Simulator of table tennis play; Simulatory, diagnostic and training possibilities

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Abstract The construction and simulatory, diagnostic and training applications of the table tennis simulator is presented in the paper. The simulator consists of a simulator proper, controller and computer. The simulator proper allows table tennis play conditions to be simulated. It consists of a stimuli board, a set of sensors and a special table tennis bat. There are seven lamps on the stimuli board. These lamps (anticipatory stimuli) simulate the place where the ball is struck by one's opponent. The lamps in the seven sensors (target stimuli) indicate the spot where the simulated ball is to be struck by the subject. Programming enables the different directions and speed of the ball's flight to be simulated. The ball's direction of flight is simulated by constant pairs of lamps on the board and in the sensors, which are switched on sequentially. The break between the switching on of the lamp on the board and in the sensor determines the speed of the simulated ball's flight. The simulator enables seven ball-hitting movements to be simulated. The simulated forehand or backhand strokes require a flexible strap attached to the sensors to be hit with a special table tennis bat. The instant when the simulated ball is hit is identified photoelectrically, so the strokes can be executed at maximum speed. The simulator may simulate a single stroke or a series of strokes or play for points and can have diagnostic and training applications. The diagnostic and training possibilities of the simulator were verified on the basis of studies on children playing table tennis, highly skilled female players, as well as the junior and senior Polish male national table tennis team. In diagnostic applications the simulator can be used to examine psychomotor efficiency, degree of sporting aptitude, and readiness for competition. Psychomotor efficiency can be treated as the capability of rapid and effective motor behaviour in different situations. The table tennis simulator is able to measure the following general and detailed factors of psychomotor efficiency: speed of anticipatory (speed of 'brain' and 'body') and simple ball-hitting movements (speed of 'body') and the components of these movements speed (time of movement initiation and execution), level of behavioural fluctuations (capability of optimising attention concentration, motivation, arousal, resistance to disturbance), capability of anticipation, degree of benefit of anticipation of different ball flight directions, speed of movements in different directions. The research has shown up individual differences and differences between the

groups tested with respect to the measured factors. Most of the factors examined correlate strongly with sporting results in professional table tennis play. These factors can be treated as predispositions for table tennis play and can be used to estimate the degree of sporting aptitude, as well as the strong and weak aspects of the psychomotor efficiency of particular players. Cluster analysis can be used to undertake a comprehensive assessment of sporting aptitude. This analysis enables the groups tested to be divided according to aptitude level and is useful for selecting very talented players. The research based on cluster analysis enabled the two most talented players to be selected from the senior male Polish national team. One of them achieved world class results. Aptitude profiles can be used to indicate psychomotor deficiencies. This information may be very useful for coaches to individualise the training process. The table tennis simulator can also simulate play for points. This score can be treated as a complex factor of psychomotor efficiency and used to estimate the level of readiness for competitions. The simulated play scores of the junior male Polish national table tennis team showed that the best players in this play achieved very high rankings in real tournaments. The training applications of table tennis play make it possible to improve the speed of single, randomly-chosen strokes (for example, a return or an attacking stroke), special speed (repetition of a short series of different strokes), special speed endurance (repetition of a longer series of different strokes). The junior male Polish national tennis team was trained with the simulator just before the European Championships in 1999; they went on to win the championship. It was found for this group that there were improvements of 35 % in special speed and 33 % in special speed endurance after training with the simulator. The research demonstrated the very considerable diagnostic and training applications of the table tennis simulator.

1 Introduction

In table tennis play motor behaviour one can differentiate two kinds of movements: *regulation and ball-hitting movements*.

The regulation movements are executed before service, return and between particular ball-hitting movements already during play. The regulation movements before service and return are often called 'rituals'. These rituals enable optimisation of the psychomotor state (Łapszo, 1999), which is connected with the level of motivation, fear and attention concentration.

Except for the service, the ball-hitting movements are performed in response to the movements of the opponent and the ball, so these are the motor reacting movements. The single ball-hitting movement consists of four separate, sequentially performed movements: *preparatory movement, displacement to hit the ball, ball-hitting proper, displacement after ball-hitting.*

The task of the preparatory movements is preparing to move the body towards

the ball. The preparation for starting towards the ball often takes the form of single jump on both feet. This movement induces the initial tension in the leg muscles so that this start is faster.

The displacement to hit the ball is directed towards moving the body as fast as possible to the place, where the ball is flying.

Except for the service, the ball-hitting proper are performed with respect to the place, speed, spin and path of the ball's flight and the position of the opponent. The final purpose of the ball-hitting proper is to win a point or cause the opponent to mishit the return.

The purpose of displacement after the ball has been hit is to reach as quickly as possible the best position at the playing table for covering the possible lines of flight of the returning ball.

The structure of the single ball-hitting movement in table tennis is shown in Figure 1.

Contemporary table-tennis requires the ball-hitting movements to be performed in an economical way, at the right time (preparatory movements), very fast and with very high precision (displacing and ball-hitting proper movements).

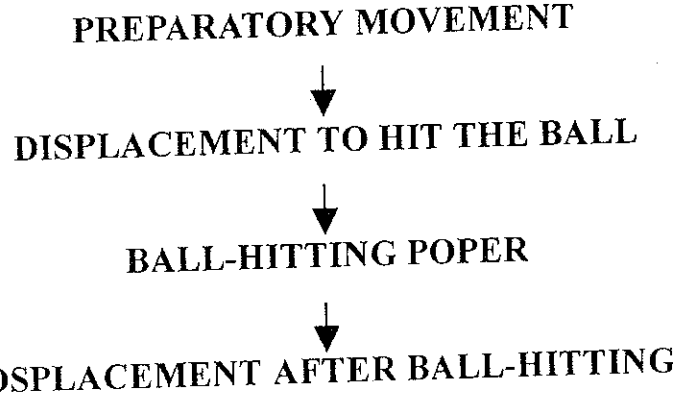

Figure 1. The structure of single ball-hitting movement in table tennis.

The speed and accuracy of ball-hitting movements are related to the anticipation of coincidence (Belisle, 1963), which consists of predicting the time or place (or both) where the opponent or ball will arrive and performing a movement coincident with the time and the place. This anticipation can be divided into place and movement coincidence anticipation (Łapszo, 1999a). In the first case, the anticipation consists in predicting the place towards which the ball is moving and executing a displacement movement in order to approach this place. In the second case, the anticipation is responsible for the spatial and temporal coincidence of the act of striking the ball or opponent with the path of the moving ball or opponent.

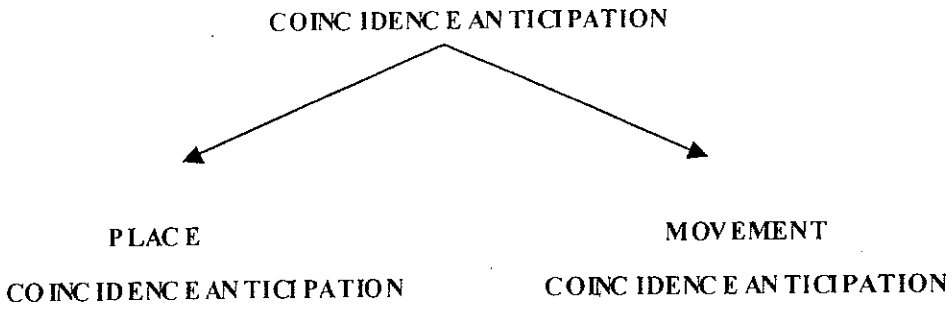

Figure 2. The division of coincidence anticipation.

Place coincidence anticipation is based on the perception of the opponent's movement or of the early phase of the ball's path. This information can be treated as an anticipatory stimulus, indirectly indicating the place towards which the subject's displacement movement should be carried out. The final phase of the ball's path or of the opponent's movement is the basis for the movement coincidence anticipation, and can be regarded as a target stimulus, directly indicating the exact spot and time of contact with the ball or opponent. The ball-hitting movements can be initiated by anticipatory or target stimuli. These movements initiated by anticipatory stimuli are called anticipatory ball-hitting movements. The initiation of these movements on the basis of target stimuli is characteristic of simple ball-hitting movements. The division of ball-hitting movements in table tennis is shown in Figure 2.

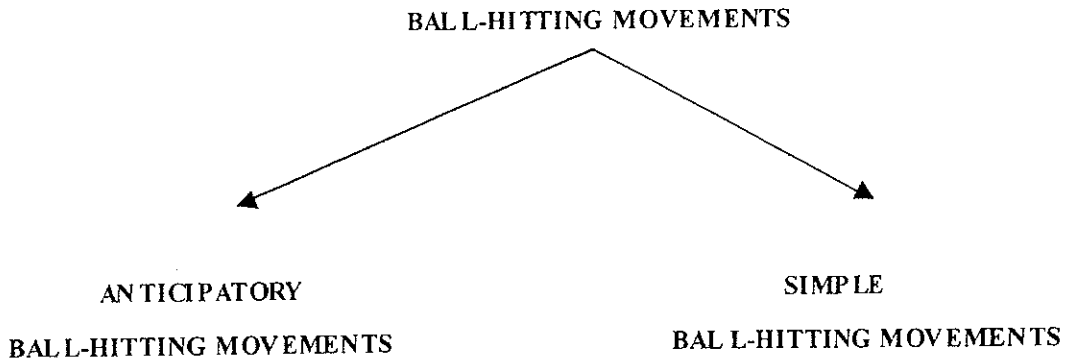

Figure 3. The division of ball-hitting movements in table tennis

Place coincidence anticipation is based on memorisation of the way in which the ball was struck and the place where the ball ended up. Memorised

experiences of this kind make up an anticipatory schema (Łapszo, 1999a,b, 2000a), the essence of which is similar to Schmidt's motor schema (Schmidt, 1975).

The concept of anticipatory and target stimuli, anticipatory and simple ball-hitting movements and anticipatory schemas was used to construct the table tennis simulator. The purpose of this paper is to present the construction, simulatory, diagnostic and training possibilities of this simulator. As this paper is a review, its structure is a little different from the structure of a standard paper. Each part describing the diagnostic or training applications of the simulator has the following form: subjects, method, results and discussion. The conclusions of the research are presented at the end of the paper.

The diagnostic application of the simulator is based on the concept of psychomotor efficiency (Łapszo, 1999b), sporting aptitude and talent, efficiency profiles, types of ball-hitting movements and anticipation. *Psychomotor efficiency can be treated as the capability of rapid and effective motor behaviour in different situations*, and can be investigated in both a general and a detailed way. In the application of the table-tennis play simulator to general measurements of psychomotor efficiency, the following factors can be measured (general factors of psychomotor efficiency): the speed of anticipatory ('brain' and 'body' speeds) and simple sequential ball-hitting movements ('body' speed), the level of behavioural fluctuations (the capability of optimising attention concentration, motivation, arousal, resistance to disturbance), and the capability of anticipation. In the more detailed approach the following detailed factors of psychomotor efficiency, among others, can be measured: the speeds of the components of anticipatory and simple ball-hitting movements, i.e. the times taken for these movements to be initiated and executed, the speed of movements in different directions, the degree of benefit of anticipation of different ball flight directions.

The psychomotor efficiency can be estimated on the basis of *psychomotor profiles*. By means of graphs and statistical parameters, these profiles constitute the indices of psychomotor efficiency distribution (general and detailed) expressed on a uniform scale (Skorny, 1974). These profiles can be divided into group or individual, general or detailed, single or multidimensional, left- or right-sided, or bilateral.

The profiles can be also created for test movements with respect to their speed, movement initiation and execution and anticipation. The psychomotor profiles describing the distribution of psychomotor predispositions enable the aptitude level for table tennis to be estimated. Sporting predispositions constitute such psychomotor factors which have a strong influence on sporting results. *A very talented player* is a person whose predispositions for table tennis are at a very high level though not necessarily at the top level. Cluster analysis can be used to classify players with respect to their level of aptitude for table tennis.

The training application of table tennis simulator is directed towards improving the 'brain speed' (mental processes such as the recognition of stimuli, decision making and movement programming) and the 'body speed'. The simulator enables the speed of single, freely-chosen strokes (for example, a return or an attacking stroke), the special speed (repetition of short series of different strokes), and the special speed endurance (repetition of longer series of different

strokes) to be improved. The application of a constant anticipatory schema (constant pairs of anticipatory and simple stimuli) allows the speed of information processing, which is the basis of the increase in 'mental speed', to be raised. The aim of applying the table tennis simulator to improve the 'body speed' is so that the simulated ball-hitting movements can be executed at top speed. Only in this way can the brain be forced to recruit a greater number of motor units. This process adapts the human organism to greater motor requirements (training loads). In the traditional method of practising special speed and endurance in table tennis, the players have to hit, very fast, balls which are serially served by a coach or a ball-throwing-machine, and the player's first priority is to locate the ball on the playing table. The way the ball is used in this method makes it impossible to perform movements at top speed, which means that the body speed will not rise.

2 Simulator of table tennis play – construction and simulatory possibilities

The simulator consists of a simulator proper, controller and computer. The simulator proper allows table tennis play conditions to be simulated. It consists of a stimuli board, a set of sensors and a special table tennis bat. There are seven lamps – stimuli - on the stimuli board. These lamps (anticipatory stimuli) simulate the place where the ball is struck by one's opponent. There are also two light signals: the one on the right (red) informs the subject that a test or simulated play is starting. The one on the left indicates the end of a test or a break between the series of simulated strokes (a particular way of striking the ball). The lamps in the seven sensors (target stimuli) indicate the spot where the simulated ball is to be struck by the subject. Programming enables the different directions and speed of the ball's flight to be simulated. The ball's line of flight is simulated in discrete way by the constant pairs of lamps on the board and in the sensors, which are switched on sequentially. The break between the switching on of the lamp on the board and in the sensor determines the speed of the simulated ball's flight. The simulator enables 42 different directions of the ball's flight and 7 ball-hitting movements specific to table tennis to be simulated. The simulated forehand or backhand strokes require a flexible strap attached to the sensors to be hit with a special table tennis bat. The instant when the simulated ball is hit is identified photoelectrically, so the strokes can be executed at maximum speed. The construction of the simulator enables seven different anticipatory and simple ball-hitting movements to be investigated.

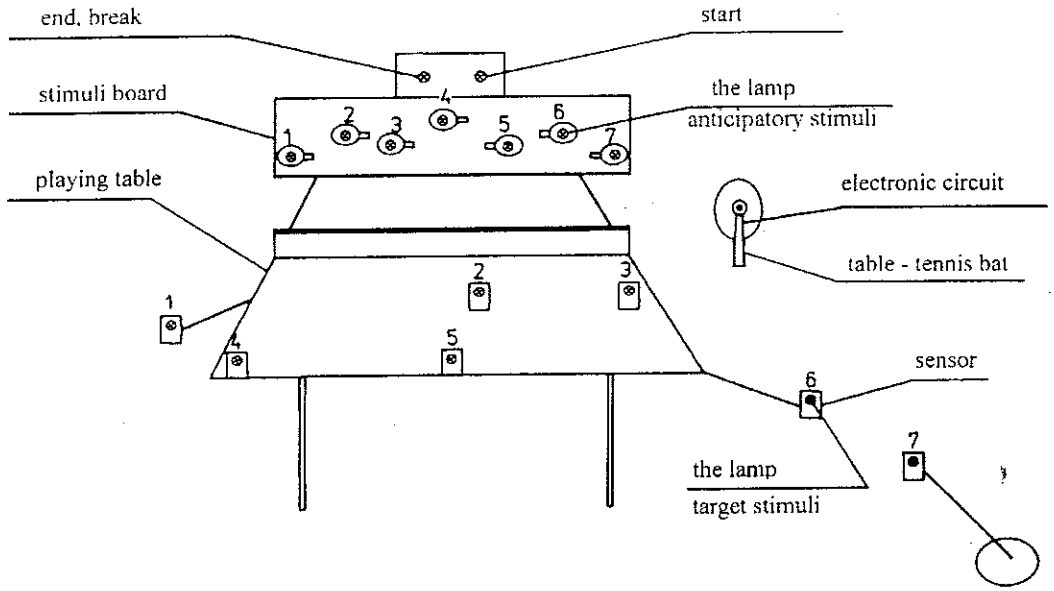

Figure 4. The simulator of table tennis play.

The anticipatory ball-hitting movements were stimulated by seven constant pairs of lamps (one on the board and another in the sensor), which constitute the anticipatory schema. In this research the following anticipatory schema was created (lamp on the board – lamp in the sensor): 1–7, 2–6, 3–2, 4–5, 5–3, 6–4, 7–1. Other anticipatory schemas can also be set up. It is also possible to locate the anticipatory stimuli (lamps on the board) in freely chosen places on the stimuli board. One can also alter the location of the sensors, and their height and inclination, which determines the type of spin (forwards and backwards). The break between switching on the lamps on the board and the lamps in the sensors (simulated speed of the ball's flight) is 0.5 seconds and can also be changed. The memorising of this schema allows the place of the required simulated ball-hitting movement to be predicted on the basis of the lamp on the stimuli board switching on.

The simple ball-hitting movements were stimulated only by the lamps in the sensors. The photoelectric sensors identified the instant of the simulated stroke.

The speed of both kinds of ball-hitting movements was timed in seconds from the instant the lamps in the sensors were switched on, so the shorter the time, the higher the speed. The simulator enables the following freely-chosen factors/parameters to be simulated: the spot where the opponent hits the ball, the ball's line/direction of flight and speed, the type of spin (forwards or backwards) and the number of simulated strokes in a rally.

The simulator also permits the simulation of play for points. The play can consist of any number of sets, and every set can be played to any number of points won. To win a point all the simulated strokes in a rally of limited time have to be performed. This time limit is realised by altering the break between the switching on of the lamps on the board and in the sensors (the speed of the simulated ball's flight) and by limiting the time the sensors have to wait for the

performance of the simulated strokes. The speed of the simulated ball's flight can be altered in the computer programme, so the subject can be made to play against a simulated opponent who plays faster or slower.

With the simulator one can use the lamps indicating the place and time of the ball's contact with the playing table on the subject's side. These lamps can be very useful in practising the right timing of strokes.

3 Diagnostic possibilities of table tennis simulator

3.1. General factors of psychomotor efficiency

3.1.1 Research into the behavioural fluctuations

Subjects

Ten adult male members of the Polish national table-tennis team, and 22 children with an average age of 13.15 years and an average of 4.34 years of special training participated in this research.

Measurements

The subject's task was to simulate the striking of the ball at the places indicated indirectly by the lamps on the board (anticipatory ball-hitting movements) or directly by the lamps in the sensors (simple ball-hitting movements). The time (in seconds) elapsing from switching on the lamp on the stimuli board (learning process) or in the sensor (speed of anticipatory and simple ball-hitting movements) to the instant of simulating the hitting of the ball was the measure of the speed of particular movements. Accordingly, the shorter the measured time, the higher the tested speed. The speed of 7 different anticipatory and simple sequential movements was investigated in two series (tests) of 17 different measurements (combination of 7 tested movements). The result of the whole test was the average speed of these 17 measurements.

The curve of anticipatory schema learning

Learning curves were used to investigate behavioural fluctuations (Łapszo, 1998a). These curves illustrate the process by which the anticipatory schema develops. A test of the speed of anticipatory ball-hitting movements was used to investigate the learning process. This test was repeated many times until the measurements stabilised. The results obtained were approximated by the exponential learning curve. An example of the learning curve is shown in Figure 5.

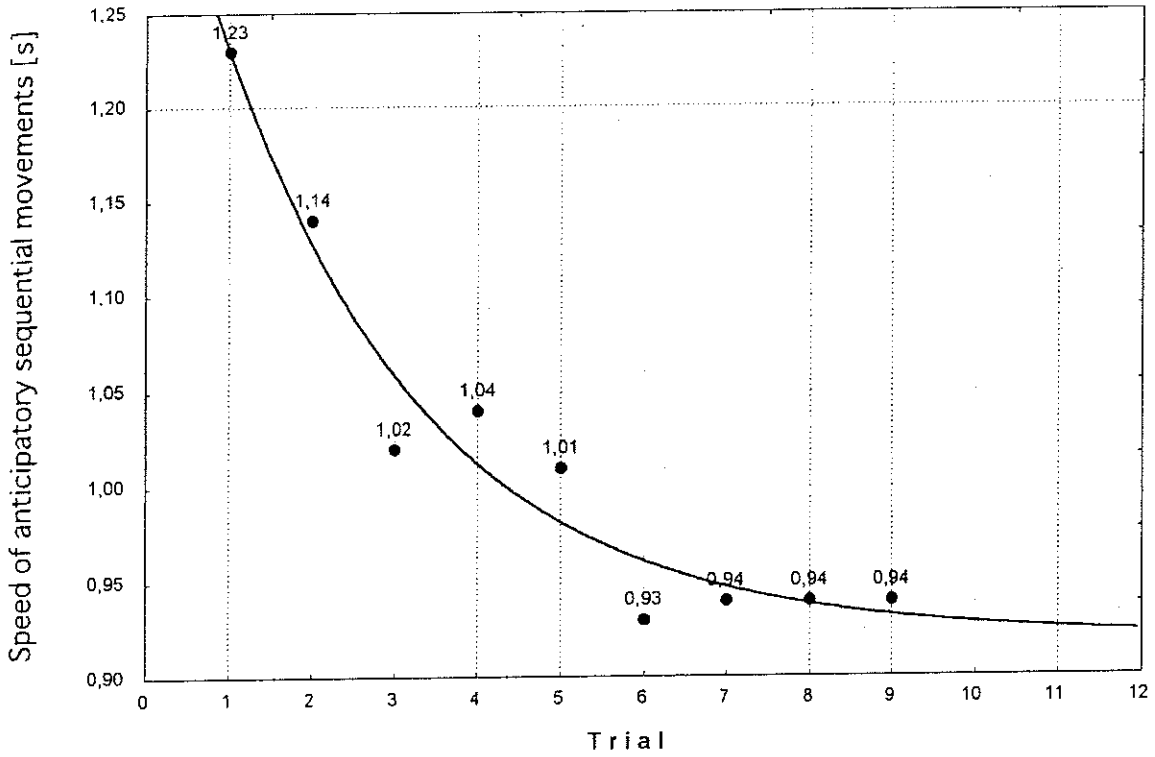

Figure 5. The learning curve for a Polish national senior male table tennis team player.

The following formula of this curve was used:

$$T(p) = (T_{max} - T_p) \times (1 - I_t)^{(P-1)} + T_p \qquad (1)$$

where p - serial number of the trial, T(p) - the result of the test as a function of the trial, T_{max} - the lowest speed of anticipatory ball-hitting movements, I_t -increase in learning (memory) in each trial (computed), T_p - potential speed (the asymptote of the learning curve, computed).

The index of behavioural fluctuations

The changes in attention concentration, motivation and arousal produced a scatter of test results around the learning curve. The statistical parameter R^2 showing the magnitude

of this scatter was used as the index of behavioural fluctuations I_f (Łapszo, 1997). If $R^2 = 1$, all the test results lie on the learning curve.

Table 1. The mean index of behavioural fluctuations (I_f) for men and children

Group tested	N	I_f	
		M	SD
Men	10	0.84	0.11
Children	22	0.78	0.12

SD: standard deviation

Results and discussion

The index I_f is greater than 0.75 (the lower limit of the occurrence of learning). This implies that both groups are able to learn anticipatory behaviour. The fluctuations in attention concentration, motivation and arousal are less in men (0.84>0.78, less dispersal). These results are in accordance with Nettleton's (1986) research, which indicated the differences in attention flexibility between elite and less skilled athletes in fast ball games. The high standard deviation also indicates high individual differences in behavioural fluctuations.

3.1.2 Research into the speed of anticipatory and simple ball-hitting movements and anticipation

Subjects

Ten male members of the Polish national table-tennis team and 22 children practising table tennis play for more than 4 years.

Method of measurement of anticipatory and simple ball-hitting movements

Two different tests were used to investigate the speed of anticipatory and simple ball-hitting movements. The research lasted 5 days and the tests were repeated twice a day. The 10 results obtained for each kind of movement were then averaged in order to obtain the final speed of anticipatory and simple ball-hitting movements.

The index of place coincidence anticipation

The increase (as a percentage) in the speed of sequential movements resulting from place coincidence anticipation was treated as an index of this anticipation (I_a). Place coincidence anticipation is based on the association of the position of the sensor with a particular lamp (anticipatory stimuli) on the stimuli board. The speeds of the anticipatory (T_a) and simple (T_s) ball-hitting movements described above were used to calculate the index I_a according to the following formula (Łapszo and Morawski, 1994):

$$I_a = T_s - T_a / T_s \times 100\ \% \qquad (2)$$

This shows the extent to which the speed of displacement to the place towards which the ball is moving increases as a result of place coincidence anticipation.

Table 2. The mean speeds of anticipatory (T_a) and simple ball-hitting (T_s) movements, and the index of anticipation (I_a) for men and children

Group tested	N	T_a (s)		T_s (s)		I_a (%)	
		M	SD	M	SD	M	SD
men	10	0.4	0.07	0.55	0.05	27.5	7.5
children	22	0.63	0.09	0.71	0.07	11.1	8.5

SD - standard deviation

Results and Discussion

Men displayed a much higher speed in both ball-hitting movements and a greater capacity for anticipation. Their speeds of anticipatory and simple ball-hitting movements were higher by 37% and 23% respectively, and their anticipation was two and a half times as good as that of children. The average range of table-tennis bat movement from starting position to the sensors was 0.93 m. This means that in each movement the men outstripped the children by an average of 0.34 m in anticipatory and 0.21 m in simple ball-hitting movements. The place coincidence anticipation enabled the men to move 0.26 m towards the flight path of the ball, the children only 0.10 m. The differences in ball-hitting movement speed and anticipation are statistically significant (Student's test, $p < 0.05$), and are probably due to age, period of special training, and level of skills (sporting experience). These findings are in disagreement with those in published investigations, in which the reaction and movement time (Keele, 1982) and anticipation (Meeusen, 1991) were found not to differentiate between highly proficient and less skilled players. The standard deviations indicate high individual differences in the level of development of the factors investigated in the two groups.

3.2. Detailed factors of psychomotor efficiency

3.2.1. The movement initiation and execution times as components of the speed of anticipatory and simple ball-hitting movements

Subjects

Five male members of the Polish national senior male table-tennis team, with an average age of 19.15 years and an average of 8.34 years of special training.

Methods

Testing the speed of simple and anticipatory ball-hitting movements with the table tennis simulator described in earlier research was recorded on a video cassette, which was used to measure the movement initiation time (Łapszo, 2000b). The time (in seconds) elapsing from switching on the lamp on the stimuli board (anticipatory ball-hitting movements) or in the sensor (simple ball-hitting movements) to the instant of simulating the hitting of the ball was the measure of

the speed of particular movements. This speed can be treated as the 'response times' of anticipatory and simple ball-hitting movements (RsT), because these movements are performed as a response to anticipatory and target stimuli. Accordingly, the anticipatory and simple ball-hitting movements in this research will be named 'anticipatory and simple responses'.

A frame change code was recorded on the tape to measure movement initiation time (MIT) with an accuracy to 0.04 s (25 exposures per sec.). The initiation time of anticipatory ball-hitting movements was measured from the number of frames counted from the moment the lamps on the board lit up to the initial movement of the table tennis bat. The initiation time was measured in relation to the simple ball-hitting movements in the same way as before, but from the moment the lamps in the sensors lit up. A standard TV set-up consisting of TV camera, TV and VCR were used in the measurements. The movement execution time of simple and anticipatory ball-hitting movements (MET) was calculated as the difference between the response time (RsT) and the movement initiation time (MIT) for these movements.

Results

The average movement initiation MIT, execution MET and motor response RsT times for simple and anticipatory ball-hitting movements (motor responses) were obtained. The results are shown in Table 3.

Table 3. Movement initiation (MIT), execution (MET) and motor response RsT times for simple and anticipatory ball-hitting movements (average values M ± SD)

Type of ball-hitting movements	N	MIT		MET		RsT	
		M	SD	M	SD	M	SD
Simple	5	0.16	0.02	0.4	0.05	0.56	0.06
Anticipatory	5	0.36	0.04	0.57	0.05	0.93	0.09

SD: standard deviation

The initiation time of simple ball-hitting movements appeared to be twice as short as the anticipatory responses initiation time. This finding corroborates the results of earlier research (Woodworth and Schlosberg, 1966). The simple response initiation time breaks down into 28.6 % response time and 71.4 % time of movement execution.

Table 4. The ratio of correlation Cc between movement initiation MIT, execution time MET, motor response RsT, sporting results SR for simple and anticipatory motor responses.

Correlated Factors	Type of ball-hitting movements			
	Simple		Anticipatory	
	Cc	p	Cc	p
MIT – MET	X		X	
MIT – RsT	0.8	0.09	0.94	0.02
MET – RsT	0.97	0.01	0.95	0.01
MIT – SR	0.86	0.06	0.95	0.01
MET – SR	0.84	0.07	0.87	0.05
RsT – SR	0.91	0.02	0.96	0.01

x: statistically insignificant correlation. p: level of significance.

In the anticipatory responses, the respective figures are 38.4% and 61.6%. The research shows that the time of movement execution makes up a larger proportion of the simple response time (71.4 %) than in the anticipatory responses (61.6 %). On this basis, presumably, the simple motor response time depends more on the speed capabilities of the human body than of the speed of the neuro-motor system. In the case of anticipatory responses, the influence of movement execution time on motor response appears to be much less.

The results have shown that highly skilled players have a shorter movement initiation and execution time of anticipatory ball-hitting movements than less skilled players. These findings are in disagreement with Keele's (1982) investigations, in which the movement initiation and execution time were found not to differentiate between highly proficient and less skilled players.

3.2.2. The research into the capacity for anticipation of different places and direction of ball-hitting

Subjects

11 members of the senior male Polish national team participated in the research.

Methods

The index of place coincidence anticipation (section 3.1.2) described earlier was calculated on the basis of previous research into the anticipatory and simple ball-hitting movements separately for each of 7 different places and directions of ball-hitting by an opponent (Łapszo and Wrońska, 1998c). These directions are determined by the 7 following pairs of lamps on the board and in the sensors (Figure 1): 1–7, 2–6, 3–2, 4–5, 5–3, 6–2, 7–1.

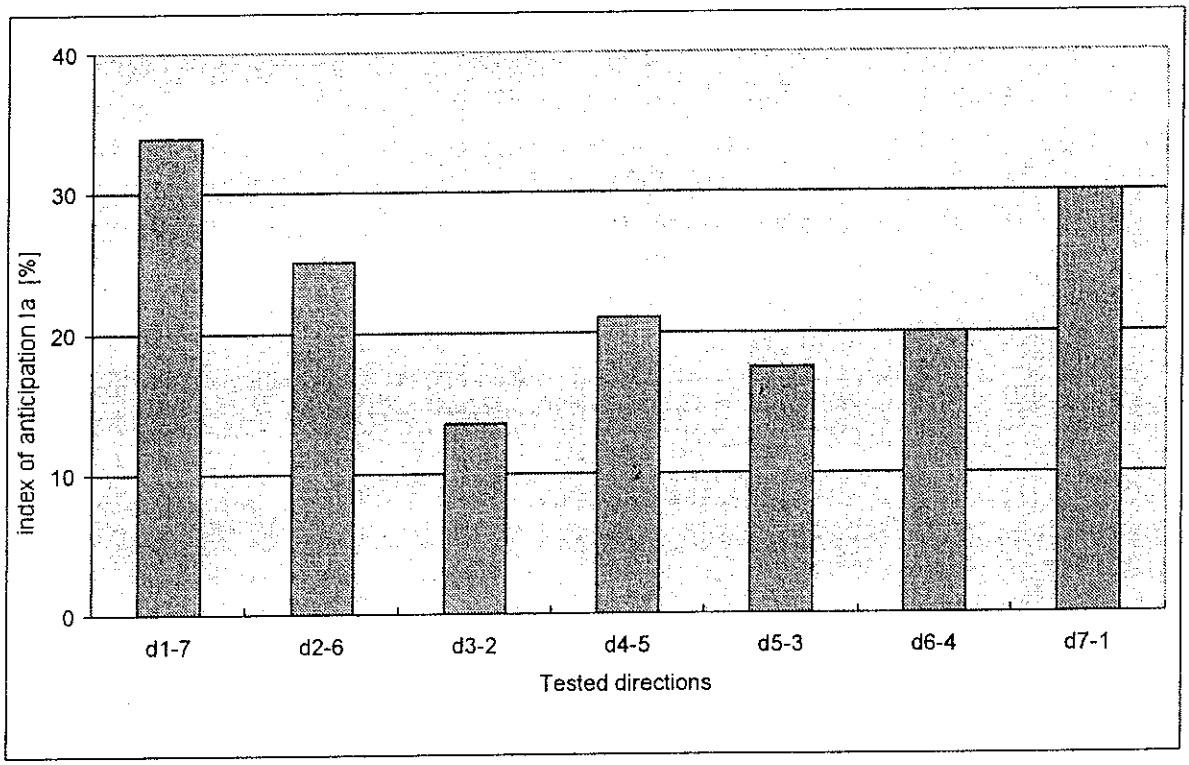

Figure 6. The anticipation capability profile for different directions of ball-hitting movements.

The results and discussion

The results are presented in Figure 6. It was found that balls struck diagonally across the table from both right and left are anticipated the fastest (Figure 6, directions 1-7, 7-1, 6-4). Anticipation of balls moving centrally down the playing table (4-5) and from the opponent's left corner to the subject's right corner of the playing table (6-4) is also troublesome. The most problems are caused by anticipation of service balls (3-2) and backhand strokes along the edge of the playing table (5-3).

3.3. Research into the aptitude for table tennis, the degree of aptitude for table tennis and psychomotor profiles

Subjects

This research is illustrated on the basis of results of measurements of general psychomotor efficiency factors of 10 senior and 10 junior members of the Polish male national team and 22 children with an average age of 13.15 years and an average of 4.34 years of special table tennis training.

Methods

The general factors of psychomotor efficiency, that mean index of behavioural fluctuations (I_f), speed of anticipatory (T_a) and simple (T_s) ball-hitting movements and index of place coincidence anticipation (I_a), obtained in previous measurements, were used in the research into the predispositions for table tennis, degree of aptitudes for table tennis (Łapszo, 1995, 1997) and profiles of

psychomotor efficiency. These generals factors were correlated with the sporting ranking of the senior male Polish national team. In order to examine the degree of aptitude for table tennis the group of seniors and children were divided into 6 subgroups (A, B, C, D, E, F) using cluster analysis (multidimensional graduation). The dimensions of this analysis were also the general factors of psychomotor efficiency (speeds of anticipatory and simple ball-hitting movements, and the indices of behavioural fluctuations and anticipation). Cluster analysis was used to select very talented seniors and children and to discover the psychomotor weaknesses of less talented players. In order to investigate the strong sides and the type and level of psychomotor weaknesses of particular groups or players, the profiles of general factors (general profiles) of psychomotor efficiency were analysed. In this research, the profiles of the senior and junior national team were taken into consideration. These profiles make up a graphic presentation of general psychomotor efficiency factors for the tested groups and players on the same scale.

Results and Discussion

The computed coefficient of correlation between general factors of psychomotor efficiency and sporting ranking for the Polish senior male national team are presented in Table 5.

Table 5. The correlation coefficients (Cc) between sporting ranking and the speed of anticipatory and simple ball-hitting movements (T_a, T_s), the indices I_f and I_a in the senior male Polish national team.

	T_a		T_s		I_f		I_a	
men	Cc	p	Cc	p	Cc	p	Cc	p
sporting ranking	0.89	0.001	0.84	0.002	–0.81	0.002	–0.80	0.006

T_{asm}, T_{ssm}: speed of anticipatory and simple ball-hitting movements
p: level of significance

A very strong correlation was found between all the general factors of psychomotor efficiency and sporting ranking for senior Polish national team. These general factors are probably strongly genetically conditioned. Accordingly, these factors can be treated as predispositions for table tennis and can be used to investigate the degree of aptitude for table tennis on the basis of cluster analysis. The results of this analysis in group of seniors and children is shown in Figure 7. Cluster analysis divided both groups tested into very talented players (A), talented (B) and those who have psychomotor deficiencies (C,D,E,F). The group A of seniors included a player who, three years after this research, achieved world class results. In this player all the tested factors are at a very high level, but not all are at the highest level. This is evidence that the predispositions of a highly talented player do not all need to be at the highest level, though they must

all be at a very high level. The highly talented person must be complete. In groups B and C there were also players who later several times won medals at the Polish Table Tennis Championships. Cluster analysis was also used to define the degree of aptitudes for table tennis in children. Unfortunately, the author does not know how the sporting career of the most talented children developed.

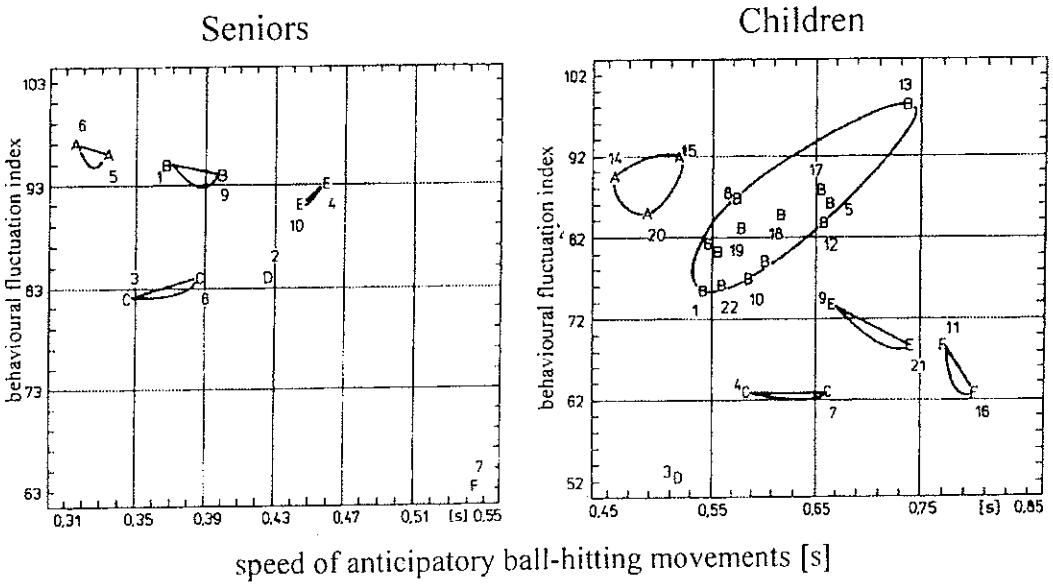

Figure 7. Cluster analysis of seniors and children.

The results of measurements of general psychomotor efficiency for seniors and juniors were used to draw up the profiles of this efficiency (Figure 8; Łapszo, 1999b). The figure shows the profiles of both groups tested and of two members of the senior national Polish table tennis team. One of these players is a champion, as his results are world-class. The other player was chosen at random from the senior group.

The champion was shown to possess the highest psychomotor efficiency. Three of the four general psychomotor efficiency factors are higher for seniors and juniors. However, statistically significant differences were found only in the speed of the simple ball-hitting movement (T_s).

The differences in psychomotor efficiency profiles are given as percentages. It was found that the speed of anticipatory ball-hitting movements (T_a) of the juniors was lower than that of the seniors by 14.4 % and that of the champion by 32.5 %. In this case, this speed was measured from the moment of switching on the lamp in the sensors. The speed T_a of the seniors is 21.2 % poorer than that of the champion. The speed capability of the body, represented by the speed of simple ball-hitting movements (T_s), of the seniors is 8.9 % higher than that of the juniors but 13.9 % lower than that of the champion. The respective indices of anticipation (I_a) and behavioural fluctuation (I_{bf}) of the juniors are lower than the corresponding figures of the champion by 33.8 % and 20.3 %; the indices relevant to the seniors are lower by 4.1 % and 8.2 %.

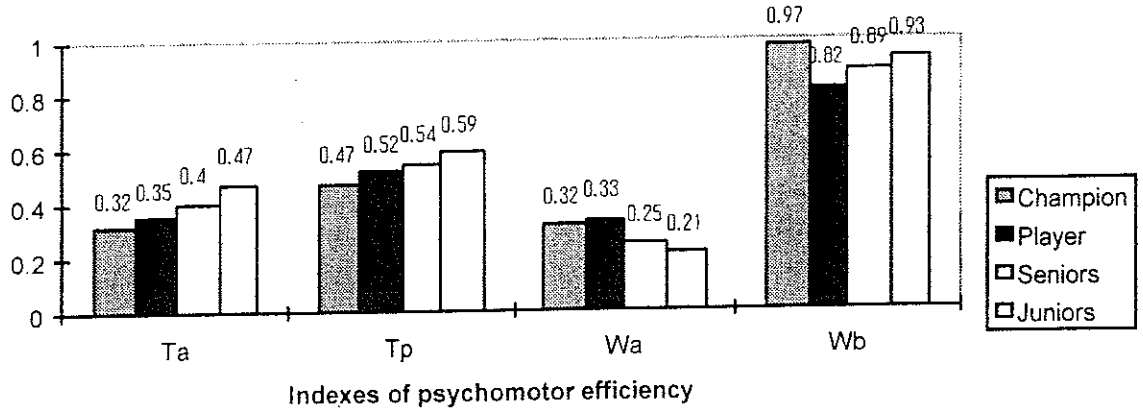

Figure 8. The psychomotor efficiency profiles of the senior and junior Polish national table tennis team, the champion and a player chosen at random (Łapszo, 1999b).

The respective speed of anticipatory and simple ball-hitting movements and behavioural fluctuation indexes in the randomly selected player are lower than those of the champion by 9.2 %, 11.1% and 15.5 %, but the anticipation index of this player is 3.1 % higher than the champion's.

This method of analysing psychomotor efficiency profiles enables the type and magnitude of differences in psychomotor efficiency structure between different groups and particular players to be elucidated. The results of such research can be implemented to guide and individualise the learning and training process.

4 The training applications of table tennis play simulator

4.1 The improvement of special speed and endurance

Subjects

Ten members of the junior male Polish table tennis team participated in the practising of special speed endurance with the use of table tennis simulator.

Methods

Two methods of practising special speed and endurance were applied: the repeating and starting methods (play for points). In the repeating method the series of 7 different simulated anticipatory ball-hitting movements was repeated 6 times in every session (training) for 4 days. The session with the simulator took place in the morning before the normal training session (all players were rested). The initial and final level of special speed and endurance was measured as the average speed of 6 (T_{ss} – special speed) and 10 (T_{se} – special endurance) series of 7 different simulated strokes. The speed of the tested movements was measured as the time elapsing from the moment of switching on the lamps in the sensors to the performance of simulated ball-hitting.

After a week's break the starting method was used to practise special speed

and endurance. In the starting method every player played one set (11 points to win) every day for 5 days. On each consecutive day the speed of the simulated ball's flight was increased by 10 %. In simulated play for points a player had to perform simulated ball-hitting movements in series from 3 to 7 movements. The time required to execute every movement was limited and depended on the speed of the simulated ball's flight, which could be altered in the simulator's computer programme. The delayed execution of any movement in a series caused the loss of a point. The score in the last set was treated as the index of readiness for competitions. This last session of simulated play took place just before the European Championships in Frydek-Mistek in the Czech Republic in 1999. Immediately after the simulated play the results of this training were measured by using the same test as after the repeating method of training.

Results and discussion

The measured special speed and endurance for the repeating and starting methods before and after the training session of the Polish male junior table tennis team are shown in Table 6.

It was found for this group for the repeating and starting method respectively that there were improvements of 35 % and 34 % in special speed and 33 % and 32 % in special speed endurance following a training session with the simulator. This method of practise improves the speed of mental processes (stimuli recognition, decision making and movement programming) and the 'body speed'. The main advantage of using the table tennis simulator to practise the speed and endurance specific to table tennis is that the simulated ball-hitting movements can be executed at top speed. Only in this way one can make the brain recruit a larger number of motor units. This process adapts the body to greater motor requirements (training loads). In the traditional method of practising special speed and endurance in table tennis, the players have to hit, at very high speed, a series of balls served by a coach or a ball-throwing-machine. The principal object of this method is for the player to locate the ball on the playing table. The way the ball is used in this method makes it impossible to practise these movements at top speed, which means that the body speed will not rise. The repeating and starting method were used as the training method of special speed and endurance just before the European Championships in Frydek-Mistek in the Czech Republic in 1999, where the junior male Polish table tennis team went on to win the championship and the best player in the simulated play took the silver medal. This can be treated as evidence that simulated play for points is also quite a good reflection of the level of readiness for competitions.

Table 6. The level of special speed (T_{ss}) and endurance (T_{se}) at the beginning and end of the repeating and starting training session of the junior Polish national team.

Practised factors	Method of practise						
	N	repeating			starting		
		T_i	T_f	I	T_i	T_f	I
Special speed	11	0.462	0.30	35	0.462	0.307	34
Special speed endurance		0.479	0.323	33	0.479	0.327	32

T_i, T_f - initial and final special speed T_{ss} and endurance T_{se} in seconds,

I – increase in percentage

5 Conclusions

The considerations and research presented in this paper certainly do not exhaust the problem of the theoretical basis of motor behaviour in table tennis and the possible diagnostic and training applications of the table tennis simulator presented in this paper. Nevertheless, the following general conclusions can be drawn:

- The ball-hitting movements in table tennis are sequential motor reacting to the movements of one's opponent and the ball, in which the preparatory movements, displacements to hit the ball, ball-hitting proper and displacements after ball-hitting can be differentiated.
- Fast and accurate table tennis play is founded on coincidence anticipation, which can be divided into place and movement coincidence anticipation.
- Ball-hitting movements in table tennis can be divided into simple and anticipatory movements.
- Effective play in table tennis is based on psychomotor efficiency defined as the capability of rapid and effective motor behaviour in different situations.
- Psychomotor efficiency can be diagnosed in general and in detail.
- Psychomotor efficiency profiles can be used to estimate the differences in this efficiency between groups and subjects.
- The table tennis simulator enables:
  a) the simulation of:
     - 7 different places, where the ball is struck by one's opponent,
     - 7 different spots to which an opponent hits the ball,
     - 42 ball flight directions,
     - 7 different styles of ball-hitting by the subject,

- series of simulated strokes of any duration,
- different ball flight speeds,
- different anticipatory schemas,
- play with scoring to any number of sets and points won and with different speeds of play.

b) measurement of:

- the speeds of simple (without anticipation) and anticipatory ball-hitting movements and the components of these speeds (time of movement initiation and execution),
- the level of behavioural fluctuations (reflecting the capability of optimising attention concentration, motivation, arousal, resistance to disturbance),
- the ability to anticipate the ball's line/direction of flight,
- the degree of benefit conferred by the ability to anticipate different lines/directions of the ball's flight,
- speed of movements in different directions,
- aptitude for table tennis ,
- readiness for competitions,
- type and magnitude of psychomotor deficiencies.

c) practice of;

- the speed and means of executing freely chosen strokes,
- the speed of mental processes (anticipation; stimuli recognition, decision making, programming of movements),
- body speed (clearance of neuronal pathways and increase in the number of recruited motor units),
- special motor and mental endurance (ability to maintain a high level of concentration for a long time),
- the ability to optimise the psychomotor state (arousal, motivation and attention concentration).

♦ The research presented in this paper using the table tennis simulator has demonstrated:

- the differences in general psychomotor efficiency factors (speed of simple and anticipatory ball-hitting movements, indices of behavioural fluctuations and anticipation) and detailed psychomotor efficiency factors (movement initiation and execution times, speed of movements in different directions, ability to anticipate different lines/directions of the ball's flight),
- the highest level of psychomotor efficiency in a group of very highly skilled players (Polish senior national team),
- that in simple response situations a 'quick body' (movement execution time) has a greater influence on the overall speed of reacting than the speed of the neuro-motor system (movement initiation time); in anticipatory responses, the movement initiation ('quick brain') and execution times ('quick body') play an equally important role,
- that the general psychomotor efficiency factors can be treated as predispositions for table tennis,
- that cluster analysis is a very useful method for assessing aptitude for

table tennis in players with varying degrees of skill,
- that the type and magnitude of psychomotor deficiency can be recognised on the basis of psychomotor profiles,
- that special speed and endurance can be successfully practised with use of the repeating and starting methods,
- that special speed and endurance can be improved by more than 30 % (increase in the speed of mental processes and the body),
- that play with scoring yields quite a good picture of the current level of readiness for competitions.

On the basis of diagnostic and training possibilities of table tennis simulator presented in this paper, one can say that this simulator is very useful for both researchers and coaches.

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