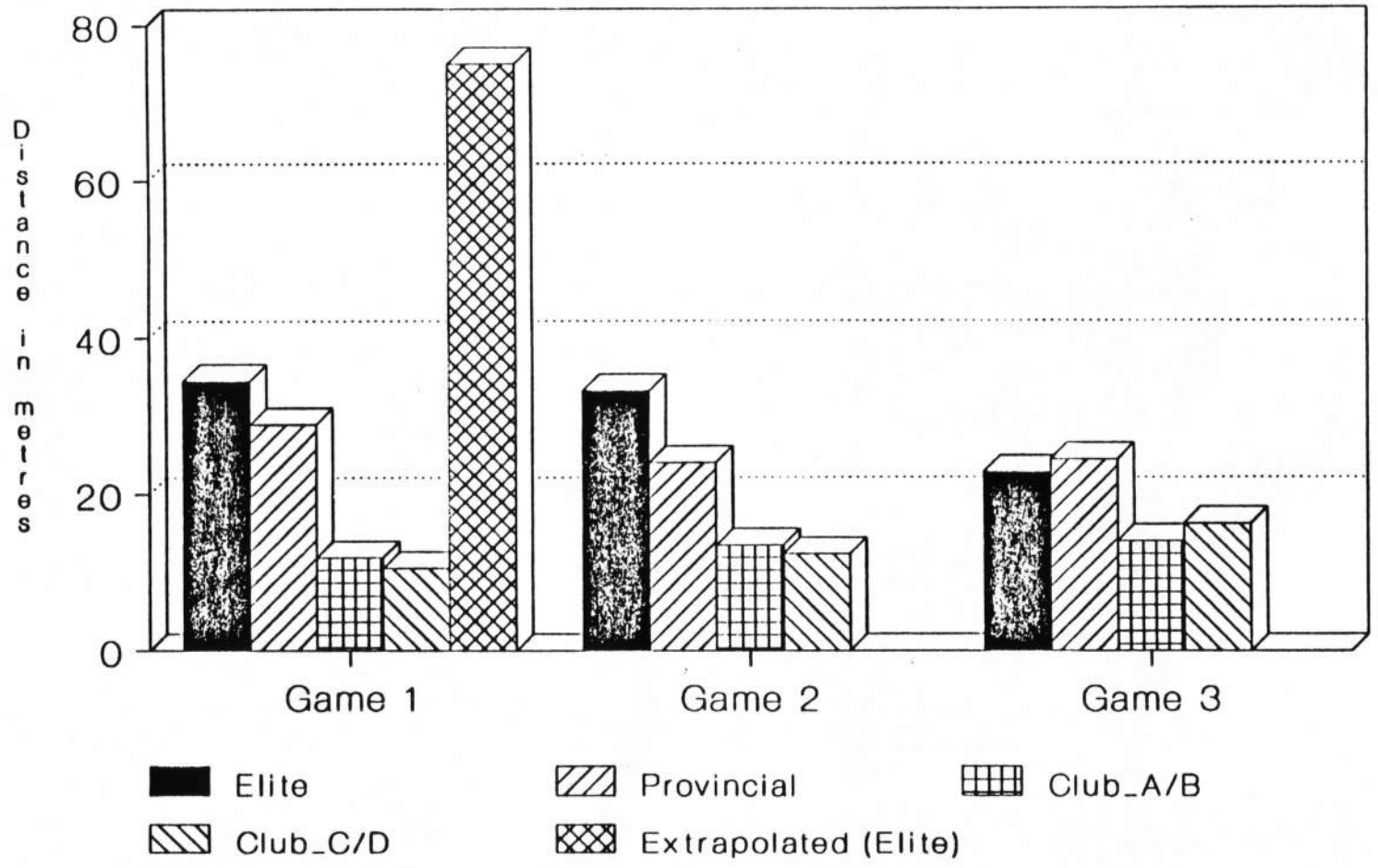


GK	GT													END OF POSSESSION	
GS	GC														
	1	2	3	4	5	6	7	8	9	10	11	12		GOAL	
FOUL	DRIB.	RUN	CLEAR	PASS	LOST POSS.	THROW IN	FREE KICK	CORNER	PEN.	SHOT	⁞	——	BLOCK	RE-BOUND	SAVED

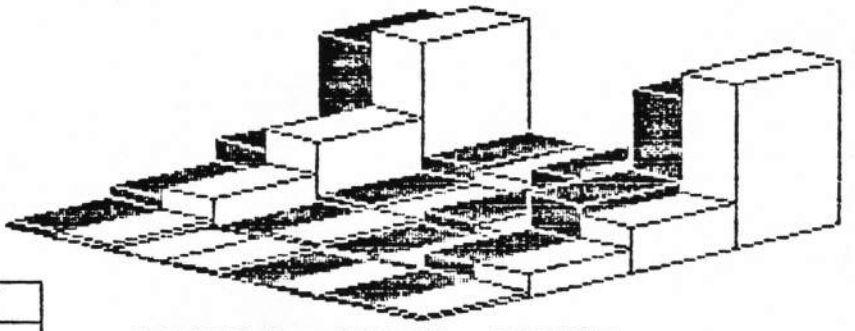

COMPETITION
VIDEO ANALYSIS
SYNCHRONIZED IN TIME
COMPUTER ANALYSIS
OBSERVED RESULTS
EXPECTED RESULTS FROM PAST DATA
COMPARISON
PRIORITY PROBLEMS FROM COMPUTER ANALYSIS
1, a, b, c...
2, a.
3, a, b, c, d ...
DETAILED VIEWING OF EACH PROBLEM VIA COMPUTER INTERACTIVE VIDEO REVIEW
PLANNING OF REALISTIC PRACTICES TO REMEDY PROBLEMS
EDITING OF VIDEO TAPE FOR VIEWING BY ATHLETES
PRACTICE
SHOW EDITED VIDEO OF COMPETITION
COMPUTER ANALYSIS OF AN ATHLETE'S TECHNICAL BEHAVIORS IN PRACTICE
COMPUTER ANALYSIS OF COACHING BEHAVIORS IN PRACTICE
COMPUTER ANALYSIS OF TIME MANAGEMENT SKILLS OF THE COACH IN PRACTICE
COACHING EFFECTIVENESS DATA


MONITOR
video in
video switch
APPLE II e
video out
peripheral card
control
lines
cassette out
game port
cassette in
PANASONIC AG 6300
video out
remote port
audio in
audio out
video in
ANALYST INPUT DEVICE
GAME EVENTS
ANALYST
VIDEO CAMERA
VISUAL IMAGE
GAME

Distance moved per rally.



A	5
B	2
C	7
D	7
E	2
F	3
G	5
H	2
I	8
J	4
K	6
L	1
M	2
N	7
O	6
P	2
M	16
N	2
O	4
P	5
O	2
P	0
P	13
P	7



COURT

* U21E88 TOTAL DRIVE
U21F88 TOTAL DRIVE

A	5	E	21	I	56	M	138
B	1	F	3	J	16	N	34
C	0	G	2	K	9	O	24
D	7	H	19	L	42	P	123

(+/-)rotate Contrast Fraction Hardcopy
Jumble Menu Next Reverse Scale Text