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Analysis of the influence of special equipment materials on decisive strokes

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Abstract

This analysis aims at predicting how equipment related changes in the Rules of Table Tennis could possibly affect decisive strokes. A setup of computer programs was used to simulate the effect of different equipment - nominally sponge thickness, speed glue, net height and ball's size and weight. The programs are based upon the mechanical laws of the ball's movement and the corresponding parameters that were extracted in previous researches. At first the general reaction of the mechanical system to a change at the input was studied. Then indicators were defined that are able to express numerically game aspects such as danger for the opponent and risk for the player himself. Different decisive strokes, such as topspin against an arriving topspin, were studied. The two indicators (TimeX and ΔAngle) are used to express the results for different equipment in graphs where the first indicator is the ordinate and the abscissa is the second. The graphs might serve as a base to find the most suitable equipment change.

Introduction and Definition

This study aims to show the influence of different aspects of equipment. It should help to find a way for our sport out of its gradual decrease of interest for both the players and spectators. As reported by George Segun, Exec. VP, ITTF, an example for the description of the problems was given by Hans-Wilhelm Gäb, former continental Vice-President for Europe:

> "Our sport has become so tricky and fast that only a very small group can understand the tactical measures of the players and their strategic plans. The incredibly high degree of spin and speed forces the players to take high risks and look for the first opportunity to win the point at the expense of rallies. The present development has led to an almost complete elimination of defensive players, the athletic performance of whom every fan could see, understand and admire. The service has developed into a destructive element of our sport. The variety of coverings and rubbers have substantially contributed to a table tennis image that is associated with tricks and confusion rather than with an athletic sport."

Subject to the analysis is the ball's movement after being hit by the racket (trajectory across the net, rebound on the opponent's court and final trajectory) and before its impact on the opponent's racket. In the following this movement will be called "FLIGHT", whereas the word "stroke" describes the racket's movement before the impact.
The different striking techniques will be abbreviated in the following way: Topspin-Block means playing a Topspin against an arriving Block.

Premises

We used two simulation tools that were the results of previous experimental and theoretical researches of our group:

a) the TTSim software containing physical models for the table tennis ball's aerodynamical flight (1) and the ball's impact on the table (2). This program allows us to deal with the experimentally determined circumstances in a quite practical way.

b) the model of the impact between racket and ball taken from the corresponding analysis (3). This model includes a change of frame of reference. The model allows to calculate the result of the impact (stroke) depending on the racket materials, where the material properties are taken into account by the use of the parameters EPar and TPar. These parameters were experimentally obtained for several strokes and materials. To explain the impact theory in detail (e.g. giving the definitions and several values of the parameters) would be beyond the scope of this article, the more so as it has no further evidence for the understanding of the present research.

The initial conditions for the FLIGHT are determined by the impact between racket and ball, and the impact itself depends on its own initial conditions. Theoretically, there are 14 degrees of freedom concerning the kinematic initial condition before the impact:

striking movement: 5 (racket velocity 3; racket orientation 2);

ball's movement: 6 (velocity 3; spin 3);

position: 3.

Looking at the FLIGHT's initial conditions we find 9 degrees of freedom (6 concerning the ball's velocity and 3 concerning the initial position).

To reduce the number of situations to analyze, only pure and parallel topspin/backspin FLIGHTs were simulated. That leaves us with five degrees of freedom concerning the FLIGHT's initial conditions (initial position 2; velocity 2; rotation 1).

The movement values measured for the different strokes during play (1) and/or approximated (3) served as input data (see table 1).

Striking Technique	v [m/s]	Rot [Hz]
Topspin-Topspin	20	140
Topspin-Block	16	120
Smash	30	40
Counter-Counter	16	40
Topspin-Push	15	130
Topspin-Chop	13	110

Table 1: Velocity and rotation of the ball after the impact depending on the stroke used

Using the racket parameters TPar and EPar measured separately for each technique the model of the impact between racket and ball allows us to calculate the dependence of the values of the movement of the ball on the racket material (Table 2) (3). This table includes values for a very common Japanese backside covering. The numbers in the column 'covering' mean the thickness of the sponge (all conservatively glued), f means speed glued and ft means speed glued with a nowadays prohibited glue. Speeds are always given in m/s and rotations are given in Hz.

Material Number	Covering	Topspin-Top		Topspin-Block		Smash		Counter-Count.		Topspin-Push		Topspin-Chop	
		v	Rot	v	Rot	v	Rot	v	Rot	v	Rot	v	Rot
1	1.0	19.40	127	15.64	112	29.78	37	15.75	37	14.89	125	12.90	108
2	1.3	19.60	132	15.76	115	29.85	38	15.84	38	14.93	127		
3	1.7	19.80	136	15.88	117	29.93	39	15.92	39	14.96	128		
4	2.0	20.00	140	16.00	120	30.00	40	16.00	40	15.00	130	13.00	110
5	2.3	20.20	144	16.12	123	30.08	41	16.08	41	15.04	132		
6	2.0 f	20.60	153	16.36	128	30.23	43	16.24	43	15.11	135		
7	2.0 ft	20.80	157	16.48	131	30.30	44	16.32	44	15.15	137	13.13	112

Table 2: Velocity and rotation after the impact in dependence on different coverings and strokes

Indicators

Indicators had to be found to judge the quality of a FLIGHT.

For absolute indicators we defined (see also figure 1 for illustration) angle indicator, angle increase indicator, window indicator and time indicator:

A) angle indicator (ΔAngle):

Determined to an accuracy of up to 0.001°, ΔAngle represents the range of angles over which a ball will pass the net and hit the table from a certain given position ("good" ball in difference to "bad" ball). This indicator was found by keeping a certain initial condition and gradually changing the initial angle until there was a threshold between "good" and "bad" balls. The difference between upper threshold (edge ball) and lower (net ball) is called ΔAngle.

The absolute angle alone still doesn't have much to tell us; for instance, take a racket covering that causes the ball to rebound in a lower curve than another covering and therefore hit the net; in that case the player simply has to change the orientation of the racket and/or the direction of its movement to get the ball across the net.

On the other hand, if the range of angles is wider for a certain material than for others, striking becomes easier, since bigger mistakes don't cause a ball to become "bad". That's why we can take ΔAngle for a measurement of how simple a certain stroke can be carried out.

The software defines every ball to be good that does not touch the net and fully hits the table, thus excluding net balls and edge balls.

B) angle increase indicator (ΔAngle+):

ΔAngle+ gives us the difference between the angle indicator ΔAngle and an "optical" angle indicator, the latter defined by assuming the ball to travel along a straight line from the given initial position. This "optical" angle indicator is calculated simply from trigonometric considerations.

This angle increase indicator ΔAngle+ indicates the influence of rotation and gravity on the ball's trajectory.

For most of the FLIGHTs studied ΔAngle+ was greater than ΔAngle, i.e. the "optical" angle indicator was less than zero, meaning that only by use of rotation and gravity was it possible to play a "good" ball at all.

We need the angle increase indicator because its reliability does not depend on the initial position too much as ΔAngle does (see below).

C) window indicator:

This indicator is the size of the imaginary window above the net, through which the ball has to pass to be "good". The window indicator strongly corresponds with the angle indicator ΔAngle (especially with merely curved trajectories and small angles), but it is more comprehensible than the angle indicator, because in general lines are clearer than angles.

However, we will not use the window indicator with the detailed presentation of the simulation results; because of its high clarity you tend to overestimate its quantitative value, which is quite risky for it very strongly depends on the more or less arbitrarily chosen initial position.

D) time indicator (TimeX):

This indicator gives the time elapsed before the ball reaches a certain position along its horizontal direction. Various times are taken into consideration: the time the ball passes the opponent's base line (Time0), 20 cm (Time20), 50 cm (Time50) and 100 cm (Time100) behind it. Regardless of the opponent possibly anticipating the stroke, this is the time he has to respond to the oncoming ball. So the time indicator is a measurement for how dangerous a stroke can be.

The following example gives an impression of the time dimension: An analysis covering the combination of striking techniques revealed that the best players make their decision on how to play the ball 80 ms before the impact. For weaker players this takes considerably longer (4). A decisive hard stroked FLIGHT takes about 250 ms.

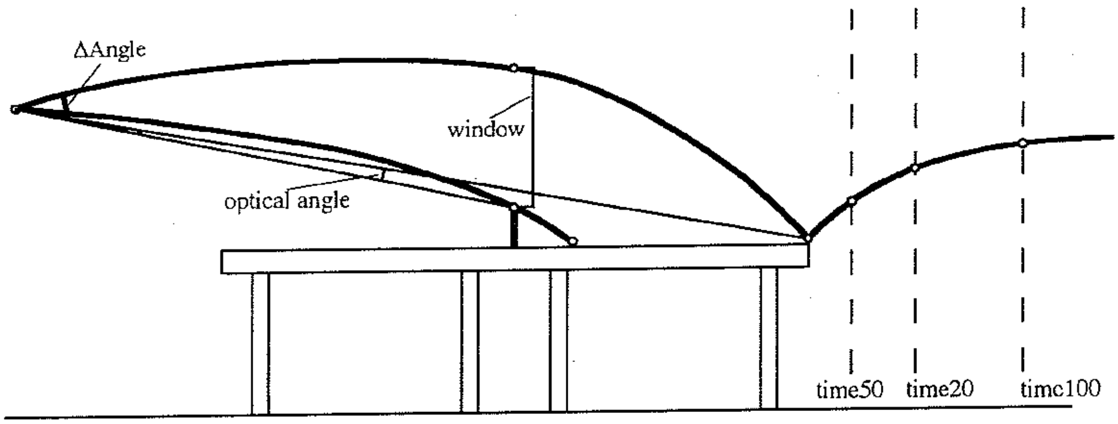


Fig. 1: Illustration of the indicators

Complicating circumstances

1) One of the major difficulties is that even the effect of different racket coverings on the initial conditions is not trivial: Since a change in material not only results in a different amount of speed but also in a different direction of the ball's movement, in reality the movement of the racket has to be fundamentally changed to get the ball into the same direction as before. But adjusting the motion of the racket like this in turn alters the initial conditions. This interactive influence was taken into consideration when the movement values were obtained from the model for the impact between racket and ball. This model exists as a computer based simulation permitting us to analyze interdependencies and optimizations. The plausibility of the method has been affirmed by an analysis (5) that evaluated the difference in play between speed glued and conventionally glued coverings for one particular striking technique.

2) When a player tries to send the ball into two different directions - let us say a high ball that lands on the edge and a low ball that touches the net - it is incorrect to assume that both balls would have the same speed and spin. Even if the player is able to produce the same racket speeds he will try to achieve the goal by changing the orientation of the racket and/or the direction of the racket. Generally the player will obtain different speeds and spins in a way impossible to predict exactly. So to play just with the starting direction of the ball in the simulations is not completely realistic. But for the decisive strokes that we analyzed we found an angle range of less than 3°, leading to the conclusion of only a minor influence, which was therefore entirely neglected.

3) Since the decisive strokes that we analyzed are the more extreme striking techniques (because their speeds are always as high as possible), we cannot expect players being able to compensate for reduced velocity by hitting harder. Therefore this is not a complicating circumstance.

General Parameters

Dependencies on the initial position

To get an overall impression of the circumstances the simulation of the striking technique "topspin against topspin" included 9 different initial positions (7, 15.25 and 30 cm above the table's surface; 60, 100 and 140 cm from behind the edge).

In the first place we found that the absolute differences (in angle, window and time indicators) between two materials were pretty much the same for all 9 positions although the values vary a lot for one material (see table 3).

		ΔAngle [°]	ΔAngle+ [°]	Window [cm]	Time20 [ms]
Material 4	Average	2.208	4.533	9.34	254.0
	SD	1.055	0.232	4.91	29.0
Mat.4 - Mat.1	Average	0.178	0.178	0.74	-7.2
	SD	0.004	0.004	0.12	0.8
Mat.6 - Mat.4	Average	0.157	0.157	0.65	-6.2
	SD	0.002	0.002	0.10	0.5

Table 3: Differences in the indicators

It is possible therefore to determine the dependence on the position for the different materials out of the dependence for one single material.

We can see the initial influence of the initial position on the topspin-topspin stroke (using material 4) from Fig. 2. The initial position (either the distance to the edge or the height above the table) strongly influences ΔAngle.

This is why we introduced the angle increase indicator ΔAngle+: its dependence on the initial height is negligible (the curves almost entirely match). Taking initial height and ΔAngle+ we are able to deduce the simulation results for different heights out of the result for one particular height.

That is true for all submaximum strokes.

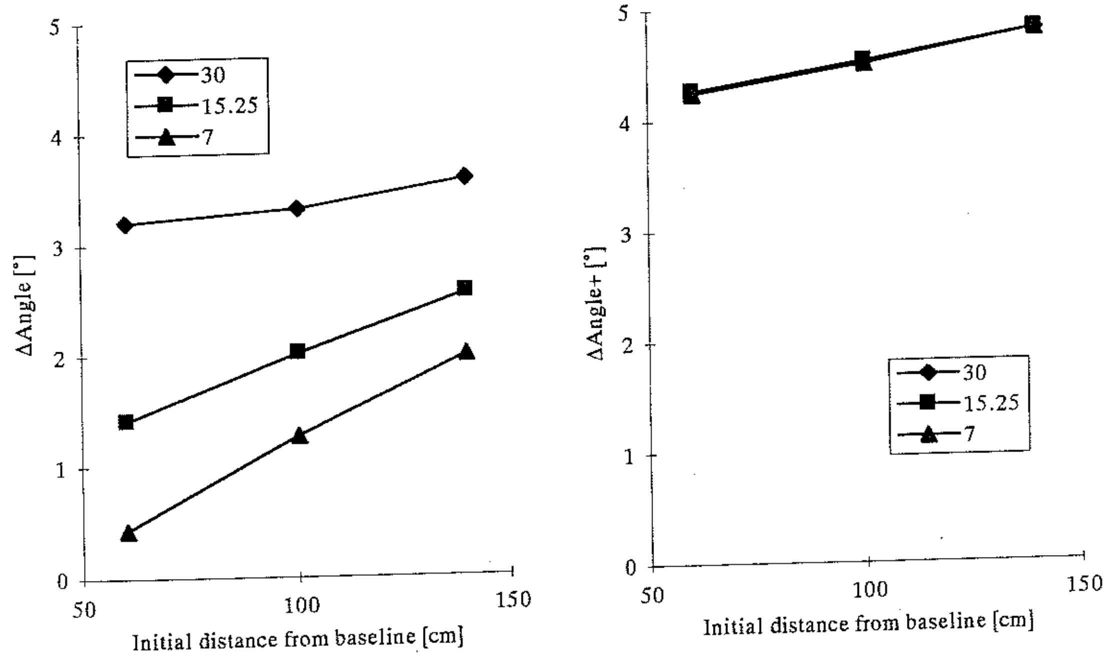


Fig. 2: Dependence of ΔAngle and ΔAngle+ on the initial position for Topspin-Topspin

Position inputs

For initial position and return distance we assumed the values given in table 4. For other initial heights ΔAngle could be deduced as described in "Dependencies on the initial position". We used the return distance to select the most suggestive time indicator.

Striking technique	Initial position		Opponents contact point behind the table
	Distance [cm]	Height [cm]	[cm]
Topspin-Topspin	100	7	100
Topspin-Block	50	7	20
Smash	43	30	100
Counter-Counter	43	20	20
Topspin-Push	43	7	20
Topspin-Chop	30	0	100

Table 4: Initial positions for the different strokes

Result figures

The results for each of the strokes are depicted in the form of a diagram showing the relation of TimeX and ΔAngle for the different materials. We chose ΔAngle and not ΔAngle+ for the presentation of the results because for different net heights we get the same ΔAngle+. ΔAngle+ is an indicator only for the trajectories curvature (for an explanation please see chapter "Indicators B"). The further a point lies on the right, the more time the opponent has, and the less dangerous a stroke is. The further up a point lies, the greater the range of angles under which a stroke is "good" is, i.e. the easier it can be carried out.

From the position the points "B0 2.0mm f" and "B0 1.0mm" have in relation to "B0 2.0mm" we can figure out where the points for Ball1, Ball2, Net2 and Net3 would lie for both materials.

The terms in the legend mean:

B0, B1 and B2:	Balls of different size and/or weight; For details see "Study II".
N2, N3:	Net of different height; For details see "Study III".
1.0mm, 2.0mm:	Thickness of the sponge of the covering. For details see "Study I".
f:	Speed glued. For details see "Study I".

The three main studies

Figures 3 to 8 give the results of the following three main studies.

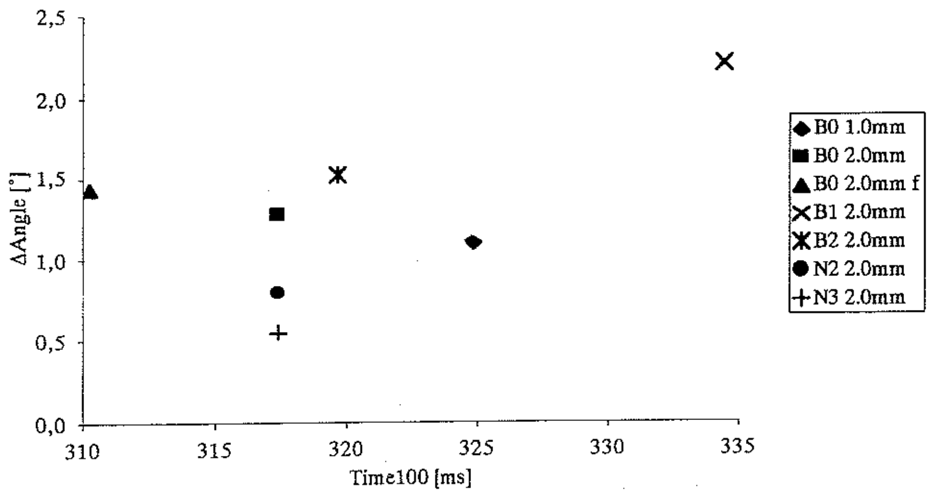


Fig. 3: Topspin-Topspin

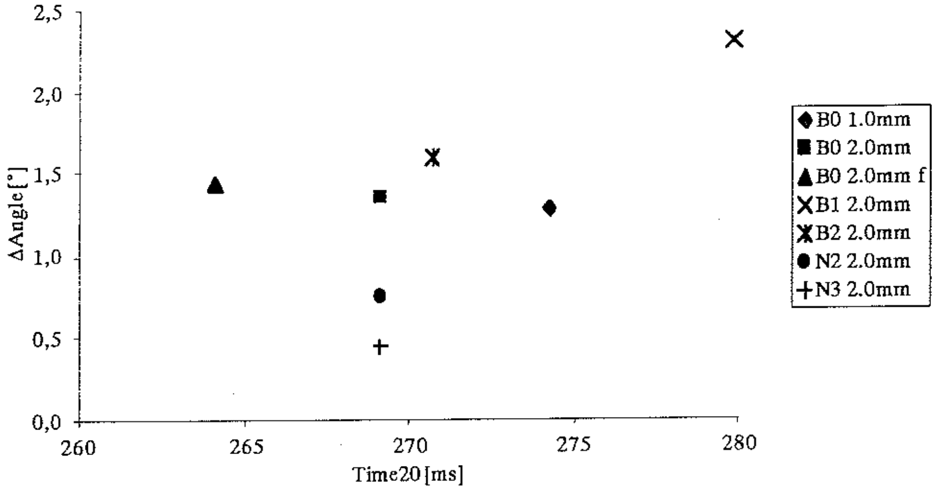


Fig. 4: Topspin-Block

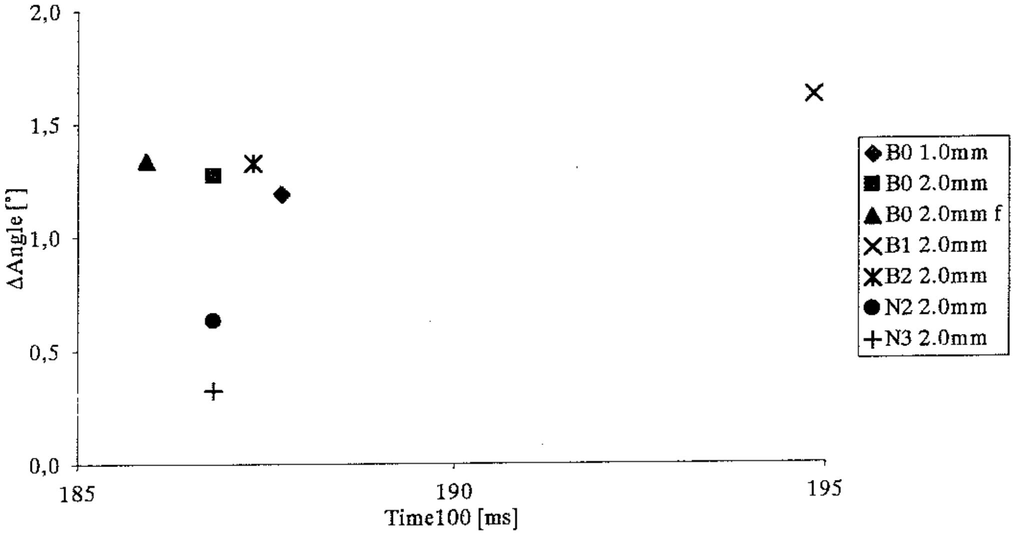


Fig. 5: Smash

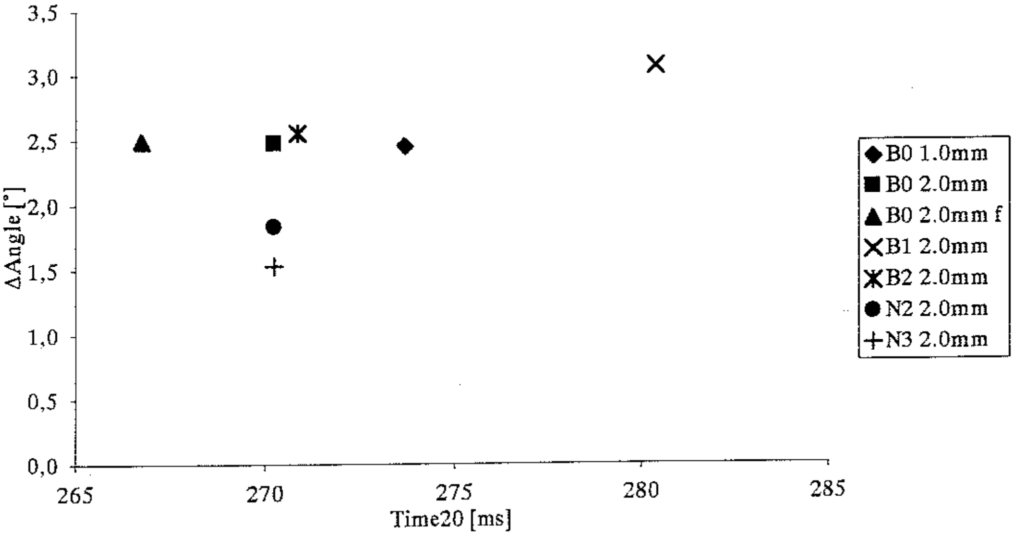


Fig. 6: Counter

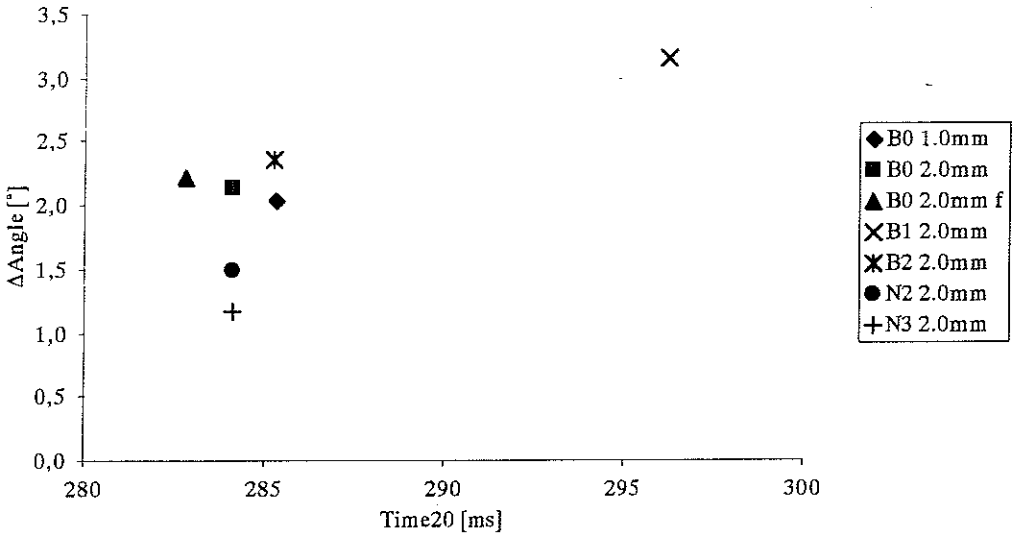
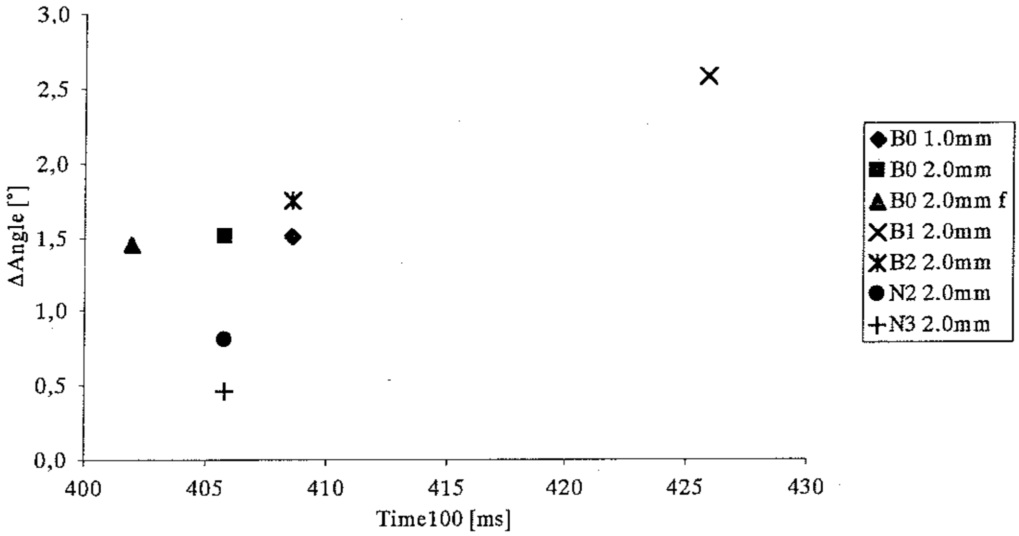


Fig. 7: Topspin-



Push

Fig. 8: Topspin-Chop

Study I): Parameters depending on the racket

Here we studied the influence of speed glued and conventionally glued coverings and the influence of changing the covering thickness, using the standard ball (ball 0: 2.47g in mass and 37.7 mm in diameter; i.e. the average values within the ranges agreed upon by the ITTF).

Increasing the thickness of the covering and speed gluing both increase ΔAngle (by 0.44° between material 1 and 4 for Top-Top) and decrease Time20 (by 6.5 ms between material 1 and 4 for Top-Top). The decrease of Time20 is due to the higher velocity. Normally this is associated with a decrease of ΔAngle, but the latter is here overcompensated by the effect of an increase in spin.

Note that we did pay no attention to the influence of the blade, since this aspect - unlike the coverings - currently is not of interest.

Study II): Parameters depending on the ball

This study deals with the influence of the ball's mass and size on the different strokes using different coverings (material.: 1, 4, 7).

In addition to the standard ball (ball 0: 2.47g; 37.7 mm in diameter) simulations were carried out using a ball of the same weight but larger in diameter (ball 1: 2.47g; 40 mm) and a ball the same size as ball 1 with the same celluloid thickness as ball 0 (ball 2: 2.78g; 40 mm).

To avoid confusing parameter changes, we used the same initial conditions as before in Study I. I.e., we did not yet take into account that:

a) the ball's speed before the impact is already lower and

b) the use of the changed balls will on the one hand reduce the today's racket parameters (EPar and TPar which is hard to predict (3)) but this effect will be compensated by adapting the coverings to the new ball. On the other hand the greater diameter will result in less spin - even if TPar stayed the same. From an analysis of the isolated influence of rotation the additional influences of these effects can be calculated.

Using ball 1 instead of ball 0 increases both ΔAngle (by 0.93° for Top-Top using material 4) and Time20 (by 11.6 ms for Top-Top using material 4). The ball is slowed down by its greater diameter and with identical rotation its trajectory becomes curved more distinctly.

In comparison to ball 0, ball 2 increases ΔAngle (by 0.25° for Top-Top using material 4) and Time20 (by 1.6 ms for Top-Top using material 4) not as much as ball 1 did. The greater mass significantly diminishes the effects of the greater diameter.

Including the findings of the impact theory we find rotation reduced by 6% (Top-Top) for ball 1 and ball 2 with velocity staying nearly the same. This leads to a decrease in ΔAngle of 0.25° but does not significantly affect Time20 which mainly depends on the velocity.

So for the stroke Top-Top ball 1 increases ΔAngle by 0.68° and Time20 by 11.6 ms. Ball 2 does not change ΔAngle but does increase Time20 by 1.6 ms.

Different balls will affect the interaction between ball and covering (along with EPar and TPar), thus creating completely different initial conditions for a FLIGHT, but this is hard to predict. The tangential qualities of coverings for example have been developed to function with the actual ball. This function depends on the ball's overall elasticity and mass. If the manufacturers manage to adapt their coverings to the new conditions, the parameter TPar will stay on the same level.

In the further course of this study (which is not yet finished) we attempt to also take such effects into consideration.

Study III): Parameters depending on the net

This study was employed to determine how the height of the net affects different strokes (for which the materials 1, 4, and 7 were used).

Along with the normal net height of 15.25 cm (all studies: B0, B1, B2) we made simulations using nets 2 cm higher (Net2: 17.25 cm) and 3 cm higher (Net3: 18.25 cm).

The major effect of a higher net is to reduce the imaginary window above the net, which becomes smaller by the amount by which the net is raised (Net2: 2 cm, Net3: 3 cm). This produces significant reductions in ΔAngle: For Topspin-Topspin strokes it is decreased by 0.49° with Net2 and by 0.73° with Net3.

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