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THE APPLICATION OF INFORMATION TECHNOLOGY IN COLLECTING DATA ON TENNIS PERFORMANCE

WYKORZYSTANIE INFORMATYKI W PROCESIE GROMADZENIA DANYCH Z MECZÓW TENISOWYCH

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Summary: This study focused on the application and accuracy of spatially marking tennis shots in a special computer interface based on the visual observation of video recorded tennis play. The interface program, graphically designed in the shape of a tennis court, is shown on a computer screen along with a video showing a series of balls being hit and landing on the court. The task of the observer was to mark on the interface the location where he/she felt the ball falls on the court. In effect, the interface functions as a coordinate system whereby tennis play (in this case balls falling on one side of the court) is catalogued into a series of coordinative points. These data are then converted into a spreadsheet allowing for statistical calculation and analysis. The results of the trial indicated that the accuracy of the designated points on the interface depended on the distance between where the ball fell and the nearest line delineating the court. Balls that landed less than 0.3 m from the nearest line featured a mean distance error of only 0.11 m. For the purpose of analysing game tactics, the interface was found to be an applicable tool in the collection of tennis match data.

Keywords: tennis, game analysis and observation, tactics.

Streszczenie: Celem przeprowadzonych badań było uzyskanie odpowiedzi na pytanie, jaka jest dokładność zaznaczania na specjalnym interfejsie punktów spostrzeżonych na filmie wideo. Interfejs miał kształt kortu tenisowego wyświetlanego na ekranie monitoru komputera. Obok interfejsu wyświetlany był program odtwarzający filmy wideo przedstawiające piłki spadające na kort. Zadanie obserwatora polegało na dostrzeganiu miejsc na korcie, w które upadała piłka, oraz ich zaznaczaniu na korcie − interfejsie. Działanie interfejsu, będącego jednocześnie układem współrzędnych, polega na zapisywaniu zaznaczonych na nim punktów w formie współrzędnych. Zapisane i przesłane do arkusza kalkulacyjnego dane, stanowią w pełnej wersji interfejsu podstawę do dokonywania żądanych wyliczeń. Wyniki wskazują, że dokładność oznaczanych na interfejsie punktów zależy od odległości między miejscem, w które spada piłka, a najbliższą linią ograniczającą pole gry. W przypadku piłek, które lądowały od najbliższej linii w odległości mniejszej niż 0,3 m, średni błąd oznaczenia wynosił tylko 0,11 m. Oznacza to, że interfejs z powodzeniem może być wykorzystywany do zbierania danych przeznaczonych dla analiz taktycznych gry.

Słowa kluczowe: tenis, obserwacja i analiza gry, taktyka.

1. Introduction

A successful training regime for today's athletes requires the individualization, quantification, and rationalization of the multifaceted developmental process that an athlete undergoes in their sports career [Panfil 2000]. In all the three cases, one important element that can ensure an athlete's optimal development is the steady influx of diverse forms of information.

The individualization and quantification of the training process requires the continuous methodical acquisition of performance metrics that can be used to quantitatively assess the athlete. Rationalization concerns itself with preparing the athlete for competition by continually researching the theoretical basis for competitive success in their sport – this is closely associated with observing and analysing the most successful athletes.

Up till now, the most advanced areas of knowledge on athletic performance were based on physiology, biochemistry, and biomechanics. The methodology of these fields of research has advanced tremendously and is constantly expanding. However the impact of technological advances in recent years has allowed for new ways to collect data on athletic performance, especially during the dynamic phases of competition, thus allowing for an increasingly pragmatic assessment of not just technique and skill, but also the athlete's efficacy.

Recent research has taken advantage of a 'praxeological approach' in the analysis of team sports [Panfil 2006]. Using a similar approach in individual sports would also require not just sound methodology, but also a need for relatively economical, yet sufficiently precise, tools to assist the process of data collection during a game.

2. Data collection and analyses in tennis

2.1. Need for new research methods

There are a number of research problems in tennis whose solutions are highly dependent on the quality of the data obtained and the speed at which it can be processed. Technological advances in recent years have allowed for the application of new approaches and concepts to explain the complex reality in which tennis functions.

One of the most promising fields where modern technology can be applied is the study of in-game tennis tactics. An example of this may be the attempt to define the more common temporal-spatial patterns players face when implementing various tactical objectives [Chu, Tsai 2010]. Other authors made use of a specially designed 'computerised scorebook' to study the duration of individual shots, the time required to score a point, and the time needed to score a point depending on the tennis court surface [Takahashi et al. 2006]. Other studies used information technology to determine the positions of players during a rally to examine the influence of location on interpersonal coordination [Carvalho et al. 2013]. A detailed study used a computerised database to analyse the lower limb movement patterns of high-class tennis players during gameplay [Hughes, Meyers 2005].

Other forms of information important in the study of tennis tactics and strategy are found in the analysis of selectively researched aspects of tennis gameplay. One such example is studying video recorded matches to analyse player awareness during various in-game situations [Caserta, Singer 2007]. In fact, analysis of in-game player actions by using video appears to be a particularly innovative approach in studying tactics, especially when considering that a tennis rally between two players behaves as a non-linear oscillator. Such analysis could then be quantified based on the procedures to solve non-linear oscillator equations [Palut, Zanone 2005]. Other studies have analysed the tactics behind tennis by examining professional tennis players using video recordings [Triolet et al. 2013]. The combination of current computer software with video recording could provide an incredibly valuable research tool to precisely observe and quantify in-game player behaviour (of both competitors at the same time).

Outside the realm of information technology potential, of significance are the studies that have applied movement analysis methods towards identifying on-court actions [Guangyu et al. 2007]. There also exist numerous reports specifying more general relationships in tennis, such as the strategies adopted by the world's best players in terms of gender or the tennis court surface [O'Donoghue, Ingram 2001]. Other examples include an attempt to develop statistical indicators that could correlate player performance with their Association of Tennis Professionals world ranking [Reid, McMurtrie, Crespo 2010].

2.2. Modern commercial solutions

The application of digital recording and processing in tennis was first shown during the 2014 BNP Paribas Open at Indian Wells in the United States. These tennis matches were recorded using the FreeD Camera Feature [Internet 3], a system composed of multiple specialised cameras that can create three-dimensional virtual images from almost anywhere on the court. However, one of the most important features of this system is that it can provide digital video recordings of everything that happens in the field of view of the cameras. This system builds upon the earlier Hawk-Eye [Internet 4] system developed in 1999, whose main goal was to track the ball so as to allow players to double check the umpire's decision whether a ball was in or out. However, some scientific research was performed using the Hawk-Eye system, such as the analysis of service shot trajectories [Kolbinger, Lames 2013].

Besides actual video recordings, other modern applications that may assist the collection of data during the course of a tennis match come from the use of different kinds of software. One such example is ProTracker Tennis [Internet 1], a program recommended primarily for coaching. Data such as the location from where the service, return, and key shots are taken are entered. The program then generates statistics for the types of shots taken, as well as graphically illustrates their location (scatter diagrams) and duration in terms of the entire match (momentum chart). Another advanced form of software that has shown promise in the training process for many sports is Kinovea [Internet 2], although it appears to be more useful in the development of teaching materials.

2.3. Mathematical and statistical tools

As presented above, a great deal of valuable research material has been obtained through current video recording and information technology. This is due to the current state of high quality equipment (cameras, sensors, and computers) as well as advanced software. Still, lower quality video recordings have already been used to develop mathematical formulae to accurately identify and track the movement of various objects during a match (mainly the tennis ball). Conversely, various authors have used various mathematical tools such as Hidden Markov Models (HMMs) or Receiver Operating Characteristic (ROC) graphs to help analyse video images by analysing sound recordings [Dahyot et al. 2003; Kijak et al. 2006].

A comprehensive overview of the possible mathematical tools for use in the detection of the ball (Ball Candidate Detection) and its flight path (Object Candidate Tracking) were performed by Fei Yan in a dissertation from 2007 [Fei 2007]. A number of specific tools were distinguished, including the Kalman Filter and Kalman Smoother, Nearest Neighbor Standard Filter, Optimal Bayesian Filter, Probabilistic Data Association, Probabilistic Multi-Hypothesis Tracker, Sequential Monte-Carlo Method, and The Random Sample Consensus Algorithm. The author proposed a number of optimal mathematical solutions for problems associated with the detection and tracking of moving objects in video recordings.

3. Study purpose

In light of the above, this study focused on the application and accuracy of spatially marking tennis shots in a special computer interface based on the visual observation of video recorded tennis play. Specifically, its aim was to analyse the relationship between the accuracy of spatially marking points and the variables of this method that determine accuracy. The direct inspiration for its creation is the need for a program that can collect, record, and later analyse match data using criteria and concepts that are still relatively novel in tennis. Currently the most sophisticated and advanced computational software does not allow for the input of observer details that take into account this new approach, hence the need for designing and testing a dedicated interface that can allow for the praxeological analysis of game play.

As this is still a relatively novel approach, this study aims to only analyse one aspect of this software's application, namely user accuracy, by cross-referencing the accuracy of marking various spatial points on the computer interface in accordance to what was observed during a video recording of tennis play, in this case a tennis ball being served and landing on one side of the court. This interface (as an image of a tennis court displayed on a monitor) was treated as a coordinate system that saves each of the marked points. Observers have to mark on the interface the point they felt most closely matched where the ball actually bounced off the court. The next stage of research consisted of transferring the marked points on the interface to a spreadsheet and comparing the differences between the locations marked by the user on the interface and their actual position to determine the user accuracy of the above method.

The full version of the interface program allows for the selection of other importation spatial points, such as the point of contact between the tennis ball and the racket, players' positions, and other data that can quantify the player's ability to keep the ball in play during a rally. Obtaining such data can lay the ground work for performing various calculations on a number of parameters explaining gameplay in tennis in a systematic way [Nowak, Panfil 2012; Nowak 2014].

4. Material and methods

4.1. Description of the interface

The research tool under study was a computer program with a graphical interface displaying a tennis court (Figure 1). This interface works by marking selected points on the plane of the tennis court. An integral part of the system is the observer, who would watch a video recording of a selected element of tennis play or tennis match and mark, for example, where the ball makes contact with the ground on the graphical interface. The proportions of the tennis court shown in the graphical interface are maintained in accordance to the dimensions of a real tennis court. The distances between the baseline and area outside the court (limiting the field of vision from the rear) were reproduced with proportionally identical dimensions on the interface.

In the lower left corner of the interface a counter was placed where each tennis play could be numbered. A 'back' button allowed users to reposition the selected point for where they think the ball hit the court, however, after clicking on the ‘confirm’ button no additional modifications were possible. The ‘confirm’ button needed to be pressed after selecting the location of where each ball hit the court for the coordinates to be stored in a spreadsheet. A ‘save’ button was used to save the entire series of marked locations in a CSV file in a three-column format, 1.p – as the sequence number, x – the interface’s *x*-coordinate, and y – the interface’s *y*-coordinate. The origin of the coordinate system was marked at the upper left-hand corner of the singles line, i.e. at the junction of the left singles line with the baseline at the opposite end of the net (Figure 1). This coordinate system was flipped around the *y*-axis so that all points marked on the court would have positive values.

For the purposes of this study, the software was simplified and designed to be used only as a marker for where the balls landed on a court. However, the full version of the program can also be used to mark the locations of other important points (such as players’ positions) that can be used to assess in-game tactics in detail.

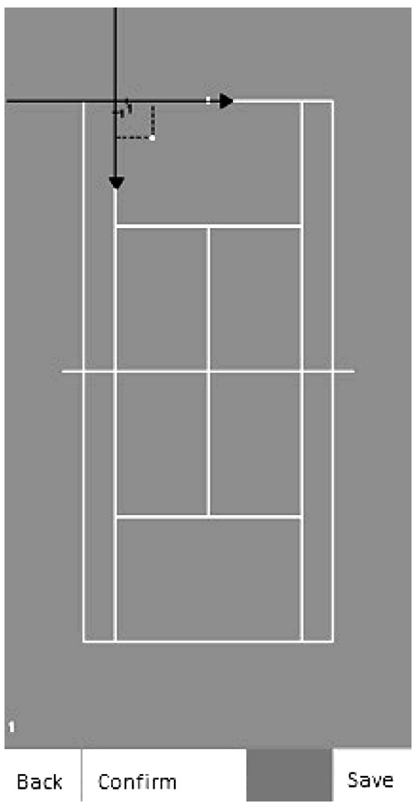

Figure 1. A representation of the computer interface program used to log match data; the coordinate system is shown, flipped around the vertical axis (*y*)

Source: own elaboration.

4.2. Video footage

Thirty short films were recorded on an indoor tennis court depicting the ball being served and landing on the opposite side of the court from a camera set at a height of 4.5 m and at a distance of 6 m from the baseline. The videos lasted from 4 to 15 seconds. When filming, each recording was identified by a subsequent number shown next to the left service box (Figure 2).

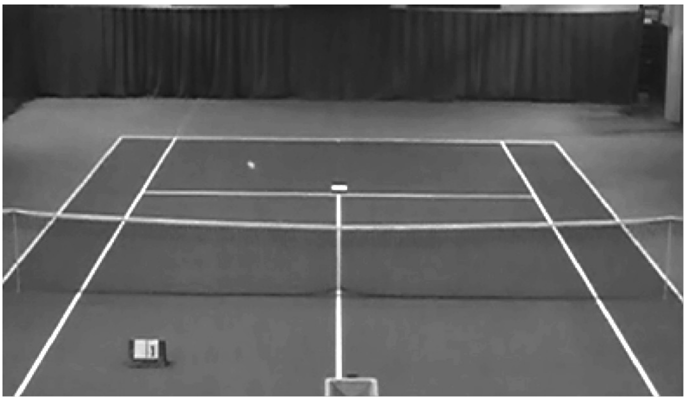

Figure 2. A frame from one of the videos showing a tennis service

Source: own elaboration.

During each service the ball left a physical mark of where it landed on the court. This was measured using a tape measure to the nearest 0.01 m so as to obtain the actual coordinates of where the ball made contact with the court.

4.3. Task description

The task of the observer was to watch the video of the ball falling on the court and determine its position by marking that point on the interface's court. The observer was allowed to replay the video if needed. After clicking the 'save' button, the interface program created a file in which all the ball coordinates were saved.

Analysis was then performed using a spreadsheet to calculate the difference between the marked and actual positions of the balls. Thus the differences in the x (width) and y (length) axes, as well as the differences between the actual and 'interface' points were obtained.

Errors made by the observers were defined according to their types. The first error was treated as the error between the actual point where the ball hit and the point marked by the observer on the interface (Figure 3). The second and third errors were determined by measuring the distance from where the ball hit to the nearest line (serviceline or singles sideline) on the court. The second error was calculated by the marked point's distance away from the line while the third error was considered to be the difference between the locations of the actual point where the ball hit to the one marked on the interface by measuring the distance perpendicular to the nearest line. (Figure 3). In this way the third error was used to check the direction of the error, as shown in Figure 4.

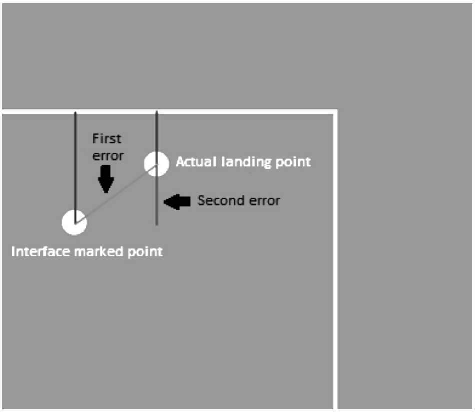

Figure 3. Identifying first and second errors

Source: own elaboration.

The size of the second error is particularly important for tactical analysis. Hitting the ball to the nearest line (whether inside or outside the court) can determine how 'out' the ball was (shooting accuracy) and the risk taken by a player by indicating how close they were willing to aim the ball to the nearest line.

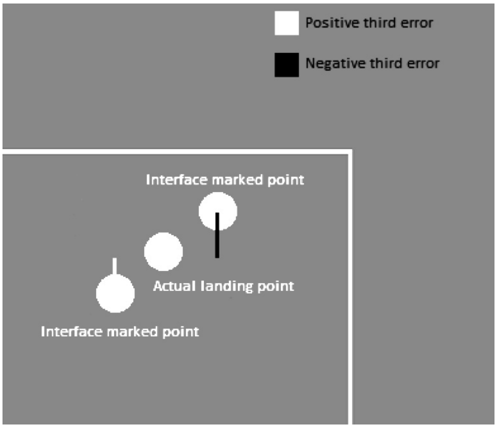

Figure 4. An illustration of the third error

Source: own elaboration.

4.4. Observers

To test the accuracy of the interface system, trials composed of the 30 videos were shown to a group of test observers. Eight 23-year-old tennis instructors were recruited to watch each 30 video tests one hundred times and mark the coordinates of the balls on the interface; all were involved in preparing their master's thesis on using the interface as a research tool. The total time spent on testing was two months. During testing, a minimum of two hours of rest was provided between each subsequent trial.

The participants had one month before the test period to observe a set of 100 videos of balls landing on the court so as to familiarise themselves with the coordinate differences between where the ball actually lands and the points marked on the interface. This familiarization period served as a training tool for the participants, with each having spent a total of 10 hours practicing.

4.5. Data analysis

In order to determine if the accuracy of the interface is sufficient for tactical analysis, the following parameters were measured:

- the relationship between the distance of the ball from the nearest reference point (the nearest point where the court lines intersected) and the size of the mean first error calculated and tested using Spearman's rank correlation coefficient,
- the mean first error for balls landing within 0.3 m from the nearest line as above,
- the mean second error for balls landing within 0.3 m from the nearest line as above,
- the mean first error for different areas of the court,
- the mean error for the coordinate points marked by the participants,
- the percentage of balls found with second error,
- the mean third error for all balls for all participants.

Data sets were investigated using tests for randomness and normality via the Mann-Whitney non-parametric *U* test, the Kruskal-Wallis test, the correlation test based on Spearman's rank correlation coefficient, and interval estimation for binomial proportion. Nonparametric tests were applied due to the small sample sizes and that data was not normally distributed.

5. Results

5.1. The relationship between the mean first error and the distance of the ball from the nearest point of reference

Figure 5 presents the relationship between the mean first error and the distance of the ball from the nearest point of reference for all participants (sample size = 30). In order to verify the significance of this relationship, Spearman's rank-order correlation was calculated, finding a value of 0.60. After applying the test for significance, it was found that this correlation was positive, suggesting that the closer the ball falls to a point of reference, the lower the error.

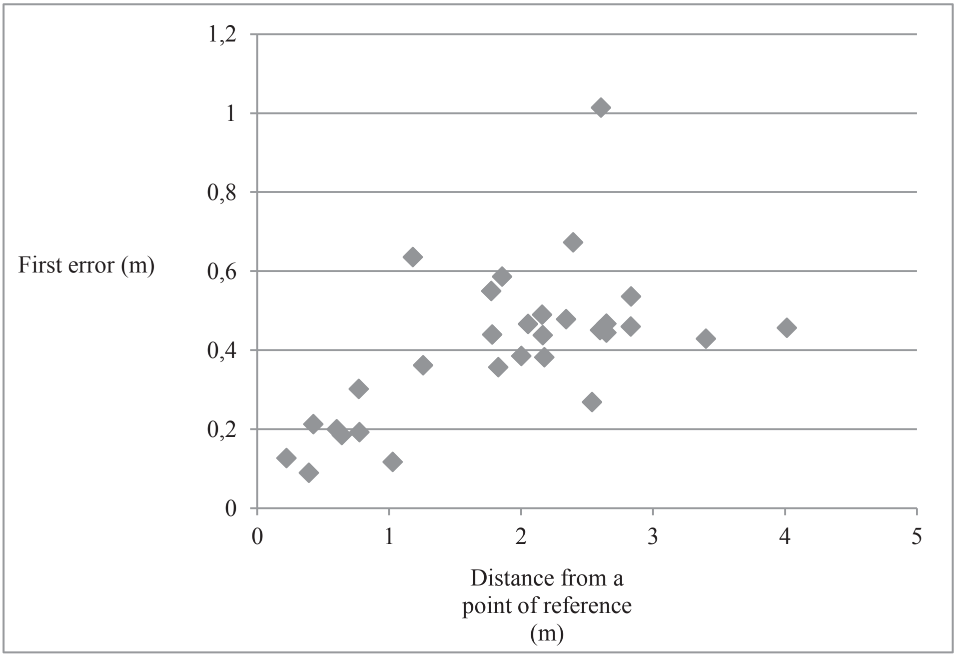

Figure 5. A scatterplot showing the distance of the ball from the nearest point of reference and mean first error for all participants

Source: own elaboration.

5.2. Mean first and second errors of balls landing on the court at a distance up to and greater than 0.3 m to the nearest line

Figures 6 and 7 show the mean first and second error of balls landing on the court at a distance up to and greater than 0.3 m to the nearest line (sample sizes = 8 and 22, respectively). Balls that hit the court closer than 0.3 m to the nearest line had first error and second error means twice less than those that fell elsewhere. It is noteworthy that the mean second error is half of the first error for balls landing at a distance of up to 0.3 m to the nearest line and for the rest. The Mann-Whitney U test found this difference to be significant.

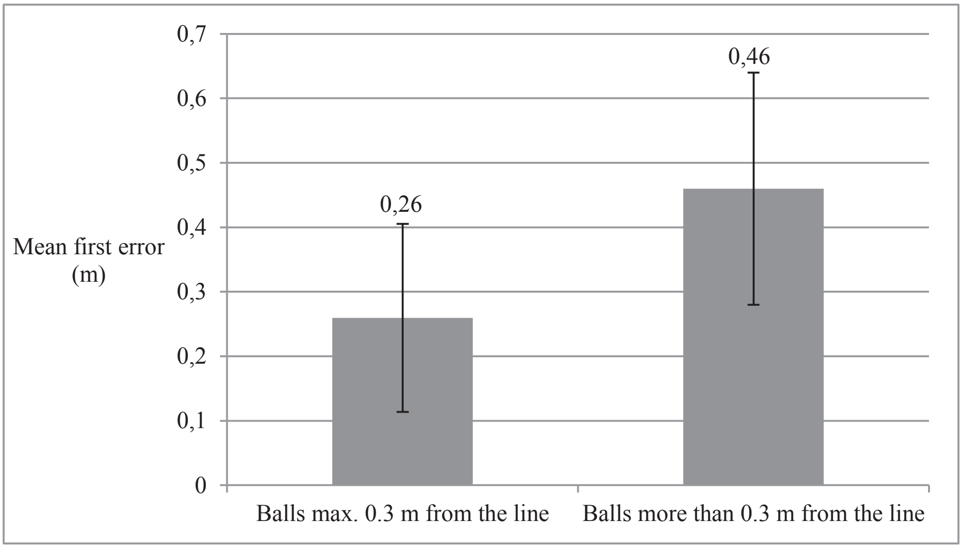

Figure 6. Mean first error for balls landing on the court at a distance up to and greater than 0.3 m to the nearest line; standard deviation calculated for balls

Source: own elaboration.

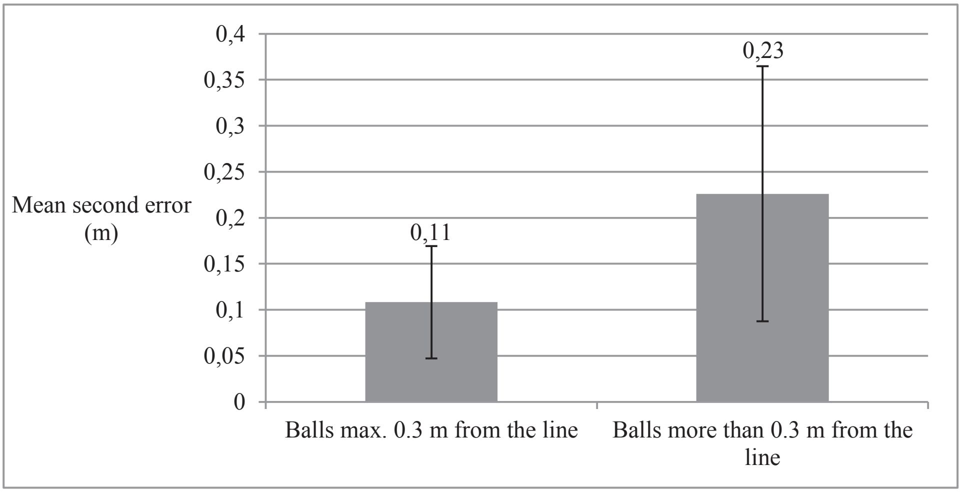

Figure 7. Mean second error for balls landing on the court at a distance up to and greater than 0.3 m to the nearest line; standard deviation calculated for balls

Source: own elaboration.

5.3. Mean first error specified separately for balls landing between the lines outlining the rear of the court and the baseline, the baseline and service line, and the service line and net

Figure 8 illustrates the mean first error for balls landing between the lines outlining the rear of the court and the tennis net. The first area is defined between the lines outlining the rear of the court and the baseline, the second between the baseline and serviceline, and the third between the serviceline and net (sample sizes = 8, 10, and 12, respectively). The results for the mean errors in these subdivided areas of the court show a dependency between the distance between the observer and where the ball lands, although the Kruskal-Wallis test did not show these differences to be significant.

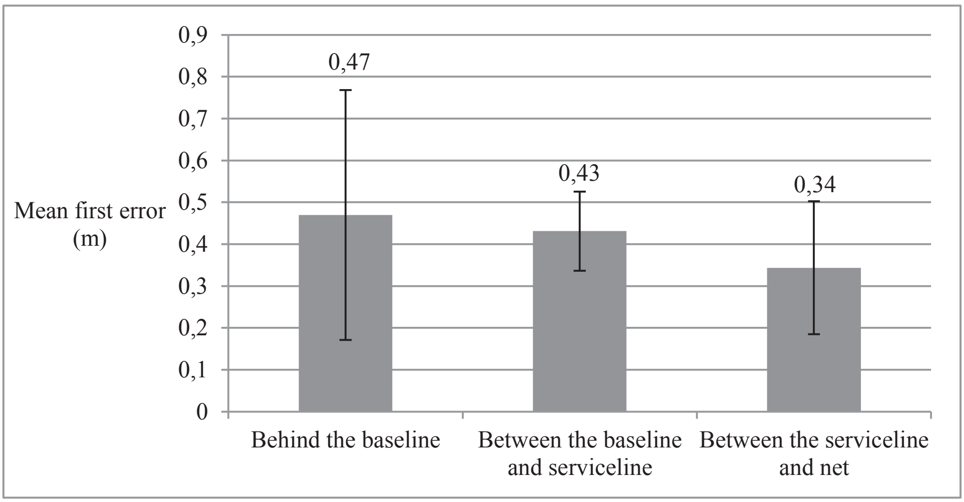

Figure 8. Mean first error specified separately for balls landing between the lines outlining the rear of the court and the baseline, the baseline and serviceline, and the serviceline and net; standard deviation calculated for balls

Source: own elaboration.

5.4. Mean error by *x* (width) and *y* (length) coordinates

Figure 9 shows the mean error in the *x* (width) and *y* (length) coordinates at 0.42 m and 0.14 m, respectively (sample size = 30). The Mann-Whitney U test found this difference to be of significance.

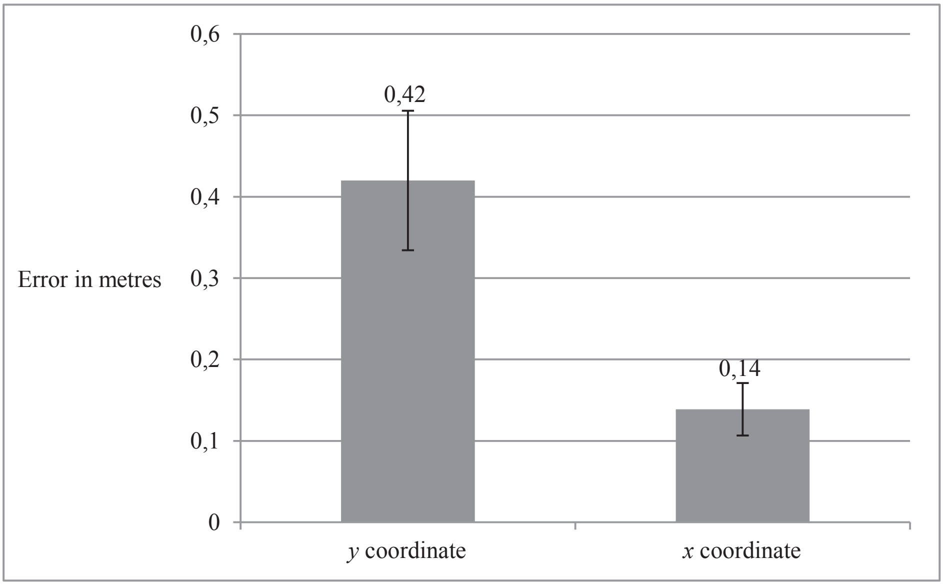

Figure 9. Mean error in *x* (width) and *y* (length) coordinates; standard deviation calculated for observers

Source: own elaboration.

5.5. Percentage of balls with an error within an area of 0.09, 0.04, and 0.01 m² and the size of a tennis ball from where the ball actually landed

Figure 10 presents the percentage of marked balls with second error within an area of 0.3, 0.2, and 0.1 m^2 and within the size of a tennis ball away from the actual point of contact. The results find that errors less than 0.3 m correspond to 93%, with an error of 2%, of correctly marked points on the interface. For second error smaller than the size of the ball, the percentage of correctly marked points was 47% with an error of 3.5%.

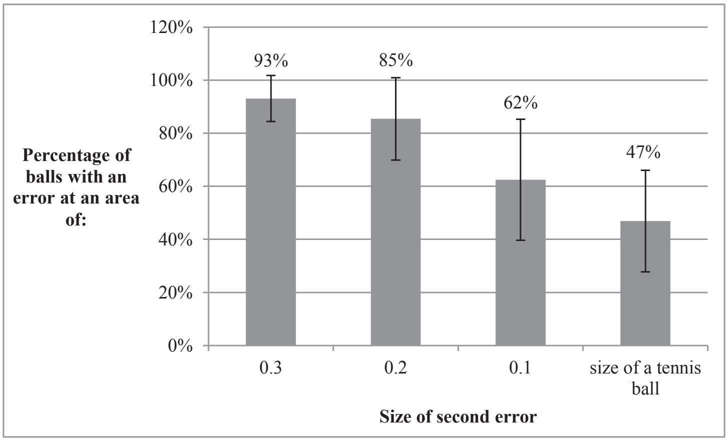

Figure 10. Percentage of balls with an error at a distance of 0.3, 0.2, and 0.1 m and within the size of a tennis ball; standard deviation calculated for balls

Source: own elaboration.

5.6. Mean third error for all balls for all participants

Figure 11 represents the mean third error (100 trials) calculated for the entire study group for all videos (240 samples). The mean error in this regard was –0.05 m. The expected value for error was significantly different from zero, which finds that this assessment includes a negligible, albeit systematic, error.

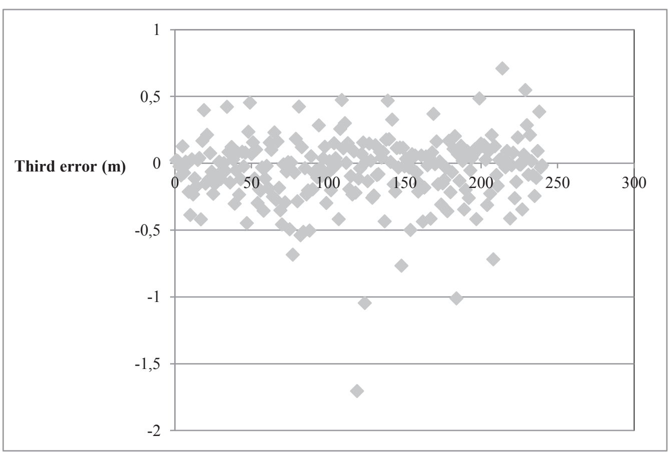

Figure 11. Relative mean third error was –0.05 m for all balls and all participants; errors show symmetry

Source: own elaboration.

6. Discussion

6.1. Interface program potential

The present study analysed the use of a computer interface in the collection of match data. It concerned itself with measuring the accuracy of an observer marking the location where a ball hit the ground on the graphical interface after watching a video of a tennis shot. It was assumed that for the tactical analysis an acceptable mean error of a point marked on the court 0.3 m or more from the nearest line should be larger than 0.5 m, while at a point closer than 0.3 m it should not be larger than 0.2 m. As demonstrated by the results (Figure 11), the distribution of mean third error for the entire sample was –0.05 m. This shows that the mean error after summing up the marked points on the interface will decrease. In areas where accuracy has a far more important role, i.e. where the ball falls very close to the baseline or sideline, a second error of 0.11 m was found and therefore better than expected. The results allow us to assume that the accuracy of the test interface, from the point of view of its usefulness in analysing game tactics, is entirely sufficient.

As was mentioned, this study made use of a simplified version of the interface program. The full version of the interface allows for a number of additional parameters to be noted characterizing the types of shots taken during a match, such as data on where the ball made contact with the racket and the position of the player, creating an approximate projection of the player's centre of gravity. All of the above allow researchers to create a comprehensive assessment of gameplay during a tennis match that may quantify a player's skills as well as their effectiveness.

The inspiration to systemically analyse the game of tennis was derived from research carried out on team sports and combat sports [Panfil 2006; Panfil 2011]. A praxeological approach to the problems in individual sports allows for new original criteria to be used in the assessment of player skills and to judge player efficiency in different game situations. An example of such an innovative assessment of a player's tactical skills may be distinguishing their position (situation) when hitting back the ball as one 'with freedom of action' or 'without freedom of action'.

Additional information may include assessing goal-oriented play to score a point, the preparation involved by a player to score a point, and the ability to keep the ball in play during a rally [Nowak, Lewandowski, Świst 2003]. Also of interest may be assessing the entire game by taking into account overall game play. This would require distinguishing aspects such as positioning and the ability to create point-scoring situations. Positioning is assessed by the variety of methods a player uses and the amount of risk incurred during positioning [Nowak 2014]. The creation of point-scoring situations is assessed from play variety, spatial flexibility, and the types of risks a player takes [Nowak, Panfil 2012]. The interface program studied herein would serve as a valuable research tool in all of the above cases.

6.2. The studied interface and other match data collection systems

The proposed interface tool is an instrument that is difficult to compare with the previously mentioned commercial systems or mathematical tools.

It is certain that the Free-D system provides incomparably more accurate data and a greater deal of information, such as ball speed and its exact flight path. However, one of the largest hindrances to the wide application of this technology is the costs associated with the necessary hardware. Analogically, even the older Hawk-Eye system can cost one hundred thousand dollars per court. To date, even the largest tennis tournaments in the world (Grand Slam) do not offer this system on all courts. On the other hand, if the raw video of these matches could be shared it could significantly contribute to increasing knowledge about game theory in tennis.

When comparing the studied interface with the applicable mathematical tools used for identifying and tracking a ball, it is important to realise that, as in the case of the proposed interface program, the 'responsibility' of marking where the ball made contact with the ground still lies with the observer. Therefore, of considerable significance would be the observer's experience with tennis (such as being a tennis player/instructor) and also experience, in this case, on how to accurately mark a point in the interface program.

7. Conclusions

The accuracy of the interface used in collecting data from video recordings was found to depend on the distance from where the ball bounced to a point of reference, i.e. the lines outlining the court. This relationship was found to be proportional, the closer the ball bounces to the nearest line the more accurately it can be marked on the interface's coordinate system. Based on the results, it seems reasonable to state that the observer-interface accuracy is sufficient in the collection of match data for the later tactical analysis of a tennis match.

Additionally, the need for such an interface has been highlighted in the present study, as existing solutions do not allow for the collection and storing of data that can allow for a praxeological-inspired analysis of tennis gameplay. More advanced solutions are prohibitively expensive and practically unobtainable (FreeD, Hawk--Eye), while more available and inexpensive programs (ProTracker Tennis) do not fulfil the requirements in adopting a more pragmatic approach in the analysis of individual sports.

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