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The Impact of the Table Tennis Ball on the Racket (Backside Coverings)

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Abstract

We modelled the impact racket-ball in table tennis and introduced parameters for the equipment. With some thousands of impacts we measured the parameters for a big number of different materials - such as racket woods, coverings, speed glue and balls - so we know about their different effects. With the model the measured parameters can be interpreted for table tennis.

I. Introduction

The table tennis (tt) players and coaches all over the world have a opinion and give anecdotal comments about how the tt equipment influences their sport. So in the recent world-wide discussion on how to make the sport of table tennis more attractive there are several proposals to change the rules and equipment. But the administrators had no objective base how the equipment influences the game.
A modelisation done by Seydel (1) of the trajectory of the tt-ball in the air was finished 1990. The rebound of the ball on the table was modelled by Durey (2) 1987. Here we summarize our actual physical research done in Cachan (Paris) in the laboratory of Alain Durey concerning the impact of the tt-ball on the racket.
Now we have the pieces for the complete simulation of the tt-mechanics. With such a simulation we can help to find rules' changes that make sense for the player and the spectator.

Here we want to try to eliminate some of the current mysticisms concerning the impact racket-ball which make a discussion very difficult.

The impact between the table tennis ball and the racket is a very important physical process in table tennis, because it is the only process where the player influences the ball. The continual development of the racket has pushed the continual development of the tt-sport and vice versa. It was recognized that besides the speed the rotation of the ball could play an important part in tt-sport.

The rotation influences:

The rebound on the table.
The rebound on the racket.
The trajectory. In comparison to a spinless ball a ball played with topspin has a simplifying effect, which is a result of the trajectory's curvature caused by the spin :

This permits a higher trajectory, so that the range of good angles to play the ball increases. A similar increase could be achieved by a reduction of the net height or an enlargement of the table.

Equipment was developed, with the object to enable the player producing as much rotation - along with as much speed - as possible to confront the opponent with as extreme states of movement of the ball as possible. The technique of speed glue advances the effect which is produced by the offensive coverings anyhow.

To make the interpretation of the following experimental results possible, at first a short theoretical survey is given.

II. Theoretical survey

II.1. Change of frame of reference

The ball and racket are moving against each other before the impact, each with its own (momental, time-varying) velocity. This initial condition is similar to a condition with a racket at rest that can be calculated by a change of frame of reference. This change is a mathematical process that "places the laboratory on the racket". The change of frame of reference can be also inverted. This allows us to experimentate with a racket at rest and to define a model for the racket at rest and then to draw conclusions on the tt game.

II.2. Modelisation

The tt-racket weighs about 180 g, the ball about 2.5 g, so the masses are in the ratio 70:1. If we consider that in the game the racket is held by a hand (which weighs itself some 100 g) the ratio is even larger. Because of this we can consider the mass of the impact-partner at the side of the racket, with good approximation, as infinite.
The maximum acceleration of the tt-racket can be neglected compared with the corresponding - 200 times bigger - acceleration of the ball. So a change of frame of reference is possible and we can calculate the rebound for a moving racket (i.e. for table tennis itself) out of the rebound on a racket at rest.

For simplicity we examine only impacts with back- or top-spin and not those with side spin.

In the model that we built up there are two parameters that chracterize the partners of impact.

The first parameter characterizes what happens perpendicularly to the plane of the racket; we call the parameter E_{Par} (historical loss of energy parameter or coefficient of restitution). It is defined as the negated ratio of the normal velocity after the impact and the normal velocity before the impact ($E_{Par} = - v'_n / v_n$). The ball itself, the type of the wood of the racket and the type of the covering have great influences on this parameter.

The value of E_{Par} is inevitably between 0 and 1.
$E_{Par} = 1$ for ideal elastic partners of impact, and the perpendicular velocity is completely reflected by impact. The ball doesn't lose energy.
For ideal inelastic partners of impact is $E_{Par} = 0$. The ball rests on the racket after the impact, its energy being completely absorbed.
The bigger E_{Par} is, the "faster" the racket is in the perpendicular direction.

We found, that for the modern offensive coverings there are very special effects parallel (tangential) to the plane of the racket. These effects cannot be described by the introduction of a coefficient of friction as it is used for the model of the impact on the table by Durey (2). In table tennis friction is of just secondary significance. It is the tangential elasticity of the covering that is **the** important factor for its quality : For the modern offensive coverings the friction force is always high enough to decelerate the relative tangential contact velocity v_{Pt} to the value 0. Then during the impact the covering charges potential energy by tangential deformation and discharges a part of this energy back into the ball. We found that v_{Pt} is reflected by impact.

The effect can be demonstrated easily (figure 1) : We take an offensive racket and place it on a table. We take a ball, marked with black points to allow the rotation to be seen and play it at an angle downward onto the rubber with backspin.

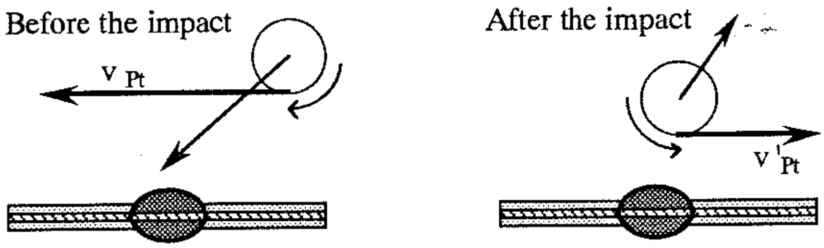


Figure 1 : Demonstration of the tangential effect

To characterize what happens parallel to the plane of the racket we introduce the parameter T_{Par} (tangential parameter). It is defined as the negated ratio of the the relative tangential contact velocity (which is produced by rotation and tangential velocity) after the impact and the relative tangential contact velocity before the impact ($T_{Par} = - v'_{Pt} / v_{Pt}$). The covering (e.g. the thickness of the sponge and speed gluing) has great influence on this direction.
The power of the modern offensive tt-equipment is founded on this parameter. T_{Par} is responsible for the ability to produce spin **and** tangential velocity.

The value of T_{Par} is also inevitably between 0 and 1.
$T_{Par} = 1$ for ideal elastic partners of impact, and the tangential contact velocity is completely reflected by impact. The ball doesn't lose energy.
For tangetially inelastic coverings is $T_{Par} = 0$. At the end of the impact the ball rolls on the covering, the ball has lost some energy.
The bigger T_{Par} the more spin **and** speed can be produced.

To design a covering with a high T_{Par} is much more difficult than to produce a high E_{Par}. For a high T_{Par} there is a certain co-ordination of the tangential elasticity of the covering needed. The rules of this co-ordination are too complex to discuss them here, they are the results of theoretical mechanical calculations. But one interesting thing has to be told: The co-ordination is only valid for a certain combination of impact time and mass of the ball. The current coverings are developed for the actual ball

II.3. Impact model

The introduction of E_{Par} and T_{Par} is the base of an impact model, which can predict the rebound conditions for the racket at rest. If we add the method for changing the frame of reference, it's also possible to predict the rebound for a moving racket (i.e. for table tennis itself). To do this, the following information is needed: a) speed and direction of ball and racket, state of rotation of the ball and angle of inclination of the racket before the impact; b) the values of the parameters E_{Par} and T_{Par} which define the racket. The basic procedure of the complete model is shown in figure 2.

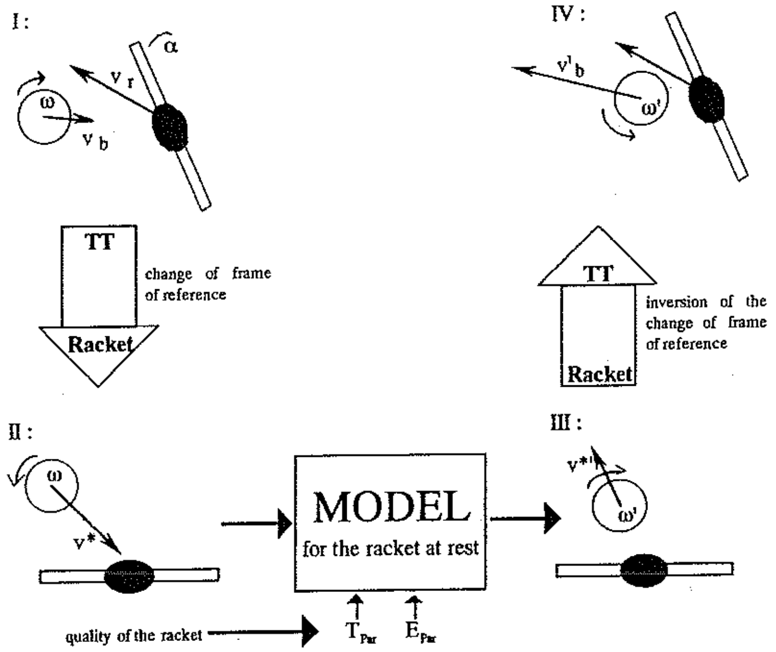


Figure 2: Principle of the complete impact model

Aided by the complete model it is possible to calculate out of one incident condition the influence of T_{Par} and E_{Par} on the velocity and the rotation of the ball after the impact for all possible types of stroke. Here the results of the simulation for topspin strokes are given (figures 3, 4 and 5) . The figures show the effect of variation of T_{Par} (at constant E_{Par}) and E_{Par} (at constant T_{Par}) on speed (v') and spin (f') of the ball after the impact.

For topspin against backspin-balls the speed of the ball is only influenced by the normal parameter E_{Par}. The spin doesn't depend on T_{Par} and E_{Par} very much.

For topspin against block and even more for topspin against topspin great effects of T_{Par} are appearing: If it would be possible to produce a racket with $T_{Par} = 1$ speeds of more than 30m/s and rotations of more than 300Hz would be possible. **For topspin against topspin the speed is produced on equal parts by T_{Par} and E_{Par}.**

III Experimental Part:

III.1. The influence of the materials of the racket

We developed a method to measure the introduced parameters: A high perfomance ball-throwing-machine (which can produce freely chosen all necessary speeds and spins) throws the ball on a fixed racket. We filmed the impact illuminated with stroboscopic flash in SVHS Video. The ball is black and glossy, marked with white spots in tetraedron corner configuration, so one of them is always visible. Seen from the ball's position the camera and the flash appear under a small angle of less than 3° so the reflection of the flash on the ball marks the centre of the ball. The stroboscope is set at 500Hz so we see 10 positions of the ball on each frame. Then the frame is digitized and the points are marked out. After processing and calculating the speed is measured with

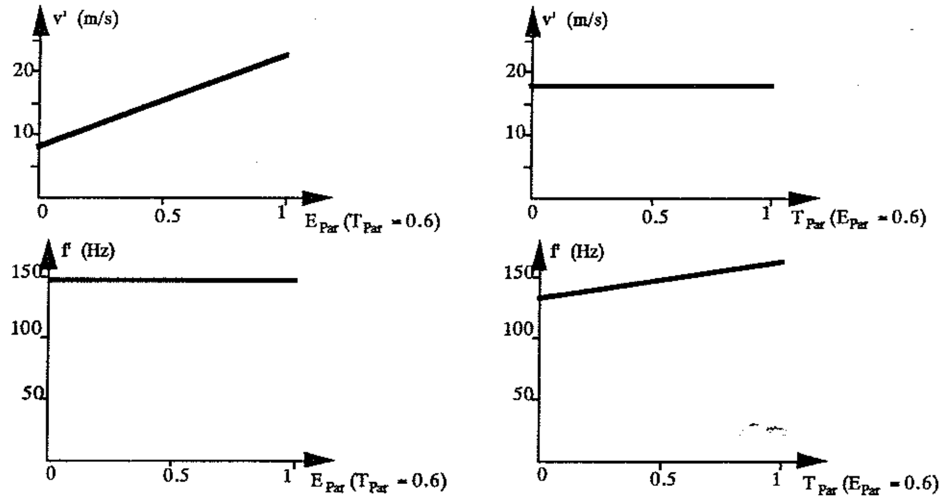


Figure 3 Topspin with maximum speed of the racket against defensive ball with very much backspin.

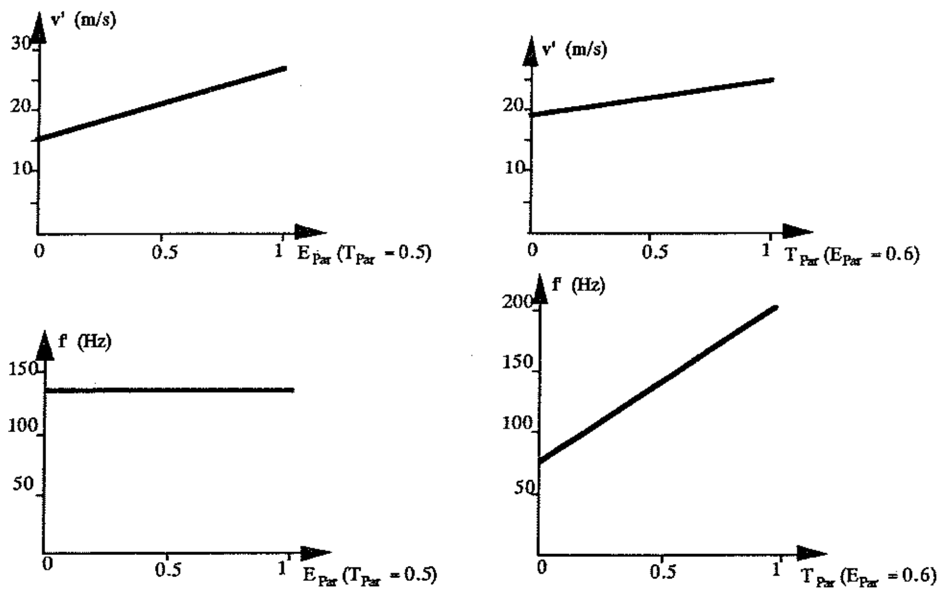


Figure 4 Topspin against block

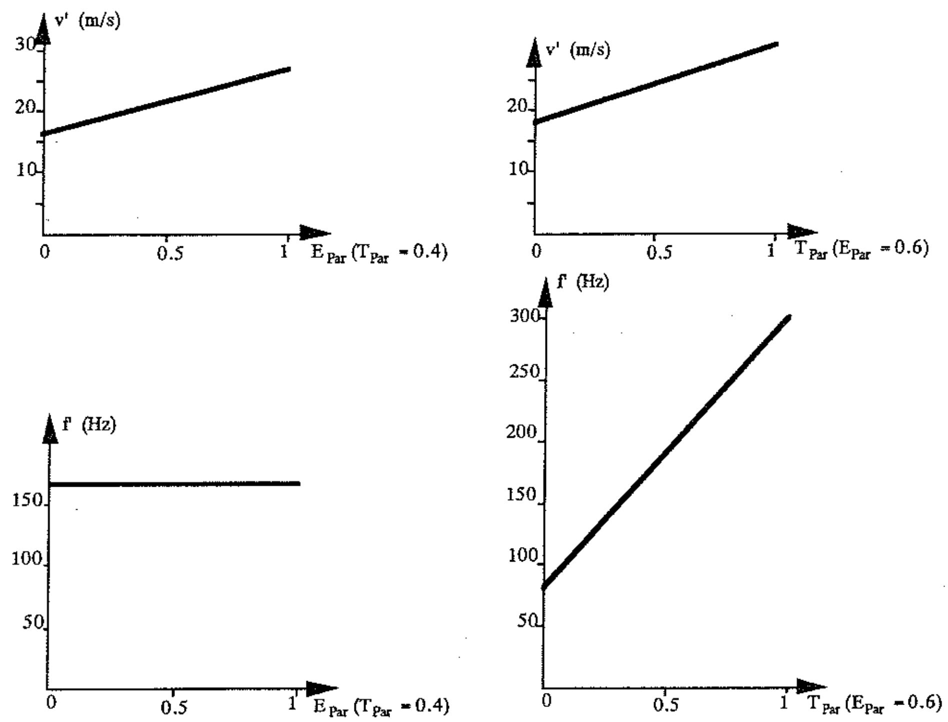


Figure 5 Topspin against topspin

a precission of 0.1m/s and the spin of the ball with a precision of 1Hz. Then E_{Par} and T_{Par} are calculated. Each impact is repeated at least 12 times in the same initial condition to reduce statistically the incertainty of the average value. Many of the current tt-materials were examined with some thousands of impacts.
To give spins and speeds as results does not make sense for most of the readers, because for each experiment the reference is given by another couple of numbers. But by using the above theory the indication of E_{Par} and T_{Par} can be interpreted easily.

A bigger value of E_{Par} results in a higher speed of the ball after a stroke. Particularly for strokes with topspin, a bigger value of T_{Par} results in a higher speed of the ball **and** more spin of the ball. If we assume that the aim of a high level offensive player is to produce the fastest ball with the highest rotation, we can conclude that a racket with the biggest values of E_{Par} and T_{Par} would be the best for him. The greater E_{Par} and T_{Par} the less kinetic energy is dissipated, the more ideal elastic was the impact. This conclusion allows us to speak of "better" and "worse" when discussing the qualities of a covering.

The measured values of E_{Par} and T_{Par} could replace the mystic and non-objective speed-&-spin-tables that are often found in the distributors' catalogues

III.1.2. The influence on E_{Par}

To research the influence of the materials and the speed on E_{Par} many perpendicular impacts were made (figure 6) . E_{Par} always decreased with increasing speed.

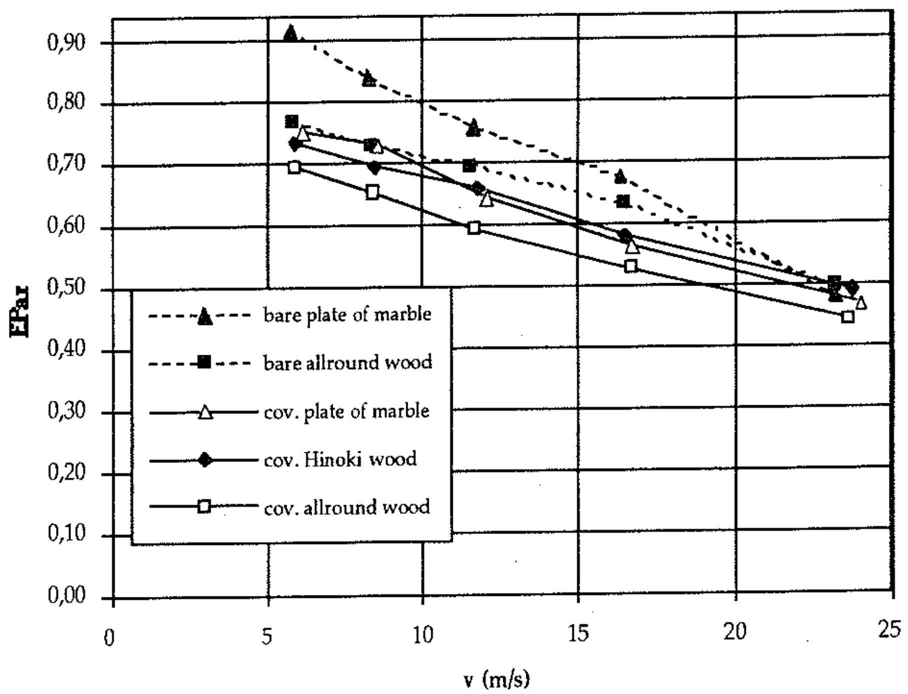


Figure 6: Normal impact: Bare and covered materials.

III.1.2.1 The influences of the wood on E_{Par}

To determine the influence of the wood on E_{Par}, impacts were made on bare woods with covering only on backside and on covered woods.

For bare materials we found the higher the speed the smaller is the difference between the woods. The reason for this is that for high speeds (energies) it is the ball that dissipates (absorbs) a big amount of the kinetic energy itself by deformation, no matter how elastic (or stiff) the other impact partner is. For bare materials the more stiff the material is the bigger is E_{Par}. The absolutely fastest "wood" was a massive plate of marble.

For the materials with covering there seems to be a constant difference in E_{Par} regardless what speed. The difference between marble and the woods is much smaller here.
The fastest wood is not the carbon wood: much faster is the one-ply Hinoki wood, which is as fast as the covered plate of marble.

From this consideration of E_{Par} we can deduce that, if the ball remains as it is today, faster woods cannot be developed.

To determine which kind of stiffness is important, a special series of normal impacts was measured. There were:
a) a complete (coverings on both sides) racket fixed at the grip.
b) the same racket, but hung as a pendulum.
c) the racket without covering on the backside (40g lighter), but fixed at the grip.

For speeds higher than 10m/s there was nearly no difference between the three conditions. We found the surprising result, that for small speeds (less than 10m/s) the racket is under condition b) much faster than under condition c). The difference is of the same order as the difference between the allround wood and the carbon wood. The difference between the condition a) and b) is of the half size of that order.
This means that the fixation is not very important; much more important is the weight of the region where the impact happens. That is comprehensive if we consider what we also measured: the duration of the impact is of the order of just 1 ms. For fixation to have an effect on the impact, it is necessary that within this 1 ms a shock wave is reflected and returns to the point of contact. We saw in films of the impacts that the top of the racket is beginning to move after the impact.

Because of the influence of the (local) weight of the racket on the "speed" of the racket, but also because of reasons of its "feel", we recommend the distributors to indicate, not only the weight of the blades, which they usually provide, but also the weight of the coverings. There are e.g. big differences between the weight of Japanese and Chinese coverings. When we measured the parameters, we normally used complete rackets with coverings on both sides

III.1.2.2. The influence of the covering on E_{Par}

As far as E_{Par} is concerned, the covering is a dissipator of energy in comparison to bare materials. From the known influence of the weight of the racket we can judge that the dissipation is even higher: One covering was absent on the bare woods which means that they were lighter.

Why do the players glue a covering of rubber on their woods, which slows down the "speed" of the racket ? The answer to this question will be given in the following section.

Among other things it is the aim of an Antispin covering to absorb the perpendicular velocity. We found that it doesn't do its job as well as might be expected.

The stickier a covering is, the smaller is its E_{Par}. At the rebound the ball loses some energy by breaking the adhesion.

III.1.3. The influence of the racket materials on T_{Par}

Research on T_{Par} is not as easy as on E_{Par}. Purely tangential impact does not exist. Furthermore, for reasons stemming from the theory of elasticity the effects in the tangential direction are influenced by the perpendicular velocity before the impact.
To determine the effects of the racket's materials, we simulated the stroke that plays the greatest part in modern table tennis : submaximum topspin against arriving balls with topspin. This stroke causes the greatest stress for the covering in the tangential direction.

The wood has just a small influence on T_{Par}. for the submaximum topspin condition T_{Par} was measured on the defensive wood 0.43 ($E_{Par} = 0.61$) and on the Hinoki wood 0.42 ($E_{Par} = 0.63$).

The covering influences a lot. Here the main differences between the coverings can be found, resulting from the development work by the producers. We show the results in a E_{Par}-T_{Par}-diagram (figures 7a and 7b) .
It is possible to make a distinction between following types (classes) of coverings:

a) Coverings with very high tangential elasticity (J1):
These have the biggest T_{Par} and therefore the biggest capability to produce spin and tangential speed. In addition this type of covering absorbs the least velocity in the normal direction. This type of covering is used by most of European offensive-players. Following the fat line from the left to right for increasing thickness of the sponge (1.3, 1.5, 1.8, 2.0 and 2.1mm (max)) T_{Par} also increases. Responsible for the effect being not too clear is possibly the inaccuracy of the measurement but also the individuality of each covering which is based on production (rubber is a natural product) and on the conditions of storage (time, temperature and air are influencing the rubber).

b) Coverings with high tangential elasticity (J2):
They are similar as J1 and are probably the result of an attempt to copy J1, but have a lower T_{Par} and are hence less effective.

c) Coverings with high stickiness (J3):
These are often supposed to produce more spin but, as explained earlier, tangential elasticity is much more important than friction (it is sufficient for a covering to be sticky enough that the ball cannot slide); in this respect these coverings are poorer than J1 and the two samples we tested, with thicknesses of 2.0mm and 2.2mm, had about the same T_{Par} as 1.5mm J1.
As noted under III.1.2.2. stickiness causes a loss of energy in breaking the adhesion. So not only does it not increase T_{Par}, but it also decreases E_{Par}.

d) Coverings with extremely high stickiness (Ch)
For these the same arguments apply as given under c). For them the stickiness is carried to extremes. For the submaximum topspin that coverings are much worse than J1 coverings.

III.2. Speed gluing

Speed gluing improves the quality of the covering.
On the one hand the fresh glue enables the covering to move on the wood (increase of the tangential elasticity of the covering), on the other hand the quality of the materials of the covering changes completely under the influence of the solvent of the glue.
Just one aspect of the change is the swelling of the sponge. The sponge expands quickly (some minutes) to an extent dependent on the solvent. The most extreme with the solvent, trichlorethanol, gave a factor 1.3 in the expansion in all dimensions; this means a factor 2.2 for expansion in volume. This expansion means e.g. that when a 2.2mm sponge in a covering of the maximum allowed thickness (4mm total) is freshly glued, the sponge expands to 2.9mm (4.7mm total). This covering will no longer be legal.

The influence of speed gluing on the game cannot be explained easily:

Speed gluing increases E_{Par} **only** for small perpendicular velocities (figure 8) . The difference is lost at the higher velocities which are corresponding to most tt-strokes.

But a remarkable increase of T_{Par} is found for all velocities. The difference between gluing conservatively and speed gluing is bigger than the difference between a 1.3mm and a 2.1mm sponge (figures 7b, 9, 10a and 10b) .

Our interpretation of these results:

For small velocities (as in pushing play) a speed glued racket is much "faster" than a conservatively glued racket in both tangential and normal components. This stroke is therefore made more difficult, if we assume that to aim is to play controlled slow balls. This effect is obvious if you simply bounce the ball on the racket.

At higher speeds speed gluing has only slight influence on E_{Par} (both small increases and small decreases were found), but T_{Par} on the other hand is increased.
This increase has different influence on different types of stroke. Because of the type of stress it has the biggest influence on topspin against topspin.

What the increase of T_{Par} changes for the submaximum topspin

The increase of the values of velocity and rotation by speed gluing is small. Our measurements show, that they don't change very much, if you play with a 2.0mm speed glued covering instead of a conservatively glued one. Speed gluing gives only 4% increase in speed (20.5m/s instead of 19.8m/s) and 12% increase in rotation (124Hz instead of 111Hz) (same racket movement assumed). But the values are not very expressive.
These little differences decide the game. If we measure the differences for this stroke between a 1.3mm and a 2.1mm covering, we find differences of the same magnitude (plus 3.4% velocity (19.4m/s & 20.0m/s) and plus 10% rotation (105Hz & 116Hz). Any club player who plays with "normal" offensive equipment knows how great the difference is if he plays with a 2.2mm sponge covering instead his usual 1.7mm sponge: The ball is "much" faster and nearly uncontrollable, but if he does succeed placing the ball on the table, the ball is much more dangerous for the opponent.
On the other hand if a player, who plays habitually with a 2.2mm sponge covering plays a 1.7mm sponge covering, he has the impression that he cannot win a point with his first topspin. It's necessary to play a second, third... topspin to break through where before one topspin was enough. The player feels the necessity to exert much more for a strong stroke.
These circumstances are the key for the understanding of the results of this research: If such a small difference between the thickness of the sponge has such a great effect in

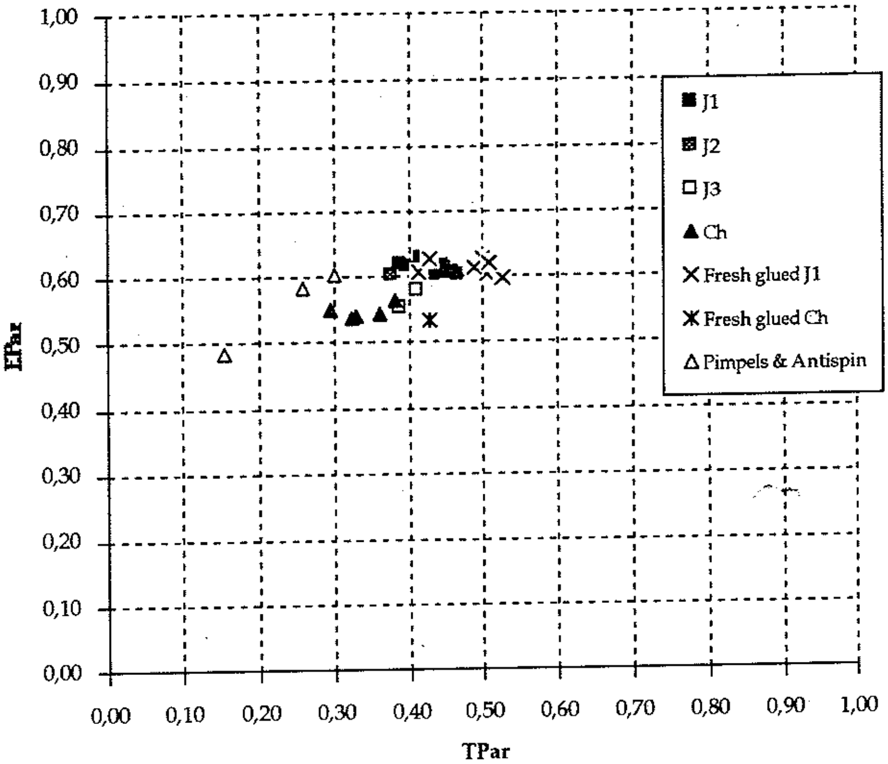


Figure 7 a) Submaximum topspin against topspin: Different types of covering. The following graph is an enlargement of this graph.

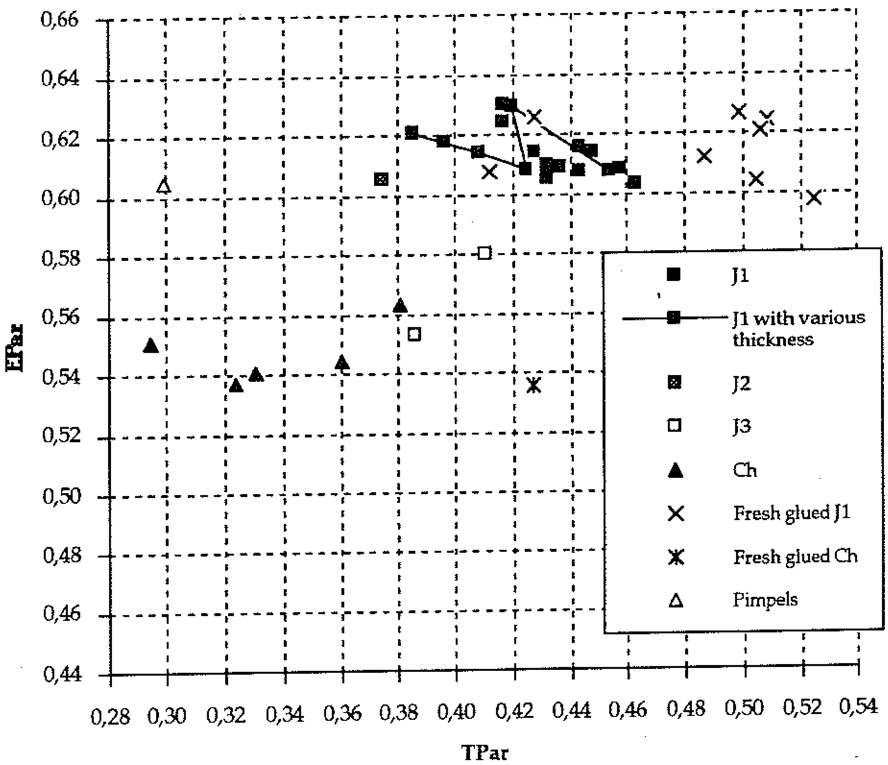


Figure 7 b) Submaximum topspin-against-topspin condition: Different types of coverings. Partial extension of graph 2a).

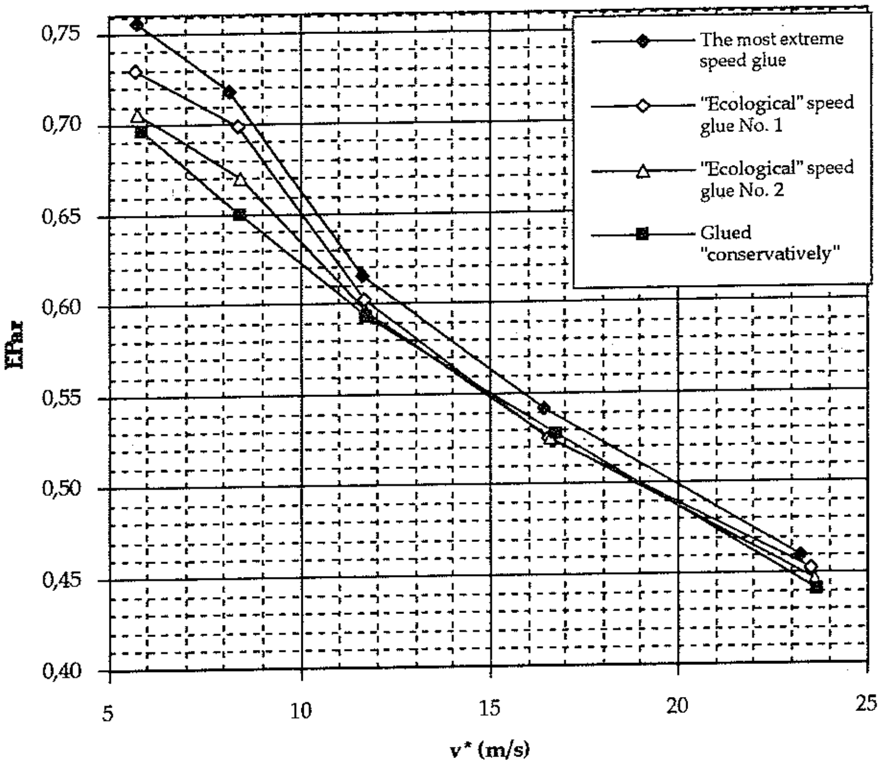


Figure 8 Normal impact: Comparison of different types of glue. *) **)

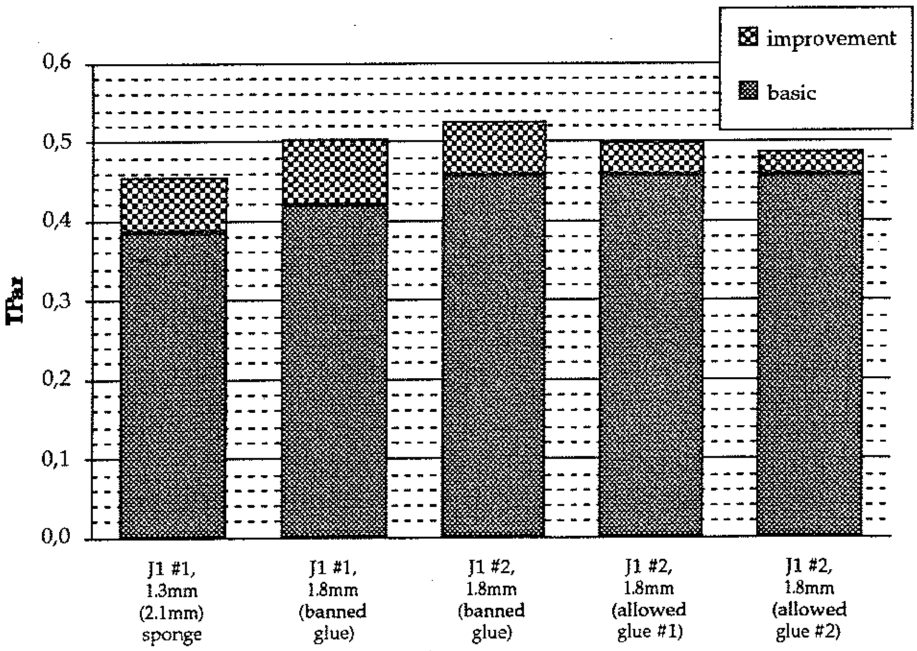
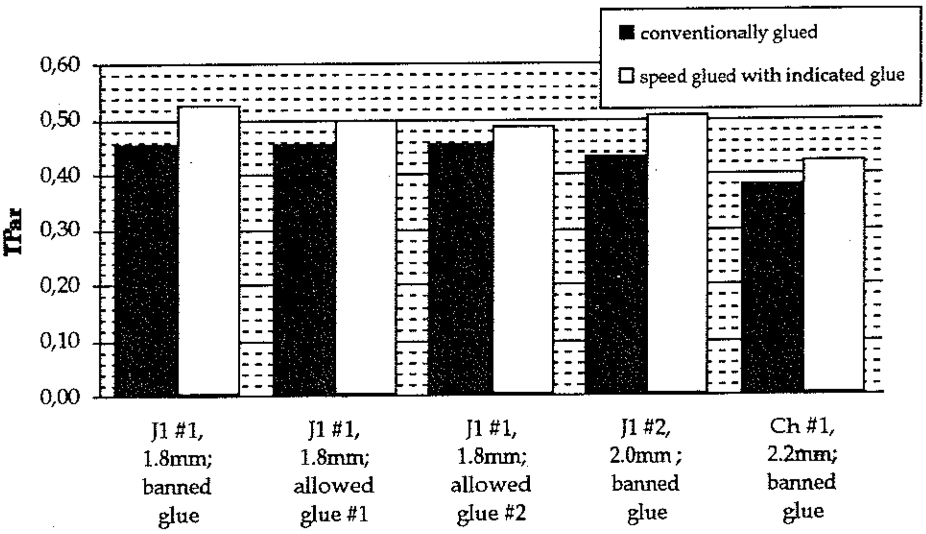


Figure 9 T_{Par} for submaximum topspin against topspin. Improvement by increasing the thickness of the sponge and by speed-gluing.



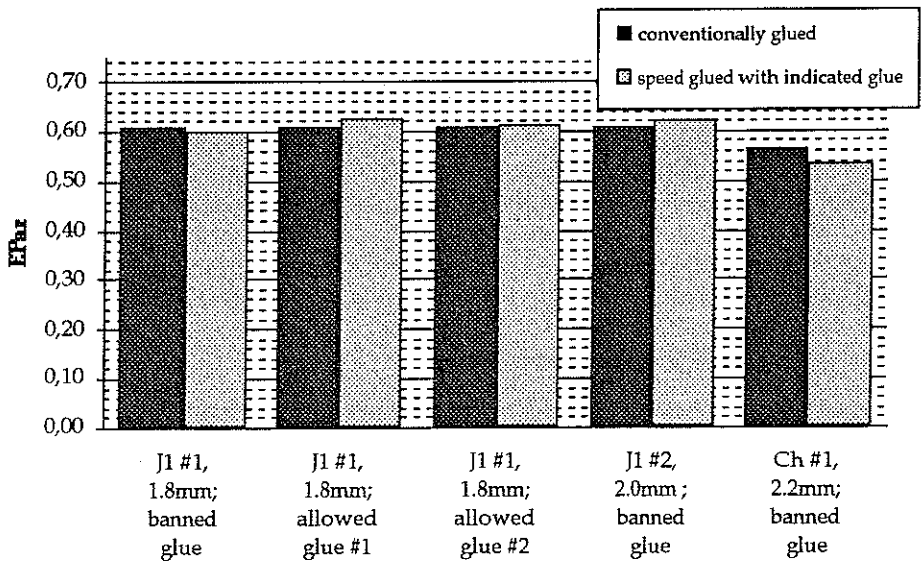


Figure 10 a) & 10 b) T_{Par} and E_{Par} for submaximum topspin against topspin: The difference between speed gluing, non gluing, different types of glues and types of coverings.

the game, how great will be the effect if we measure the difference between speed gluing and non-gluing?!

The psychological aspect is also important, we present this aspect only briefly as it is not our discipline.
Both the higher rebound by bouncing the ball and the snapping sound by playing strong topspins gives an impression to the player that he holds a weapon in his hand.
The difficulty of playing short balls with a speed glued racket can also have a positive effect: Because the player feels insecure with a speed glued racket when playing short, passive balls, he is forced to play offensively and aggressively.

The effect of "ecological" glues is about 2/3 of the effect of prohibited glues.

III.3. The fault effected by the ball

The ball consists of two halves and it has a seam, where there is more material than in other regions of the ball.
This seam changes the rebound of the ball. This is obvious if we look at the mark remaining on a coloured ball after an impact. The mark is either elliptical (on areas that are far away from the seam) or triangular (when the impact was near the seam).
A 2° variation in the angle of rebound was found for the submaximum topspin against topspin. This made it necessary to make all experiments more than once, so that statistic methods could be used.
We believe that if this variation could be eliminated the game would be easier to play.

IV Possibilities of application of the impact model

Our mathematical model and together with the existing models of the trajectory of the ball in the air and the impact of the ball on the table permits various relationships to be examined. We now have the instruments to research the mechanical effects of changes of rules and equipment. There is still a lot of work, that can be done with these instruments, but first we need to know what the questions are.

Finally here is a small example showing the potential:
We heard about the proposal to prohibit highly thrown services, and we read some arguments of the resulting discussion. But nowhere did anyone show the effect of throwing the ball high in service.
The effect of throwing the ball high in service is that it reduces the potential for backspin, but increases that for topspin. Furthermore it is possible to produce fast long services with only a small racket movement.

V References

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2) Durey, A.; Vers des activités didactique de mise au point des modèles : trajectoires, frappés, rebonds de balles en rotation, Thèse d'état Paris 7, 1987.