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Towards a Stroke Construction Model

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Abstract

Expert table tennis performance involves dealing with many spatial and temporal constraints. This paper discusses how expert table tennis players coordinate their movements in order to achieve efficient strokes for any given ball. We applied Bernstein's hypothesis that top players seem to solve this problem by using a simplifying process, which allows them to perform a complex series of movements. Our results show a double spatial adjustment with reference both to the external environment (including ball events) and the body. Our model of stroke execution identifies at least three simplifying rules.
Key words: Perceptual-motor skill, stroke production, expertise, spatial and temporal adjustments.

Definitions:

Systems of reference: There are two systems of reference.
1) The game area (game system of reference): consists of a series of displacements about the table and in relation to the ball, it relates to the environment.
2) The body (body system of reference): consists of all the movements which are managed in relation to the body. All body movements are plotted mainly with reference to a frontal and a sagittal plan (the horizontal plan being of secondary importance for this study).
Ball events: The trajectory of the ball is divided in 'ball events': bounces, crossing net, strokes.
Degrees of freedom: The degrees of freedom in a system relate to the number of dimensions in which the components of a system can vary independently.
A system has different degrees of freedom according to the number of variations possible for any of its components.

I - Background

I-1. Field of investigation : expert table-tennis

Mastering the table-tennis stroke is not a simple task. Rosenbaum (1989) asserts that returning an oncoming ball is considered by some to be the most demanding of all

perceptual-motor skills. In this author's words, the players task involves:" Besides determining when a ball should be hit, and where it will be at that particular moment, players face the additional complication of identifying the direction in which the ball will be travelling at the moment of impact. Then, assimilating all this information, the player must place his bat in the correct position at the correct time, with the exact force required, directed in such a fashion as to propel the ball towards the desired location."
Expert players, however, manage to consistently produce efficient strokes despite extreme variations in the conditions prior to impact. They achieve this by regulating such factors as speed, direction, force and spin, which determine the movement of the ball. We thus sought to establish how table tennis players achieve such consistently high levels of performance by examining how they co-ordinate their movements to respond efficiently to any given shot by their opponent.
According to Bernstein (1967), expert players simplify the 'degrees of freedom' in their movements and limit the number of variables when planning and performing a shot. Many sport studies establish that expert players reduce the number of movement/ factors to be controlled while increasing their dexterity in controlling them.
We found that expert players reduce the level of difficulty of most of the factors involved and co-ordinate their movements to produce efficient strokes in the most complex situations by developing both a set of standard movement features and of situation-specific ones.

I-2. Scope of the study : global functional properties of motor behaviour

We hope that this study of expert player movement execution processes will shed new light on global functional properties of motor behaviour.
Our level of analysis is the one proposed by Colley and Beech (1988). According to these two authors, "....the acquisition of movement occurs when movement structures are constrained to behave in a manner appropriate to the attainment of a particular goal."

I-3. Description of problems to be solved in table-tennis action

Expert table tennis performance can be said to comprise two different set of criteria:

I-3.1. The first set concerns the impact of bat and ball ;
three requirements have to be fulfilled :
a) The trajectory of the bat must coincide with the trajectory of the ball.
b) At the moment of impact, the bat has to move in a certain direction with a certain velocity if it is to control the subsequent path of the ball after contact. The velocity vector of the bat at impact determines the characteristics of the ball's trajectory after this point.
c) The ball must reach the other side of the table, over the net.

These three constraints cannot be separated. For instance, the fact that the ball must be hit while the bat is travelling at high speed makes the control of bat direction at the moment of contact considerably more difficult. This speed constraint means that the bat must be propelled with a swinging motion, rather than a pushing or stopping motion. This swinging movement in turn gives rise to a greater variability in the bat direction at the moment of contact (Bootsma, 1991). The shock duration is only 1000th of a second (Tiffenbacher & Durey, 1994). The temporal 'window' (McLaughlin, 1986) is the time interval in which impact can occur. The length of the temporal window depends on the speed of bat motion, the plane on which the bat is travelling, and the size of the area targeted on the table. For example, Bootsma (1991) calculated that a forehand shot at a target of a given size on the table, must be timed within 6,5000th of a second.

I-3.2. Body adaptation

The second problem concerns the way the whole body adapts to the perceived place and moment of contact. The requirements listed above concerning the bat-ball contact problem are contingent on body adjustments in time and space which facilitate preparation and execution of a stroke. For instance, bat angle and velocity vector at the moment of impact must be adapted to the stroke location in terms of external environment (back and lateral game area) and the ball characteristics (direction, speed, spin, length...) Therefore, the task of executing a stroke requires a double spacial tuning (Beaubaton 1984). The first spacial tuning concerns the adjustment with reference to the external environment, that is, inside the game area relative to the table (ball direction, opponent location). The second spacial tuning consists in body co-ordinating constraints with a system of reference to the body.

I-4. The Simplifying Process

We advance the hypothesis that top players use a simplifying process, which allows them to perform a complex series of movements. We believe that a reduction in the degree of freedom actually enables the player to use his body efficiently to perform a chosen stroke in relation to ball characteristics. We identified and analysed standard movement features and detected some rules governing the co-ordination of internal and external spacial systems to achieve a perfect timing of the ball.

II- Method

II-1. We used two complementary analytical tools:
1) a macroscopic performance features analysis of efficient interaction between the player and his external environment and,
2) a human operator process analysis.

II.2. We tried to demonstrate that Bernstein's theory in relation to movement execution could be formulated in terms of cost-cutting or optimization. We therefore tried to define skill in terms of standard movements and to discover how they combine to make up patterns.

II-3. Our study of the kinetic characteristics of stroke movement is structured as follows :

II-3.1. Firstly, we look into the kinetic characteristics of stroke movement in order to identify the key features of stroke modelling. The choice of this criterion results from two considerations :

-*The kinematics of the bat* is the resultant of the series of sub-movements comprising the stroke. The bat trajectory can, therefore, be viewed as the interface between the operator, the conditions for achieving his goal, and the environment.

- *The point of impact of the ball.* We consider the point of impact of the ball to be the crucial event in the chain since it is the final step. It is, therefore, useful to study the process backwards from the point of impact, in order to understand the succession and the complementary nature of the different stroke adjustments tin time and space which contribute to the definition of the bat velocity vector at the time of impact. We consider the interval of time between two consecutive strokes by the same player as the temporal unit in which the player specifies and implements his stroke.

II-3.2. Secondly, under the Discussion we put forward a stroke model on the basis of our results. The model will need to be confirmed in a wider study. Our model will also have to be adapted to reflect different degrees of expertise and game styles.

III-Subject

Our research is based on a top French player : J.P.Gatien, who was silver medallist at the Olympic games in Barcelona in 1992.

IV- Apparatus

A camera recording of the player was made during matches, with a frequency sample of 100 frames per second. Different technical processes allowed the data on the picture to be digitalized. The data was then reconstructed in the three dimensions, and linked to the ball events (the strokes, the bounces and the net passages). The player, his bat and the ball are coded into 29 digit points. The set of data refers to the two relevant systems in space : game area, and space of body action. The data were collected in the course of ten points chosen in mid-set. The sequence begins with the service and finishes with the losing point. Five services are made by Gatien and another five by two successive opponents. We studied all of Gatien's strokes in these exchanges i.e. thirteen forehands and ten backhands.

V- Results

The results are derived from kinematic bat analysis (trajectory, and derivates) and also from the analysis of the whole body postures (Fig. 1). All the data are given with reference to the ball events.

V-1. In the game area. Game system of reference

V-1.1. Description of phases :

a) .Concerning the evolution of bat trajectory between two consecutive same player strokes, four phases can be systematically described :

- The first one was the follow-through of the swinging motion preceding the stroke.
- The second one consisted mainly of backward/forward displacements.
- In the third phase, the spacial orientation is different for the forehand and the backhand. For the former, phases 2 and 3 were in the same plane. For the backhand, phase 3 was on a frontal plane nearly perpendicular to phase 2.
- Phase 4 was composed of two sub-phases. Phase 4a was identified relative to both previous and subsequent phases. It consisted of a lateral movement. Phase 4b started with the forward bat movement and stopped with the stroke (Fig. 2 and Fig 3).

b) A characteristic trait concerning phases 4a and 4b :
When the movement of the racket, as a function of time, is plotted on the Y axis (parallel to the border of the table), the resulting function is a system of curves with a notable characteristic: the points of impact occupy the most extreme points on these curves (or those immediately before or after), as demonstrated in Fig.4.

This demonstrates that during this final phase of the circular movement of the racket, the evolution of the direction of the velocity vector could be analysed as follows : the value of this vector, as seen on the Y axis, tends towards zero, or very near it, up until the moment of impact. On contrary as seen on the X axis, this velocity vector increases, and reaches its apex at the moment of impact. This means that at the moment the ball is struck, the bat trajectory is at its ultimate lateral point and its highest velocity.

V-1.2. Timing of phases

The movement phases followed some characteristic ball events:
• Phase 1 ended when the ball crossed over the net, onto the opponent's side.
• Phase 3 began when the ball was returned over the net
• Phase 4b lasted always 80.000th of a second for both forehands and backhands.

V-2. In the body system of reference
(the data refers to the calculated pelvic-middle point)

V-2.1. description of phases

The general spacial pattern (reconstructed like a top view) described above in figures 2 and 3 was maintained (Fig. 5). Yet, concerning the studied player, some observations could be made :

a) The bat developments around the pelvis were circular during phases 2 and 3 and were similar during phase 4b. Different strokes were identified in phase 4 a. in terms of length and delay (Fig. 6 and 7).

b) His forehand strokes were mainly located in two areas: one around 1m and the other around 1,5 m relative to the lateral axis (Fig. 6).

c) At the bat-ball impact, an imaginary straight line between pelvis and racket top ran parallel to the table border. However, this line took a small angle relative to the side of the table when the stroke was made in the lateral areas of the game. (Fig.6 and 7)

V-2.2. Timing of phases

The racket development time relative to the X axis (forward and backwards to the pelvis) and relative to the Y axis (sideways to the pelvis) followed some interesting curves : During phases 2 and 3 the curve slopes were parallel, i.e. the velocity of the bat during these phases was constant. On the contrary, we observed variations in the later stages of the movement. (Fig 8).

VI- Discussion

The player had to adjust his movement in space and in time with the ball not only to make contact with it (necessary condition) but also to propel it with efficiency (necessary condition for competitive matches). This task was very complex : to give the ball an efficient initial velocity vector when striking it, the player had to take into account numerous other factors together with those already mentioned in our presentation. The ability for him to assess accurately a large volume of data is a key factor in the success of a player's shot. The expert has adapted his behaviour to this complex situation, and in a sense makes him able to create this complexity as is shown by the high difficulty degree of expert matches. We have worked on the hypothesis that such adaptation was made possible through the use of simplifying processes that focus on a number of relevant variables while standardising the other factors so as to achieve an economy of time and energy in the management of the system. The analysis of the expert stroke execution allowed to infer a model of his method of efficient stroke construction.

Our results revealed three procedures:

VI-1. The first procedure consisted of progressive specification of the stroke.

Both the selection of the stroke and its location in time and space were progressively determined in relation with the information contents of the ball.This information was, at first, managed predictively, allowing perceptive orientations and motor preparation ; afterwards, the assessment was progressively confirmed or not during the ball's return travel.

- The player's decision to use either a forehand or a backhand stroke could be traced to phase 3. The begining of the observed movement (at least for the backhand) occured as the ball crossed the net; thus the decision was taken before this event. For both types of shot, it was very difficult to place the decision in time with any accuracy. It was wiser to consider the decision as a process based on several different criteria and executed as from the moment the ball crosses the net.

• The predicted and later the perceived direction of the ball contributed to the chosen and later confirmed player response.

• The length of time between the adversary's ball impact and its crossing of the net seemed also to have some bearing on the nature of the choice (Ramanantsoa, Durey, 1991).

• The strategic choice of the player.

The spacial and temporal movement organisation showed a progressive specification :

1-. Relatively to the general pattern of the bat trajectory, (in the game system of reference) phase 2 varied from one stroke to the next. Its amplitude was a function of the forward/backward distance which was necessary to cover get to the required future location of the stroke. These adjustments could be observed from the moment the opponent struck the ball, and seemed to finish around the time the ball crossed the net. The global body displacement during Phase 2 could sometimes occur along an oblique line which was due to lateral displacement, coupled with backward /forward displacement. These rare instances happened when the player, thrown off center by the previous shot, returned to a central position.

These movements tend to indicate that the events observed prior to the opponent's shot (and more specifically, those occurring between the bounce and the opponent's shot) allowed some pertinent predictions to be made regarding the future length and height of the ball in the area at the back of the table. Depending on this prediction and his game plan, the player seemed to approximately determine the future (forward or backward) position at which he will strike the ball. This location determined also roughly the future height of bat-ball contact.

2.-. If the direction of the ball demanded a lateral body displacement, this took place essentially during Phase 3 for the backhand and during Phases 3 and 4a for the forehand.Amplitude depended on ball direction relatively to body positionning at the time when the ball crossed the net.

3.-. Phase 4a happened before the propulsion phase (Phase 4 b) and manifested itself by lateral adjustments based on the shot. It was as variable in time as it was in space, depending on the shots. At this post-bounce phase (4 a), all the kinematic charcateristics of the ball were therefore available, and it can be said that the final spacial adjustments occur during this phase of movement. The degree of precision and the complexity of the stroke depended on the time available for its ultimate specification during this phase. This length of time depended on the number of adjustments to be made in space after the bounce of the ball. A large lateral and / or foreward -backward amplitude in Phase 4a would indicate that the adjustments carried out during Phases 2 and 3 would not be sufficient, and need to be completed and corrected during this phase. If the first spacial ajustements were roughly accurate, the player had to correct his movement but could not specify with speed and accuracy the racket velocity vector at the time of impact. On the other hand, the accuracy of the first ajustments (during phase 2 and 3) liberated time (during phase 4a) for the final specification of a complex and sophisticated definition of the stroke velocity vector.

VI-2. The second procedure concerned the interaction of two types of movement adjustment.

We observed that the stroke was the product of a co-ordination of movements in the two systems of reference identified in the study. These two systems of reference in space seemed to work independently up until the final movement phases.

1) independent management of the systems of reference

Invariably, during *Phases 2 and 3*, the speed variations only related to the player's displacements while the bat velocity relative to his body remained constant. In other words, during these earlier movement phases: a) player adjustments in space and time *in the game area* relative to the return trajectory of the ball seemed to be controlled by means of global body displacements and b) the bat was controlled independently and in a constant fashion *in the body's system of reference*. The amplitude and the speed of these global movements depended on the player's location relative to the ball's return trajectory at the time the opponent struck the ball and on the player's strategy.

2) The two systems coalesce

As from Phase 4, on one hand, the necessary closeness of the ball to the body in the final movement phases and on the other hand, the adaptation of body location with the ball trajectory require to be controled in both two systems of reference.

1. In the game system of reference, we observed the final global adjustments (large or small depending on the accuracy of the first adjustments relative to the ball's trajectory).

2. In the body's system of reference, we observed that impact locations in the case of the forehands were located sideways from the middle of the pelvis in two areas around the intersection of the frontal and sagital plans : one about 1 meter and the other 1, 50m. We also observed that at the end of phase 4 b), the body-bat system was located on an imaginary line between the pelvis and the bat-head runnning through the pelvic frontal plan parallel or nearly parallel to the table border (fig 6 and fig 7).
The articulation of phases 2 and 3 and phase 4 appeared as follows:
First, in the game system of reference, the amplitude of the movements (backward, forward and later lateral) during phases 2 and 3 determined roughly both the speed at which the bat would hit the ball and the timing and position of the stroke. *Secondly, in both systems of reference,* the bat velocity and a fictive 'target' (point at which the ball should be struck) were defined with more accuracy.
The position adjustments during the final phases had two aims :
1) *bring the body closer to the ball* (in the game system of reference) and to the future location of impact/'target' (in the body's system of reference) in order to reach one of the two preferred 'targets' sideways to the pelvis.
2) in a final preparation before hitting the ball, *locate the body-bat systems* on an axis roughly parallel to the table at the impact moment.

As shown above, the double final tunings of the 'target' served to pinpoint in space and time a virtual 'target' which the player identifies increasingly precisely. This 'virtual target ' is reaches by mean of swing movement wich is at its ultimate lateral point and its hightest velocity at the bat-ball contact.

VI-3. The third procedure related to temporal control of the stroke.

1.*Timing phases of movement with ball events* . We have shown that certain phases of the bat matched ball events, indicating an efficient timing of movement relative to the speed variations of the ball. This is an efficient way of keeping up with the ball's speed.

2.*Using movement phase of constant duration.* Litterature on the topic demonstrates that the propulsive phase (phase 4 b) is constant for any given player independent of the characteristics of the ball. There are two main hypotheses to explain this invariability.

• Boostma and Wierringen (1989) showed that this active phase could be continuously regulated by an external factor pertaining to the optic flux created by the movement of both the ball and the player. According to this theory, the start of this propulsion phase coincides with a specific signal (different for each player), called the 'tau factor', which provides an assessment of the time remaining before the ball reaches the player. This temporal indication is thought to be be a function of the perceived size of the ball on the retina as it approaches.

• Thydesley and Whitting (1975) felt that the constant duration related to an internal mechanism they called 'Operational Timing'. They saw this as a sort of clock which determines the starting point of this phase of constant duration.

Our own results confirmed a constant duration for this movement phase. The speed of the bat is largely determined by adjusting the amplitude of the movement in the propulsion phase, ie by chosing the starting point of the swing. This procedure clearly forms a simplifying process.

VII - Conclusion

As expected, the adjustments in space and time allowing the player to model his stroke were founded on three simplifying procedures of this complex task.

These three simplifying procedures were :

- progressive definition of the 'target' to arrive at a precise location of the point of impact
- separate or joint management of the two systems of reference
- management of available time matching specific ball events and using movement phases of constant duration.

All three such procedures are in line with the Bernstein's theory of skill as a reduction of the degrees of freedom.

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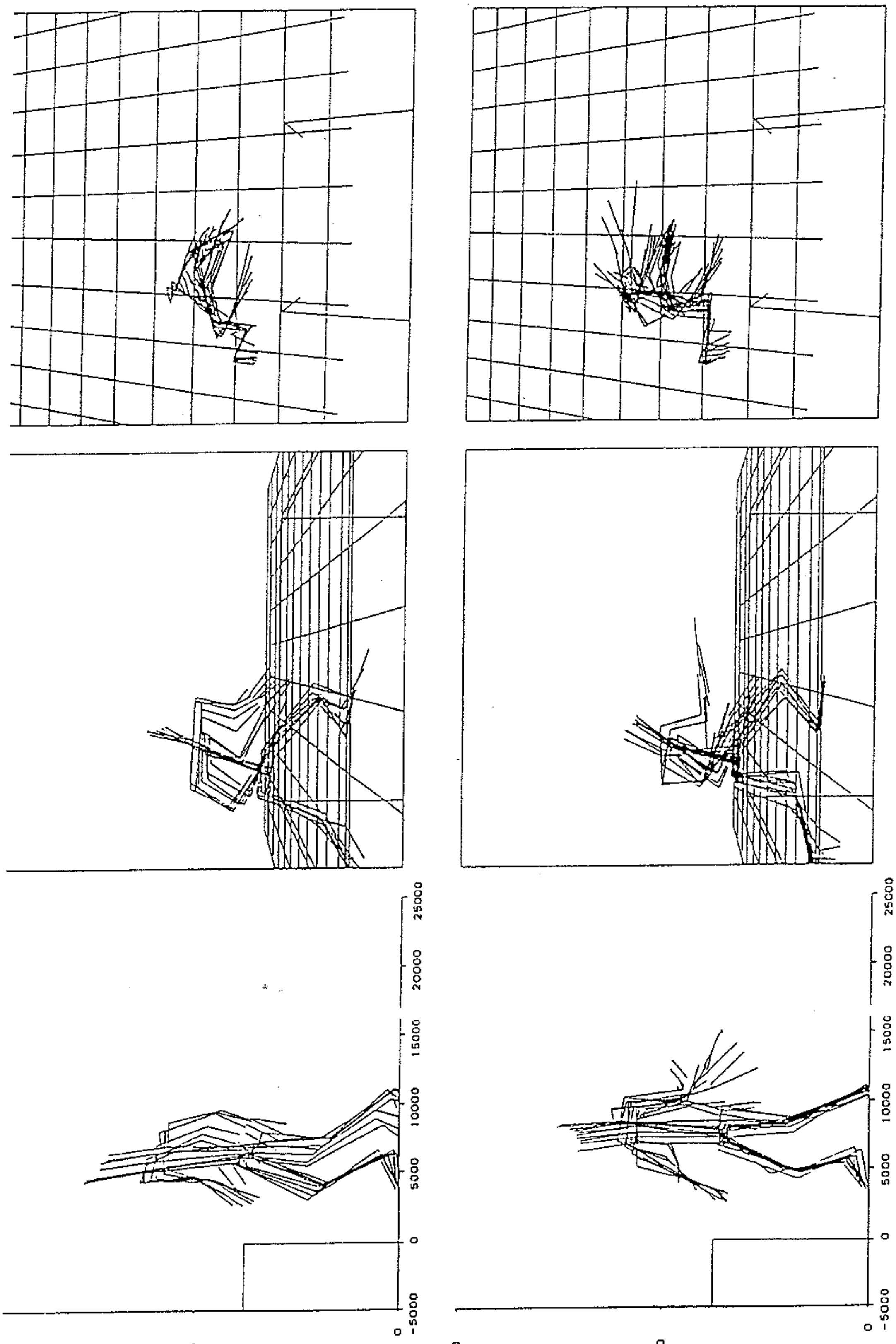


Figure 1 Kinetics of the player

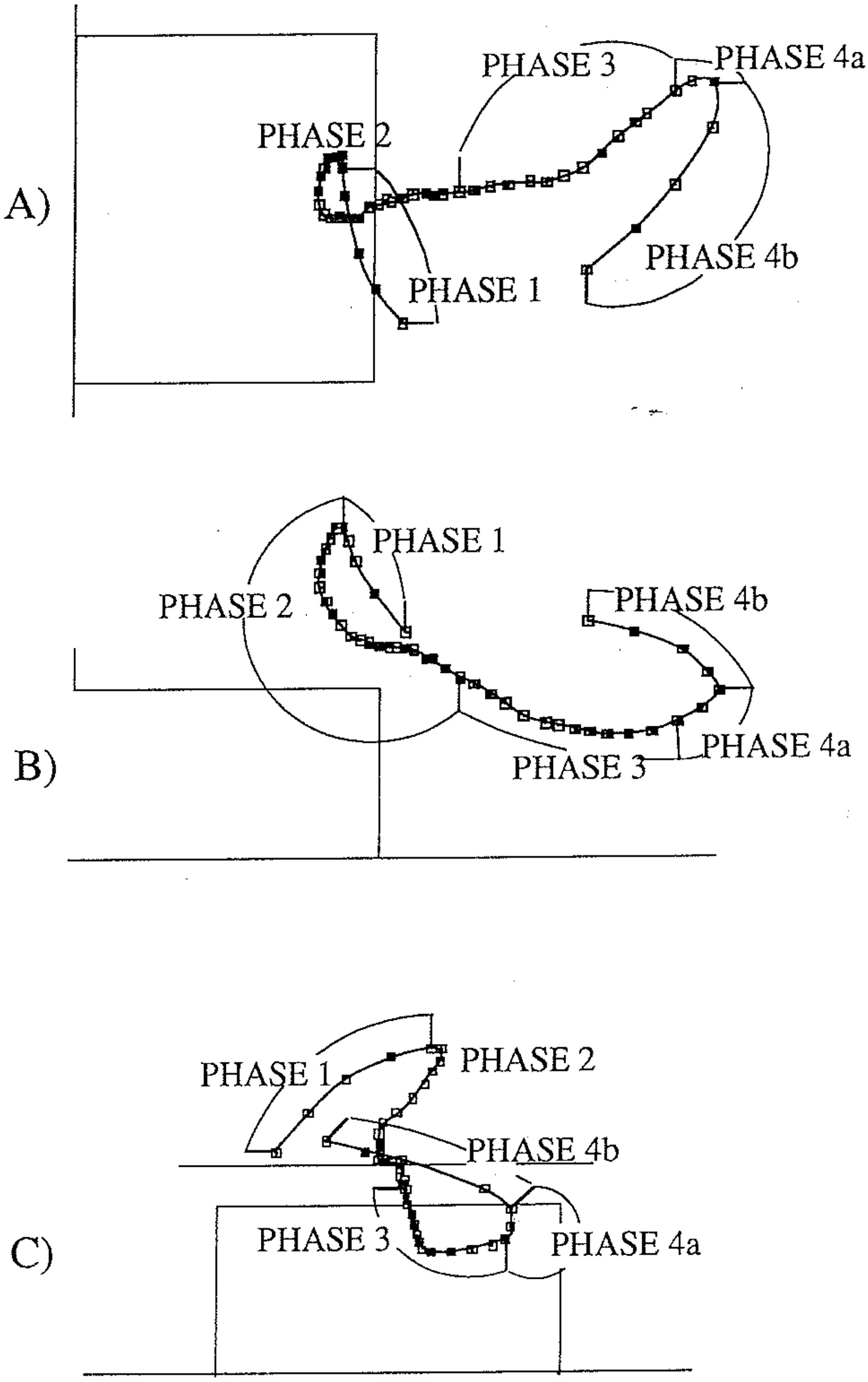


Figure 2 Racket head trajectory between two forehand strokes. a) - top view, b) prof view, c) front view.

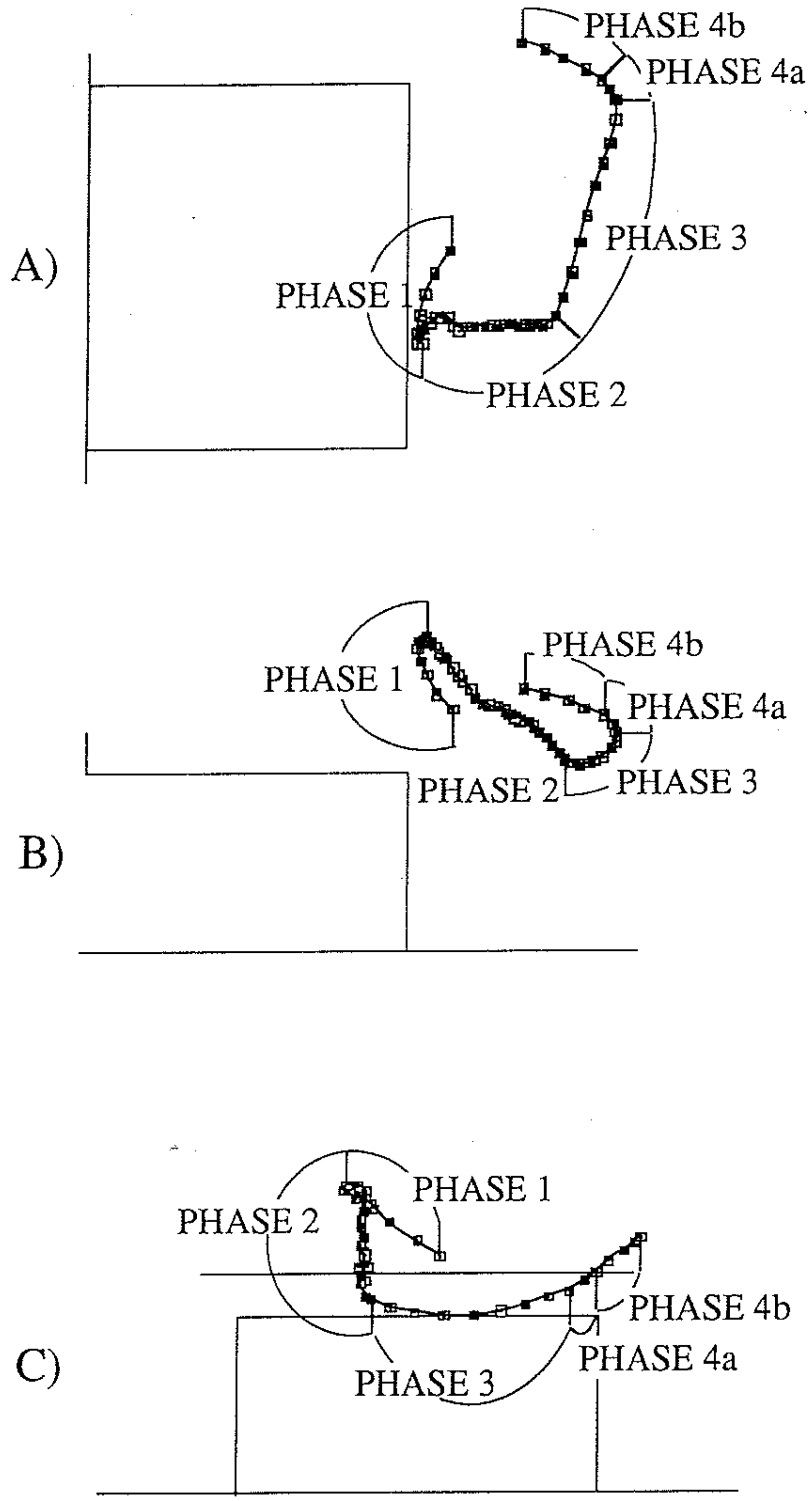


Figure 3 Racket head trajectory between a forehand stroke and a backhand stroke. a) - top view, b) profil view, c) front view.

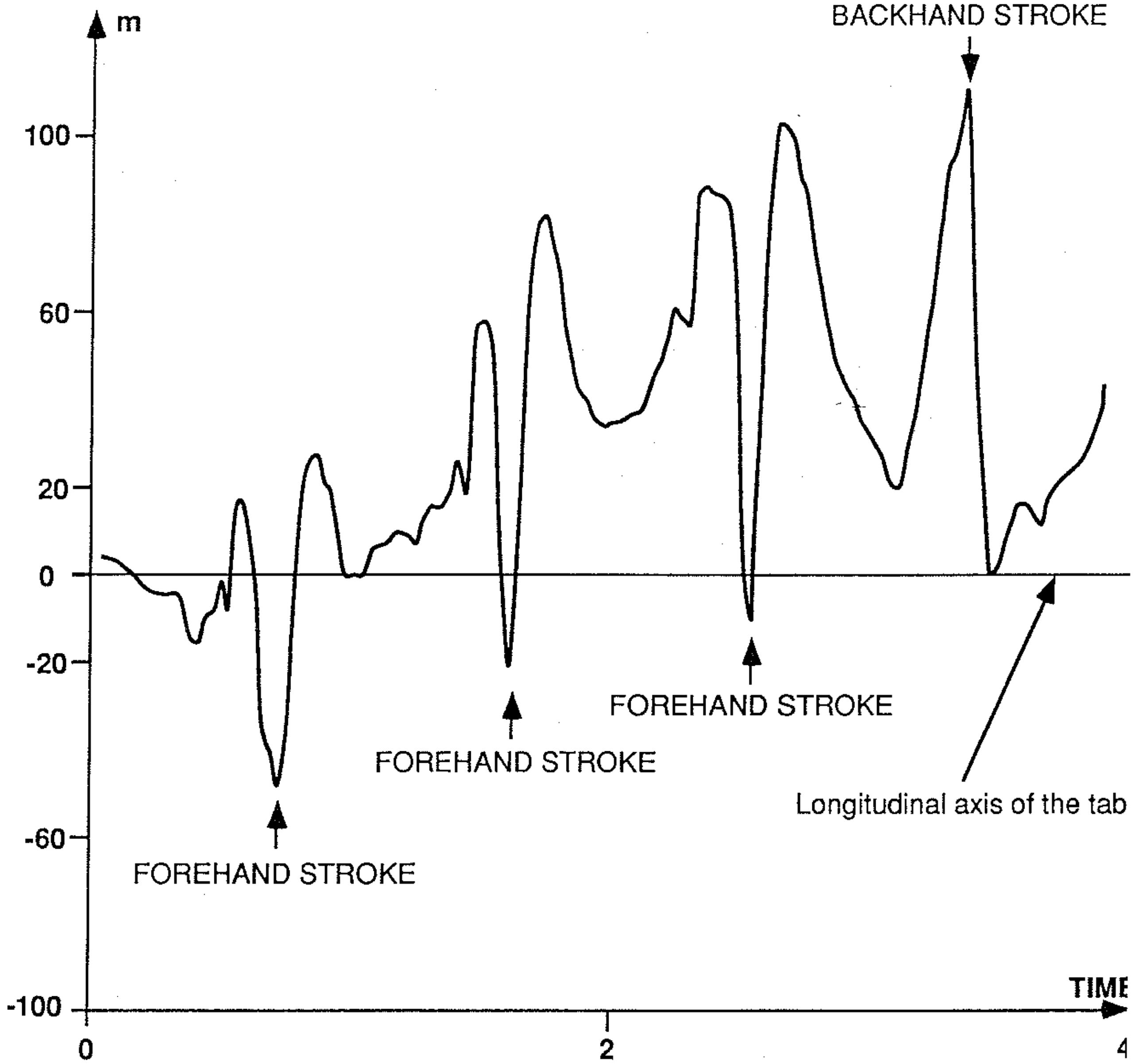
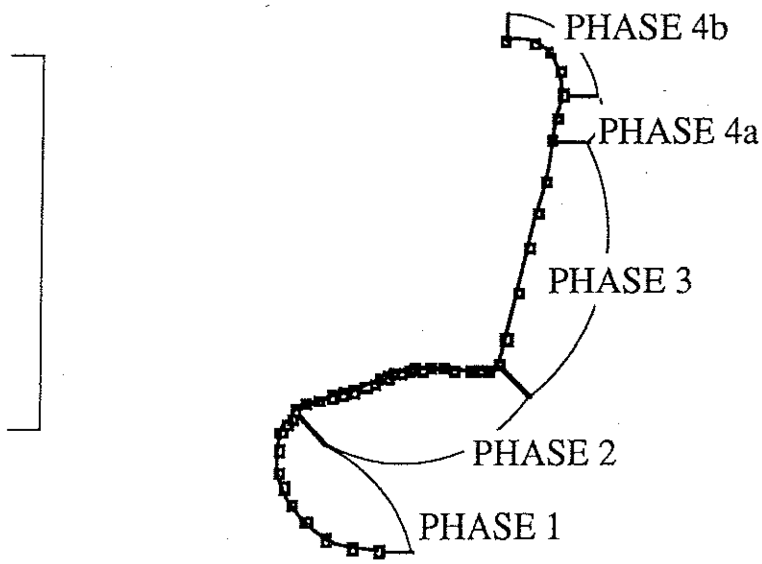


Figure 4 Lateral movement of the racket (y axis) as a function of time (x axis), with the reference to the game area.

A)



B)

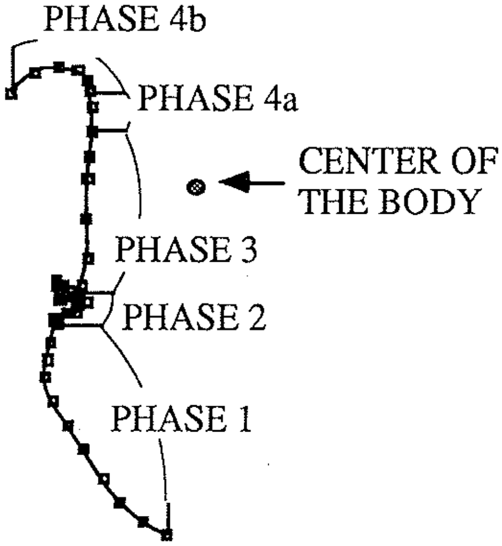


Figure 5 Comparison of general spatial pattern with reference to the game area (a) and body (b) (Top view)

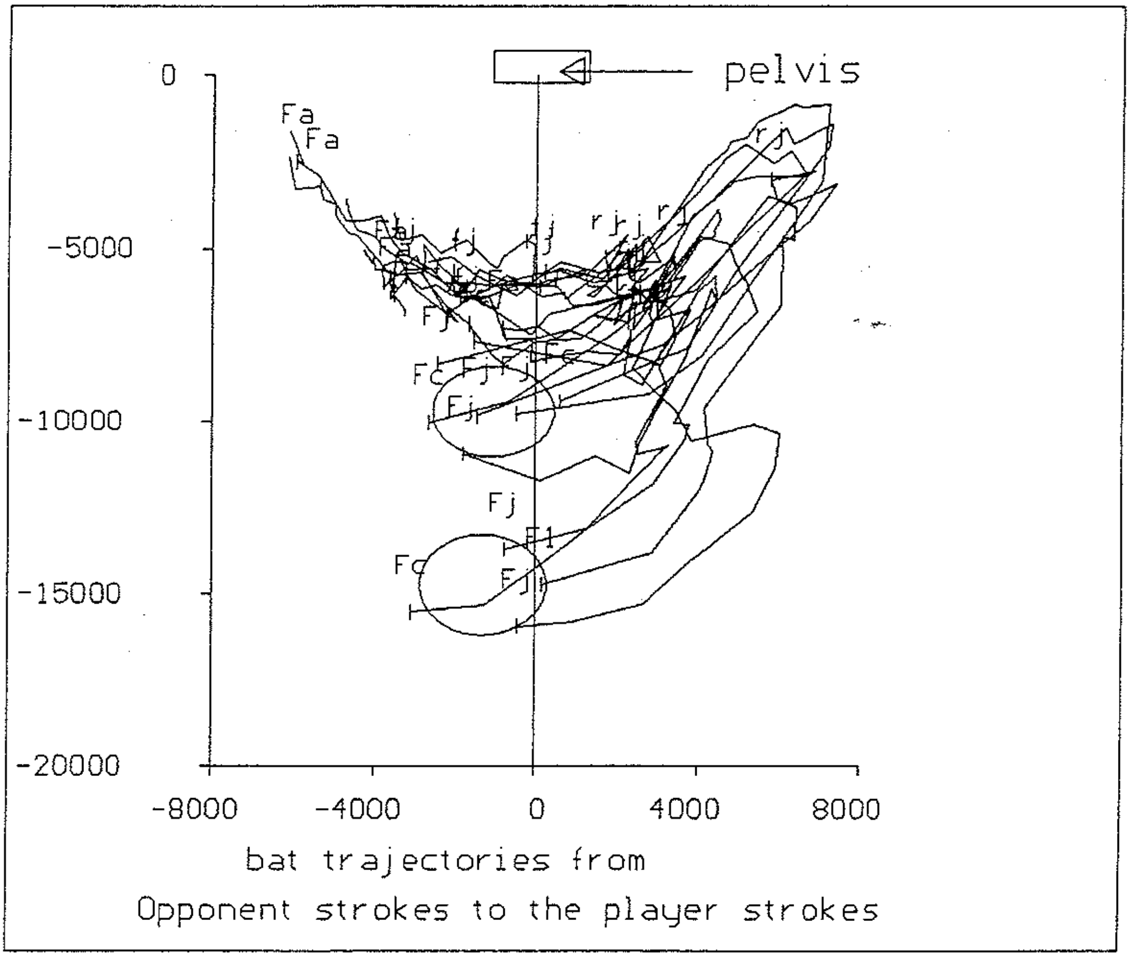


Figure 6 Set of bat developments around the pelvis (top view)

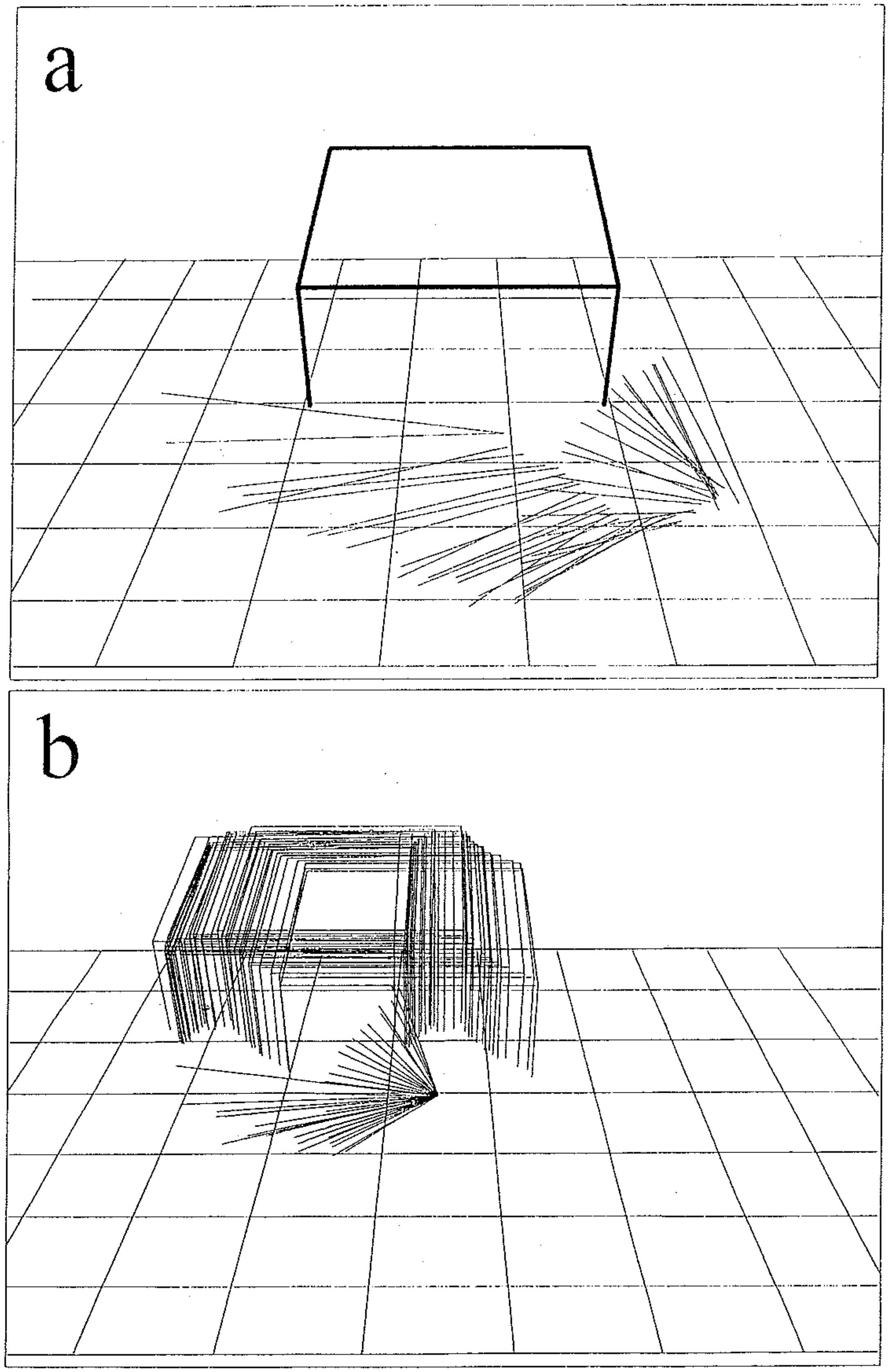


Figure 7 Evolution of the imaginary line between the racket head and the pelvis (back view)

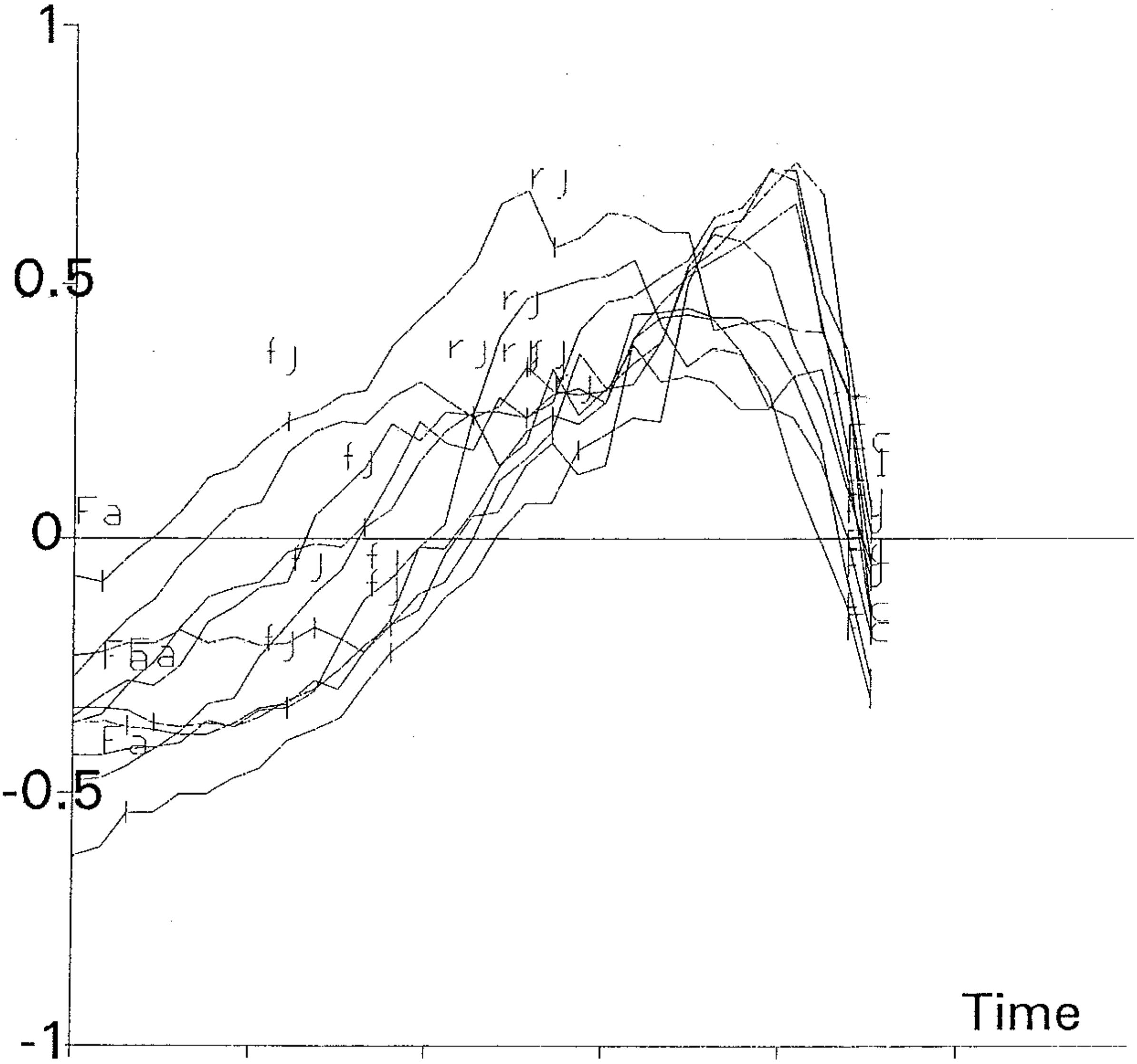


Figure 8 Foreward and backward swing of the racket (y axis) as a function of time (x axis), with reference to the body.