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# The Human Impact Biomechanics in Rugby Game

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## Introduction

The collision of two or more humans in a game can be seen from two perspectives:

- from that of the sportive performance, during the offensive, the sportsmen that succeed to break up through the defensive lines of the opposite team, may gather points;
- from the medical point of view, direct taking over of the shock provoked by the impact may result in injuries that can make unavailable the sportsman.

Sportive performance in a team plays, like rugby, basket-ball etc., can be influenced by the penetration of a player beyond the other's team defence lines, using a useful technique of impact with competitive players. The knowledge of details regarding dynamic parameters of impact can help the coach and the player in obtaining a performance. From this view, the applied studies in rugby game deals with the biomechanics aspects of the impact into the ordered crowd (Rodano and Pedotti, 1988; Milburn, 1989, 1990, 1993, 1994; Quarrie and Wilson, 2000), being pointed out the link between the force and the body's position (Bartlett, 1999; Mills and Robinson, 2005), the position of feet (Enoka, 1994) or individual physical characteristics (Zatsiorski, 1995). McClymont and Cron (2002) do an interesting analysis, proposing a method of "total impact", to realize a maximum force of impact of the ordered crowd, by positioning the 8-th player. In change, the problem of individual impact between two players during the game, when one of them is possessing the ball, is analyzed only from the view of game's technique (Rugby Smart), and the biomechanical characteristics of the impact from sport performance point of view, are not analyzed.

From the medical point of view, accidents from games are caused by collision between humans. The accidents can be prevent if the player knows details about dynamic impact, impact techniques, how to protect himself during impacts. Thus, there was analyzed the dependence between the frequency and intensity of the impact and cervical accidents, for the ordered crowd (Milburn, 1997: Quarrie, 2001: Scher, 1982), the spinal column accidents (Silver, 1988, 1992, 1994; Bier, 1991) or knee accidents (Collett et al., 2003) due to impact during the game.

The impact of two solid bodies, rigid or elastic, represents the movement which take place under the action of a great force that exists for a short time (Harris, Crede, 1976). This movement is characterized by a sudden variation of velocity during

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a very short time of the phenomenon. As a result, the parameters of movement (impulse and kinetic energy) have very large variations. The average percussion force is connected to the mechanical impulse variation at impact, depending of the mass of the bodies and the velocities immediately before and after collision. The mathematical models of impact between two bodies presumes the knowledge of biomechanics characteristics, like the return coefficient.

The impact, centric or oblique, may be mathematically modelled through: the equation of impulse preservation and the equation defining the return coefficient. The second equation makes the link between a known parameter, the return coefficient, and the speeds of the two sportsmen immediately before and after the impact. Depending on the value of the return coefficient, the impact may be: elastic, plastic or elastic-plastic.

The paper deals with the problems of impact in rugby game from theoretical point of view, that is modelling this phenomenon, and from experimental point of view, that is determining the return coefficient. At the same time, there are analyzed the simulation performed for a two generics sportsmen. Aided by impact model and knowing some input data (sportsmen masses and before impact velocities), we can determinate the sportsmen velocities after impact.

## Methods

Collision of two objects or two human subjects is a process taking place in a very short time. During this action, on the two human subjects a very big percussion force $\bar{P}$ acts, representing the force of reciprocal pressing of the impacting bodies.

During the impact, the percussion force $\bar{F}$ is subjected to very big variations. The exact mathematical law of variation is relatively difficult to evaluate. Usual calculus is using an average percussion force $\bar{F}_m$, that is defined as a percussion force causing the same effect as the real percussion force. The average percussion force is calculated with the

following relation:

$$\bar{F}_m = \frac{m \cdot (\bar{v}_2 - \bar{v}_1)}{t_2 - t_1}, \tag{1}$$

where: m – is the mass of the colliding body;

$\bar{v}_2$, $\bar{v}_1$ – the velocities of the body at the end, and respectively at the beginning of the impact;

$t_2 - t_1 = \Delta t$ – the time interval of the impact.

The observation and analysis of the impact phenomenon allowed the following findings:

The usual forces like gravity force, elastic force, resistant force and reaction forces can be neglected when studying the collision (Harris, Crede, 1976).

Because the duration $\Delta t$ of the impact is very small, the position of the colliding bodies does not modify very much, and the colliding bodies can be considered to be immobile.

The collision of two sports-men is of "oblique" type, that is, the direction of the velocities before the impact have accidental orientation (figure 1). These velocities, at the moment of impact, are inclined with different angles about the line joining the mass centers of the colliding bodies. Assuming that the contact between the two sports-men is without friction, so that forces that occur are oriented only along the line of the mass centers, the percussion force will have the same direction.

At the "oblique" impact, the components of vectors velocity remain unchanged in the tangent plane during the collision, that is, the components of the velocities $\bar{a}_1$ and $\bar{a}_2$ (figure 1) do not change, so $\bar{a}_1 = \bar{b}_1$ and $\bar{a}_2 = \bar{b}_2$.

From the specialty literature (Harris, Crede, 1976;Snowdon, 1968; Wilson, 1959), the percussion is defined as being the variation of the impulse during the impact, or, equivalently, the integral of the impact force with respect to time of the impact.


before collision time of collision after collision

Figure 1: The velocities in oblique collision

During the impact two phases occur:

- deformation phase, characterized by compression of the bodies and reaching the same speed and maximum deformation at the end of this phase. At this phase, the percussion has the same value for both bodies. Denoting the common speed at the end of the phase with "v", the percussion for the two bodies can be written as follows:

$$m_1 \cdot (v - v_1) = -P_1, \quad m_2 \cdot (v - u_1) = P_1. \tag{2}$$

From relations (2) the expression of the common speed results:

$$v = \frac{m_1 \cdot v_1 + m_2 \cdot u_1}{m_1 + m_2}, \tag{3}$$

and if relation (3) is replaced in relations (2), the percussion is:

$$P_1 = \frac{m_1 \cdot m_2 \cdot (v_1 - u_1)}{m_1 + m_2}. \quad (4)$$

- the return phase, characterized by relaxation of the bodies and different modification of the velocities from the common value of the precedent phase.
  In this phase, the percussion acting on the two bodies, of the same value, is denoted with $P_2$. The expressions of this percussion are:

$$m_1 \cdot (v_2 - v) = -P_2, \quad m_2 \cdot (u_2 - v) = P_2. \quad (5)$$

As above, the relations (5) lead to:

$$v = \frac{m_1 \cdot v_2 + m_2 \cdot u_2}{m_1 + m_2}, \quad (6)$$

$$P_2 = \frac{m_1 \cdot m_2 \cdot (u_2 - v_2)}{m_1 + m_2}. \quad (7)$$

Making equal (3) with (6) for common speed "v", the following relation is determined:

$$m_1 \cdot v_1 + m_2 \cdot u_1 = m_1 \cdot v_2 + m_2 \cdot u_2, \quad (8)$$

that represents the law of impulse preservation during the impact.

The ration between the percussions $P_2$ and $P_1$ represents a characteristic of the impact, called restitutio coefficient. The restitutio coefficient has the expression:

$$R = \frac{P_2}{P_1} = \frac{u_2 - v_2}{v_1 - u_1}. \quad (9)$$

The velocities at the end of the impact are determined from (8) and (9):

$$v_2 = v_1 - \frac{(v_1 - u_1) \cdot (1 + R)}{1 + \frac{m_1}{m_2}} \quad (10)$$

and:

$$u_2 = u_1 + \frac{(v_1 - u_1) \cdot (1 + R)}{1 + \frac{m_2}{m_1}}. \quad (11)$$

In practical case of collision in a sport-game, interesting for the trainer can be the speed reached by a sport-man when colliding with an opponent, as value, and the sense of the velocity given to the opponent to be the same with the sense of the velocity of the own sport-man, but with a smaller value than that of the own player and the average force of impact to have a superior limit so that major lesions can not occur and no accidents to result.

## Results and Discussion

For the experimental determination of the return coefficient, there where made impacts between rugby players from Iasi, inside a gym. All these impacts, 52 in number, where filmed and digitally processed on computer. The images, frame by frame, permitted the visualization of the moment of impact and the possibility of velocity measures before and after impact. For measurement of space along the direction of movement, was used a marking 5 centimeters on the background of the images. Picture 1 presents some frames during impact between two players. 20 experimental measurements were chosen, among the total of 52 experimental measurements, acceptable from the point of view of pursued goal.

Outcomes for speeds presented in table 1, permitted the calculation of return coefficient. The value found ($R = 0.195$), shows that the impact, almost-elastic, has a strong plastic characteristic, soft tissues suffering an important deformation.

Basing on the value of the return coefficient and on the relative velocities of the players before the impact, it can be determinated calculating the values of the velocities and directions of them after impact.

In figure 2 there are represented the graphics of the two final velocities, $v_2$ and $u_2$, calculated with relations (10) and (11), corresponding to the three given values of mass $m_1$, respectively 90, 100 and 110 [kg]. The order of the graphics for speeds $u_2$ is the same as for the speeds $v_2$.

It can be observed from the graphics of speeds that as the mass of the sportsman denoted with "1" increases, the mass of the sportsman "2" has to increase too, so that the speeds $v_2$ and $u_2$ have the negative algebraic sign. Thus, from graphics it results that when the mass of the sport-man "1" has the value of 110 [kg], the mass of the sportsman "2" has to be $m_2 > 195$ [kg], but the value of speed $u_2$ is much lower than that of speed $v_2$.

The calculus of the average percussion force, for a time interval of 1.0 [s] as long as the impact was considered to last, determined with a video record, pointed out that for masses $m_1 = 90$ [kg] and $m_2 = 180$ [kg], respecting the condition of wished sense of final speeds, the value of the average percussion force is about 1000 [kgf]. For any other values of masses and speeds, using the above presented relations, the average percussion force may be computed. With the help of that force we can check if any lesions may occur in the zone where the impact produces, that could injury the sportsman.

The second situation considered in the numerical application is represented by the case when the initial speeds are equal as value and opposite as sense, respectively $|\bar{v}_1| = -|\bar{u}_1|$. For the same value R = 0.195, the final speeds calculated with

Table 1: The experimental determinations

| The number of impact | $v_1$ [m/s] | $v_2$ [m/s] | $u_1$ [m/s] | $u_2$ [m/s] | $R$ |
|---|---|---|---|---|---|
| 1 | 10.241 | 8.442 | 1.260 | 1.607 | 0.192 |
| 2 | 12.067 | 7.233 | 1.317 | 2.264 | 0.195 |
| 3 | 9.682 | 13.547 | 2.335 | 1.577 | 0.196 |
| 4 | 13.636 | 6.060 | 1.470 | 2.941 | 0.194 |
| 5 | 6.820 | 12.891 | 2.549 | 1.353 | 0.197 |
| 6 | 13.440 | 10.767 | 1.668 | 2.192 | 0.196 |
| 7 | 10.231 | 11.554 | 1.824 | 1.566 | 0.195 |
| 8 | 12.921 | 8.776 | 1.311 | 2.124 | 0.196 |
| 9 | 13.700 | 10.434 | 1.335 | 1.976 | 0.196 |
| 10 | 7.881 | 11.020 | 1.946 | 1.330 | 0.196 |
| 11 | 13.322 | 8.656 | 1.371 | 2.290 | 0.196 |
| 12 | 13.020 | 8.215 | 1.400 | 2.347 | 0.197 |
| 13 | 11.459 | 10.325 | 0.955 | 1.178 | 0.196 |
| 14 | 13.881 | 7.021 | 1.343 | 2.708 | 0.198 |
| 15 | 12.163 | 10.354 | 0.841 | 1.196 | 0.196 |
| 16 | 12.980 | 5.331 | 1.344 | 2.874 | 0.200 |
| 17 | 13.010 | 6.125 | 1.411 | 2.761 | 0.196 |
| 18 | 12.991 | 10.500 | 1.644 | 2.133 | 0.196 |
| 19 | 6.448 | 11.221 | 2.052 | 1.121 | 0.195 |
| 20 | 12.769 | 8.661 | 1.301 | 2.107 | 0.196 |

relations (10) and (11) lead to expressions:

$$v_2 = v_1 \cdot \frac{m_1 - 1.39 \cdot m_2}{m_1 + m_2} \text{and } u_2 = v_1 \cdot \frac{1.39 \cdot m_1 - m_2}{m_1 + m_2}. \tag{12}$$

Considering the same values of masses of the sportsmen, as for the calculus of the average percussion force, for an initial common speed before impact of 8 [m/s], the final speeds after the impact, determined with relations (12), are: $v_2 = -4.74$ [m/s], $u_2 = -1.62$ [m/s]. The average percussion force, computed with relation (1), for this case, is approximately 1146 [kgf].

For representation of impact of two sportsmen, firstly there was created a model of human subject, using a CAD program in 3D. This model may be personalized, function of body sizes of the sportsman and of the weight or biomechanical characteristics “of material” of the body (density, average elasticity modulus, coefficient of Poisson etc.). Representing two such human models on a rugby filed, as shown in figure 3, there were introduced equations defining the motion of bodies, taking into account the speeds before collision, the relative position of the two sportsmen,

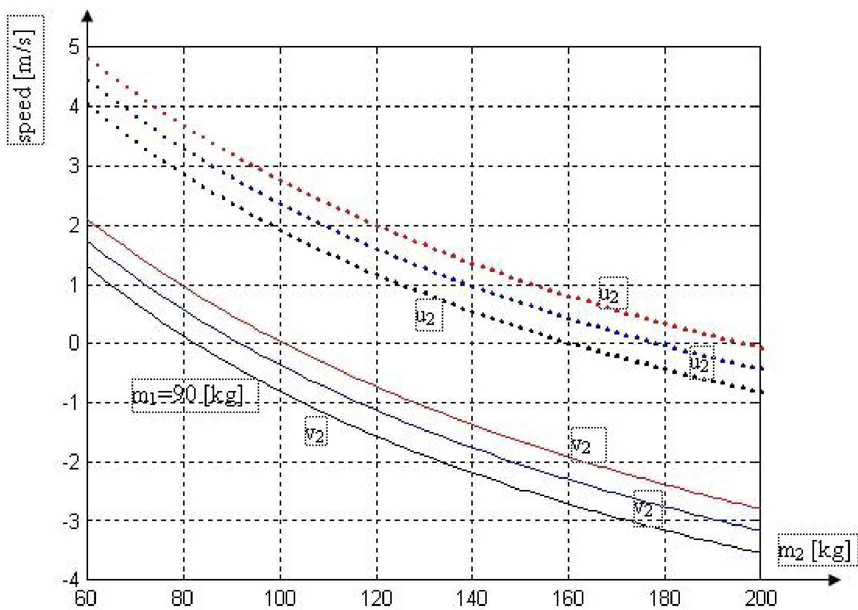


Figure 2: Dependence between the final speeds and the mass of the sportsmen

the friction coefficients with the ground and the restitutio coefficient at the impact between the two subjects.

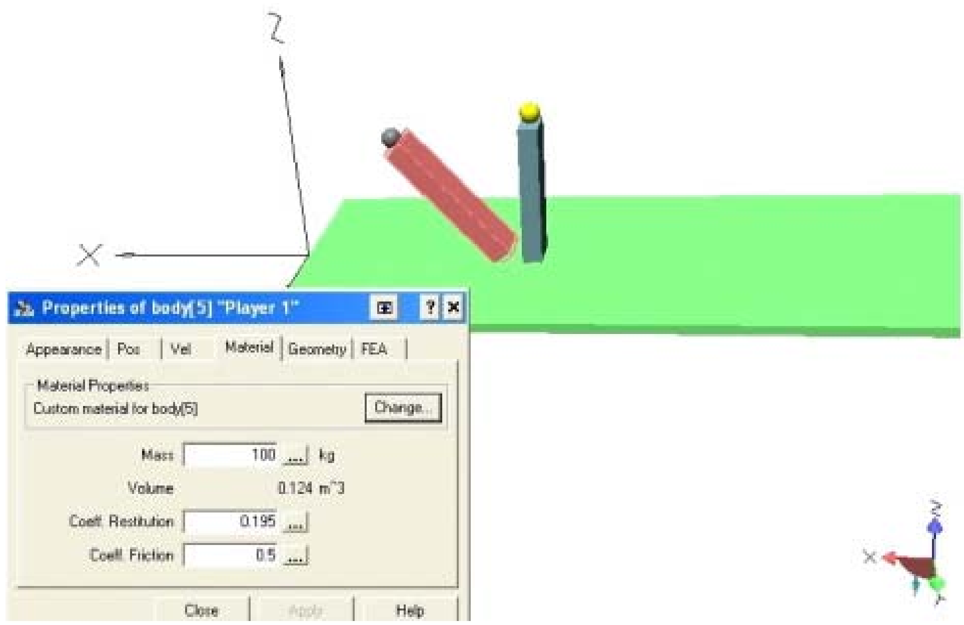


Figure 3: Sequence from the software graphical modulus

As output data, the graphical modulus yields the following information, for each sportsman:

- the speeds of sportsmen after impact, these being given both as components x, y and z, and resultant speeds;
- sportsmen accelerations, in the same way like the speeds;
- the stress distribution within the two bodies during impact, which allows to calculate the maximum force of impact.

The simulations may be done immediately, by changing the input data, the program giving the interest data, kinematics for the sport trainer and dynamics for the sport physician.

Knowing these speeds, as modulus and sense, the trainer may arrange the team onto the field depending on the "impact criterion", so that after collision with an opponent player, the own player to maintain unchanged the sense of speed and to cancel it for the opponent player or to change it as sense. The initial approximate speeds may be estimated by the trainer by various investigation methods (using previous video records, from other games), and by simulation there are observed the consequences of impact between the own analyzed sportsman and various possible opponents.

## Conclusion

The biomechanical analysis of the collision of two sportsmen, for the instance the case of two rugby players could be useful to a coach in defining the structure of a team.

The presented procedure of calculus could be used in Sports Medicine in order to evaluate and prevent possible accidents.

Simulations using the calculated biomechanical parameters and the anthropological data of the sportsmen could eliminate unwanted situations causing accidents.

The accuracy of the presented procedure is related to the existence of input data which have to be established experimentally.

Mathematical modelling of the impact of two sport-men can help a trainer in preparing the team for competition. Thus, on the basis of some video records of opposite team, the speeds developed during a game by the players of that team can be determined, so that the initial speed and the necessary mass for a sport-man can be calculated so he can defeat his opposites. All these possible variants can be easily computed by the trainer or a physical coach having biomechanics knowledge, on the basis of those previously presented.

At the same time, knowing the value of the average percussion force, on the basis of impact duration approximation, the sport physician may specify if accident may occur or not. The best variants, both concerning the lesions and the performance, can be chosen.

On the basis of the study of the impact of two sport-men, the trainer can recommend certain techniques of impact force taking over, so that can not produce accident.

The described mathematical modelling allows calculus with multiple parameters so a wished optimum can be reached.

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## References

1. Bartlett, R.M. (1999) *Introduction to Sports Biomechanics*. E.& F.N. Spon. London.

2. Brach, R.M. (1993) Classical planar impact theory and the tip impact of a slender rod, *International Journal of Impact Engineering* **13**(1), 21-33.

   Enoka, R.M. (1994) *Neuromechanical Basis of Kinesiology*. Champaign Ill. Kinetic Books.

3. Harris, C.M., Crede, C.E. (1976) *Shock and vibration*. Handbook, $2^{nd}$ edition, McGraw-Hill.

4. McClymont, D., Cron, M. (2006) Total Impact method: A Variation on Engagement Technique in the Rugby Scrum, Coaches Information Service Website. Available in URL: http://coachesinfo.com/category/rugby/84/.

5. Milburn, P.D. (1989) The kinetics of various rugby union scrummaging techniques. In RJ Gregor, RF Zernicke, & WC Whiting (eds.) *Proceedings XIIth International Congress of Biomechanics*, Los Angeles: University of California Los Angeles, 293-294.

6. Milburn, P.D. (1990). The kinetics of rugby union scrummaging. *Journal of Sports Science* **8**, 47-60.

7. Milburn, P.D. (1993). The biomechanics of rugby union scrummaging: Implications for technique and injury. *Sports Medicine* **16**(3), 168-179.

   Milburn, P.D., O'Shea, B.P. (1994). The sequential scrum engagement: a biomechanical analysis. *Australian Journal of Science and Medicine in Sport* **26**, 32-35.

8. Mills, S., Robinson, P. (2006) Assessment of Scrummaging Performance, Coaches Information Service Website. Available from URL:

http://coachesinfo.com/category/rugby/82/.

9. Quarrie, K.L. and Wilson, B.D. (2000) Force Production in the Rugby Union Scrum. *Journal of Sport Sciences* **18**, 237-246.

10. Rodano, R. and Pedotti, A. (1987) A Qualitative Analysis of Thrust and Motor Coordination in a Rugby Scrum. *Proceedings of First World Congress of Science and Football*. T.Reilly et al ed. 1988. London E.& F.N.Spon.

11. Rugby Smart (2002) *A Guide to Injury Prevention and Peak Performance*. N.Z. Rugby Union and Accident Compensation Corporation.

12. Snowdon, J.C. (1968) *Vibration a shocks in damped mechanical systems*. John Willey & Sons, New York.

13. Wilson, W. (1959) *Vibration Engineering*. Charles Griffin Company Limited, London.

14. Zatsiorski, V.M. (1995) *Science and Practice of Strength Training*. Champaign Ill. Kinetic Books.